ENERGY EFFICIENT LIGHTING DESIGN FOR OFFICE INTERIOR

A thesis
Submitted towards partial fulfillment of The requirements of the degree of

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in
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Submitted by

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CERTIFICATE OF RECOMMENDATION

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CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a creditable study in the area of Illumination Engineering, carried out and presented by SWARNAVA DEY (Examination Roll no: - **M4ILN22028**, Registration No: - **149751 of 2019-2020**) in a manner of satisfactory warrant its acceptance as a pre-requisite to the degree for which it has been submitted. It is notified to be understood that by this approval, the undersigned does not necessarily endorse or approved the thesis only for the purpose for which it has been submitted.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

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

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

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

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ABSTRACT

Illumination is the term used for lighting applications designed to ensure desired levels of visual perception in an ambient and of objects inside that ambient. Proper illumination primarily necessitates a thorough analysis of the requirements and dimensions of the ambient and selecting the right lighting source by considering several technical and economical parameters like luminous colour, colour rendering, lamp efficiency, lamp life, armature dimensions and installation-maintenance. Correct lamp selection can only be made by knowing the light source characteristics and evaluating these in accordance with our needs.

The need for light in the room especially in an office room or workplace premises is something that cannot be negotiated. Meeting these needs can be obtained through natural lighting and artificial lighting or a combination of both. The purpose of this study is to analyse the energy consumption along with the lighting parameters, especially the average illuminance & uniformity in the departments of JMS MINING PVT. LTD. Office at Newtown, Kolkata and provide solutions to improve lighting performance in the room. The research method was carried out through a computer simulation (computer simulation) with DIALux 4.13 software by comparing the existing model and the engineering design model.

The main benefits of energy efficient lighting include reduced electricity demand, dramatic energy and maintenance savings, and a lower operating cost. There are also less quantifiable benefits, such as improved lighting quality, better light distribution, productivity boosts, and a lower carbon footprint, which may be even more important to business.

Use of energy efficient lighting equipment such as low energy halogen lamps, fluorescent tubes, and LED (light emitting diode) in combination with electronically controlled systems for dimming, automatic shut off, etc. is continuously developed as the focus on energy and environment has increased. The new technology has been applied only to a limited extent to the shipping industry and standard normal design does not include low energy lighting. Implementing energy efficient light system will in addition reduce the maintenance hours and operating cost.

Chapter 1
INTRODUCTION

Introduction

1.1 General Introduction:

It has been estimated that lighting accounts for about 20% of the total power generation of the world. The quality and quantity of light not only affects our health, comfort, safety, and productivity but also affects the economy. Many nations have been spending a huge amount of their electricity budget on lighting.

For achieving efficient use of electricity, nations have been taking a sustained switch to the energy efficient lighting which is the most cost effective and reliable method of energy-saving. A well-known technology has been in use in the area of lighting to optimize the existing controls and lighting equipment for reducing the energy consumption with higher lighting quality.[1]

Lighting is necessary for visibility of objects in dark places or situations. Efficiency refers to how well the light is produced for a given input power. In conventional lamps like incandescent and gas discharge lamps, most of the electricity is wasted in terms of heat and also since ballast requires high voltage at the time of starting these consumes more power. Energy efficient lighting includes the use of more illumination from less power lights by replacing high power consumption lights like incandescent, high discharge lamps, etc. [2]

Besides affecting the physical and emotional well-being of the building occupants, a building's interior lighting system is both a dominant consumer of electrical energy and a major source of internal heat. In the United States about one-quarter of the electricity budget is spent on lighting, or more than $37 billion annually. In commercial buildings it normally accounts for more than 30% of the total electrical energy consumed. Yet much of this expense can be avoided.

Specifying a high-quality energy efficient lighting system that utilizes both natural and electric sources as well as lighting controls can provide a comfortable yet visually interesting environment for the occupants of a space. Recently developed energy efficient lighting equipment such as compact fluorescent lamps and "soft-start" electronic ballasts can be used to help cut lighting operational costs 30% to 60% while enhancing lighting quality, reducing environmental impacts, and promoting health and work productivity. [3]

With the reduction in energy consumption, there shouldn’t be any kind of sacrifice in quality and quantity of light required as per the lighting codes. The shortage of Electrical energy is increasing gradually. As it is the energy source of lighting, the lighting designers should be more concerned about energy efficient lighting system design. LED consumes less power than the conventional luminaires & maintains almost the same lighting level. So, lighting designers are using LED luminaires into their designs now a days. Also, renewable energy sources driven lighting systems should be used. It will be environmental-friendly also. A proper lighting design requires consideration of the amount of functional light level provided, the energy consumed, and the aesthetic effect supplied by the lighting system. The electrical lighting systems should also consider the impacts of, and ideally be integrated with, daylighting systems. [4]

1.2 **Literature Review:**

Lighting is the basic requirement of any facility, and it impacts the day-to-day activities of the people. This accounts a considerable amount of total energy consumption in domestic, commercial, and industrial installations. In industries, energy consumption for lighting constitutes only a small component of the total energy consumed, which is nearly 2-5 percent of total energy consumption. It accounts for 50 to 90 per cent in the domestic sector and it may go up to 20-40 percent in case of commercial /building sectors, information technology complexes, and hotels. So, it becomes an important area wherein energy to be conserved, especially in the domestic sector. Lighting efficiency solutions therefore play a key role in energy saving opportunities. Due to the high energy consumption, traditional incandescent lamps and high discharge lamps have to be substituted with energy efficient lamps. Traditional lamps not only consume large amounts of electric power, but they use much of its consumed energy to produce heat rather than light (for instance 90% of consuming energy in case of incandescent lamps). With the installation of energy efficient lighting, the amount of energy consumption eventually will get reduced, and it results in lower electricity bills. [5]

Building lighting design focuses on three fundamental aspects of the illumination of buildings or spaces. The first is the aesthetic appeal of a building. Secondly, the ergonomic aspect: the measure of how much of a function the lighting can achieve. Thirdly is the energy efficiency issue to ensure that light is not wasted by over-illumination, light pollution, by illuminating vacant spaces unnecessarily or by providing lighter than needed for the aesthetics or the task. [6]

The use of LED lighting in the office buildings has significant contribution on total energy consumption of the building. With the increase in the price of energy and public becoming more energy conscious, more attention has been given to the energy efficient lighting. On the other hand, with increased trend to go for efficient lighting systems, the quality of lighting has to be maintained. Efficient lighting and quality lighting are not contradictory to each other and the better understanding of these two terms would be helpful to promote the improvement of the energy efficiency. The present paper first gives an overview of the different factors related to the quality of lighting in office environment. Different studies about the illuminance level, illuminance distribution, uniformity, and other quality aspects have been summarized. The result of the energy consumption measurement carried out in office rooms with different lighting control systems and their comparison shows that significant improvement in efficiency can be made without compromising on quality.

The primary function of office lighting is to enable workers to see, in order to perform their tasks comfortably and safely. Modern lighting system today should meet the energy-efficient requirements for the conservation of the limited energy resources, while without compromising on the quality. Significant savings in energy consumption, and therefore cost, of providing lighting without affecting the visual comfort and task performance of occupant can be achieved by applying an energy-effective-design approach to lighting installations. This needs the better understanding of different quality and quantity aspects of lighting. [7]

1.3 **Problem Statement:**

In Corporate office premises, for the sake of maintaining elegance and attraction, lighting arrangements become too power consuming as well as financially affected. Keeping this in mind, an analytical modification over this real time problem statement through simulation procedure has been done so that illumination set up can be less power consuming without losing its aesthetic value.

1.4 **Objectives:**

The goal of this thesis work was to develop and validate an alternative lighting design system to better adhere to the visual needs of space occupants for completion of tasks and overall satisfaction of the lit environment. Computer simulations was utilized as aiding tools in the realization of the research goal. All design and results of this study are based on a personal office and in absence of daylight. Nevertheless, it is believed that similar results could occur in building types of similar conditions. Essential to this research is the understanding that measured luminance is related to, but different from perceived brightness. Subjective analysis of brightness is dependent upon individual preferences, conditions, and visual performance, so an accurate relationship cannot be drawn between measured luminance and subjective brightness. Therefore, this research focused on the employment of physical luminance for evaluating perception-based lighting design within an objective frame. [8]

The following research aims were established to accomplish the goal of the study:

- To reduce the power consumption of lighting arrangements of the departmental rooms for the sake of cost cutting.
- To reduce the no. of luminaires in all the four departmental rooms of the office premises but keeping the **Illuminance Level** as per BIS standard.
- To reduce the no. of luminaires in all the four departmental rooms of the office premises but keeping the **Uniformity** as per BIS standard.

1.5 **Methodology:**

Survey of research can be fragmented down into two stages. Stage 1 relates to discovering the illuminance and luminance effects of different lighting layouts by means of computer simulations. Current illuminance-based design codes are utilized in the investigation of this stage. Stage 2 examines luminance patterns. illuminance values, uniformity, load consumption. For a successful completion of the above-mentioned objectives, some methods are followed so that the problem can be resolved fully or to some extent.

This research activity took place in the office environment of JMS MINING PVT. LTD. located in Newton Kolkata. This research is a quantitative study using a simulation method. The simulation results are made in the form of tables and graphs, which are then described. Lighting performance analysis was performed using the lighting design software DIALux 4.13 to simulate. DIALux is a fast-growing natural and artificial lighting program that meets the information needs of the latest lighting technology and can generate automatic technical reports and have improved visual rendering capabilities. This study uses three methods, namely numerical calculations based on the reference of the BIS standard study on lighting, direct measurement methods, and computer simulation using DIALux. This study uses measurement and simulation methods using DIALux 4.13. [9]

- ✓ As this project involves the improvement of an existing lighting setup from the aspect of reduction in power consumption and no. of lights, so to make a comparison for the improvisation, the existing model with all the correct data is required.
- ✓ So firstly, existing prototype or constructional designs have to be created for all the four rooms in DIALux /AutoCAD. (Here we will use DIALux 4.13)
- ✓ The design should be correct from the aspect of room dimension and all three measurements i.e., length, width, height of the rooms, the materials which are in the room should be exact.
- ✓ So now, the existing lighting arrangements will be implemented in the DIALux 4.13 software to determine the existing lighting parameters i.e., uniformity, luminance. For this, the .ies file of the existing luminaires with proper data associated with its rating is required.
- ✓ After getting the lighting parameters as an output, it will be possible to make a comparison and take the decision that which luminaire and how much quantity is required to use for the further design by which the objectives can be obtained.
- ✓ For creating the further lighting design in all the four rooms with the same dimensional measurements and materials but with different luminaire, the .ies file of the new luminaire is also required.

1.6 THESIS OUTLINE

This thesis investigates how to make lighting in offices more sustainable and focus on energy efficiency, to save energy through creating guidelines related to light source technologies, lighting control systems and the user behavior, then apply those guidelines to an existing office through suggesting a new lighting design.

This thesis consists of five (8) chapters. Chapter one (1) will describe the introduction, literature review, problem statement, objectives, describe the methodology for achieving the final goal. In the Chapter (2), Office Illumination is described, how these effects the cognitive activity of the employees, Circadian System. Chapter three (3) will explain about energy efficient lamination in Office, how energy is controlled as per National Lighting Code and its mathematical approach. Chapter four (4) is where the survey results of the Office and the luminaire simulation outputs are discussed. In chapter five (5) involves the whole design, simulation of existing luminaire setup in DIALux, the parameter values from simulation, illuminance distribution. Chapter (6) follows the schema of Chapter (5), but data are different as it involves the simulation with new luminaire. Finally, Chapter (7) is where it summarizes the whole project development process along with comparison (both graphical and tabular) between two different outputs of same parameters and determine if the modifications are following National Lighting Code or not. Lastly, Chapter (8) ends with Conclusion and future scope of this work.

Chapter 2
INTRODUCTION
TO
OFFICE ILLUMINATION

OFFICE LIGHTING

Whether an office's light source is natural, artificial, bright, and blue, or dim and yellow, the type of light that employees are exposed to not only impacts mood, circadian rhythms, and physical health but also affects productivity and creativity as shown in Fig. 2.1. "There are a lot of interesting studies around the nature of your environment and how it affects your brain's ability to perceive and function in different ways," says Star Davis, who heads up WeWork's global team of dedicated lighting specialists. [10]

Employees who were exposed to natural light in the office reported an 84% [11] drop in eye strain, headaches, and blurred vision, according to research by the department of design and environmental analysis at Cornell University. Research from the American Academy of Sleep Medicine also showed that exposure to natural light helps regulate hormones and keeps your circadian rhythm in check, helping employees sleep soundly at night and work productively the next day.

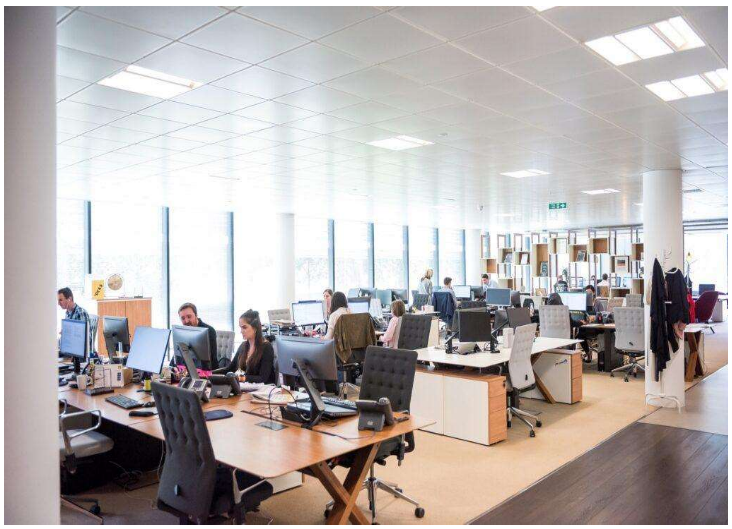


Fig. 2.1: Office Lighting Setup [12]

2.1 Factors & techniques that influence Energy Efficient in lighting systems

In order to save energy, lighting systems should consume energy as efficiently as possible, so it is important to understand what Energy Efficient Lighting is. When the energy usage of a product is reduced without affecting its output or final response or user comfort levels is referred to as energy efficiency. An energy efficient product consumes less energy to perform the same function when compared to the same product with more energy consumption. The energy efficiency in the lighting sector gives the required illumination level of the lighting scheme for the application it has been designed for, while consuming the least amount of energy. Simply, energy efficient lighting can save the electricity while maintaining good quality and quantity of the light [13]

Fig. 2.2: Office Lighting Setup [14]

Energy efficient lamps as shown in Fig. 2.2 can deliver the same amount of lighting with greater energy saving at low cost, when compared with conventional lamps. Traditional incandescent lamps consume a lot of energy to produce light in which 90 percent of consumed energy is given off as heat and also, they consume more energy, typically 3-5 times more than the actual amount to produce light. Office lighting has a bigger impact on employee mood, health, and productivity. It's an important aspect of office design, one that might sometimes be overlooked or considered as an afterthought.[15]

2.2 Explanation of Office Lighting:

Lighting is one of the most influential factors in the office environment. And if an office is designed with poor lighting choices, it can seriously affect employee well-being and performance. Negative effects of bad lighting include[16]

- ✓ Eye strain that causes headaches
- ✓ Discomfort caused by burning sensations
- ✓ Drowsiness & lack of focus leading to decreased productivity
- ✓ Sleep disruptions that affect overall health
- ✓ Fatigue

2.3 Circadian Rhythm:

Due to **CIRCADIAN RHYTHM** human bodies run on an internal 24-hour clock that correlates with one earth day. It more or less dictates when one will wake up and when he/she will go to sleep. Our circadian rhythm can be interrupted by a set of environmental factors such as artificial lighting and the infamous "blue light" emitted by computer screens. Human engineering has found a workaround that can help readjust our circadian rhythms—it's called circadian lighting. [17]

2.4 CIRCADIAN LIGHTING:

It is as close to natural daylight. This kind of lighting can be achieved by installing a **tunable white lighting system** that automatically changes the color temperature and intensity throughout the day as shown in Fig. 2.3, mimicking the sun's cycle. [18]

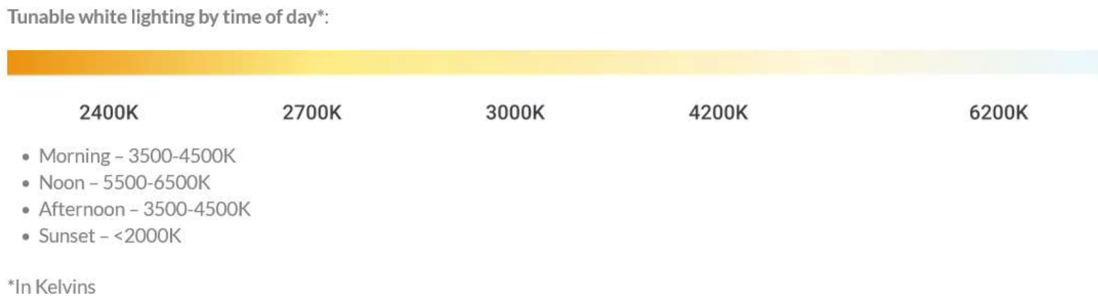


Fig. 2.3: Tunable white lighting by time of day [19]

A circadian light bulb produces bioactive circadian white light which regulates Circadian rhythms and improves overall productivity. Circadian lighting basically controls the blue light wavelength as shown in Fig. 2.4, which is disastrous for health in long term, and reduces the chances of harmful disorders such as heart diseases, obesity, depression, and sleep disorders. Circadian lighting bulbs are designed with circadian rhythms in mind. By regulating our circadian cycle, the futuristic lighting products prevent health problems such as sleep disorders, fatigue, depression, etc. Exposure to circadian light at night results in better sleep and uninterrupted circadian cycle.

