A STUDY ON ILLUMINATION BASED DESIGN METHODOLOGIES ADOPTED IN LIGHTING INDUSTRIES

A Thesis Submitted Towards Partial Fulfilment of the Requirement for the Degree of

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IN

ILLUMINATION TECHNOLOGY & DESIGN

Submitted By

PRATEEM CHATTOPADHYAY

Examination Roll No. – M6ILT22028
University Registration No. – 150192 of 2019-20

Under the Supervision of

PARTHASARATHI SATVAYA
Assistant Professor
School of Illumination Science, Engineering and Design
Jadavpur University

Course Affiliated to
Faculty of Engineering and Technology
Jadavpur University
Kolkata-700032
India

2022

M.Tech. (Illumination Technology and Design)

Course affiliated to

Faculty of Engineering and Technology

Jadavpur University

Kolkata, India

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THESIS SUPERVISOR
Parthasarathi Satvaya
Assistant Professor
School of Illumination Science, Engineering and Design
Jadavpur University,
Kolkata-700 032

DIRECTOR
Parthasarathi Satvaya
School of Illumination Science, Engineering and Design
Jadavpur University,
Kolkata-700 032

DEAN -FISLM
Prof. Subenoy Chakraborty
Jadavpur University,
Kolkata-700 032

M.Tech. (Illumination Technology and Design)

Course affiliated to

Faculty of Engineering and Technology

Jadavpur University

Kolkata, India

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THESIS TITLE:	A STUDY ON ILLUMINATION BASED DESIGN METHODOLOGIES ADOPTED IN LIGHTING INDUSTRIES

SIGNATURE: DATE:

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ABOUT THE AUTHOR

Prateem Chattopadhyay, born in Jadavpur, Kolkata, West Bengal, has completed B.Tech in Electrical Engineering from Future Institute of Engineering and Manager, Kolkata, West Bengal in 2019 and has been pursuing his M.Tech in Illumination Technology and Design from Jadavpur University, Kolkata, West Bengal. He is currently performing internship as Lighting Solution Engineer from Wipro Consumer Care and Lighting, Chandigarh. He is an enthusiastic, energetic and dynamic individual who loves working with people, besides being keenly interested in technology with a constant thirst to learn and implement the best solutions to any problem. He has an insatiable passion for learning new technologies and concepts.

ABSTRACT

The lighting design process is complex, because it includes a number of variables some of which are hard to measure precisely especially in industrial and commercial applications. The lighting design process involves a few steps and it is needed to follow them in order to avoid mistakes. The steps are: identifying the requirements, determining the method of lighting, selecting the lighting equipment, calculating the lighting parameters and adjusting the design, determining the light control system, checking the fittings and finally checking the installation when finished. This thesis is mainly focused to provide energy efficient lighting design which can be used to renovate the existing lighting systems as well as the areas where lighting system has not been incorporated yet. This thesis comprises of both indoor and outdoor lighting designs. This thesis illustrates how interior illumination can be presented in a manner, which can solve both task lighting and ambient lighting requirements simultaneously. Same goes for outdoor lighting also. Indoor lighting studies include industrial lighting, office lighting, cleanroom lighting and educational lighting. Outdoor lighting studies include sports and road lighting. Each of these designs is described through lighting layouts of the space, illumination level charts and results obtained through software computations. The main objectives of the project are to propose a new energy efficient, aesthetic and modern lighting design with help of modern and energy efficient luminaires. The light-emitting diode (LED) is today's most energy-efficient and rapidly-developing lighting technology. All the designs included in this thesis, are performed with LED luminaires. The purpose of this thesis is to enlighten the lighting industry regarding the increasing importance of modern lighting design and its contribution to the overall building design and construction process. This thesis also includes a brief study on Road lighting visibility analysis based on surface properties by photometric computations.

CONTENTS

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Background

Lighting is an important aspect of interior design as it enhances the aesthetic appeal and creates the mood and ambiance of a living space. Lighting fixtures that illuminate a room creates a safe and comfortable environment besides adding style to the interior décor. Light is the main element that gives the room a special look and transforms it into a seamless combination of functionality and style. Besides playing a functional role it creates a visually dynamic space. Lighting can make or break the ambiance of a room. Hence proper lighting is the key element in interior design as it enhances everything in a room – from the furniture, flooring, fittings to the finishes and textures. The use of lighting can add to or subtract from the overall colours of a room or from only those surfaces the light is meant to enhance.

The lighting of an interior should fulfil the following conditions:

- Ensure the safety of people in the interior,
- Facilitate performance of visual tasks, and
- Aid the creation of an appropriate visual environment.

Lighting affects safety, task performance and the visual environment by changing the extent to and the manner in which different elements of the interior are revealed. Safety is ensured by making any hazards visible. Task performance is facilitated by making the relevant details of the task easy to see. Different visual environments can be created by changing the relative emphasis given to the various objects and surfaces in an interior. Different aspects of lighting influence the appearance of the elements in an interior in different ways. However, it should always be remembered that lighting design involves integrating the various aspects of lighting into a unity appropriate to the design objectives.

The objectives of installing electric lighting systems can be gathered under three broad headings:

- promoting safety and security
- facilitating the performance of visual task
- revealing attractively the environment

1.2 Objectives

Following are the objectives of the thesis work:

- To analyse Industrial Lighting based design scenario through software computations.
- To examine a lighting design scenario for office space based on software computations.
- To evaluate Educational Lighting Based Design by software calculation.
- To analyse Cleanroom lighting through Pharmaceutical Lighting Based Design Scenario by software computations.
- To prepare a comparative analysis between Outdoor and Indoor Sports lighting through software computations.
- To analyse Road Lighting Based Design Scenario through Software Computations.
- Study of Road Lighting Visibility Analysis using Photometric Computations.

1.3 Project Scope

Lighting can be used as the secret weapon to a stunning and practical space. It helps to create depth, height, and style, while drawing attention to the areas that are most impressive. Light emitting diode (LED) is a revolutionary lighting technology that has made its presence felt across all major industry verticals. All the luminaires proposed in this thesis are LEDs. According to the leading commercial lighting manufacturers, longer life, low electricity consumption, and safety are some of the key characteristics that have encouraged companies to replace their conventional lighting systems with innovative and LED lighting solutions. The construction industry is one such commercial domain that has recognized the benefits of using LED industrial lighting solutions at its working sites. In this thesis, two industrial lighting designs are performed with comparative analysis between the designs. Factories are places of heavy duty work and so there is a need to use lights that are sturdy enough to withstand extreme working conditions and high temperatures while consuming less energy. From schools to research institutes, the right light can help create a space that is comforting and vibrant, yet apt itself for an institution. Similarly, two indoor lighting designs each of office lighting, industrial lighting, educational lighting and pharmaceutical lighting is performed with comparison analysis between two case studies.

Modern outdoor lighting is particularly designed with special features to meet the need for illuminating outdoor spaces correctly and efficiently. This includes precision optical design and uniform light distribution to enhance safety on roads, advanced LED technology for higher energy savings with contemporary styling and design that blends with urban architecture. In this thesis, two outdoor lighting designs each of road lighting and sports lighting design is performed with comparison analysis between the two case studies. A brief study of road lighting visibility level was also performed with the help of road surface luminance calculations.

1.4 Methodology

A Flowchart description of Lighting Design Decisions is shown below in *Figure 1.1*.

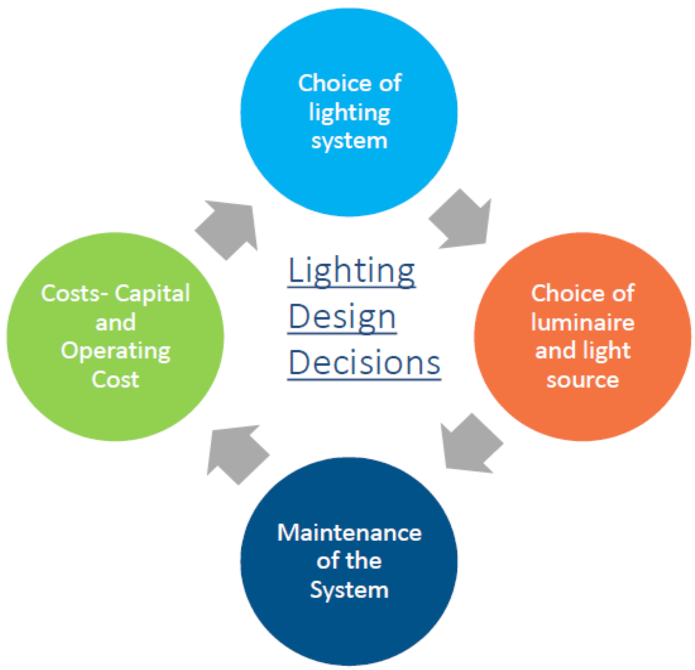


Figure 1.1: *Lighting Design Decisions*

A logical procedure for designing lighting systems consists of six steps, not all of which may be needed and where it may be necessary to loop back in the procedure because of unexpected constraints.

- **<u>Site Inspection</u>**

  Visiting the site and making sketches to extend the available plans:

1. Into three dimensions and
2. To cover adjacent areas.

- **Specifications**

  The objectives need to be translated into quantitative and qualitative design criteria. The assistance of design codes and guides should be sought. CIE documentation is rather limited, and unfortunately lacks the imagination found in National Lighting Code and guides. This is because the material needs to be a consensus, i.e. to be accepted by many countries who have their own codes and whose ideas differ.

- **Strategic Planning**

  Decisions are needed on the use to be made of daylight, the type of lamp, the type of lighting system, the type of luminaire and the type of controls to be used.

- **Detailed Planning**

  Determining the number and location of possible lighting units to satisfy both the quantitative and qualitative criteria. Alternative solutions should be found and estimated.

- **Appraisal**

  Ideally, soon after the installation has been put into use, the assets and liabilities of the scheme should be judged, by both user and designer, for the benefit of future design.

In order to more familiar with lighting design, first of all it is needed to study all the fundamentals. Besides that, operations of lighting design software (DIALux) are also important in order to understand all the design criteria. By using DIALux, will give us option to plan the lighting that is needed to be used in a room, or in a building. DIALux gives the ability to calculate and visualize the daylight, as well as planning of lighting scenes, plan the color and intensity of the lights, position on the project the emergency lighting, with the right legal number of luminaires, and many more. This advanced yet easy to use software has a simple 3D rendering functionality, which is very useful for calculations of interior, exterior and street lighting. DIALux 4.13 can be downloaded free of cost form online and installed. Along with it the associated files are also gathered like IES files for lamps, AutoCAD software and sketchers as per requirement. These files give a clear view of the catalogue of the lamps and luminaries available. Dialux Simulation analysis work is performed of modern lighting industry based projects involving Office lighting, Road Lighting, Sports Lighting, Industrial Lighting, Educational Complex lighting and Pharmaceutical industry lighting.

Chapter 2

Industrial Lighting

2.1 Introduction

The purpose of industrial lighting is to provide energy efficient illumination and to enhance visibility and productivity within a pleasant and safe environment. Industry encompasses seeing tasks, operating conditions and economic considerations of a wide range. Visual tasks may be extremely small or very large; dark or light; opaque, transparent or translucent; on specular or diffuse surfaces and may involve flat or contoured shapes. Lighting must be suitable for adequate visibility in developing raw materials into finished products. Physical hazards exist in manufacturing processes and therefore, lighting contributes to the safety factor in preventing accidents. The speed of operations may be such as to allow only minimum time for visual perception and, therefore, lighting must be a compensating factor to increase the speed of seeing.