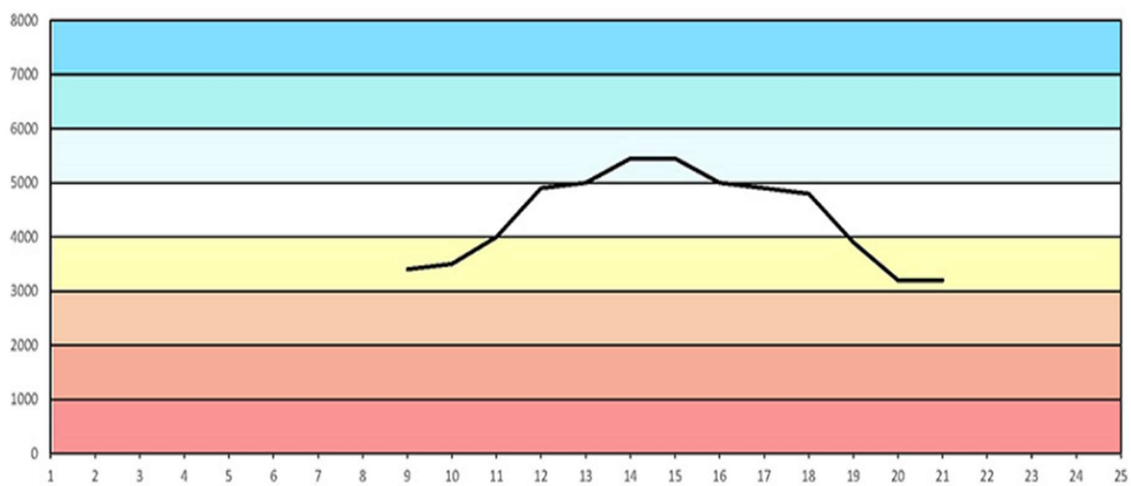


Fig. 2.4: Color Temp. Recommendation for Human Circadian rhythm [20]

When circadian rhythms are in harmony, the bodily functions perform in perfect alignment which in turns improves brain performance. Traditional lighting tech and their blue light content exert the mind, which leads to slower memory performance. This is one of the biggest reasons why business owners and managers are pushing for healthy lighting. Besides regulating the circadian cycle, circadian lighting also influences mood functions. Higher intensity of circadian light exposure results in positive emotions and enhanced mood functions. circadian lighting improves cognitive behavior and helps complete cognitive tasks faster by increasing activity in a specific region of the brain. This directly maximizes the brain's involvement during cognitive tasks. [21]

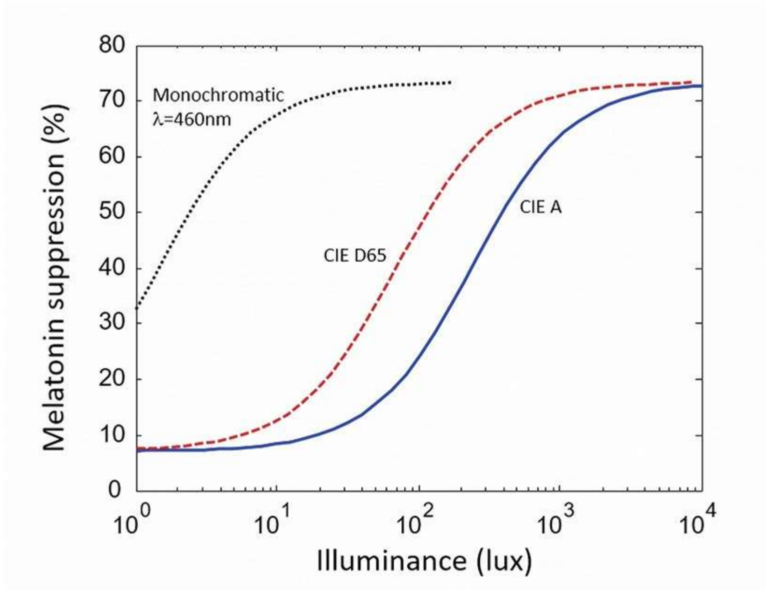


Fig. 2.5: Melatonin suppression related to Illuminance [22]

Melatonin is a hormone made in the body. It regulates night and day cycles or sleep-wake cycle. It is affected by the illuminance level at office as shown in Fig. 2.5 and its variation also contributes to the productivity of employees.

2.5 Lighting Parameters:

Here are some parameters associated with Office Illumination and convenient to this project are discussed below. These parameters are significant for this project as this project objective involves all these parameters to be modified as per design for reaching a successful completion.

I. Illuminance: [23]

Past and present lighting design techniques are heavily based on illuminance and other illuminance-based metrics. Illuminance, E, is the quantity of light which falls onto an object or surface (IES, 2011). Factors contributing to illuminance levels include light source optics and distance. Typically, the surface of measurement for illuminance is the horizontal work-plane. Illuminance values across vertical work-planes often get overlooked in lighting design unless significant tasks are expected to occur in the vertical orientation. Selection of recommended illuminance levels are primarily made based on occupant's age and tasks to be performed. For an office setting, illuminance values between 300 lx and 500 lx are typically recommended (National Lighting Code 2010, Clause 9.1). Furthermore, uniformity ratios recommended by lighting standards are based on illuminance values. The closer illuminance levels are across the measure plane, the better the uniformity. While illuminance is not actually an affecting factor of visual performance of human eyes, it continues to be used as a primary metric amongst lighting design.

II. REFLECTANCE [24]

Reflectance, ρ, is defined as the percentage of incident light reradiated from a surface. The remainder of the incident light is either absorbed, transmitted, or a combination of the two. There are two components of reflectance. The first being the reflectance value, namely the percentage of light that is reflected from a surface. The second component of reflectance refers to how specular, shiny, or diffuse, matte, the surface of interest is (IES, 2008.). High levels of reflectance can improve the lighting efficiency and brightness of a space by creating an increased number of inter-reflections. Adaptation when switching between tasks is greatly influenced by surface reflectance. Additionally, surfaces with higher reflectance values can positively effect energy efficiency.

III. BRIGHTNESS [25]

Brightness is directly related to luminance as brightness is the visual response to perceive luminance, which occurs in the human brain (Cuttle, 2008). Therefore, brightness is the subjective perception of the reflected light and cannot be quantifiably measured. Research indicates luminance is the primary influence of brightness perceptions. Other factors which influence brightness include size, gradient, surround luminance, adaption, and spectral compositions. A simplified approximation of the relationship between brightness and luminance follows the 1/3 power law: in which a doubling in brightness requires an eight-fold increase in luminance (IES, 2011). The perceived brightness of a space can be increased by increasing the room surface luminance. Matte materials of high reflectance and luminaires which graze walls and ceilings can contribute to increased space brightness.

IV. Uniformity [26]

Uniformity is the ratio of the minimum lighting level to the average lighting level in a specified area. It’s a quality parameter for the overall illuminance distribution. A working environment with 0.5 or more ratio is one in which people don’t notice different lighting levels with the naked eye and feel themselves in an environment in which light is well-distributed. Raising the ratio to 0.65 will give even better uniformity, which will make people with poorer vision more comfortable.

V. ENERGY EFFICIENCY [27]

At an early stage of lighting design, it was believed that overhead luminaires produced light only in the downward direction. Resulting in recommended levels in lighting design generally exceeding the lighting levels necessary to complete visual task. Even after it was realized that luminaires produce light in multiple directions, values for completion of visual tasks remained higher than necessary. Over-lighting a space can result in unnecessarily high energy usage. By creating a perception-based lighting design, lighting can be better tailored towards the needs of space occupants, therefore reducing energy consumed. According to electrical energy consumption data analysed by the U.S. Energy Information Administration, in 2017, 10.6% of the total energy consumed by the commercial sector was consumed by lighting (U.S. Energy Information Administration [EIA], 2018). Switching to more energy efficient light sources, providing personalized lighting control, and utilizing daylight control where applicable can all result in lower energy consumption.

Chapter 3
ENERGY EFFICIENT OFFICE ILLUMINATION

DESIGN OF OFFICE LIGHTING

The office environment has a significant impact on an individual's performance at work in a variety of ways. One of the most influential factors in the office environment is lighting. From concentration to satisfaction levels, studies have shown that an individual's health, well-being, and performance at work can change at the flick of a switch.

From eye strain to headaches, a worker's health can be directly affected by poor lighting. However, it can also affect employees in more subtle ways. From wakefulness to contentment, well designed lighting does much more than address simple health and safety issues. Office worker satisfaction and subsequent productivity can be positively affected by well-designed lighting.

The following are some tips to design a well energy efficient office premises lighting arrangement to improve office ambience both figuratively and financially. [28]

3.2 Lighting Regulations for Workplace:

Managing the above health and safety risks for employees is essential. When it comes to workplace lighting, there are regulations for new and existing buildings applicable to office spaces. Legislation governing office lighting is published by the Health and Safety Executive and covers health, safety, and minimum illumination levels for the workplace.

The Society of Light and Lighting (SLL), part of the CIBSE (Chartered Institution of Building Services Engineers) provides the office lighting guide LG7. This comprehensive guide focuses on ensuring minimum lighting levels for the office space are met while providing a stimulating working environment at the same time. [29]

Bureau of Indian Standards has published some guideline and specific range for Interior lighting. According to norms for Indoor Lighting system, maintenance of all lighting installations is essential as it keeps the performance of the system within the design limits and promotes safety and efficient use of energy. It is a fact that the lighting level provided by a lighting installation will decrease gradually throughout the life of the installation. Several terms have been used to describe the factor to account for this reduction but in this part throughout the term maintenance factor is used. [30]

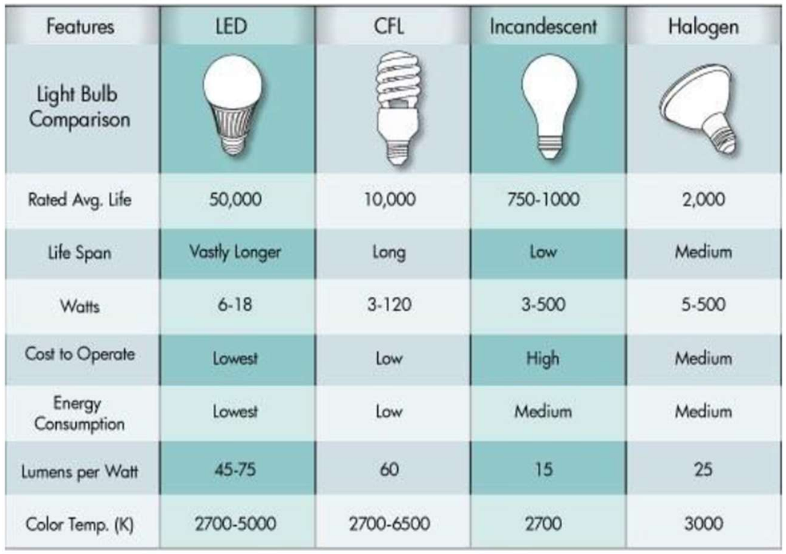
3.3 ENERGY CONSERVATION MEASURES

These lamps have an efficacy of 10 to 20 Lumen/W and a life of 1,000 burning hours, there are varieties of gas discharge lamps with efficacies ranging between 50 and 200 Lum/W and having a life between 5,000 and 15,000 burning hours. These gas discharge lamps are:[31]

- ✓ Tubular fluorescent lamps.
- ✓ Compact fluorescent lamps (CFLs)
- ✓ High pressure mercury vapour lamps (HPMV)
- ✓ High pressure sodium vapour lamps (HPSV)
- ✓ Metal halide lamps.

The best solution in this area is to gradually introduce electronic ballasts. These ballasts, not only have very low losses because of electronic components, but increase the luminous efficacy of fluorescent lamps because of high frequency operation. The overall luminous efficacy of an electronic ballast and high frequency fluorescent lamp combination is 25 percent higher than that of a conventional ballast and fluorescent lamp combination.[32]

Even the best lamp and ballast combination may not give the ideal result if used in luminaires which are poorly designed: A lot of light will be wasted in such luminaires. It is imperative today to investigate all the aspects of application and select the most optimum solution for all lighting installations. For example, luminaires with mirror optics and widespread light distributions wave approximately 25 to 33 percent energy for the same lighting level in offices. Similarly, road lighting luminaires using pot optics and tubular HPSV lamps achieve the same lighting parameters with 30 percent



Features	LED	CFL	Incandescent	Halogen
Light Bulb Comparison				
Rated Avg. Life	50,000	10,000	750-1000	2,000
Life Span	Vastly Longer	Long	Low	Medium
Watts	6-18	3-120	3-500	5-500
Cost to Operate	Lowest	Low	High	Medium
Energy Consumption	Lowest	Low	Medium	Medium
Lumens per Watt	45-75	60	15	25
Color Temp. (K)	2700-5000	2700-6500	2700	3000

Fig. 3.1: Comparison for Common Light Sources [33]

a smaller number of poles and luminaires than the conventionally designed luminaires. The associated energy and material savings are enormous.

3.4 <u>Demand Charge:</u>

This is the monthly cost based on the connected electrical load of the building. Actual demand is metered by the utility and the charge is based on the month's demand peak. With this in mind, it not only pays to reduce wattage, but reduce consumption during the day's peak load period, which is typically at midday. The utility may also impose a ratchet clause based on demand, locking in the demand charge at maximum demand for the recent past.

3.5 <u>Energy Use Charge</u>

I. It is the monthly charge by the kWh for electrical energy consumed by the building's electrical systems. The lighting energy management goals therefore can be clearly stated as:

a) Reduce wattage (power) required by the lighting system

b) Reduce energy (power x time) consumed by the lighting system

II. To measure the energy performance of lighting systems, a variety of metrics can be used:

a) <u>Total wattage:</u> For all lighting equipment (does not include impact of controls)

b) <u>Total energy consumed:</u> For all lighting equipment

c) Watts per square metre: This metric, called light power density (LPD), is determined by dividing total watts by the total area of the space in square metres. Lighting requirements in the National Building Code (NBC) and Energy Conservation Building Code (ECBC) typically set restrictions on light power density

d) kWh per square metre: This metric, called the energy utilization index, is determined by dividing the total kWh of energy consumed by the lighting system in a space by the total area of the interior space in square metres. The advantage of using the energy utilization index is that it includes the factor of time and encourages the use of lighting controls that reduce the amount of time the lighting system operates when it is not needed.