The design of a lighting system and selection of equipment may be influenced by many economic and energy related factors. Economic decisions in regard to the lighting system should not only be based on the initial and operating costs of the lighting, but also on the relationship of lighting costs to other plant facilities and costs of labour. The lighting system should be a part of an overall planned environment. The manner in which the light from the lamps is controlled by the luminaire governs to a large extent the important effects of glare, shadows, distribution and diffusion. Luminaires are classified in accordance with the way in which they control the light. Industrial installations of very poor quality are easily recognized as uncomfortable and are possibly hazardous.

2.2 Criteria for Industrial Lighting

The designer of an industrial lighting system should maintain the balance all of the energy management considerations and economic factors including initial, operating and maintenance cost, versus the quantity and quality requirements for optimum visual performance. The choice of the electric distribution system may affect overall economics. Following are the factors that must be taken into account to achieve good industrial lighting:

2.2.1 Quantity of Illumination

The desirable quantity of light for an installation depends primarily upon the seeing task, and the importance of speed and accuracy in performing the task. To ensure that a given illuminance will be maintained, it is necessary to design a system to, initially give more light than the target value. In locations where dirt will collect very rapidly on luminaire surfaces and where adequate maintenance is not provided, the initial value should be even higher.

2.2.2 Quality of Illumination

Quality of illumination pertains to the distribution of luminance in the visual environment. It is used in a positive sense and implies that all luminances contribute favourably to visual performance, visual comfort, ease of seeing, 'safety and aesthetics for the specific visual task involved. Glare, diffusion, direction, uniformity, colour, luminance and luminance ratios all have a significant effect on visibility and the ability to see easily, accurately and quickly. Certain seeing tasks, such as discernment of fine details, require much more careful analysis and higher quality illumination than others. Areas where the seeing tasks are severe and performed over long periods of time require much higher quality than where seeing tasks are casual or of relatively short duration.

2.3 Luminaires for Industrial Lighting

Generally high roofing is provided in the heavy engineering industry, where overhead travelling cranes are provided and/or fumes and smoke have to be evacuated. The artificial lighting has to be located at a greater height in the roof structure to allow unobstructed movement of cranes, etc.

Some of the important considerations that must be taken into account for selection of luminaires for industrial lighting are as follows:

- **Ingress Protection IP65/IP66**: Level of Protection provided against dust and water entry.
- **Impact Protection IK08:** Degrees of Protection provided by luminaires against external mechanical impacts. IK rating scale identifies the ability of an enclosure to resist impact energy levels measured in Joules (J).
- **Protection against Electrical and Thermal Conditions**
- **Long Service Life:** LED chip selection and driver configuration should be such that burning hours should be minimum of 50000 Hours.

Table 2.1: Classification of Industrial Luminaires Based on Mounting Height

Mounting Height	Application	Suitable Wattage
4m to 6m	Lowbay	65W to 100W
7m to 10m	Midbay	120W to 150W
12m to 20m	Highbay	180W to 200W

2.4 Case Study: 1

One of the major industrial lighting project performed was of a tractor production factory. Site picture of the factory is shown in *Figure 2.1*. This factory already has 140 Watt metal halide luminaires installed, and these lamps nearly reached to the end of life and therefore, they are to be replaced to LED luminaires.

Figure 2.1: *Tractor Production Factory*

2.4.1 Project Background

The Tractor Production Factory consists of 4115 sq. metres of ground area and its height is 4 metres. It is one of the major production areas of several tractor parts used for agricultural applications. It is basically a refurbishment project where outdated conventional luminaires is to replaced to LED luminaires, thereby maintaining the desired lux level as per as the standards. A tractor is an engineering vehicle specifically designed to deliver a high tractive effort (or torque) at slow speeds, for the purposes of hauling a trailer or machinery such as that used in agriculture, mining or construction. Most commonly, the term is used to describe a farm vehicle that provides the power and traction to mechanize agricultural tasks, especially (and originally) tillage, and since many more. Agricultural implements may be towed behind or mounted on the tractor, and the tractor may also provide a source of power if the implement is mechanised. The Production factory consists of Receiving area, Receiving Quality Assurance (RQA) area, Washing Parts Storage Area, Washing Machine Area, Main Line Production Area, Minor Hold Area, Chassis Storage area, Empty Skids Storage area, Storage of engine, Dispatch Vehicle Parking area and Aisle.

Table 2.2: *Area Dimensions*

Area	Dimensions	Height
Receiving Area	7.5 m X 11 m	4 m
Aisle	140 m X 3 m	4 m
RQA	10 m X 12 m	4 m
Washing Parts Storage Area	15 m X 12 m	4 m
Washing Machine Area	15 m X 12 m	4 m
Main line Production	52 m X 12 m	4 m
Chassis Storage Area	16.5 m X 12 m	4 m
Empty Skids Storage Area	10.5 m X 12 m	4 m
Storage of Engine	30 m X 2 m	4 m
Front Axle Bracket	25 m X 7 m	4 m
Dispatch Vehicle Parking	30 m X 3 m	4 m

2.4.2 Lighting Planning Layout

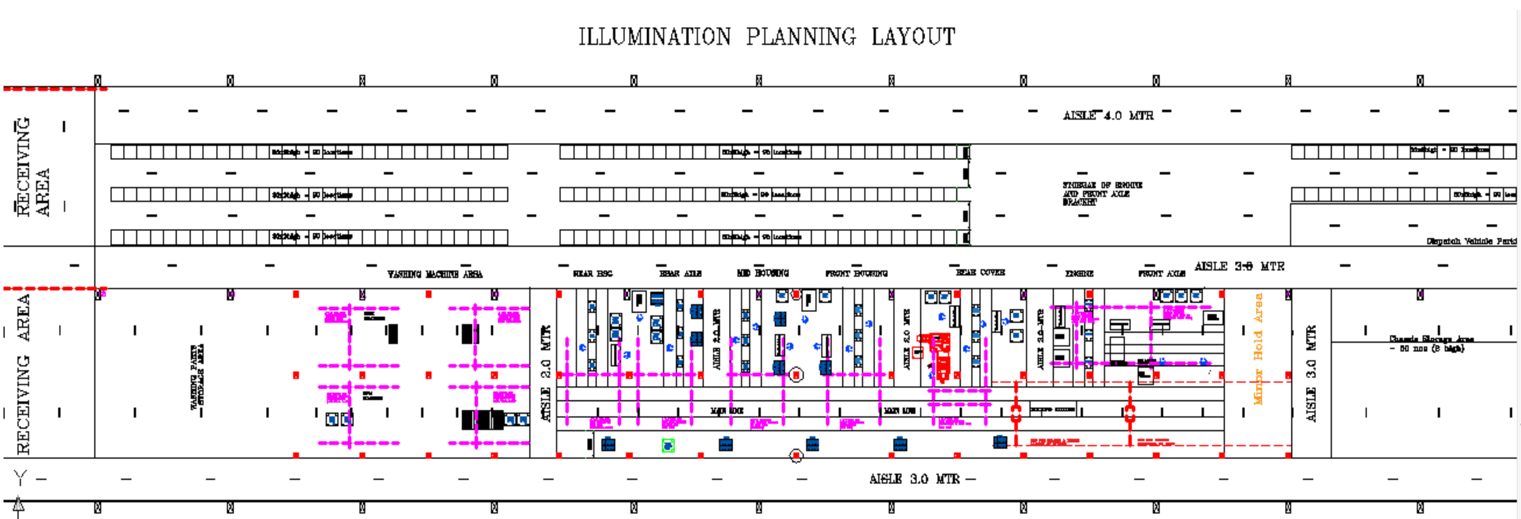


Figure 2.2: *Complete Lighting Layout*

The lighting layout and descriptive analysis of some of the major rooms are given as follows:

A. Receiving Area:

In the manufacturing section of the tractor producing factory, the receiving plays an important role. In the receiving area, the raw materials required for the Production unit is collected. Receiving area is like a scaled-down version of the entire warehouse. In a warehouse, the action starts at the receiving area. The recommended average lux level for the Receiving Area is 300 lux. Also in this area proper uniformity is needed. The lighting layout for the Receiving Area is given in *Figure 2.3.* Light Fixtures are marked with green colour legend in the Figure.

Figure 2.3: *Lighting Layout for Receiving Area*

B. Aisle:

An Aisle is a space for walking with rows of non-walking spaces on both sides. The recommended average lux level for the AISLE is 300 lux. The lighting layout for the Aisle is given in *Figure 2.4.* Light Fixtures are marked with green colour legend in the Figure.

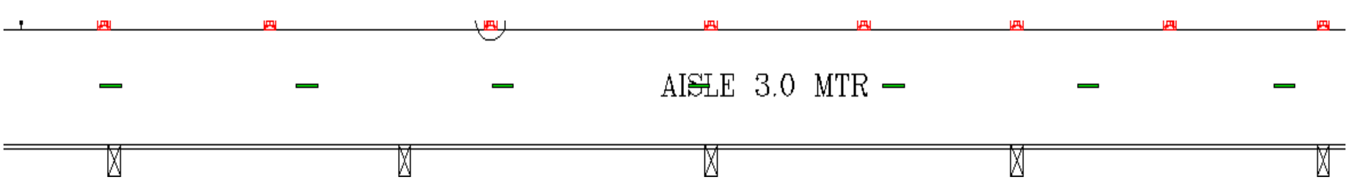


Figure 2.4: *Lighting Layout for AISLE*

C. RQA Area:

In the Tractor Production factory, RQA Area is one where quality assurance of the received goods is tested. Quality assurance is a way of preventing mistakes and defects in manufactured products and avoiding problems when delivering products or services to customers. The recommended average lux level for the RQA is 300 lux. The lighting layout for the RQA is given in *Figure 2.5*. Light Fixtures are marked with green colour legend in the Figure.

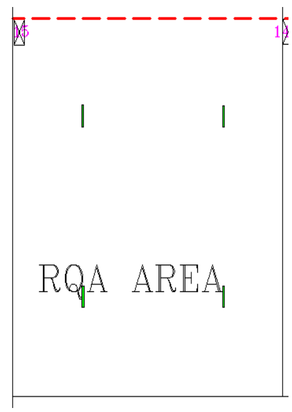


Figure 2.5: *Lighting Layout for RQA Area*

D. Washing Parts Storage Area:

In the washing parts storage area, the washed goods of the light vehicle parts are kept securely before being sent to main line production unit. The recommended average lux level for the washing parts storage area is 300 lux. The lighting layout for the washing parts storage area is given in *Figure 2.6*. Light Fixtures are marked with green colour legend in the Figure.

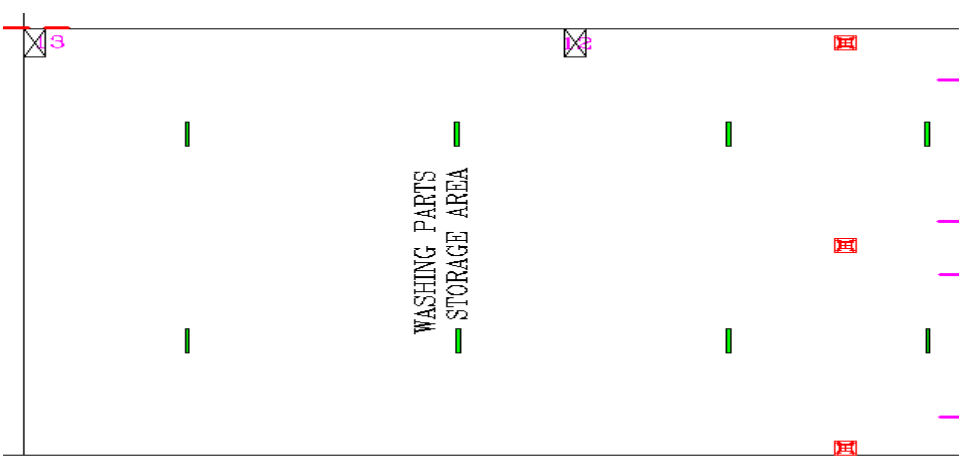


Figure 2.6: *Lighting Layout for Washing Parts Storage Area*

E. Washing Machine Area:

In the washing machine area, the finishing work of the produced vehicle parts is performed. High quality optimum illumination with proper uniformity is needed for this area. The recommended average lux level for the washing machine area is 500 lux. The lighting layout for the washing machine area is given in *Figure 2.7*.

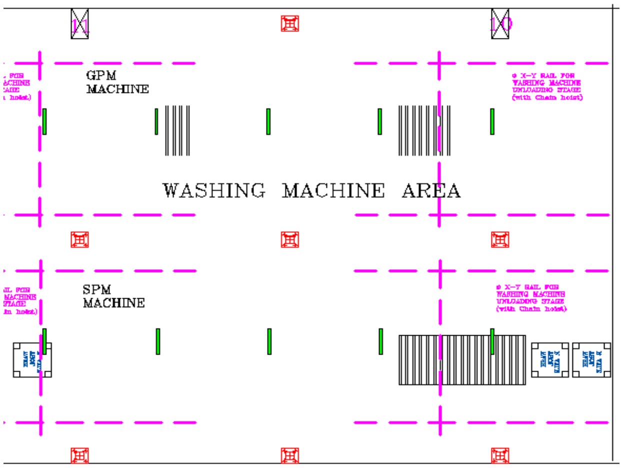


Figure 2.7: *Lighting Layout for Washing Machine Area*

F. Main line Production Area:

The most important section of the entire Tractor Production factory is the Main line Production Area. Major vehicle parts including rear hsg, rear axle, mid housing, front housing are produced in this section. High quality optimum illumination with proper uniformity is needed for this area. The recommended average lux level for the main line production area is 500 lux. The lighting layout for the main line production area is given in *Figure 2.8*.

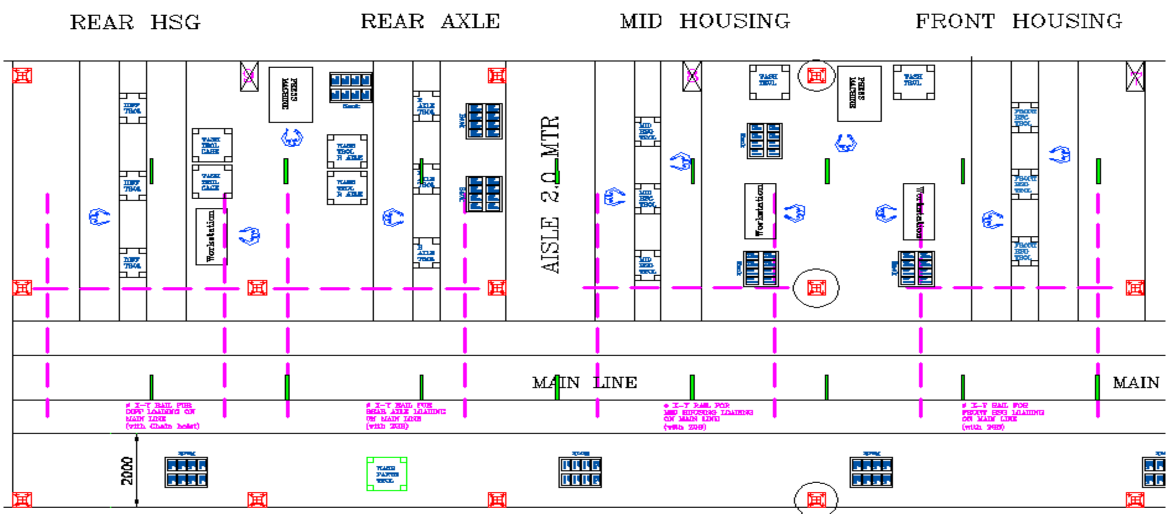


Figure 2.8: *Lighting Layout for Main Line Production Area*

G. Chassis Storage Area:

In the chassis storage area, the finished vehicle parts are stored before sent to assembling section. The recommended average lux level for the chassis storage area is 300 lux. The lighting layout for the chassis storage area is given *in Figure 2.9*. Light Fixtures are marked with green colour legend in the Figure.

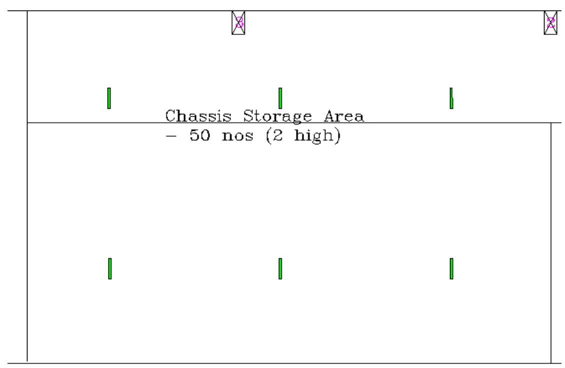


Figure 2.9: *Lighting Layout for Chassis Storage Area*

H. Dispatch Vehicle Parking Area:

In the Dispatch Vehicle Parking Area, the finished and checked Tractor Vehicles, which are ready to be dispatched to end users, are parked. The recommended average lux level for the dispatch vehicle parking area is 300 lux. The lighting layout for the dispatch vehicle parking area is given in Figure 2.10. Light Fixtures are marked with green colour legend in the Figure.

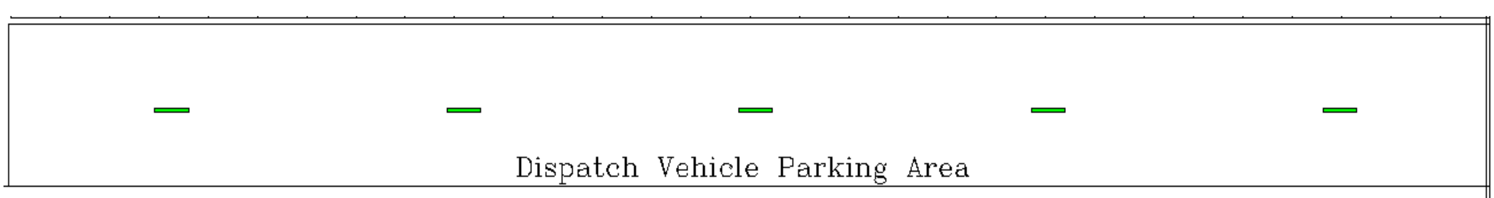


Figure 2.10: *Lighting Layout for Dispatch Vehicle Parking Area*

2.4.3 Lighting Design

The luminaire selected for this design is 80 Watt Linear Highbay. This highbay luminaire is suitable for industrial application having luminous efficacy of 145 lm/Watt and this 80 Watt product is having wide beam angle of 120°. The luminaire used for the design is shown in *Figure 2.11*.

Figure 2.11: *Linear Highbay Luminaire*[1]

From the lux level chart as mentioned in *Table 2.3*, the critical areas of lighting are the Main Line Production area and Washing Machine Area where good quality lighting is required along with proper uniformity. So desired light output with uniform light distribution in critical areas can be achieved with linear highbay luminaire. Total number of luminaires required to illuminate the entire area is 186 and Lighting Power Density for the entire area is 3.62 Watt/m^2.