III. Relevant Formulae

Using local environmental data and system performance data from manufacturers' literature, we can use the formulae below to determine the energy characteristics of an application:

a) **Demand for power (kW)** = System input wattage (W) + 1000

b) **Energy consumption (kWh)** = System input wattage (kW) x hours of operation/year

c) **Hours of operation/year** = Operating hours/day x Operating days/week x Operating weeks/year

d) **Lighting system efficacy (lumens per watt or LPW)** = System lumen output + Input wattage

e) **Light power density (W/m^2)** = Total system input wattage (W) + Total area (square metres)

f) **Watts (W)** = Volts (V) x Current in amperes. (A) x Power-factor (pf)

g) **Voltage (V)** = Current in amperes (A) x Impedance (Ohms)

3.6 UPGRADE STRATEGIES

I. Several simple strategies can be employed to adopt energy-effective lighting in existing installations, commonly called an 'upgrade' or 'retrofit' Regardless of strategy, however, every lighting upgrade requires the same though process, as shown below in a simplified form

a) Determine the required maintained light level. As the industry proverb goes, "Light is for people, not buildings." The lighting system's first task is to provide sufficient quantity and quality of light for occupants to perform relevant tasks. In existing installations, this will require a lighting system audit

b) Determine the qualitative lighting requirements. Identify all quality issues such as glare, colour, aesthetics, distribution, and attendant factors (such as surface reflectance and ceiling heights) that must be given priority during equipment selection and design. In existing installations, this will require a lighting system audit.

c) Identify equipment options that produce the desired maintained quantity and quality of light and also save energy. Equipment options will include lamps, ballasts, luminaires, and advanced controls (occupancy sensors, dimming controls, photocells, lighting management systems, etc).

d) Identify strategies that support the goal of reducing energy consumption, such as planned lighting maintenance, repainting room surfaces to give them a higher reflectance (if appropriate) and developing a written lighting energy policy

e) Choose the best package of equipment and strategies that 'will achieve the desired lighting goals while delivering desired economic performance.

II. Lighting Upgrade Strategies

a) **Maintained Light Levels:** With this strategy, the same level is maintained as in 'the existing system after upgradation. This goal can be accomplished by incorporating automatic controls and more efficient lamps and ballasts into the lighting system.

b) **Optimized Light Levels:** In some applications, lighting audit may reveal considerable opportunities to reduce lighting levels. in a renovation or new construction situation, we can reduce light levels by focusing higher intensities closer to the task. For example, in an open plan office, indirect lighting can be specified to provide lower light levels for ambient illumination, while higher light levels are provided at the task by workstation task lighting.

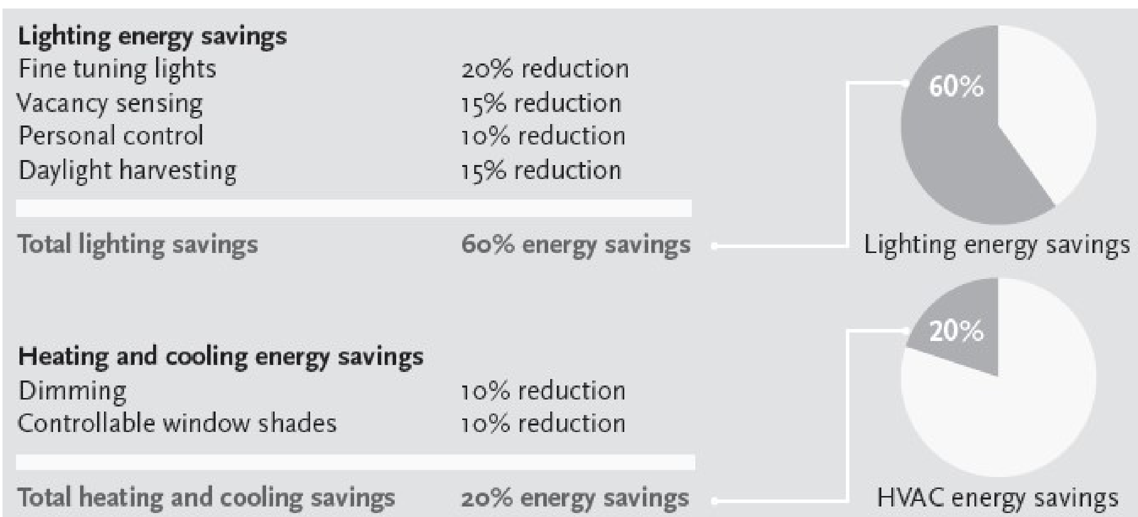


Fig. 3.2: Possible Controls to save energy by Lighting [34]

c) **Increased Light Levels:** This strategy entails increasing light levels via strategies such as planned lighting maintenance, higher room surface reflectance and higher luminaire efficiency.

Other considerations are:

a) Incorporate day lighting into the lighting scheme as much as possible; there are many ways that help daylight penetration into the building and distribute the light; glare controls should be provided and daylight harvesting controls can be specified for significant energy savings

b) In new construction or renovation projects, the interior designer can affect the overall efficiency of light distribution by providing finishes that give proper ceiling, wall, and task reflectance values

c) In new construction or renovation projects, the interior designer can affect the overall efficiency of light distribution by providing finishes that give proper ceiling, wall, and task reflectance values
d) All applicable safety requirements and regulations should be strictly adhered to when any work is done on an electrical system
e) Consider a planned lighting maintenance programme and opening retrofit opportunities that reduce light output and energy consumption
f) Ensure that all retrofits are permanent and understood by the maintenance personnel in a written and communicated lighting policy, so that old components are not reintroduced back into the lighting system later
g) It has to be sure to include provisions for legal compliance in disposing of any lighting waste
h) Ensure compliance with the Energy Conservation Act and other statutory regulations

3.7 COMPARING SYSTEMS

To compare the relative efficiencies of lighting systems along with Luminaire evolution as shown in Fig. 3.3, the following may be considered:

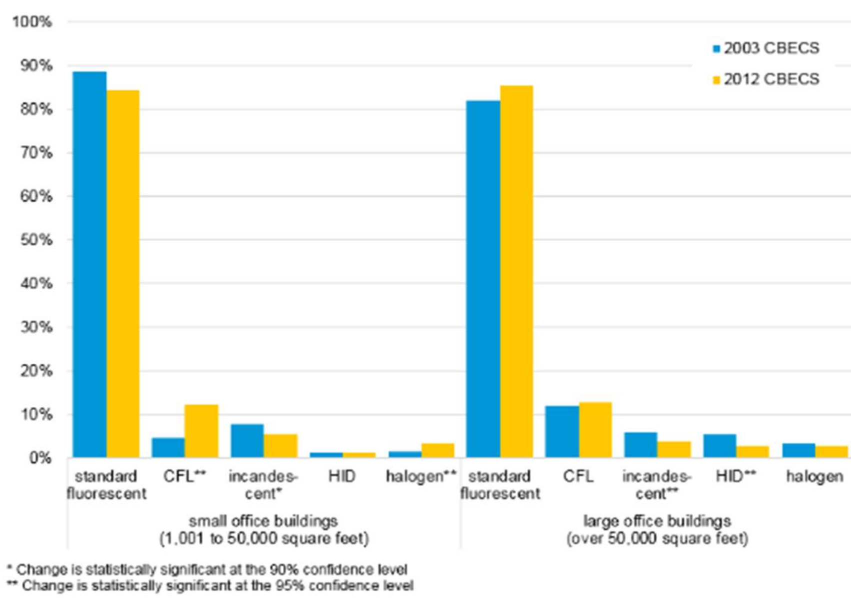


Fig. 3.3: Evolution of using different Fluorescent Light for Energy-efficient Lighting [35]

I. Compared efficacies for various light sources and lighting systems. Efficacy, expressed in lumens (light output) per watt (electrical input), is often used to compare the relative efficiencies of lamps and lighting systems. It is abbreviated LPW or Lum/Watt. Efficacy is the ratio of the lumen output of a lamp or lighting system to its rated input wattage
II. Compared power requirements. Determined the light level goals and compare various options that achieve these goals at the lowest wattage possible. From this LPD or watts per square metre can also be compared.

III. Compared energy usage. Determined the light level goals and compared various options that achieve these goals with less energy consumption. This is advantageous as it includes automatic lighting controls, which reduce operating time, not watts. From this the energy utilization index, or kWh consumed per square metre can be compared.

IV. Determine the light level goals and compare various options that achieve these goals with less energy consumption. This is advantageous as it includes automatic lighting controls, which reduce operating time, not watts. From this we can also compare the energy utilization index, or kWh consumed per square metre

A luminaire may be optimized for one type of lamp but may be relatively inefficient with a different lamp type. Both the light output ratio (LOR) and the coefficient of utilization (COD) of the system need to be considered.

Comparing energy usage for various systems that achieve the same maintained light level target is useful in that it includes controls, which affect energy consumption over time but not system wattage. With this metric, we can include more specific parameters about the installation, such as its target light level and hours of operation. LPD is most useful when screening a space for lighting efficiency and to ensure compliance with applicable lighting codes when conducting a building activity that is governed by these codes.

3.8 ECONOMICS: [36]

I. When upgrading an existing installation, a capital investment is made that produces energy savings, which deliver a payback and return on the investment. There are several ways of using economics to compare lighting systems. The most popular for screening purposes are simple payback and return on investment.

a) First, it is required to determine the initial cost of the new lighting system, and then compare energy usage to the existing system to determine energy savings. **Initial Cost (Rs)** = Equipment Cost + (Installation Hours x Labour Rate) **Annual Energy Savings** = (A - B) x Energy Rate charged by utility

A = [Existing system wattage (kW) x Annual operating hours (h)], **B**.= [New system wattage (kW) x annual operating hours (h)]

b) Now determine simple payback, five-year cash flow and simple return on investment.

[1] **Simple Payback on an Investment (Years)** = Initial Cost (Rs) / Annual Energy Savings (Rs)

[2] **5 Year Cash Flow (Rs) = 5 Years- Payback (Years) x Annual Energy Savings (Rs)**

[3] **Simple Return on Investment (%) = [Annual Energy Cost Savings (Rs) / Net Installation Cost (Rs)] x 100**

c) Another method of comparing lighting systems is to look at the cost efficacy of the system, expressed as rupees per lumen hour, and the total cost of ownership for the system over its life.

Cost of Light/Lumen Hour = (Initial Cost +Total Operating Cost)/ (Total Lumens Delivered x Hours of Operation)

** Total Operating Cost and Hours of Operation are set for any period of time that the specifier or owner wishes to consider.

Simple Life Cycle Cost = Initial Cost + (Annual Operating Cost x Life of System in Years).

Annual Operating Cost = Annual Energy Cost + Annual Maintenance Cost

** With the annual maintenance cost assuming all labour costs, replacement components, etc. The life of the system in years must be estimated. The owner can participate in determining this figure, but otherwise one could assume 20 years.

Once simple values are achieved, one can determine which lighting system makes the most economic sense to replace the existing system with. Then one can conduct a full economic analysis, including life cycle costing and return on investment that considers many economic factors such as the future value of money.

3.9 Economic Growth through Illuminance:

From fig. 3.4, it can be observed that, with the change in illuminance, the efficiency also gets effected. The behavioural change of completing a task whether complex or simple both increase with an increment in illuminance. The corelation between

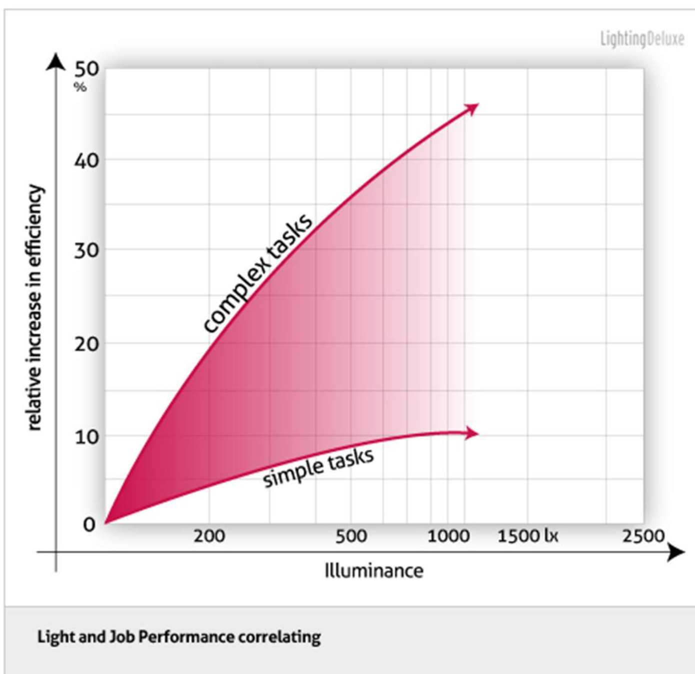


Fig. 3.4: Efficiency Behavior with change in Illuminance [37]

performing a job and illuminance is a significant decision making from the profit point of view of an organization. It can also be observed that, the efficiency of completing a complex task increases much compared to efficiency of completing a simple task. This is also very significant at the time of when organization is facing any critical situation.

Chapter 4

SURVEY & MEASUREMENT FOR BACKGROUND SETUP

4.1 Setup & Method

The motivation inspired from the need to try to implement the knowledge from the Master program and reflect it on a real-life project and try to approach sustainability aspects like energy consumption. It is important to increase the awareness about using more efficient Energy lighting designs and understand how the users of the space could affect that without forgetting the aesthetical aspects. [38]

The following are the Chosen factors and techniques used in energy efficient lighting which are commonly practiced as energy-saving opportunities:

I. Re-lamping with Energy-Efficient Lights (light source technology).

II. Improving Lighting Controls systems.

III. Making the user more efficient by Design for sustainable behaviour.

This will be done through Quantitative methods through calculating current energy consumption and light settings, Qualitative method through a survey and a personal observation method through analysing the current situation that will be added to the project design guidelines that helps at the end to suggest a new lighting design.

Both of the former parts will help creating recommendations for improvements (RFI) – shown in the methodology structure as it will serve a starting point for the suggested new lighting design.

Not all the points that will be mentioned in the simulation would be taken in consideration during the energy calculation or the suggested new lighting design, it will be there based as a literature-based result that help to understand the situation in border perspective for any future consideration. [39]

4.2 Initial Stage:

Computer simulated lighting design was conducted to explore the variability that is present in current illuminance-based lighting design standards. A total of Four lighting design layouts were designed just identical to the room of four departments in JMS MINING PVT. LTD. Corporate head office at Newtown, Kolkata. The four departments are:

- LCM Department
- Human Resource Department
- Finance Department
- Operation Department

and evaluated using DIALux. All the department rooms were on the 3rd Floor of the building. Shapes of all the rooms were totally distinct with each other. Model dimensions measured that each room has a height of 2.743 m & the work plane height was taken 0.8 m in each working area. Length & width was different for each room as we are here executing a real-life improvisation/ modification & all the rooms having different shapes as per their constructional feature.