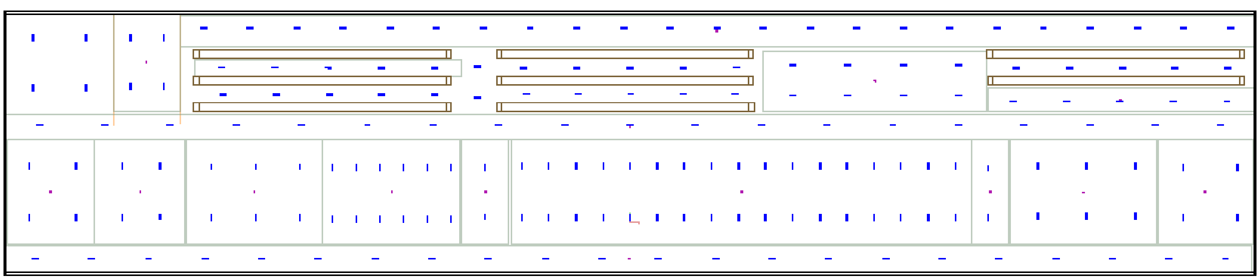


Figure 2.12: *2D View in Dialux 4.13 Software*

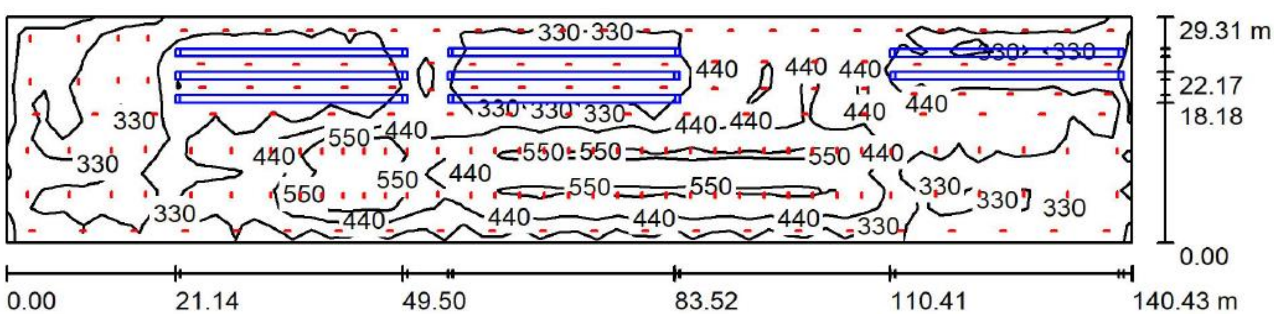


Figure 2.13: *Isolines Representation*

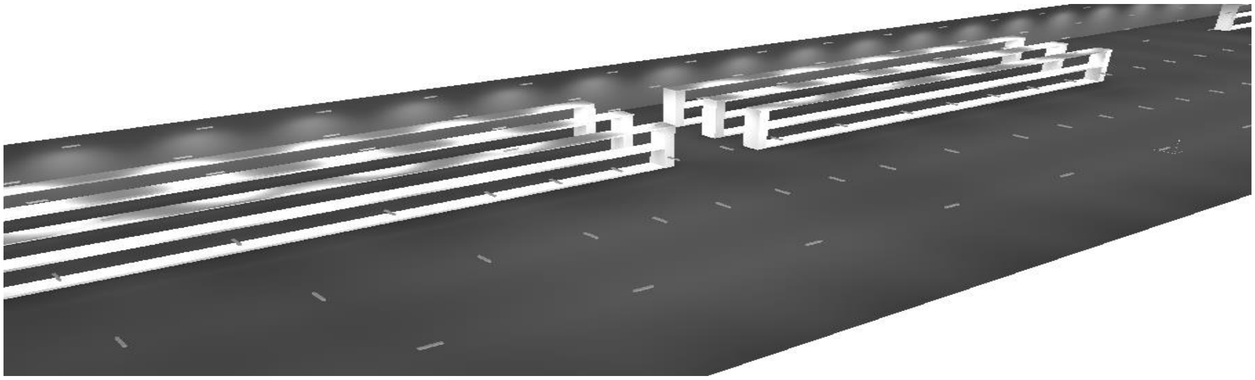


Figure 2.14: *3D View in Dialux Software*

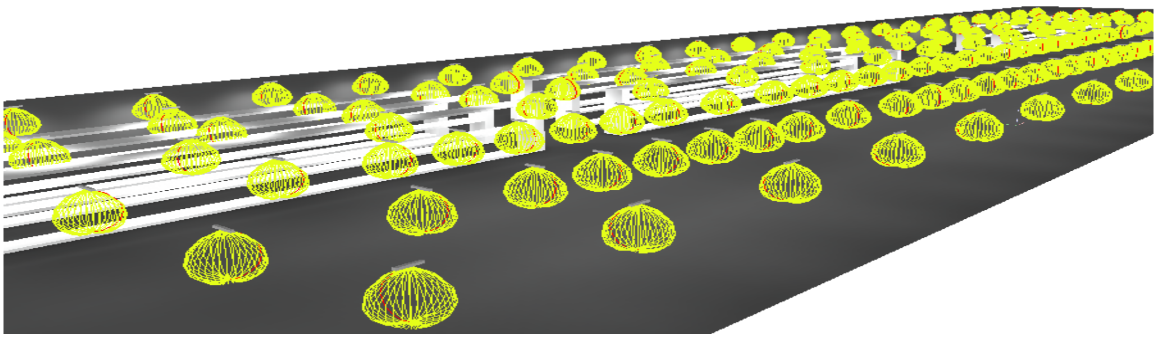


Figure 2.15: *3D View in Dialux Software with Flux Lines*

2.4.3 Results and Analysis

For general seeing tasks in industrial areas, there appears to be no effect upon visual acuity by variations in colour of light. However, where colour discrimination and colour matching are a part of the work process, the light source selected should have the desired colour rendering properties. The luminaire selected for this design have CRI value of greater than 70. Also, it is necessary to select the reflectance of all the finishes of the room surfaces and equipment as well as control the luminance distribution of the lighting equipment. For this design, reflectance of the ceiling is considered as 30%, wall reflectance is considered as 20%, and Floor reflectance is considered as 10%. Based on the simulation results obtained in *Table in 2.3* an area wise lux level chart is plotted in *Figure 2.16*. In vehicle dispatch area, racking system is considered in design. Racks have height of 2.5 metres.

Table 2.3: *Lux Level Details*

Area	Obtained Lux level	Uniformity	Recommended lux level
Receiving Area	368	0.604	300
Aisle	383	0.787	300
RQA	304	0.610	300
Washing Parts Storage Area	359	0.778	300
Washing Machine Area	550	0.700	500
Main line Production	511	0.764	500
Chassis Storage Area	327	0.856	300
Empty Skids Storage Area	299	0.749	300
Storage of Engine	300	0.721	300
Front Axle Bracket	413	0.544	300
Dispatch Vehicle Parking	359	0.426	300

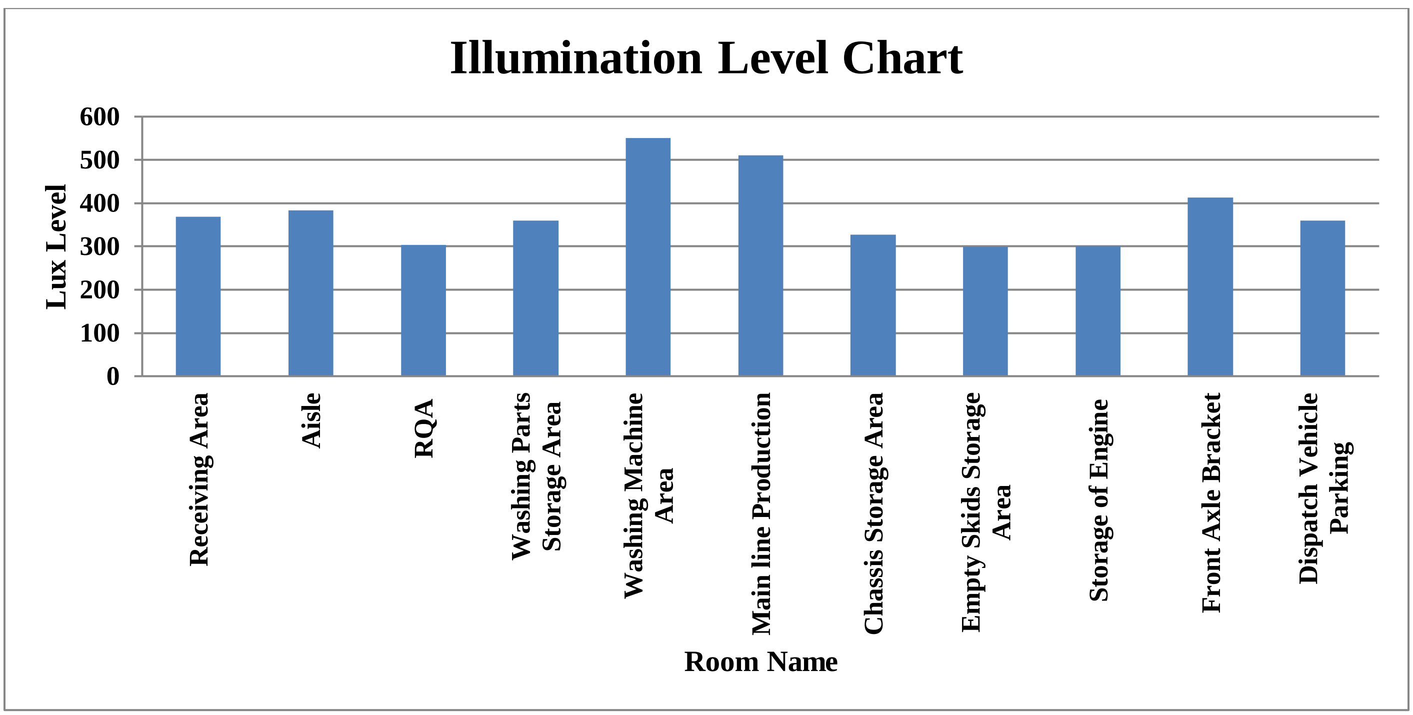


Figure 2.16: *Graphical Representation of Lux Level Sheet*

2.5 Case Study: 2

Another Industrial design performed was of Hydroelectric Power Project. It is a run-of-the-river power project on the Chenab River. Lighting Design of the Machine Hall was performed. Hydroelectric power plants are usually located in dams that impound rivers, thereby raising the level of the water behind the dam and creating as high a head as is feasible. The potential power that can be derived from a volume of water is directly proportional to the working head, so that a high-head installation requires a smaller volume of water than a low-head installation to produce an equal amount of power. In some dams, the powerhouse is constructed on one flank of the dam, part of the dam being used as a spillway over which excess water is discharged in times of flood. Where the river flows in a narrow steep gorge, the powerhouse may be located within the dam itself.

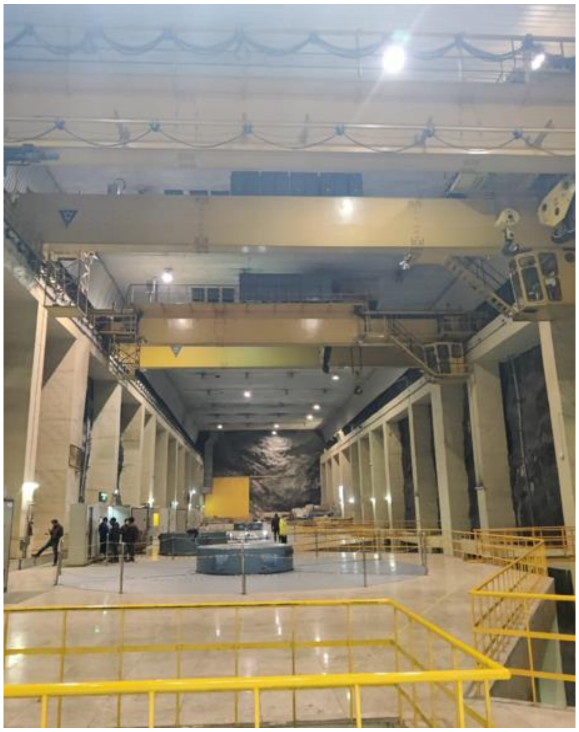


Figure 2.17: *Machine Hall of Hydro Electric Project*

2.5.1 Project Background

Machine Hall of the Hydro Electric Power Plant consists of 2200 sq. metres of ground area and its height is 15 metres. It is basically a refurbishment project where outdated 400 Watt Conventional luminaires is to be replaced to LED luminaires, thereby maintaining the desired lux level as per as the standards.

2.5.2 Lighting Planning Layout

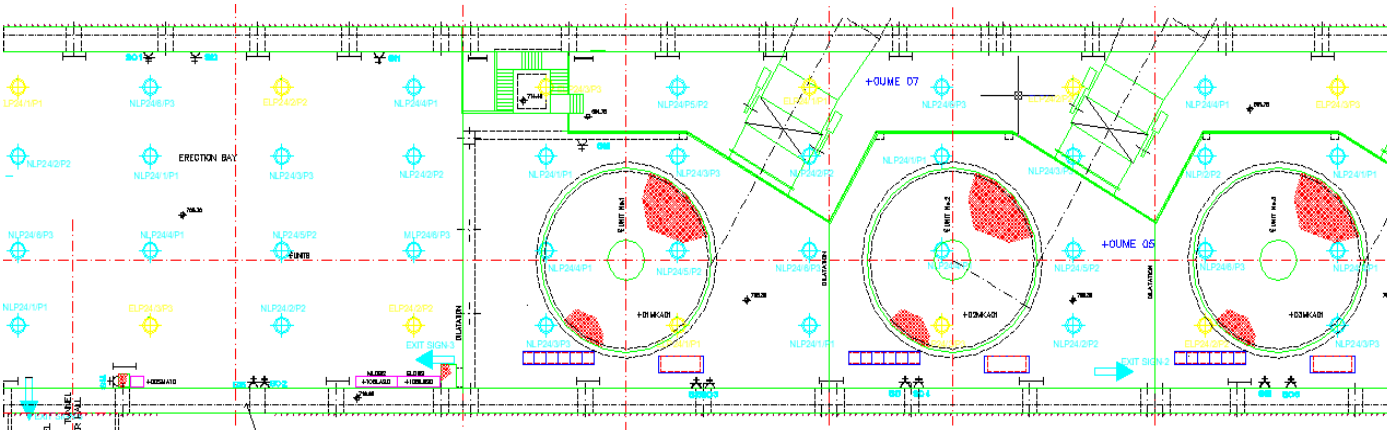


Figure 2.18: *Complete Lighting Layout*

2.5.3 Lighting Design

The luminaire selected for this design is 200 Watt Integral SMD LED Highbay. Light Fixtures are marked with blue colour legend in the *Figure 2.18.* This luminaire is suitable for industrial applications having luminous efficacy of 135 lm/Watt and this 200 Watt product is having beam angle of 60°. Total number of luminaires required to illuminate the entire area is 48 and Lighting Power Density (LPD) for the entire area is 4.38 Watt/m^2. The luminaire used for the design is shown in *Figure 2.19.* CRI value of this luminaire is greater than 70 and CCT is considered as 5700 Kelvin. The maintenance factor taken for this design is 0.8.