4.3 Room Layout Design:

I. LCM Dept.

LCM Department is one of the crucial departments of JMS MINING PVT. LTD. LCM stands for Life Cycle Management. This department involves daily co-

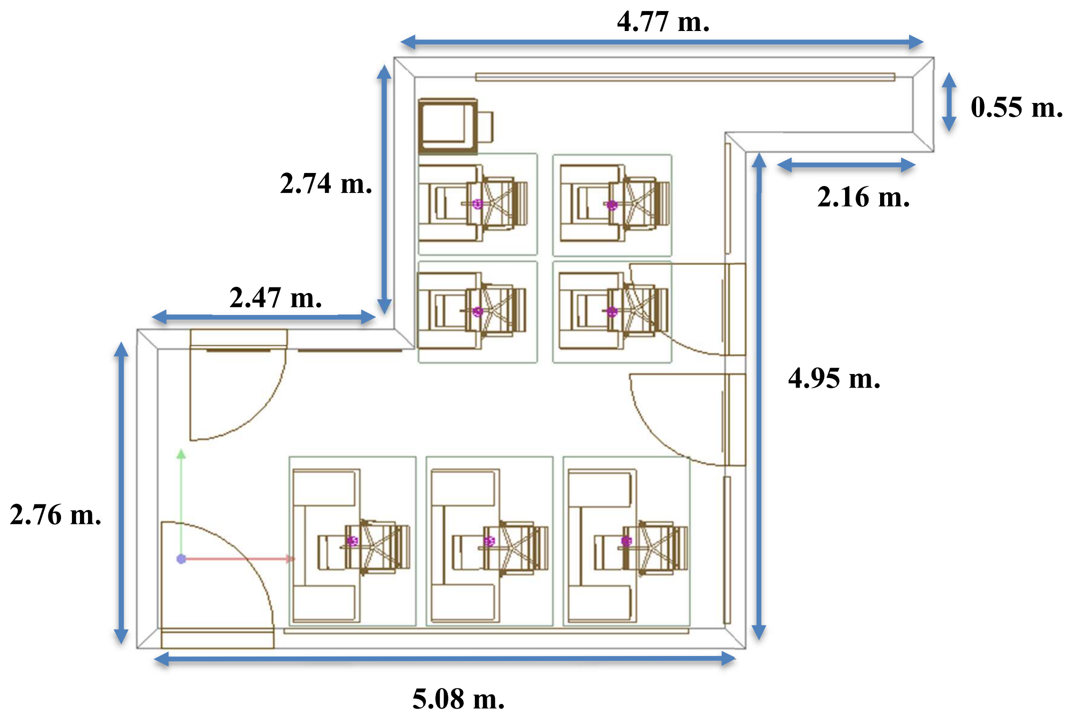


Fig. 4.1: LCM Dept. 2-D Layout

ordination with project regarding all operational machines. The department is responsible for any breakdown, machine inventory, stocks, and machine spare related issues in parallel with projects. In this Kolkata office, this department consists of 7 members who are sitting in every cubicle. From the circadian system point of view, all the people who are sitting here are in the age group of 25 to 40. So according to BIS & National Lighting Code Office Lighting Clause 9.1, illuminance level should be 300 Lux to 500 Lux. So, as per the objective of this project, this level lux has to maintained after modification. The dimensional view of this room is shown above. Based on the diagram, the area of the room is calculated below.

$$\text{Area of Workspace required Lighting} = [\{5.08*2.76\} + \{2.74*(5.08-2.47)\} + \{2.16*0.55\}]\ m^2$$

$$= 22.36\ m^2$$

II. HR Department:

HR Department is one of the crucial departments of JMS MINING PVT. LTD. HR stands for Human Resource. This department involves all the jobs related to Manpower Recruitment, Manpower engagement & manpower deployment. All the issues regarding with existing manpower i.e., payroll, provident fund, insurance etc. all are taken care by this department. In this Kolkata office, this department consists of 13 members who are sitting in every cubicle. From the circadian system point of view, all the people who are sitting here are in the age group of 25 to 45. So according to BIS & National Lighting Code Office Lighting Clause 9.1, illuminance level should be 300 Lux to 500 Lux. So, as per the objective of this project, this level lux has to maintained after modification. The dimensional view of this room is shown above. Based on the diagram, the area of the room is calculated below.

Area of Workspace required Lighting= [{(7.24-3.58) *5.5} + (1.29*3.58) + (2.3*3.58)] m^2

$= 32.98 \, m^2$

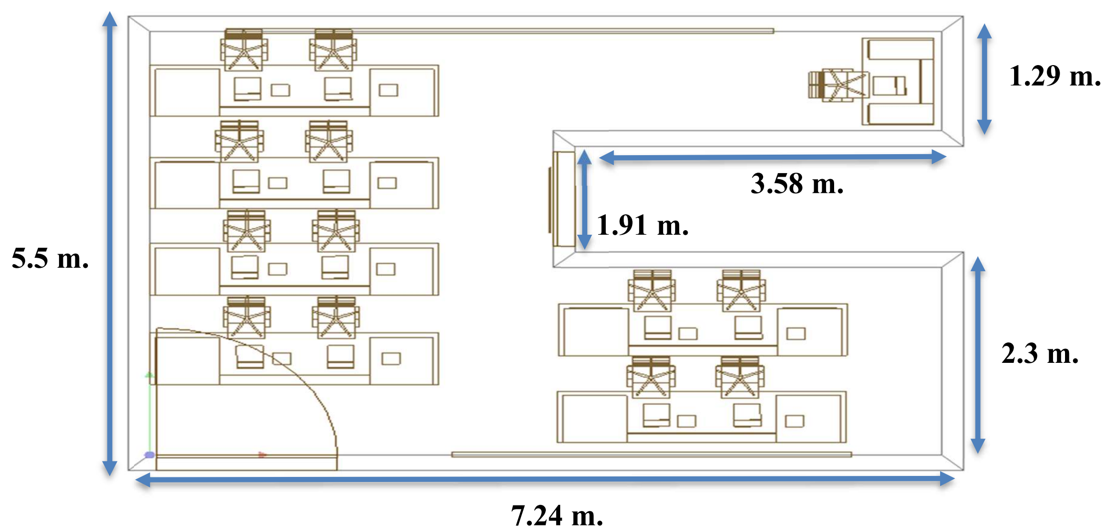


Fig. 4.2: HR Dept. 2-D Layout

III. <u>Finance Department:</u>

Finance Department is one of the crucial departments of JMS MINING PVT. LTD.

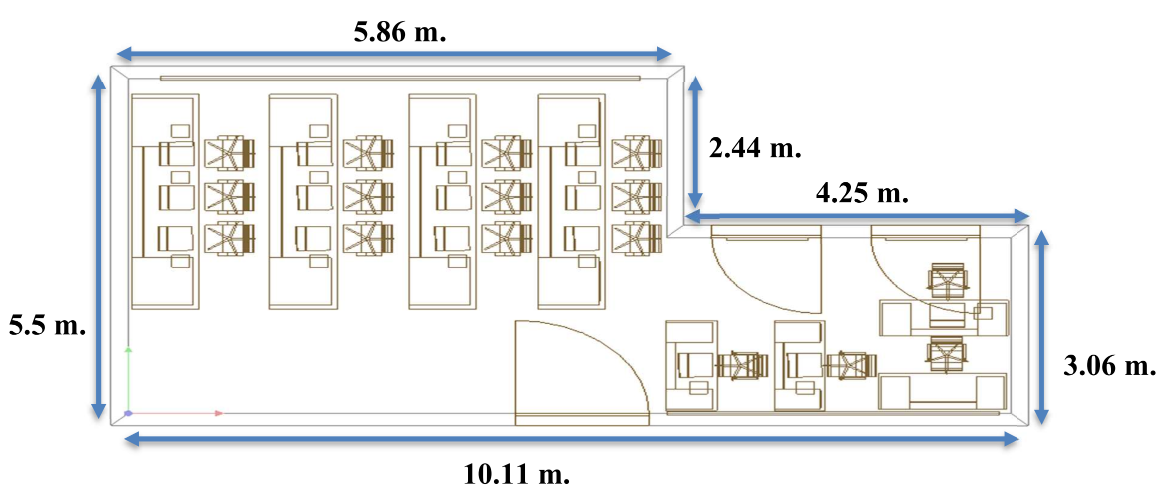


Fig. 4.3: Finance Dept. 2-D Layout

This department involves all the jobs related to Company Profit, Loss, Annual Turnover. All the issues regarding company account, books, debit, banking, asset management etc. are taken care by this department. In this Kolkata office, this department consists of 16 members who are sitting in every cubicle. From the circadian system point of view, all the people who are sitting here are in the age group of 25 to 45. So according to BIS & National Lighting Code Office Lighting Clause 9.1, illuminance level should be 300 Lux to 500 Lux. So, as per the objective of this project, this level lux has to maintained after modification. The dimensional view of this room is shown above.

Area of Workspace required Lighting= [(5.86*5.5) + (4.25*3.06)] m^2

= 45.24 m^2

IV. Operations Department:

Operation Department is heart of JMS MINING PVT. LTD. This department involves all the jobs related to production, maintenance, and manufacturing. All the issues regarding annual production, supply chain management, repairing workshop etc. are taken care by this department. In this Kolkata office, this department consists of 10 members who are sitting in every cubicle. From the circadian system point of view,

Fig. 4.4: Operation Dept. 2-D Layout

all the people who are sitting here are in the age group of 25 to 50. So according to BIS & National Lighting Code Office Lighting Clause 9.1, illuminance level should be 300 Lux to 500 Lux. So, as per the objective of this project, this level lux has to maintained after modification. The dimensional view of this room is shown above.

Area of Workspace required Lighting= (8.48*3.27) m^2

= 27.73 m^2

4.4 Survey of Departments for Luminaire Data

After designing the layout of every room, a survey was done to get the luminaire data of every room so that the .ies file of the luminaire can be added to the design for getting the existing lighting design data and improvising that for the further process of this research study. So, physical monitoring was done to get the .ies files for simulation.

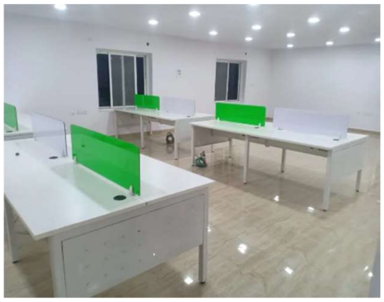


Fig. 4.5: Operation Dept.

Fig. 4.6: LCM Dept.

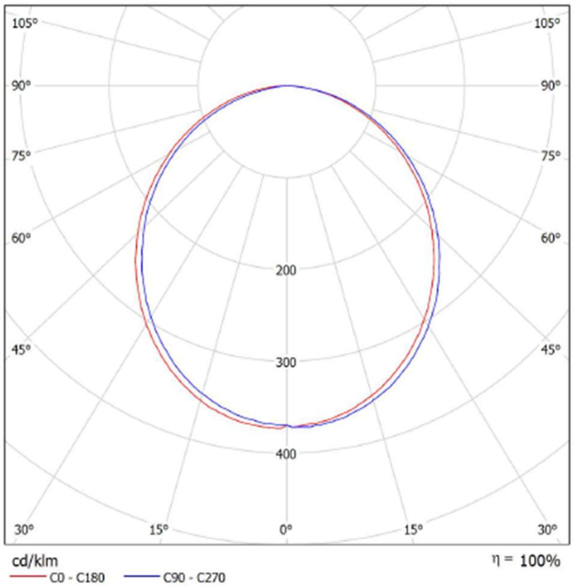
Fig. 4.7: Existing Luminaire

After visual observation, now the objective was to go through the luminaire datasheet of the luminaire used in JMS MINING PVT. LTD. Office premises and then do a thorough analysis for the purpose of improvisation. Before that, we have to know the proper rating and model, type of the luminaire that is already existing.

Parameter	**Description**
Name of Luminaire	INTENSO
Model	I01040RD00
Make	LIGHTING TECHNOLOGIES
Wattage	10 watts
Luminous flux	1525 Lumen
Correction Factor	1.00
Light Output Ratio	100.00

Table 4.1: Simulation for Existing Luminaire Parameters

Depending on the above parameters and after simulating the .ies file in DIALux, the luminaire technical database along with schematic diagram was achieved as output.



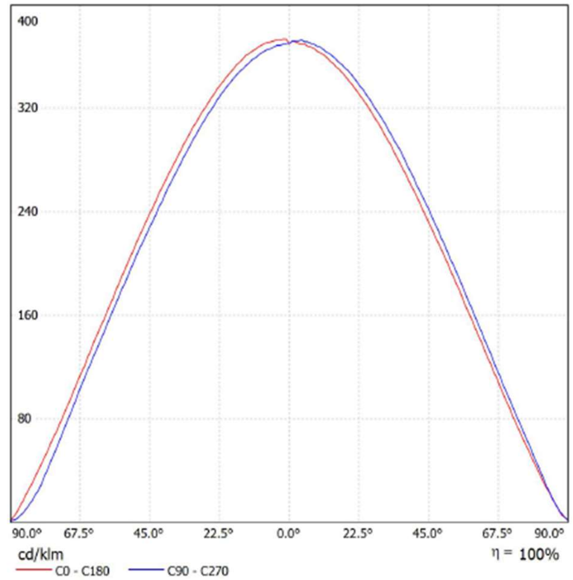


Fig. 4.8: LDC (Polar) for Intenso

Fig. 4.9: LDC (Linear) for Intenso

After going through the LDC Diagram and its variance in different γ – angle and its candela values it is now required to see the how this candela (luminous intensity) will be distributed in an enclosed room. That also can be simulated graphically from DIALux. So, let's look after its luminance simulation diagram**.

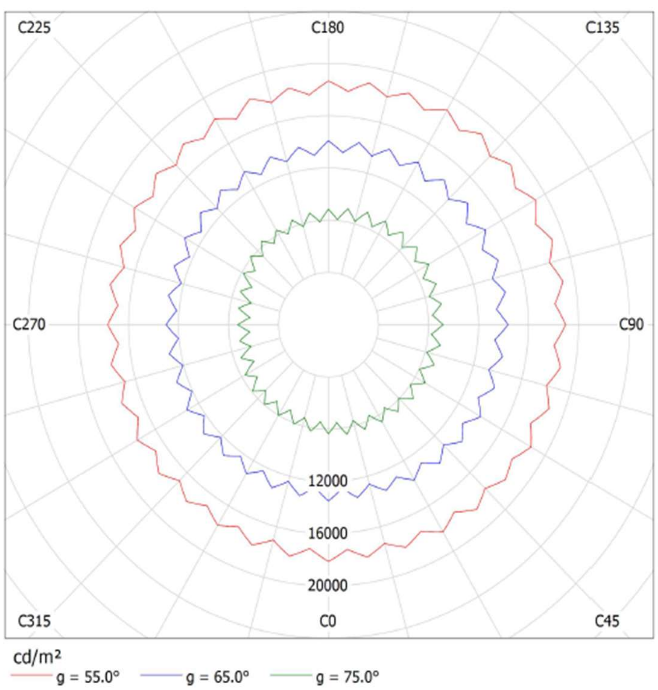


Fig. 4.10: Luminance Diagram of 10W Intenso

**This Luminance diagram in Fig. 4.10 also introduces with the Glare datasheet.

Parameter	Description
Name of Luminaire	FULLLIT
Model	F02557R0L0
Make	LIGHTING TECHNOLOGIES
Wattage	25 watts
Luminous flux	2978 Lumen
Correction Factor	1.00
Light Output Ratio	100.00

Table 4.2: Simulation for Modified Luminaire Parameters

So, based on this existing datasheet which we extracted from the simulation of existing luminaire, the task was to determine the more effective luminaire setup which can make the objective of this real-life project successful i.e., illuminance and uniformity as per BIS Standard of office lighting by less power consumption and less no. of luminaire so that it can be cost-effective.

Since, this is a quantitative approach, so another luminaire of the same manufacturer was selected with more wattage so that no. of luminaire required can be less and also, the goal was to set this luminaire in such a way that it can be cost-effective compared to the previous one.