Figure 2.19: *Integral SMD LED Highbay Luminaire* [1]

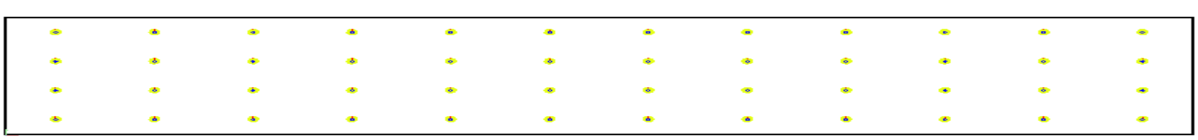


Figure 2.20: *2D View in Dialux Software*

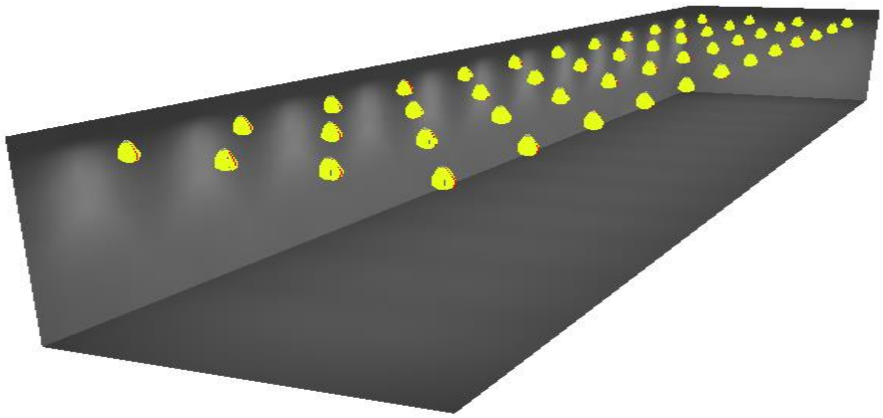


Figure 2.21: *3D View in Dialux Software with Flux lines*

2.5.4 Results and Analysis

According to Bureau of Indian Standards (BIS) as mentioned in National Lighting Code (NLC), 2010 recommended lux level for Machine Hall of Indoor Electricity Generating Stations is 300 lux. The obtained lux level for the Machine Hall for this project is 349 lux considering mounting of 14 metres. Since the mounting height is here is high, so the luminaire so be selected should have either narrow or medium beam distribution. Luminaire selected for the design is having beam angle of 60 degree. The luminaire selected for this design have CRI value of greater than 70. Also, it is necessary to select the reflectance of all the finishes of the room surfaces and equipment as well as control the luminance distribution of the lighting equipment. For this design, reflectance of the ceiling is considered as 30%, wall reflectance is considered as 20%, and Floor reflectance is considered as 10%.

Table 2.4: *Simulation Details*

Design Parameters	**Values**
Mounting Height	14 m
Average lux level	349 lux
Minimum lux level	155 lux
Maximum lux level	435 lux
Uniformity	0.444

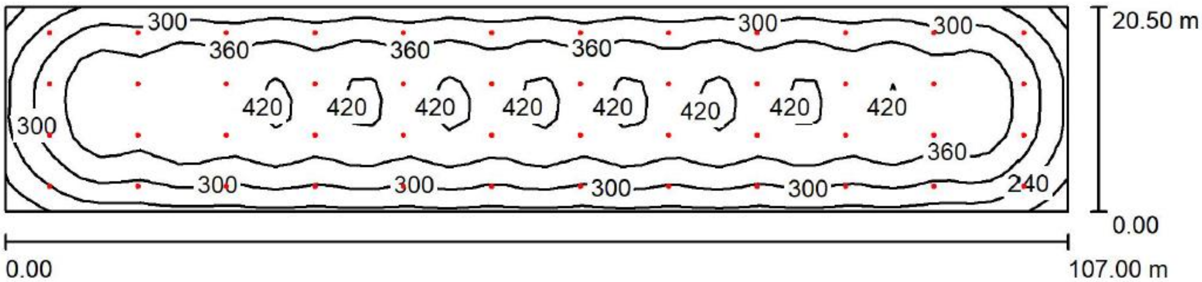


Figure 2.22: *Isolines Representation*

2.6 Comparative Analysis between Industrial Lighting Designs

In the Case Study 1, as the height of room is 4 metres, therefore the 80 Watt linear highbay luminiare having a high beam angle of 120° is ideal since good uniformity is required in the production areas. The lumninaire having system efficacy of 145 lumen/Watt is used as the recommended lux level in the main line production area and washing machine area is 500 lux. Whereas, in the Case Study 2, the height of the room is 15 metres, so the round shaped highbay luminiare with factory fitted eye bolt mounting at a mounting height of 14 metres is used. This luminaire have system efficacy of 135 lumen/Watt. Since high performance production work is carried in the industry represented in case study 1, so uniformity maintained here is almost close to 0.7. A tabular representation of comparative analysis between Case Study 1 and Case Study 2 is shown below in *Table 2.5*.

Table 2.5: *Comparison Details*

Parameters	**Case Study 1**	**Case Study 2**
Design Type	Manufacturing Industry	Machine Hall of Hydro Power Plant
Luminaire Used	Linear Highbay	Round Highbay
Luminaire Mounting Height	4 m	14 m
Lumianire Wattage	80 Watt	200 Watt
Lumianire Beam Angle	120°	60°
Luminaire Efficacy	145 lumen/Watt	135 lumen/Watt
Average lux level	*Refer to Table 2.3* (Recommended Value: 300 lux/ 500 lux)	*Refer to Table 2.4* (Recommended Value: 300 lux)
Lighting Power Desnsity (LPD)	3.62 Watt/m^2	4.38 Watt/m^2

Chapter 3

Office Lighting

3.1 Introduction

Office is a space so full of work, documents, formal atmosphere and busy time. An office space can have lots of clients to visit as well as at times the same office space may be vacant from guests. Office space has to deal with different kind of clients, meetings, guests, etc. The provision made for lighting will depend on the type of office, for example, general office, executive office, drawing office, etc and the subdivision of the floor space. So, to maintain the perfect balance of this formal and healthy working atmosphere lighting designing should be formal and luminaires must be planned in such a manner to keep going the work without any tension in the surroundings. Where the layout of partitioning is unknown or subject to alteration, provision should be made for a flexible installation that will allow luminaires to be placed in proper relation to any arrangement of partitioning. Wherever possible, the layout and operation of the lighting system should be designed in conjunction with other services. This involves dimensional coordination with the building module and positional coordination with the air input and exhausts terminals. The electrical power of the lamp and control gear contributes to the heat input of a building and allowance should be made for this in the design of the heating and cooling system. The layout should be designed to limit glare and care should be taken to avoid specular reflection of the light sources from polished furniture, glossy paper, machine surfaces or glazed partitions. Whereas good horizontal illuminance is necessary for the tasks of writing or reading, vertical illuminance is essential for presenting a true and pleasing appearance of the interiors and occupants. This may be provided by the choice of appropriate luminaires, and high surface reflectances.

3.2 Office Lighting Requirements

In office lighting designs, the recommended illumination values as given under the head 'Offices, Schools and Public Buildings' in IS 3646 (Part I). General overhead lighting will normally be satisfactory but, in relatively deep offices, integration of daylight and artificial light may be required in order to give properly balanced seeing conditions while still retaining the effect of natural lighting. The layout should be designed to limit glare and care should be taken to avoid specular reflection of the light sources from polished furniture, glossy paper, machine surfaces or glazed partitions. Viewing conditions inside an office space are influenced very much by the finishes and furnishings. Interior finishes and furnishings should have reflectances of not less than 70 percent for ceilings and 50 percent for walls.

3.3 Luminaires for Office Lighting

The choice of the light source and luminaire is made to meet both functional and architectural requirements. Layout is decided considering partitions, structural beams or waffles in the ceiling, suspended ceiling, and likely layout of office furniture. Before the layout is finalized the integration of the above with the layout of the air conditioning outlets and fire protection equipment should be verified and adjustments made as required. Dark coloured floors, furnishings and curtains, wooden panelling, etc, should be avoided as these will absorb the incident light and the resultant surface luminance will be poor. In such cases, especially on walls, additional lighting will have to be directed.

3.4 Case Study: 1

One of the major Office Lighting Project Performed was of a Web development IT Company. Complete lighting design of the second floor is performed. The major areas of the office are workstation, Managing Director's (MD) cabin, Conference room, HR room.

3.4.1 Project Background

The primary input needed before planning a indoor lighting design is the dimensions of the place. The room dimensions of all the major rooms of the office are shown in *Table 3.1*. Major rooms of the office all have RCC type Ceiling.

Table 3.1: *Room Dimensions*

Room Name	Room Dimensions	Room Height
Workstation	32.5 m X 17 m	2.8 m
MD Room	5 m X 5 m	2.8 m
HR Room	3.3 m X 2.7 m	2.8 m
Conference Room	3.65 m X 5.2 m	2.8 m
IT Room	3.8 m X 2 m	2.8 m

3.4.2 Lighting Layout

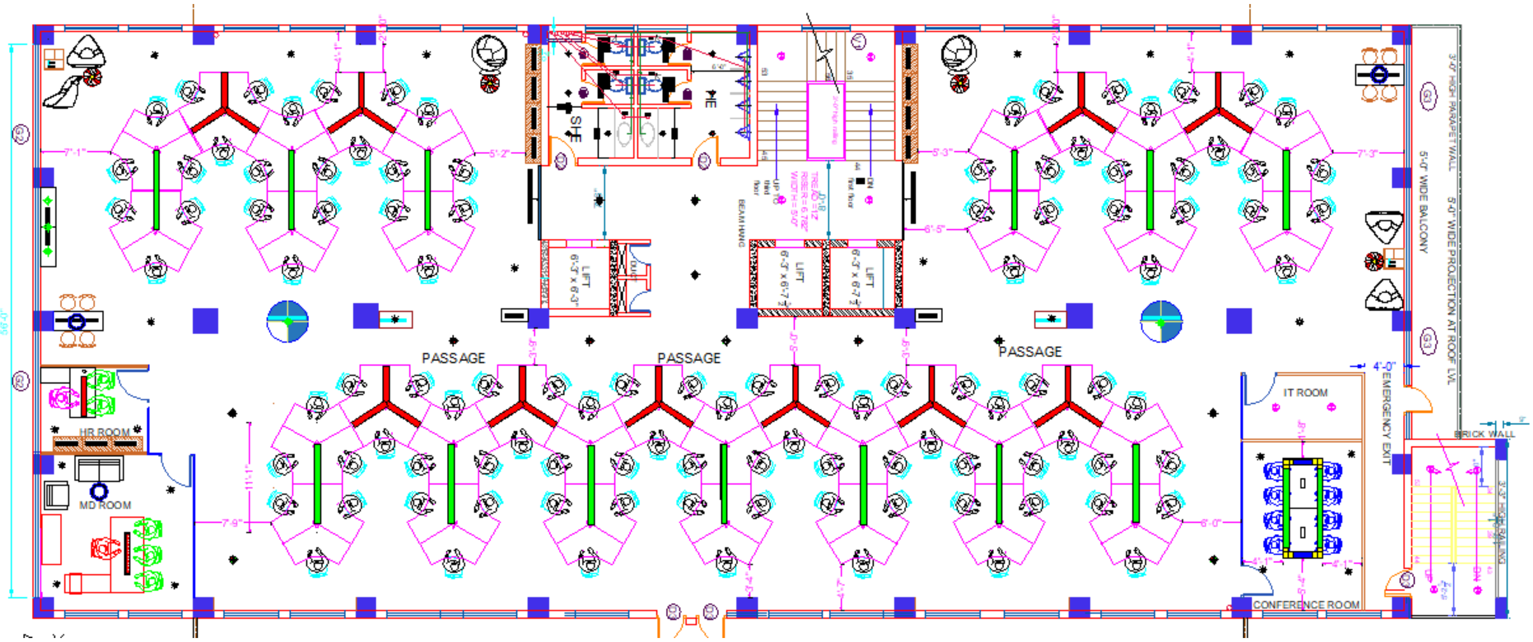


Figure 3.1: *Second Floor Complete Lighting Layout*

The lighting layout and descriptive analysis of some of the major rooms are given as follows:

A. Workstation:

Workstation is an important area in an office. The quality of lighting at office workstation can have a significant effect not only on eyes but also on productivity. Poor lighting, whether too much or too little, is a major contributing factor to the eye strain symptoms. Bright light on the display screen "washes out" images making it difficult for operators to clearly see the work. For computer work, well-distributed diffuse light is best. The advantages of diffuse lighting are two-fold: There tend to be fewer hot spots, or glare surfaces, in the visual field, and the contrasts created by the shape of objects tend to be softer. The proposed design for the workstation is illustrated in *Figure 3.2*. 6 Feet 30 Watt Linear Fixtures are marked with green colour in the figure and an eye catching Y shaped pattern is proposed using 4 feet 20 Watt linear fixture marked with red colour legend in the figure.

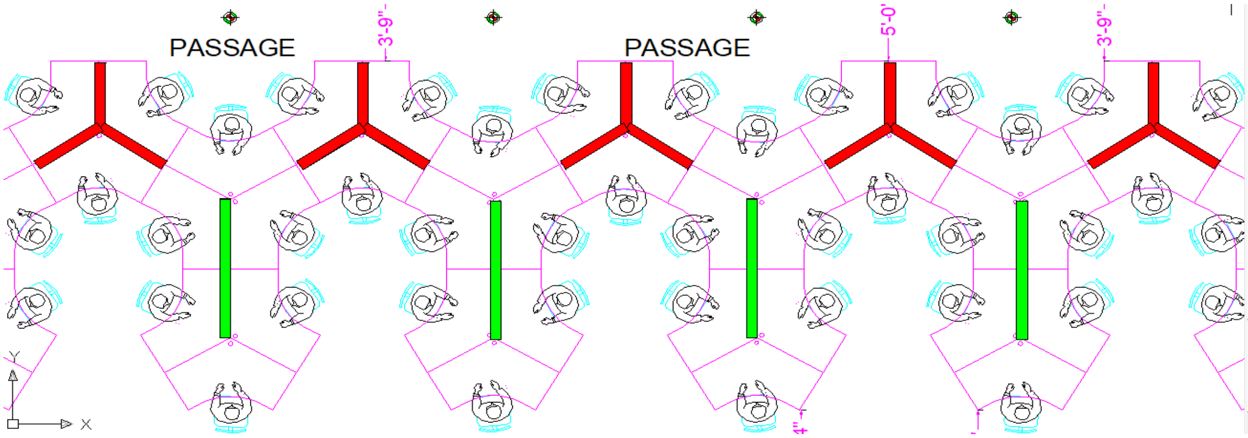


Figure 3.2: *Lighting Layout of Workstation*

B. Conference Room:

Conference Room is another important area in an office. Since there are many events in conference rooms from face to face interviews by presentations to large conferences, it is very important to gather attention in this areas. On the other hand, the design and the lighting of these areas reflects the company culture to guests by different way. Conference halls require 300 lux light level. It is recommended that the Color rendering index should be 80 or higher. A special demand in such areas is that the lighting can be controlled. Lightings which equipped with control systems, offers flexible lighting solution while using the Conference rooms. Central lighting is extremely important in meeting rooms and conference halls. Insufficient light makes eyes tired and loss of concentration. On the other hand good lighting increased concentration. Spotlights can also highlight the important areas and also various lighting schemes can be created. The proposed design for the conference room is illustrated in ***Figure 3.3.***

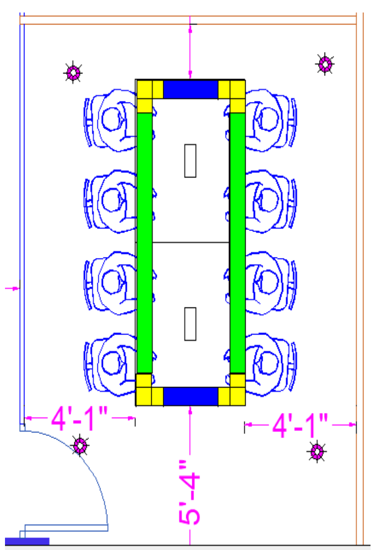


Figure 3.3: *Lighting Layout of Conference Room*

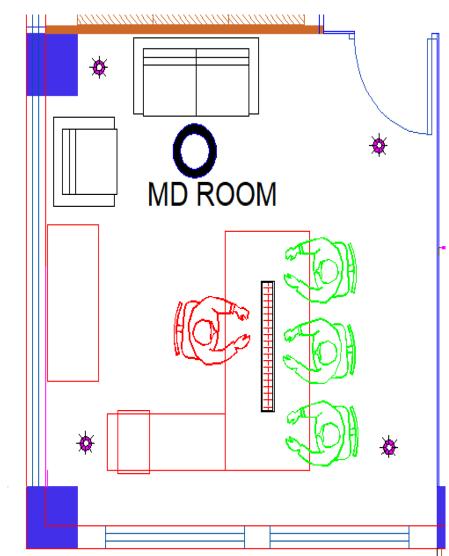


Figure 3.4: *Lighting Layout of MD Room*

C. MD Cabin:

MD office or cabin is the place which is the most royal, private, confidential, formal and at times it also servers to informal guests. It's a unique combination of formal and inform has to be designed in a very dignified and elegant manner. Design idea of MD office should be planned to serve needs of formal, informal and personal needs of the managing director as well. The proposed design for the conference room is illustrated in *Figure 3.4.*

3.4.3 Lighting Design

The luminaire selected for the design of workstation and conference room is 20 Watt suspended 4 feet linear LED luminaire. This luminaire is having a efficacy of 110 lumen/Watt and it is a linear lighting solution with extruded aluminium housing and high transmissivity High Efficiency Translucence (HET) diffuser. The luminaire used for the design is shown in *Figure 3.5.* A rectangular pattern is created using linear fittings which not satisfy the required lux level but also improve ambience of the room. The reference picture of the created pattern is shown below in *Figure 3.6.* Luminaires selected for this design have CRI value of greater than 80. Also, it is necessary to select the reflectance of all the finishes of the room surfaces and equipment as well as control the luminance distribution of the lighting equipment. For this design, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%.

Figure 3.5: *Linear Suspended LED Luminaire* [1]

Figure 3.6: *Lighting Pattern Proposed for Conference Room*

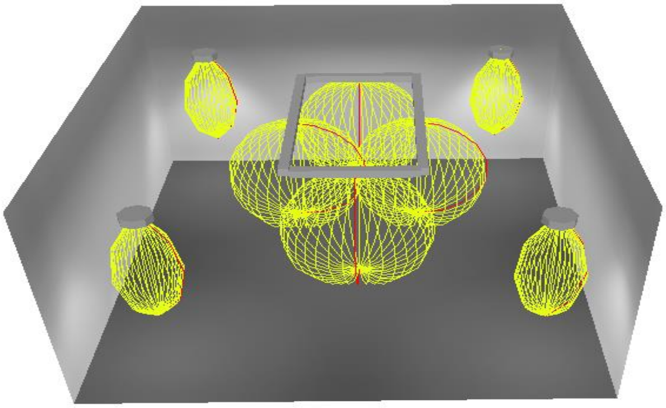


Figure 3.7: *3D View of Conference Room in Dialux Software*

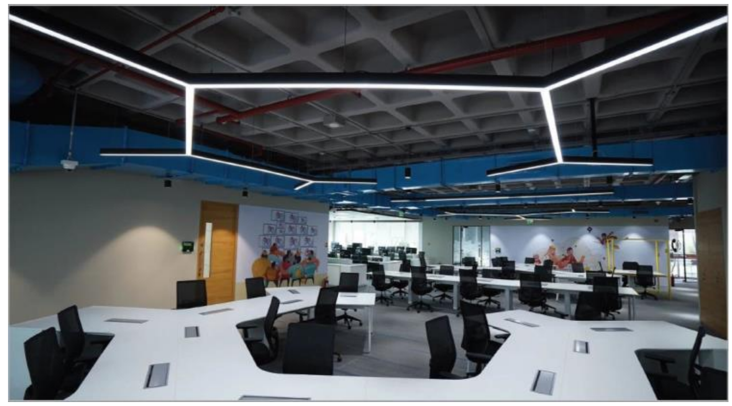


Figure 3.8: *Lighting Pattern Proposed for Workstation*

The luminaire selected for the design of MD Cabin is 30 Watt suspended 4 feet decorative linear LED luminaire. This luminaire is having a efficacy of 100 lumen/Watt and it is a linear lighting solution with extruded aluminium housing and high transmissivity HET diffuser. The luminaire used for the design is shown in *Figure 3.9***.**

Figure 3.9: *30 Watt Decorative suspended luminaire for MD Room* [1]

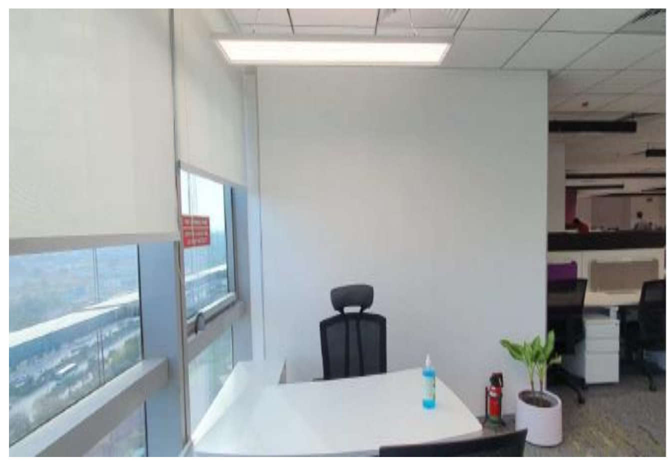


Figure 3.10: *Lighting Pattern Proposed for MD Room*

Figure 3.11: *35 Watt Decorative suspended Round Ring Type LED luminaire* [1]

3.4.4 Results and Analysis

Table 3.2: *Lux Level Details*

Room Name	Obtained Lux level	Recommended lux level
Workstation	361	350
MD Room	286	250
HR Room	299	250
Conference Room	428	350
IT Room	210	200

The illuminance and its distribution on the task area and the surrounding area have a great impact on how quickly, safely and comfortably a person perceives and carries out the visual task. A graphical representation of the room wise obtained lux level is shown below in *Figure 3.12*. Sufficient amount of lux level is achieved in conference room and workstation which are one most critical sections of a office. Lesser lux level is required for IT Room. Maintenance factors were estimated based on the agreed unified schedule for the all rooms. In lighting design software, it was necessary to put the maintenance factor. So, it was decided that the environment was clean and therefore maintenance factor is taken as 0.85.