For that reason, the below luminaire was chosen for the modification of JMS MINING PVT. LTD. Office building lighting setup:

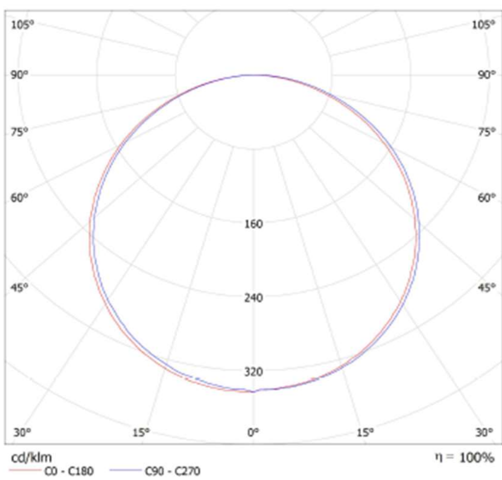


Fig. 4.11: LDC (Polar) for Fulllit

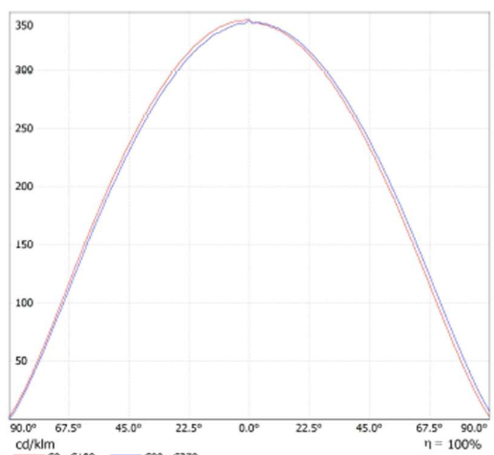


Fig. 4.12: LDC (Linear) for Fulllit

From the above data, it was compared with the existing luminaire and an idea was built that this luminaire can be used for modification. For more clear visualization, it was necessary to simulate the .ies file of this luminaire in DIALux, after going through the LDC Diagram and its variance in different γ – angle and its candela values it is now required to see the how this candela (luminous intensity) will be distributed in an enclosed room. That also can be simulated graphically from DIALux. So, here is its luminance simulation diagram**.

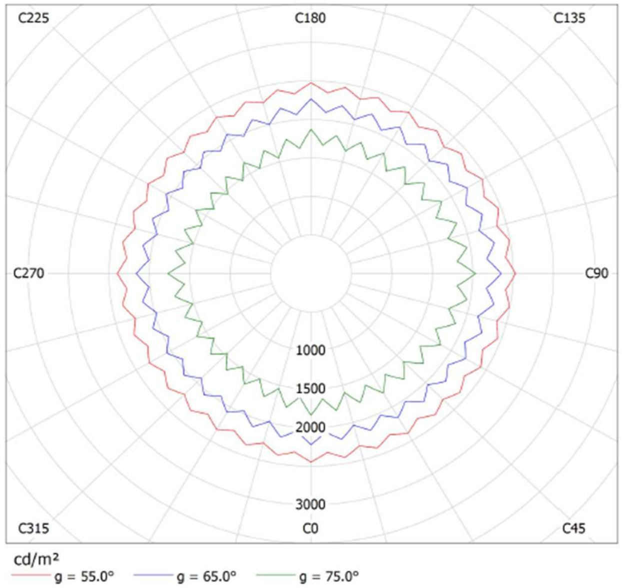


Fig. 4.13: Luminance Diagram of 25W Fulllit

**This Luminance diagram in Fig. 4.13 also introduces with the Glare datasheet.

The comparison between the output of these two types of luminaires are shown in Chapter 7 in brief. There it is clearly described that how this selected luminaire makes the objective of this project successful from all aspects.

So, the exploration of this illuminance output was carried out with one idea keeping in mind that all the improved output should not only be energy efficient & cost-effective but also all critical illumination parameter values should be as per BIS Standard.

That's why before the initiation of comparison between output achieved by DIALux simulation, the following table data was vital to be reminded as per National Lighting Code.

Parameter	Specific Plane	Unit	Value	% Value
Reflectance	Ceiling	-	0.6 - 0.9	60 - 90
	Wall	-	0.3 – 0.8	30 – 80
	Floor	-	0.1 – 0.5	10 – 50
Uniformity	-	-	0.5	50
Illuminance	Task Area	Lux	500	-
	Immediate Surrounding	Lux	300	-

Table 4.3: Parameter Values as per National Lighting Code & BIS**

**As per SP 72 (2010): National Lighting Code 2010 Part 5, Section -2, Clause 9.1

Chapter 5
EXISTING ILLUMINATION

5.1 DIALux 4.13 Simulation:

To realize the goal of Stage 1, Illuminance values across designated surfaces must be achieved for all four lighting layouts. Illuminance values were then calculated in DIALux 4.13. For that, the 3-D design of each department rooms were modelled and then luminaires were place identical to the real-life existing design.

i. LCM Department:

Fig. 5.1 shows the 3-D DIALux Model of LCM Room along with existing luminaire setup which we get after making 2-D model that already showed in Chapter 4. Room Dimension and lighting parameters has been already discussed earlier.

Fig 5.1: LCM Room 3-D Layout

ii. HR Department

Fig. 5.2 shows the 3-D DIALux Model of HR Room along with existing luminaire setup which we get after making 2-D model that already showed in Chapter 4. Room Dimension and lighting parameters has been already discussed earlier.

Fig 5.2: HR Room 3-D Layout

iii. <u>Finance Department</u>

Fig. 5.3 shows the 3-D DIALux Model of Finance Room along with existing luminaire setup which we get after making 2-D model that already showed in Chapter 4. Room Dimension and lighting parameters has been already discussed earlier.

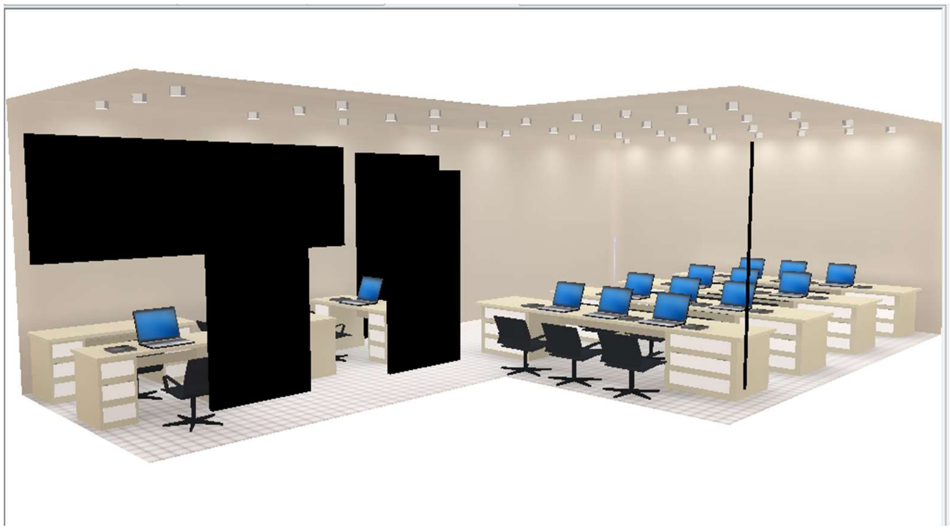


Fig 5.3: Finance Room 3-D Layout

iv. <u>Operation Department</u>

Fig. 5.4 shows the 3-D DIALux Model of Operation Room along with existing luminaire setup which we get after making 2-D model that already showed in Chapter 4. Room Dimension and lighting parameters has been already discussed earlier.

Fig 5.4: Operation Room 3-D Layout

5.2 Existing Luminaire Grid View

i. Grid at LCM

Fig. 5.5 shows the Top View of LCM Room 3-D Model so that the lighting grid can be showed up i.e., how the luminaires are mounted in the ceiling of the room and how their co-ordinates are distributed in that plane.

Fig 5.5: LCM Room Grid Configuration

ii. Grid at HR Department

Fig. 5.6 shows the Top View of HR Room 3-D Model so that the lighting grid can be showed up i.e., how the luminaires are mounted in the ceiling of the room and how their co-ordinates are distributed in that plane.

Fig 5.6: HR Room Grid Configuration

iii. Grid at Finance Department

Fig. 5.7 shows the Top View of Finance Room 3-D Model so that the lighting grid can be showed up i.e., how the luminaires are mounted in the ceiling of the room and how their co-ordinates are distributed in that plane.

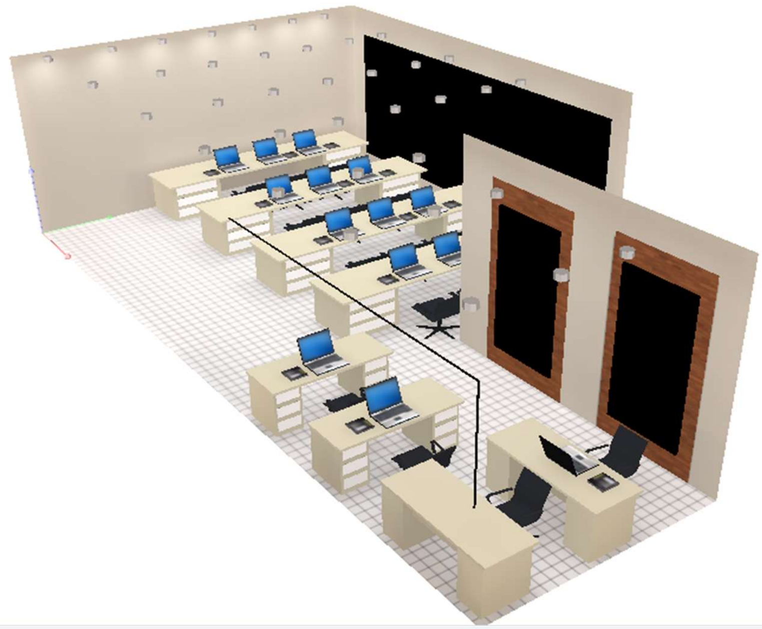


Fig 5.7: Finance Room Grid Configuration

iv. Grid at Operation Department

Fig. 5.8 shows the Top View of Operation Room 3-D Model so that the lighting grid can be showed up i.e., how the luminaires are mounted in the ceiling of the room and how their co-ordinates are distributed in that plane.

Fig 5.8: Operation Room Grid Configuration

5.3 Output Simulation through DIALux 4.13

After setting up all the designs of each room as per reality and all the materials i.e., table, desktop, chair, land phone etc. the .ies files of the luminaire was imported in the DIALux 4.13 database. Then the luminaires are set up as per their co-ordinates which measurement we got after physical survey of each room.

After simulation of the design in DIALux 4.13, a summarized report of the existing Lighting setup of JMS MINING PVT. LTD. Corporate Office premises is generated. The report will be presented below one by one department.

i. Illuminance Distribution:

a. LCM Department:

Fig. 5.9 shows the Total Illuminance Distribution of LCM Room which is an output of DIALux simulation. The diagram shows illuminance at different coordinates for the existing luminaire and working plane. From this, average illuminance, max illuminance, min illuminance can be known for LCM room.

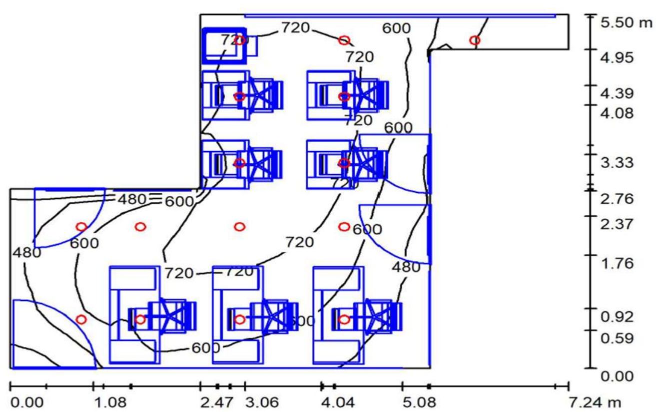


Fig. 5.9: Illuminance distribution of LCM Dept.

b. HR Department:

Fig. 5.10 shows the Total Illuminance Distribution of HR Room which is an output of DIALux simulation. The diagram shows illuminance at different coordinates for the existing luminaire and working plane. From this, average illuminance, max illuminance, min illuminance can be known for HR room.

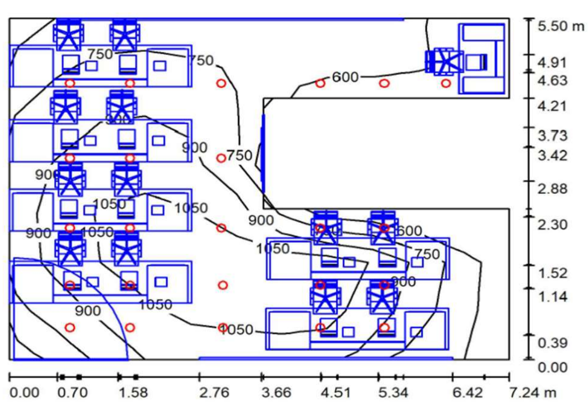


Fig. 5.10: Illuminance distribution of HR Dept.

c. Finance Department:

Fig. 5.11 shows the Total Illuminance Distribution of Finance Room which is an output of DIALux simulation. The diagram shows illuminance at different coordinates for the existing luminaire and working plane. From this, average illuminance, max illuminance, min illuminance can be known for Finance room.

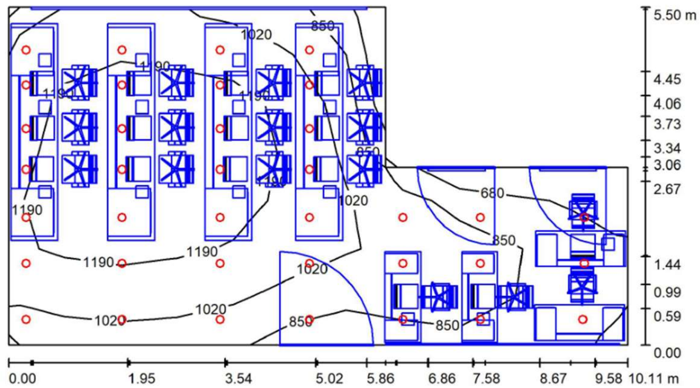


Fig. 5.11: Illuminance distribution of Finance Dept.

d. Operation Department:

Fig. 5.12 shows the Total Illuminance Distribution of Operation Room which is an output of DIALux simulation. The diagram shows illuminance at different coordinates for the existing luminaire and working plane. From this, average illuminance, max illuminance, min illuminance can be known for Operation room.

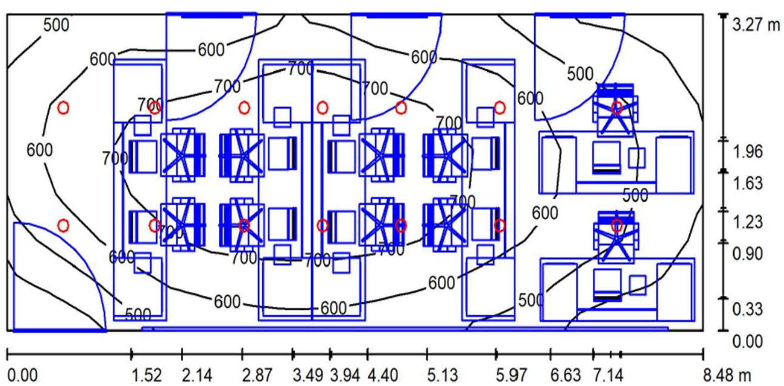


Fig. 5.12: Illuminance distribution of Operation Dept.

ii. Consideration:

Before starting the simulation of the rooms, the Luminaire data was analysed by their .ies files. Due to that, some considerations were made, and some parameters were taken of constant value as shown in Table 5.1.

Parameter	Value
Work plane Height	0.8 m.
Light Loss Factor	0.8
Boundary Zone	Nil

Table 5.1: Value of Constant Parameters

Through the whole simulation, these values were maintained based on physical survey & assumption.

iii. Simulation Data:

The basic purpose of this project is to get the real time data from which a comparison can be made so that the luminaire selection and setup can be executed based on which an idea can be constructed for making an energy efficient lighting along with keeping its aesthetic value constant or better as well as employee health.

For this reason, firstly we will simulate in DIALux 4.13 with the existing lighting setup to get the illuminance parameters values. We will simulate all the 3-D designs along with the .ies files of the existing luminaire for all the departments one by one.

a. LCM Department:

After Simulation in DIALux for the existing luminaire setup of LCM Room, the value of parameters is shown in Fig. 5.13 along with the Table 5.2,

Height of Room: 2.743 m, Mounting Height: 2.743 m, Light loss factor: 0.80 Values in Lux, Scale 1:71

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	623	249	830	0.400
Floor	27	328	30	618	0.093
Ceiling	75	264	183	864	0.693
Walls (8)	75	386	58	5374	/

Workplane:
Height: 0.800 m
Grid: 30 x 50 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.711, Ceiling / Working Plane: 0.423.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	15	LIGHTING TECHNOLOGIES I01040RD00 INTENSO 10W NW (1.000)	1525	1525	10.0
			Total: 22871	Total: 22872	150.0

Specific connected load: 6.20 W/m² = 0.99 W/m²/100 lx (Ground area: 24.21 m²)

Fig. 5.13: Simulation Data of LCM for Existing Luminaire

Parameters	Unit	Simulated Value in DIALux 4.13
No. of Luminaire used	Pc.	15
Average Illuminance of Work Plane (E_{av})	Lux	623
Uniformity on the working plane	-	0.4
Work Plane Grid	Points	30 x 50
Total Luminous Flux	Lumen	22,871
Total Load Consumption for the Luminaires	Watt	150

Table 5.2: Existing Illumination Data of LCM

b. HR Department:

After Simulation in DIALux for the existing luminaire setup of HR Room, the value of parameters is shown in Fig. 5.14 along with the Table 5.3,

Height of Room: 2.743 m, Mounting Height: 2.743 m, Light loss factor: 0.80 Values in Lux, Scale 1:71

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	852	471	1174	0.553
Floor	30	374	33	931	0.089
Ceiling	82	412	248	670	0.602
Walls (8)	82	525	73	2272	/

Workplane:
Height: 0.800 m
Grid: 11 x 7 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.679, Ceiling / Working Plane: 0.474.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	24	LIGHTING TECHNOLOGIES I01040RD00 INTENSO 10W NW (1.000)	1525	1525	10.0
			Total: 36594	Total: 36595	240.0

Specific connected load: 7.17 W/m² = 0.84 W/m²/100 lx (Ground area: 33.49 m²)

Fig. 5.14: Simulation Data of HR for Existing Luminaire

Parameters	Unit	Simulated Value in DIALux 4.13
No. of Luminaire used	Pc.	24
Average Illuminance of Work Plane (E_{av})	Lux	852
Uniformity on the working plane	-	0.553
Work Plane Grid	Points	11 x 7
Total Luminous Flux	Lumen	36,594
Total Load Consumption for the Luminaires	Watt	240

Table 5.3: Existing Illumination Data of HR

c. Finance Department:

After Simulation in DIALux for the existing luminaire setup of Finance Room, the value of parameters is shown in Fig. 5.15 along with the Table 5.4,

Height of Room: 2.743 m, Mounting Height: 2.743 m, Light loss factor: 0.80 Values in Lux, Scale 1:73

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	1018	520	1354	0.510
Floor	30	469	27	1024	0.057
Ceiling	85	444	279	861	0.629
Walls (6)	85	631	97	2128	/

Workplane:
Height: 0.800 m
Grid: 11 x 7 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.688, Ceiling / Working Plane: 0.423.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	37	LIGHTING TECHNOLOGIES I01040RD00 INTENSO 10W NW (1.000)	1525	1525	10.0
			Total: 56416	Total: 56417	370.0

Specific connected load: 8.17 W/m² = 0.80 W/m²/100 lx (Ground area: 45.31 m²)

Fig. 5.15: Simulation Data of Finance for Existing Luminaire

Parameters	Unit	Simulated Value in DIALux 4.13
No. of Luminaire used	Pc.	37
Average Illuminance of Work Plane (E_{av})	Lux	1018
Uniformity on the working plane	-	0.51
Work Plane Grid	Points	11 x 7
Total Luminous Flux	Lumen	56,416
Total Load Consumption for the Luminaires	Watt	370

Table 5.4: Existing Illumination Data of Finance

d. Operation Department:

After Simulation in DIALux for the existing luminaire setup of Operation Room, the value of parameters is shown in Fig. 5.16 along with the Table 5.5,

Height of Room: 2.743 m, Mounting Height: 2.743 m, Light loss factor: 0.80 — Values in Lux, Scale 1:61

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	606	350	800	0.577
Floor	68	258	13	631	0.050
Ceiling	75	272	202	346	0.742
Walls (4)	75	375	68	598	/

Workplane:
Height: 0.800 m
Grid: 17 x 7 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.653, Ceiling / Working Plane: 0.449.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	14	LIGHTING TECHNOLOGIES I01040RD00 INTENSO 10W NW (1.000)	1525	1525	10.0
			Total: 21347	Total: 21347	140.0

Specific connected load: 5.04 W/m² = 0.83 W/m²/100 lx (Ground area: 27.77 m²)

Fig. 5.16: Simulation Data of Operation for Existing Luminaire

Parameters	Unit	Simulated Value in DIALux 4.13
No. of Luminaire used	Pc.	14
Average Illuminance of Work Plane (E_{av})	Lux	606
Uniformity on the working plane	-	0.58
Work Plane Grid	Points	17 x 7
Total Luminous Flux	Lumen	21,347
Total Load Consumption for the Luminaires	Watt	140

Table 5.5: Existing Illumination Data of Operation

Chapter 6
MODIFICATION OF ILLUMINATION DESIGN

6.1 Initiation of Improvisation:

Since this is a real-life project for improvising a real-life problem statement, so it required a reference for comparison. Likewise, we have already got the actual existing data after physical survey of the venue and also simulate it in the DIALux 4.13, so after that we can think for an improvisation keeping our objective in mind i.e., less consumption of lighting load using less no. of luminaire but keeping the average illuminance & uniformity as per BIS standard for the sake of employee health & mind in short human circadian system.

As this project requires trial and error method in the DIALux 4.13 for quantitative analysis during simulation, so we have set the second luminaire i.e., LIGHTING TECHNOLOGIES F02557R0L0 FULLLIT CR 25W CW in various configurations and in various co-ordinates. After simulating one by one, we have got the best possible outcome in the following manner which will be demonstrated further.

6.2 Upgraded Luminaire Grid view:

i. Grid view of LCM

Fig. 6.1 shows the Top View of LCM Room with updated lighting grid i.e., how the newly selected luminaires (which has been discussed in earlier chapter) are mounted in the ceiling of the room for the modification to complete the objectives successfully and how their co-ordinates are distributed in that plane

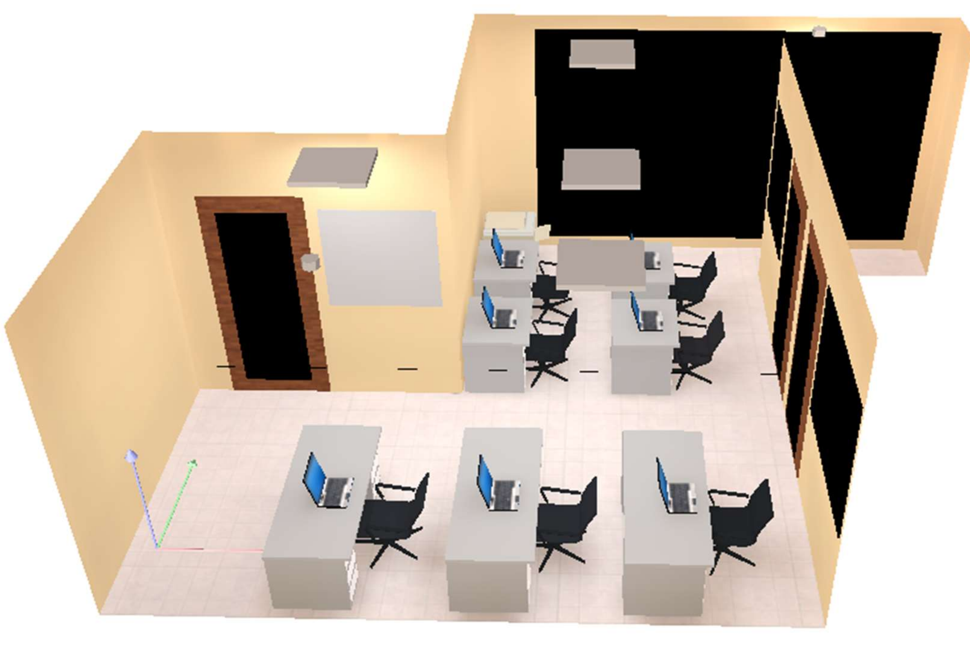


Fig 6.1: LCM Room Grid Modification

ii. Grid view of HR

Fig. 6.2 shows the Top View of HR Room with updated lighting grid i.e., how the newly selected luminaires (which has been discussed in earlier chapter) are mounted in the ceiling of the room for the modification to complete the objectives successfully and how their co-ordinates are distributed in that plane

Fig 6.2: HR Room Grid Modification

iii. Grid view of Finance

Fig. 6.3 shows the Top View of Finance Room with updated lighting grid i.e., how the newly selected luminaires (which has been discussed in earlier chapter) are mounted in the ceiling of the room for the modification to complete the objectives successfully and how their co-ordinates are distributed in that plane

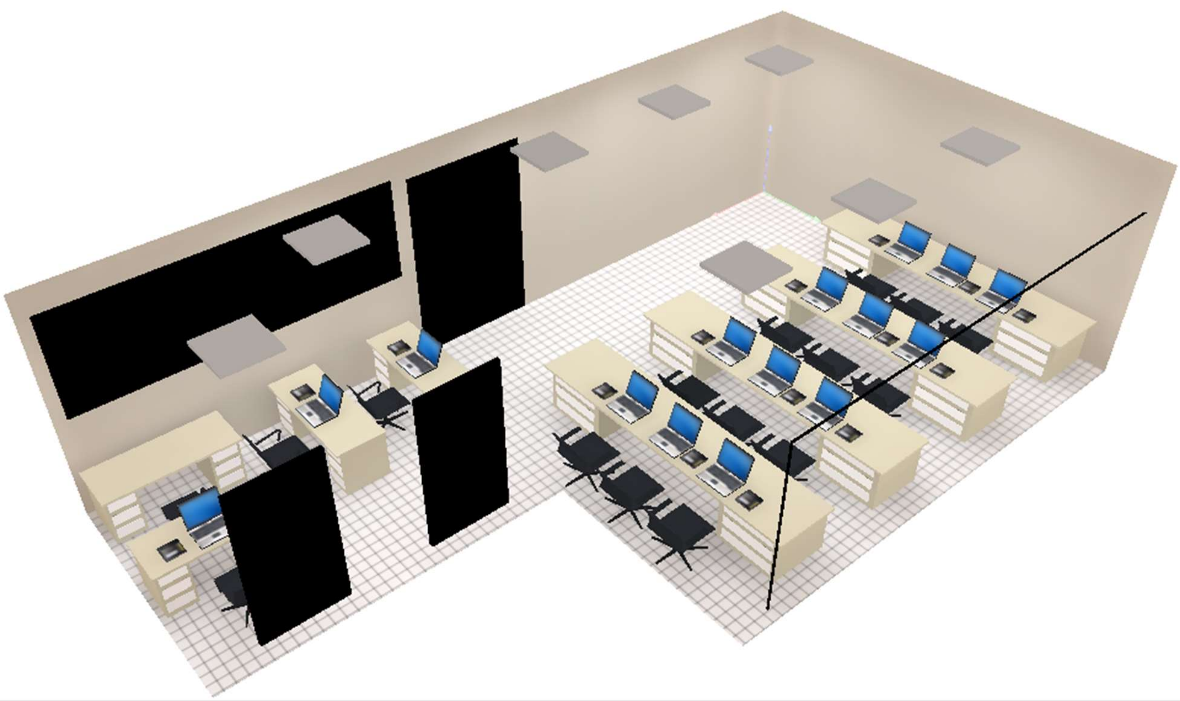


Fig 6.3: Finance Room Grid Modification

iv. Grid view of Operation

Fig. 6.4 shows the Top View of Operation Room with updated lighting grid i.e., how the newly selected luminaires (which has been discussed in earlier chapter) are mounted in the ceiling of the room for the modification to complete the objectives successfully and how their co-ordinates are distributed in that plane

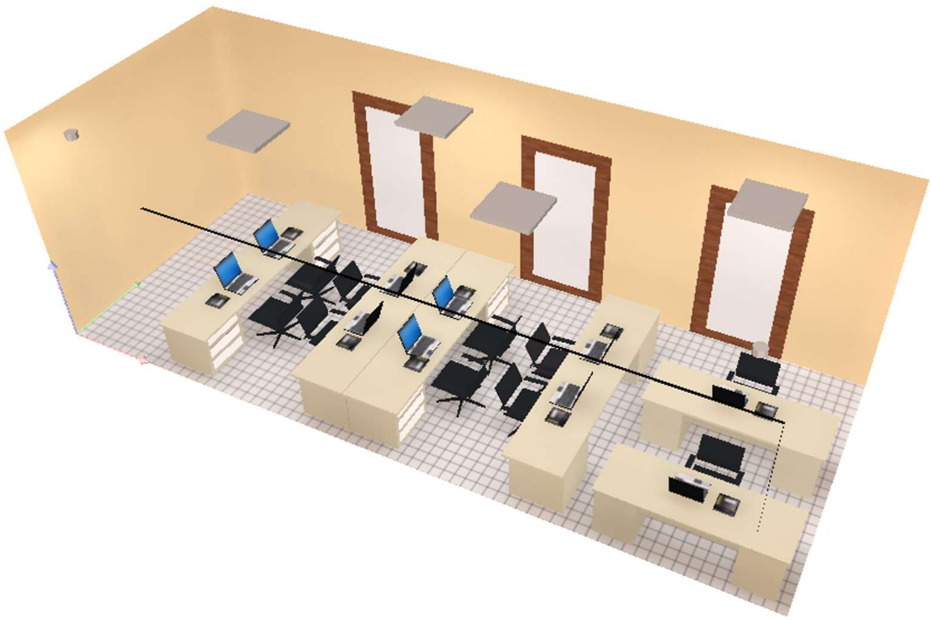


Fig 6.4: Operation Room Grid Modification

6.3 Modified Views of Rooms

I. LCM Room:

Fig. 6.5 shows the modified outlook of LCM Room after implementation of new luminaire & its setup and simulation in DIALux.

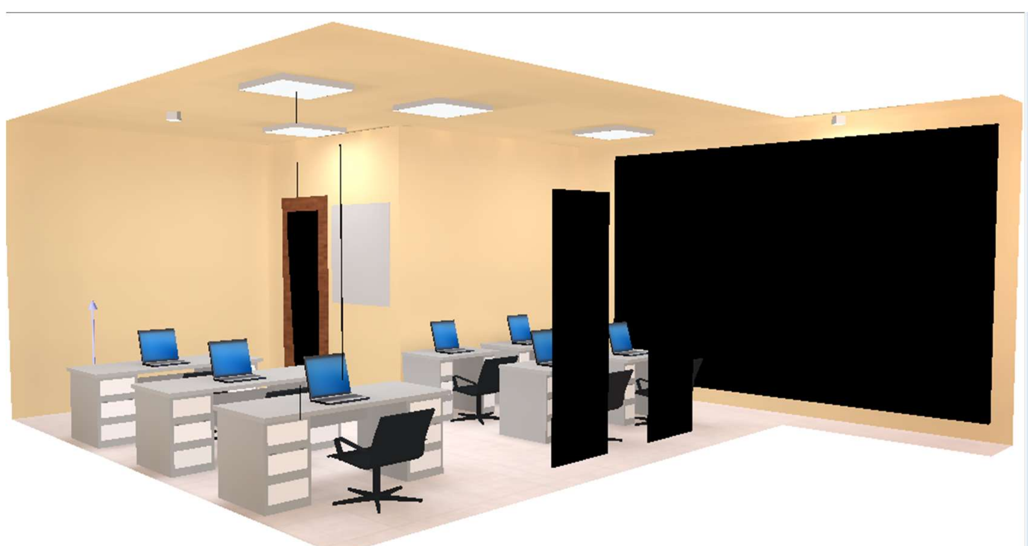


Fig 6.5: LCM Room Modified Lighting

II. **HR Room:**

Fig. 6.6 shows the modified outlook of HR Room after implementation of new luminaire & its setup and simulation in DIALux.