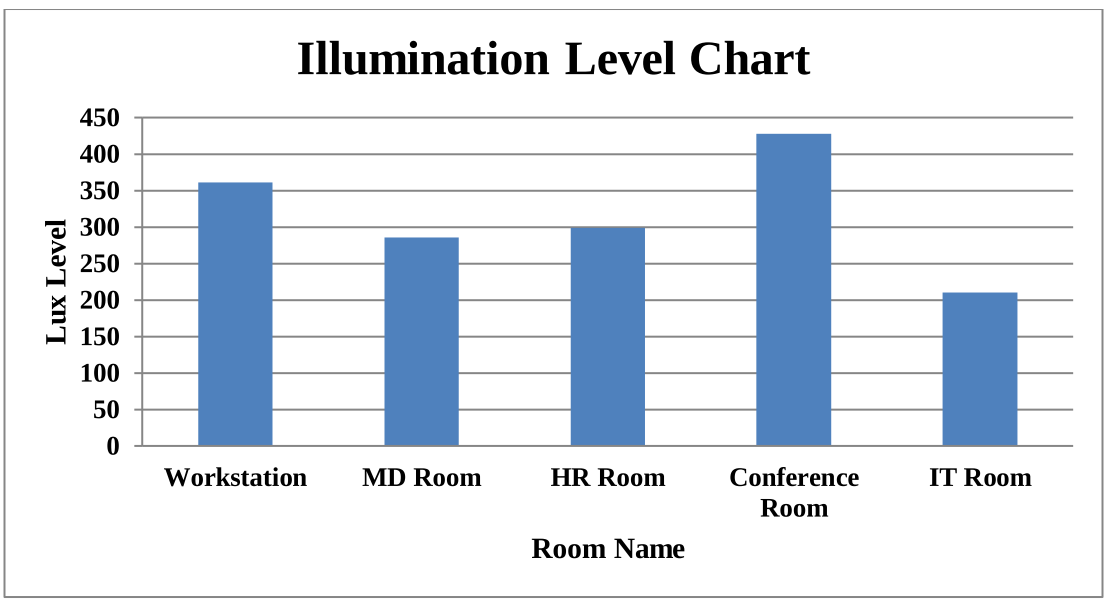


Figure 3.12: *Graphical Representation of Lux level Sheet*

3.5 Case Study: 2

Another major Office Lighting Project Performed was of a Real Estate Building Company. Complete lighting design of the seventh floor and eighth floor was performed. The major areas of the office are workstation, Director's cabin, Conference room.

3.5.1 Project Background

The room dimensions of all the major rooms of the office are shown in *Table 3.3.* All rooms of the seventh floor have RCC ceiling and rooms of eighth floor have gypsum ceiling.

Table 3.3: *Room Dimensions*

Room Name	Room Dimensions	Room Height
Workstation	9.16 m X 10.59 m	3.2 m
Conference Room	7.71 m X 6.12 m	3.2 m
MD Cain	5 m X 6.5 m	3.2 m
Waiting Lobby	8.56 m X 7.9 m	3.2 m
Passage	22 m X 3.5 m	3.2 m