Fig 6.6: HR Room Modified Lighting

III. **Finance Room:**

Fig. 6.7 shows the modified outlook of Finance Room after implementation of new luminaire & its setup and simulation in DIALux.

Fig 6.7: Finance Room Modified Lighting

IV. **Operation Room:**

Fig. 6.8 shows the modified outlook of Operation Room after implementation of new luminaire & its setup and simulation in DIALux.

Fig 6.8: Operation Room Modified

6.4 Output Simulation of Modified Design via DIALux 4.13

Let's move to the final destination of this problem i.e., analysis of the modified luminaire layout from the aspect of illuminance, uniformity, load consumption etc. It is only possible through the simulation data thar we can achieve via DIALux 4.13. So, all the simulation data are discussed further.

i. Illuminance Distribution:

a. LCM Room:

The modified design of LCM room by newly selected luminaire has been simulated in DIALux which gives a proper visualization of the illuminance distribution throughout the room as shown in Fig. 6.9

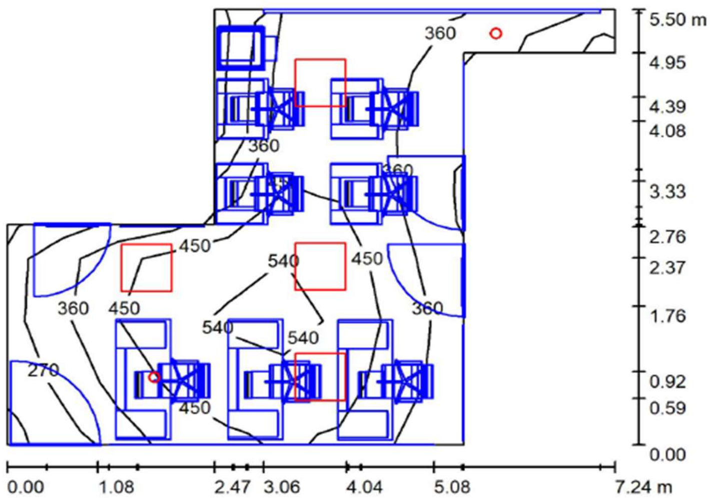


Fig 6.9: LCM Room Illuminance Distribution

b. HR Room:

The modified design of HR room by newly selected luminaire has been simulated in DIALux which gives a proper visualization of the illuminance distribution throughout the room as shown in Fig. 6.10

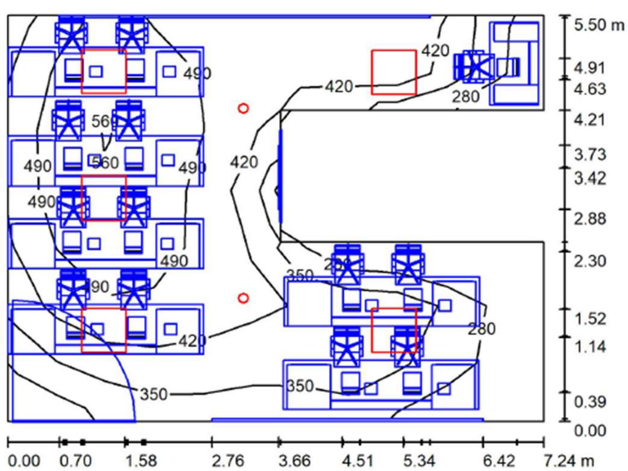


Fig 6.10: HR Room Illuminance Distribution

c. Finance Room:

The modified design of Finance room by newly selected luminaire has been simulated in DIALux which gives a proper visualization of the illuminance distribution throughout the room as shown in Fig. 6.11

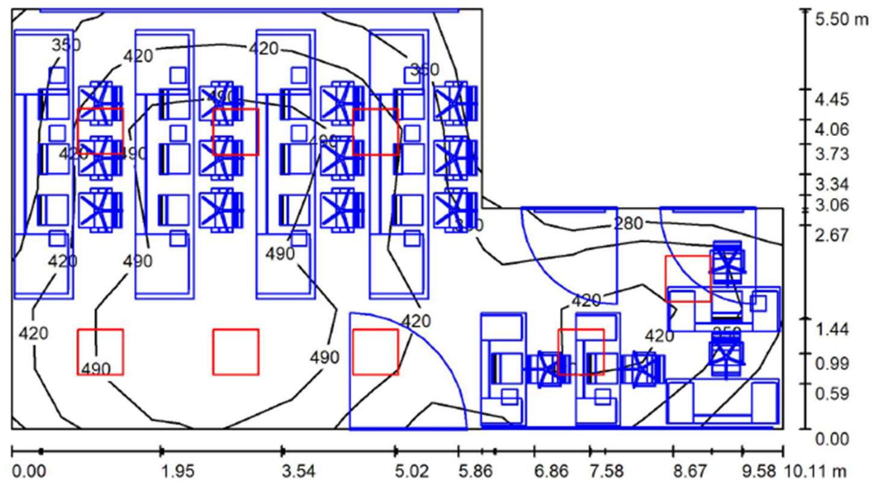


Fig 6.11: Finance Room Illuminance Distribution

d. Operation Room:

The modified design of Operation room by newly selected luminaire has been simulated in DIALux which gives a proper visualization of the illuminance distribution throughout the room as shown in Fig. 6.12

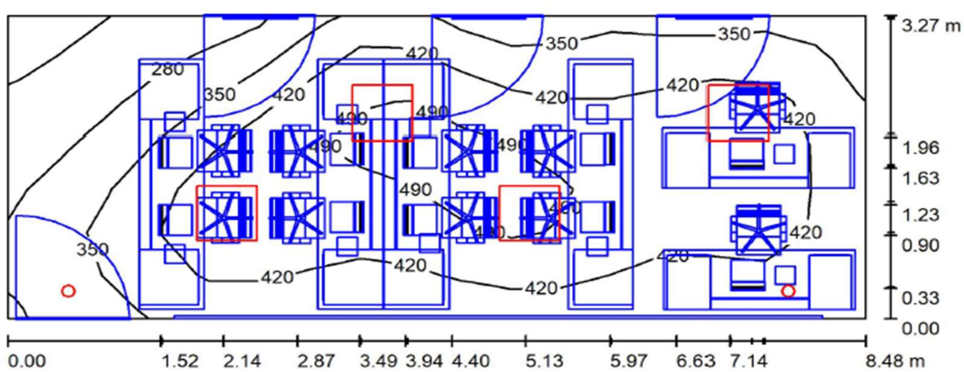


Fig 6.12: Operation Room Illuminance Distribution

ii. Consideration:

Before starting the simulation of the rooms for the output data, the Luminaire data was analysed by their .ies files at the time working with existing lighting setup. Due to that, there some considerations were made, and some parameters were taken of constant value. To keep a standard practice, the same is assumed for this modification stage also as shown in Table 6.1,

Parameter	Value
Work plane Height	0.8 m.
Light Loss Factor	0.8
Boundary Zone	Nil

Table 6.1: Pre-defined Constant Parameters

Through the whole simulation, these values were maintained based on physical survey & assumption.

iii. Simulation Data:

Here comes the final output data for all four lighting layouts design of each room. After simulating all the layout, here we got the modified analytical report through the simulation.

a. LCM Room:

Fig. 6.13 shows the simulation output data of modified LCM Room along with summarized parameter values which are shown in tabular form in Table 6.2,

Height of Room: 2.743 m, Mounting Height: 2.743 m, Light loss factor: 0.80 Values in Lux, Scale 1:71

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	412	169	573	0.411
Floor	27	213	19	435	0.091
Ceiling	75	160	43	558	0.271
Walls (8)	75	252	30	2306	/

Workplane:
Height: 0.800 m
Grid: 7 x 11 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.711, Ceiling / Working Plane: 0.394.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	4	LIGHTING TECHNOLOGIES F02557R0L0 FULLLIT CR 25W CW (1.000)	2978	2978	24.6
2	2	LIGHTING TECHNOLOGIES I01040RD00 INTENSO 10W NW (1.000)	1525	1525	10.0
			Total: 14961	Total: 14961	118.4

Specific connected load: 4.89 W/m² = 1.19 W/m²/100 lx (Ground area: 24.21 m²)

Fig. 6.13: Modified Simulation output of LCM

Parameters	Unit	Simulated Value in DIALux 4.13
No. of Luminaire used	Pc.	4 Nos 25 w, 2 nos 10 w
Average Illuminance of Work Plane (E_{av})	Lux	412
Uniformity on the working plane	-	0.41
Work Plane Grid	Points	7 x 11
Total Luminous Flux	Lumen	14,961
Total Load Consumption for the Luminaires	Watt	118.4

Table 6.2: Modified output of LCM

b. HR Room:

Fig. 6.14 shows the simulation output data of modified HR Room along with summarized parameter values which are shown in tabular form in Table 6.3,

Height of Room: 2.743 m, Mounting Height: 2.743 m, Light loss factor: 0.80 — Values in Lux, Scale 1:71

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	416	217	567	0.522
Floor	30	180	16	420	0.090
Ceiling	82	191	44	391	0.233
Walls (8)	82	259	41	1154	/

Workplane:
Height: 0.800 m
Grid: 11 x 7 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.699, Ceiling / Working Plane: 0.453.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	5	LIGHTING TECHNOLOGIES F02557R0L0 FULLLIT CR 25W CW (1.000)	2978	2978	24.6
2	2	LIGHTING TECHNOLOGIES I01040RD00 INTENSO 10W NW (1.000)	1525	1525	10.0
			Total: 17939	Total: 17939	143.0

Specific connected load: 4.27 W/m² = 1.03 W/m²/100 lx (Ground area: 33.49 m²)

Fig. 6.14: Modified Simulation output of HR

Parameters	Unit	Simulated Value in DIALux 4.13
No. of Luminaire used	Pc.	5 Nos 25 w, 2 Nos 10 w
Average Illuminance of Work Plane (E_{av})	Lux	416
Uniformity on the working plane	-	0.52
Work Plane Grid	Points	11 x 7
Total Luminous Flux	Lumen	17,939
Total Load Consumption for the Luminaires	Watt	143

Table 6.3: Modified output of HR

c. Finance Room:

Fig. 6.15 shows the simulation output data of modified Finance Room along with summarized parameter values which are shown in tabular form in Table 6.4,

Height of Room: 2.743 m, Mounting Height: 2.743 m, Light loss factor: 0.80 — Values in Lux, Scale 1:73

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	419	240	568	0.573
Floor	30	201	8.62	471	0.043
Ceiling	85	167	82	277	0.489
Walls (6)	85	254	40	458	/

Workplane:
Height: 0.800 m
Grid: 11 x 7 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.645, Ceiling / Working Plane: 0.384.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	8	LIGHTING TECHNOLOGIES F02557R0L0 FULLLIT CR 25W CW (1.000)	2978	2978	24.6
			Total: 23823	Total: 23823	196.8

Specific connected load: 4.34 W/m² = 1.04 W/m²/100 lx (Ground area: 45.31 m²)

Fig. 6.15: Modified Simulation output of Finance

Parameters	Unit	Simulated Value in DIALux 4.13
No. of Luminaire used	Pc.	8 Nos 25w
Average Illuminance of Work Plane (E_{av})	Lux	419
Uniformity on the working plane	-	0.57
Work Plane Grid	Points	11 x 7
Total Luminous Flux	Lumen	23,823
Total Load Consumption for the Luminaires	Watt	196.8

Table 6.4: Modified output of Finance

d. <u>Operation Room:</u>

Fig. 6.16 shows the simulation output data of modified Operation Room along with summarized parameter values which are shown in tabular form in Table 6.5,

Height of Room: 2.743 m, Mounting Height: 2.743 m, Light loss factor: 0.80 Values in Lux, Scale 1:61

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	402	196	522	0.488
Floor	68	166	9.75	409	0.059
Ceiling	75	181	68	311	0.376
Walls (4)	75	265	63	1456	/

Workplane:
Height: 0.800 m
Grid: 17 x 7 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.714, Ceiling / Working Plane: 0.450.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ (Luminaire) [lm]	Φ (Lamps) [lm]	P [W]
1	4	LIGHTING TECHNOLOGIES F02557R0L0 FULLLIT CR 25W CW (1.000)	2978	2978	24.6
2	2	LIGHTING TECHNOLOGIES I01040RD00 INTENSO 10W NW (1.000)	1525	1525	10.0
			Total: 14961	Total: 14961	118.4

Specific connected load: 4.26 W/m² = 1.06 W/m²/100 lx (Ground area: 27.77 m²)

Fig. 6.16: Modified Simulation output of Operation

Parameters	Unit	Simulated Value in DIALux 4.13
No. of Luminaire used	Pc.	4 Nos 25w, 2 Nos 10w
Average Illuminance of Work Plane (E_{av})	Lux	402
Uniformity on the working plane	-	0.49
Work Plane Grid	Points	17 x 7
Total Luminous Flux	Lumen	14,961
Total Load Consumption for the Luminaires	Watt	118.4

Table 6.5: Modified output of Operation

Chapter 7
RESULT ANALYSIS

7.1 Overview of Modification:

As discussed earlier, the modification is done to achieve some pre-defined objectives for which this project will reach to successful completion. For that, firstly it is required some key illumination parameters and points to keep in mind.

- ✓ Average Illuminance
- ✓ Uniformity
- ✓ Load Consumption
- ✓ No. of Luminaire

This comparison will be carried out between two simulated output data which were achieved by DIALux simulation. This tabular comparison format will provide the best clean & clear visualization regarding the successful compliance of objectives.

7.2 Comparison between Output:

It will be more specific to analyze briefly by monitoring all the parameter values of existing and modified illumination if it can be presented according to different departments. So, that's why all the comparisons are hereby executer according to different areas of the office premises. Here only existing and modified parameter values are shown and the reference value as per National Lighting Code 2010 & BIS Standard are already mentioned in Chapter 4 of this project.

a) LCM Department:

Parameter	Unit	As Per BIS	Existing	Modified
Average Illuminance (E_{av}) for Work plane	Lux	300 to 500	623	412
Uniformity for Work plane (u_0)	-	≥0.5	0.4	0.41
Total Power Consumption (P)	Watt	-	150	118.4
No. of Luminaire used	Pc.	-	15	6

Table 7.1: Output Comparison for LCM

b) HR Department:

Parameter	Unit	As Per BIS	Existing	Modified
Average Illuminance (E_{av}) for Work plane	Lux	300 to 500	852	416
Uniformity for Work plane (u_0)	-	≥0.5	0.55	0.52
Total Power Consumption (P)	Watt	-	240	143
No. of Luminaire used	Pc.	-	24	7

Table 7.2: Output Comparison for HR

c) Finance Department:

Parameter	Unit	As Per BIS	Existing	Modified
Average Illuminance (E_{av}) for Work plane	Lux	300 to 500	1018	419
Uniformity for Work plane (u_0)	-	≥0.5	0.51	0.57
Total Power Consumption (P)	Watt	-	370	196.8
No. of Luminaire used	Pc.	-	37	8

Table 7.3: Output Comparison for Finance

d) Operation Department:

Parameter	Unit	As Per BIS	Existing	Modified
Average Illuminance (E_{av}) for Work plane	Lux	300 to 500	606	402
Uniformity for Work plane (u_0)	-	≥0.5	0.58	0.49
Total Power Consumption (P)	Watt	-	140	118.4
No. of Luminaire used	Pc.	-	14	6

Table 7.4: Output Comparison for Operation

7.3 Graphical Comparison:

After the comparison based on simulation output data, the graphical comparison will be an addition for a clear visualization, and it will be easier to reach for a conclusion from the perspective of successful completion for objectives of this project.

a) Average Illuminance:

As shown in figure 7.1, it is shown that the prime parameter average illuminance has been reduced for all departments on the perspective of BIS & National Lighting Code illuminance value for office lighting (clause 9.1), so it can be said that despite of reduction in illuminance, it is still as per National Lighting Code (Clause 9.1).

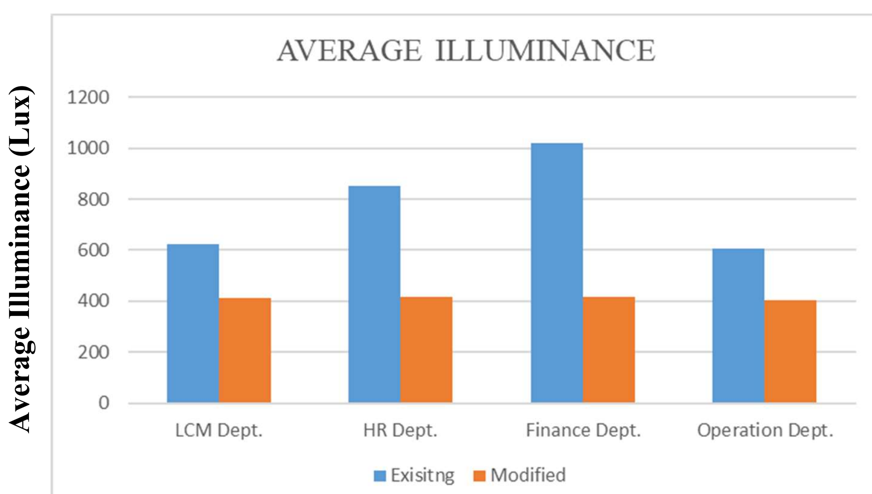


Fig. 7.1: Graphical Comparison for Average Illuminance

Uniformity:

As shown in figure 7.2, it is shown that the uniformity has been reduced in HR & Operation Departments but increased for LCM & Finance Departments. As this project is based on the perspective of BIS & National Lighting Code values for office lighting (clause 9.1), so it can be said that despite of modification in uniformity, it is still as per standard value. Also, it is observed that where uniformity is reduced that is still as per National Lighting Code and the rest are increased.

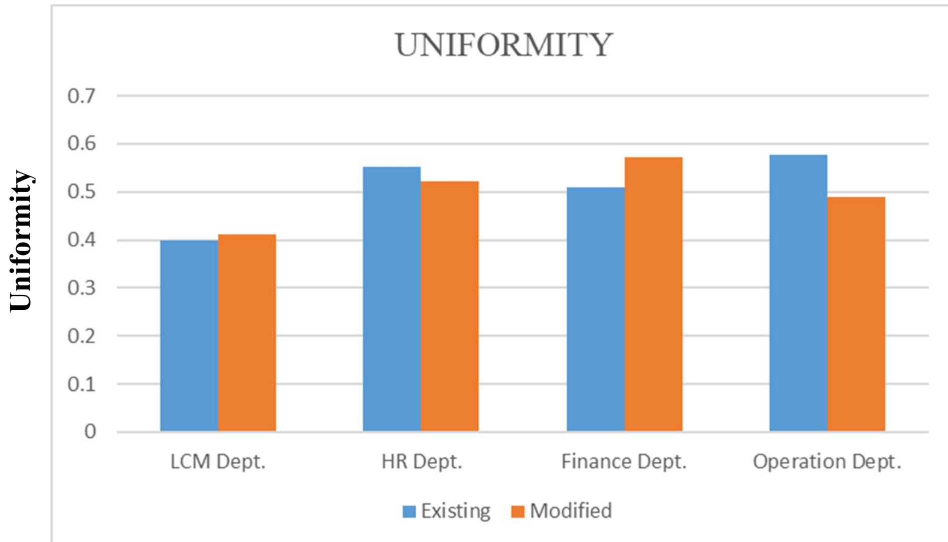


Fig. 7.2: Graphical Comparison for Uniformity

b) Total Power Consumption:

As shown in figure 7.3, it is shown that the main parameter of this project i.e., total power consumption has been reduced for all the departments. Based on the visualization, it can be surely concluded that the prime objective of this project has been successfully completed. Moreover, in HR & Finance department it has been reduced to approximately 50% of the existing values.

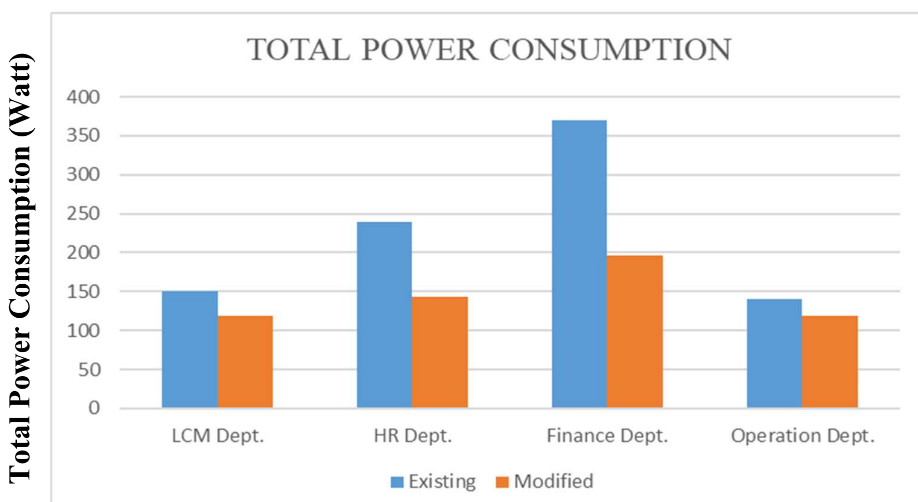


Fig. 7.3: Graphical Comparison for Total Power Consumption

c) Luminaire Quantity:

As per the figure 7.4, it is shown that the no. of required luminaires has been reduced in every department. As this parameter is not based on BIS & National Lighting Code, so it can be said that despite of not having any specific defined standard value, but for the sake of the ultimate goal of this project the reduced quantity of luminaire surely effects positively from the of financial approach.

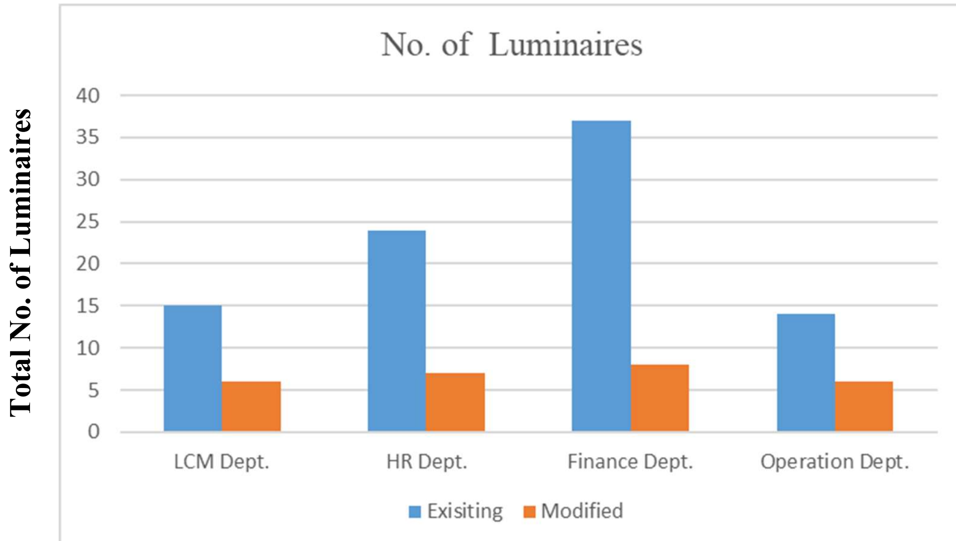


Fig. 7.4: Graphical Comparison for Luminaire Quantity

7.4 Summarized Overview:

After all the analysis, the final modification in this project can be summarized that is with reference to existing parameter values, up to what percentage the modified parameter values have been diverted as shown in Table 7.5

Parameter	LCM	HR	Finance	Operation
Average Illuminance (E_{av}) for Work plane	-33.87%	-51.17%	-58.84%	-33.66%
Uniformity for Work plane (u_0)	+2.75%	-5.61%	+12.35%	-15.42%
Total Power Consumption (P)	-21.07%	-40.42%	-46.81%	-15.43%
No. of Luminaire used	-60%	-70.83%	-78.38%	-57.14%

Table 7.5: Summarized Report of Modification

7.5 Remarks:

The above comparisons both graphical and tabular, conclude to the same points which can be summarized as a compliance of objectives for this project those were described at the initial stage of this project. If the above graphs and Table No. 7.5 are observed thoroughly then it gives a clear visualization of some facts that, average illuminance of all rooms in the office premises has been reduced to a value as per National Lighting Code. All the uniformity values are as per National Lighting Code Clause 9.1. Also, the most important purpose i.e., less power consumption has been carried out successfully by this modification with less no. of lights for all the rooms.

Chapter 8

CONCLUSION
&
FUTURE SCOPE

8.1 Conclusion:

Current lighting design practices heavily revolve around illuminance and illuminance-based metrics. While these methods have been proven reliable, it should be noted that illuminance is not only the direct factor of visual perception or performance. However, luminance, which measures the amount of light reflected from an object and transmitted to the eyes of space users, is also a direct factor of vision. A lighting design method which merges illuminance and luminance metrics could better benefit space users' productivity and performance, health, and well-being, and reduce lighting energy consumption. Computer simulations are the proposed tools for realizing this supplemental lighting design method.

This study explored the illuminance distribution caused by varying lighting layouts, in addition to, the variation of luminaire. Analysis of Stage 1 found that illuminance distribution, uniformity & energy consumption are affected by the layout of the luminaires and the existing luminaire. Stage 2 results proposed illuminance levels, uniformity recommend by BIS & National Lighting Code 2010 Clause 9.1 necessary for the completion of visual task. Also indicated in Stage 2 was power consumption was reduced as well as no. of luminaires too. [40]

Moreover, energy consumption was reduced under LED when human subjects were able to adjust the lighting levels to suit their preferences. Additional research is needed to investigate if study results are consistent over a wider population and across different types of lighting environments.

The research outcomes are therefore considered useful to assist the lighting community in the creation of a supplemental illuminance-based lighting design method which better caters to human-light interactions. The supplemental method has the potential to positively impact society by improving space users' overall satisfaction of the lit environment and reducing the amount of energy consumed by lighting systems. This research at its preliminary stage for developing a new lighting design method is expected to meet the needs of lighting society.

The world has seen a tremendous growth in technology and various other innovations in the past century. It's necessary now more than ever to make some significant changes – the most important one being conservation of power. The excessive use of this resource may produce adverse effects. There are various ways and products that one can use to do their part in this cause.

Energy efficiency is a concept that has come to be after rising concerns over consumption of power. The same function can be done in a way that it consumes less energy. Utilizing power sources that are extremely old also cause an increase in consumption of power. By avoiding this, it benefits the environment by lowering greenhouse gas emission levels and also reduces household costs. This in turn helps the economy as well in the long run.

People are increasingly being made aware of the importance of switching to energy efficient lighting, and the global market has also been anticipated to experience a boom over the coming years.

8.2 Future Scope:

There have been various historic inventions that changed the world for the better and one of them was the light bulb. Thomas Alva Edison brought a wave of change when he gave the world a chance to step out of the darkness. Ever since, the lighting industry has seen various advancements. It is said that over 20% of the world power generation is for the purpose of lighting for both personal and professional use. The various light sources have been a constant provider of comfort as well as safety. The extended duration of light available compared to just sunlight in the past also gave people the opportunity to use more of their time to make progress, thus enhancing productivity. [41]

The impact of COVID-19 was felt all around the globe and to ensure a seamless functioning of the healthcare sector, it requires a constant supply of power. Equipment such as ventilators and various monitors consume a lot of electricity. In order to maintain sufficient supply, the industry can switch to sources of light that do not consume as much power and allow it to be redirected to the equipment. It is during this crucial time, that even backup power sources were also majorly in use. With humans traversing the globe in search of more opportunities, electricity also follows as no task is complete without it. Among the various places where energy is consumed in bulk, a few need to implement lights that consume less power. Places That Need to Implement Energy Efficiency can be visualized for far future as discussed below:

a) Domestic Sources

Residential complexes, apartments and other housing communities need to ensure that they are fitted with energy efficient lights. Creating awareness among them for the same will ensure benefits for the residents.

b) Commercial Establishments

Places such as malls, shopping centers, restaurants, and other such, are usually in use 24X7. People visit these places round the clock for recreational purposes due to which it's necessary for them to be well lit up. Swapping the traditional lights and using newer ones can prove to be not only economical but pleasant to the eyes as well.

c) Industries

The industrial sector also functions round the clock and uses more power for not just lighting, but equipment for construction and production purposes as well. This constant use of power heavily impacts power sources, while adding on financially. Establishing efficiency in the lighting department, can get the work done and at a lower price.

Be it for indoor or outdoor use, the energy efficient lighting scheme enhances the quality of lighting, makes it safer, and lowers impact on the environment. It's interesting to note that traditional lights emit a lot of heat compared to LED lights that consume low power. They also consume more than 90% power which is reason enough to make the switch.

d) IOT Based Smart Energy-Efficient Lighting:

IoT for energy efficiency is with smart lighting systems is growing version of smart energy efficient lighting , where Wi-Fi-enabled LED lights which in and of themselves offer great energy savings-can be controlled based on schedules, motion, or sound to turn on and off as needed and avoid excessive lighting energy use. Often, rooms in homes and office buildings or commercial facilities remain lit all day even if there is nobody present, and this creates a significant waste of electricity. With IoT lighting systems, businesses or individuals can take advantage of more efficient lighting technologies and use the programmable abilities of smart lighting to streamline the amount of time lights are on. The significant energy savings achieved positively impacts both a business's bottom line and the environment. [42]

e) The Environment

In addition to providing savings on office's electric bill, the energy efficiency of Luminaire i.e., LED helps cut down on CO_2 emissions, making it easier for company to comply with environmental regulations. Because they last longer and they don't contain harmful materials like mercury, LEDs can also easily be recycled so they produce less waste over their lifespan. [43]

f) Aesthetics & Productivity

LEDs boast a wider range of color temperatures and offer more control over beam angle than their predecessors, which means it can easily be created a better-looking work environment that also boosts morale and productivity. With easily controllable color temperatures and dimming capabilities, a different lighting zones can be created, such as a more relaxing environment in the break room, a warm and welcoming space to greet clients, and brightly light workstations to help employees remain productive and alert. [44]

g) High Electricity/Demand Charges:

It can be easy to justify an investment in efficient lighting when energy rates are high. While the cost of installing an energy efficient lighting system remains constant, the energy cost savings over time are much greater, making lighting retrofits that would otherwise be marginal, much more likely to be cost-effective.

Investing in a lighting retrofit makes good economic sense for just about any commercial building, as an increasing number of businesses are under constant pressure to improve productivity and lower operating costs. By replacing aged lighting components with advanced energy-efficient components, a building's lighting energy costs can be reduced by as much as 60%, while maintaining, or even enhancing the quality of the visual environment. [45]

In fact, according to the Electric Power Research Institute (EPRI)'s Lighting Retrofit Manual, "Most lighting retrofits pay for themselves through energy savings in less than seven years; in some cases, simple payback can occur in under three years." [46]

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