3.5.2 Lighting Layout

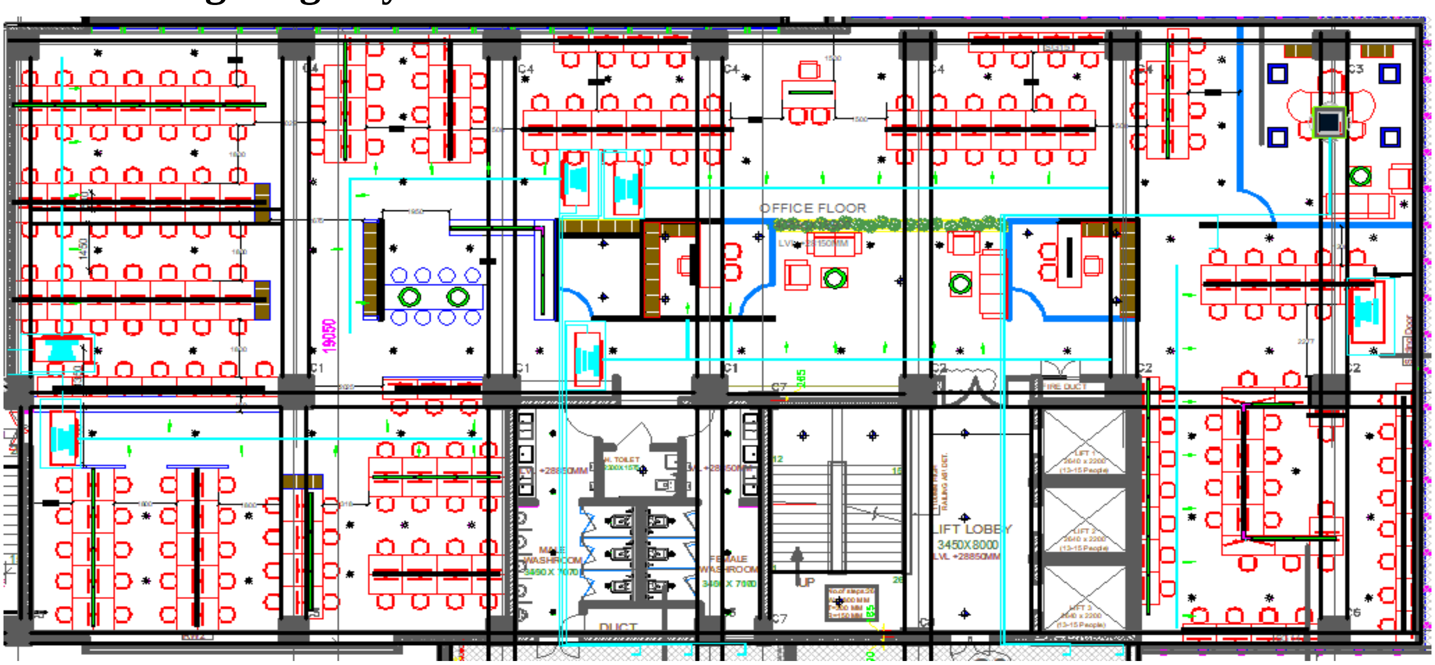


Figure 3.13: *Complete Lighting Layout of Seventh Floor*

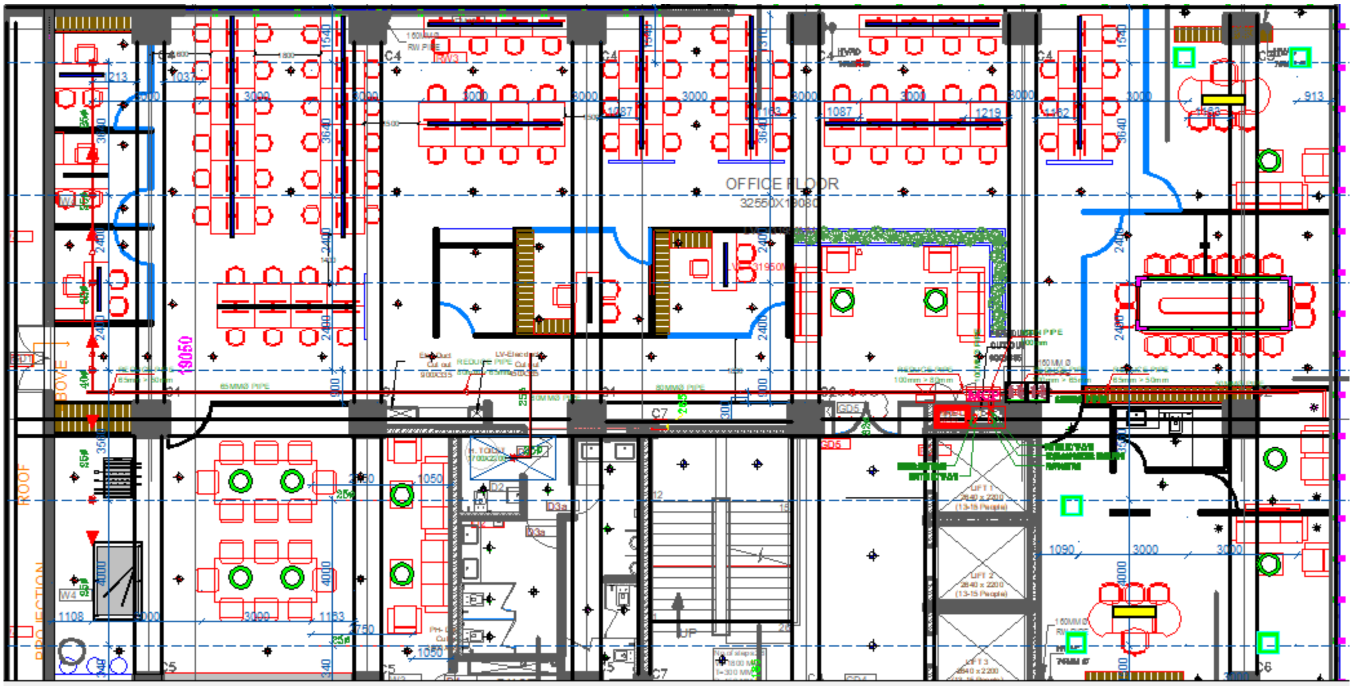


Figure 3.14: *Complete Lighting Layout of Eighth Floor*

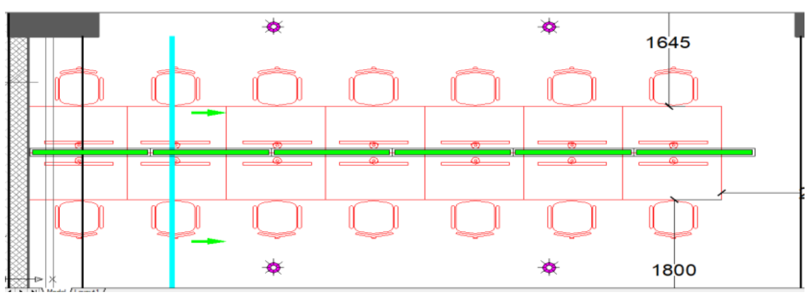


Figure 3.15: *Lighting Layout for Workstation*

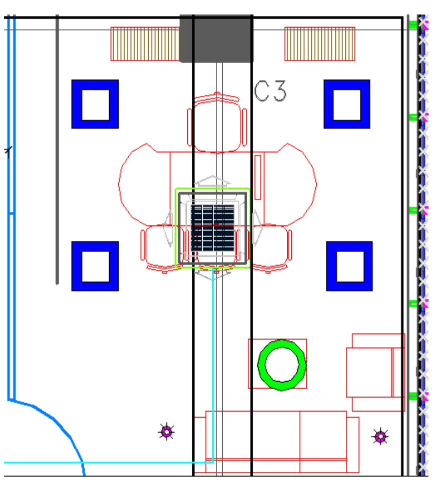


Figure 3.16: *Lighting Layout for MD Cabin*

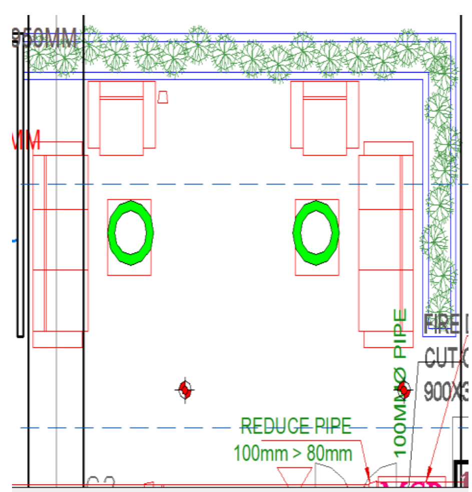


Figure 3.17: *Lighting Layout for Waiting Lobby*

3.5.3 Lighting Design

The luminaire selected for the design of MD Cabin is 33 Watt Recessed 2 feet by 2 feet decorative LED luminaire. This luminaire is having a efficacy of 95 lumen/Watt with extruded aluminium housing and drop down HET PMMA diffuser. This lumianire have light engine and diffuser only on the edeges and hollow in between with Drop Down HET Polymethyl methacrylate (PMMA) diffuser. The luminaire used for the design is shown in *Figure 3.18*. The luminaire selected for the design of workstation and conference room is 20 Watt suspended 4 feet linear LED luminaire. This luminaire is having a efficacy of 110 lumen/Watt and it is a linear lighting solution with extruded aluminium housing and high transmissivity HET diffuser. The luminaire used for the design is shown in *Figure 3.20*.

Figure 3.18: *33 Watt Recessed Decorative 2X2 Luminiare* [1]

Figure 3.19: *Lighting Pattern Proposed for MD Cabin*

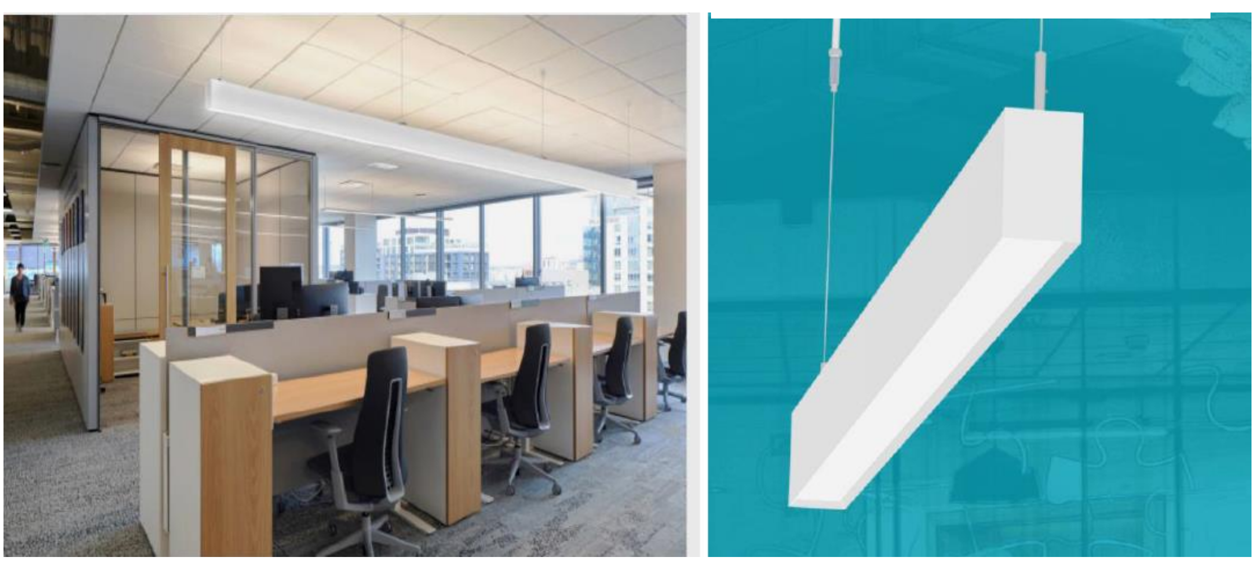


Figure 3.20: *Lighting Pattern Proposed for Workstation* [1]

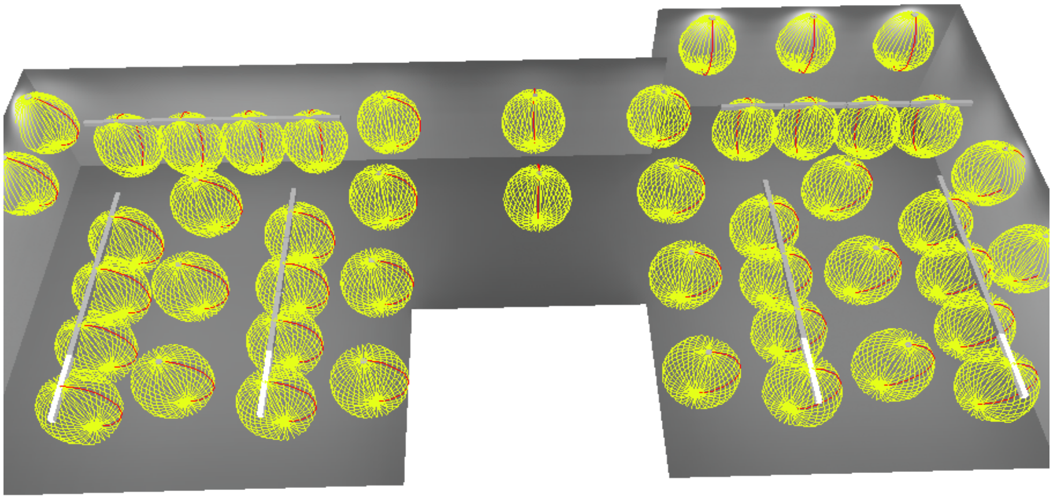


Figure 3.21: *3D View of Lighting Pattern Proposed for Workstation in Dialux Software*

The luminaire selected for the design of Waiting Lobby is 35 Watt Suspended 600 mm dia round ring type decorative LED luminaire. This luminaire is having a efficacy of 100 lumen/Watt with extruded aluminium housing and drop down HET PMMA diffuser. The luminaire used for the design is shown in *Figure 3.22*. Waiting Lobby is that type of area where lux level does not matters, what matters more is the aesthetic glamour of the space. So this round ring type lumnianire is suitable for Waiting Lobby so that it the office space becomes a eye catching space for the visitors. CRI value of this luminaire is greater than 80 and CCT taken here is of 4000 Kelvin to obtain a soothing and relaxed lighting environment. This area requires a good visual environment is for creating the required subjective impression about the space both to the short time and long time users.

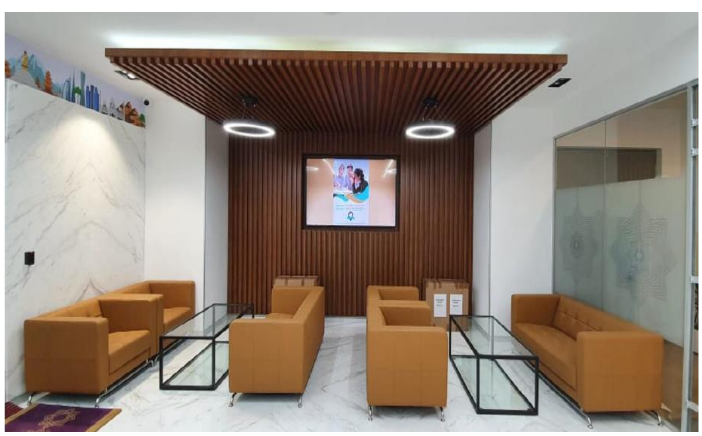


Figure 3.22: *Lighting Pattern Proposed for Waiting Lobby*

3.5.4 Results and Analysis

Table 3.4: *Lux Level Details*

Room Name	Obtained Lux level	Recommended lux level
Workstation	353	350
Conference Room	352	350
MD Cain	263	250
Waiting Lobby	179	150
Passage	201	200

Luminaires selected for this design have CRI value of greater than 80. Also, it is necessary to select the reflectance of all the finishes of the room surfaces and equipment as well as control the luminance distribution of the lighting equipment. For this design, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%. A graphical representation of the room wise obtained lux level is shown below in *Figure 3.23*. Adequate amount of lux level is achieved in conference room and workstation which are one most critical sections of this office. Lesser lux level is required for waiting lobby and passage. Uniformity maintained in Workstation and Conference room is subsequently greater compared to rest of the rooms since task lighting is a major factor in these areas.

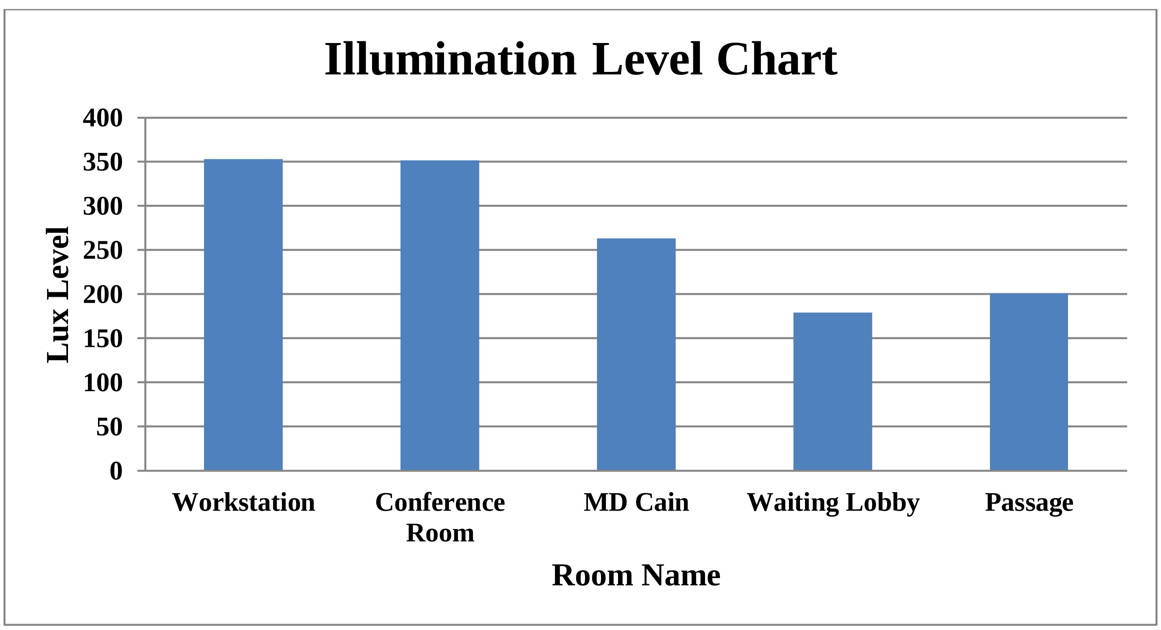


Figure 3.23: *Graphical Representation of Lux level Sheet*

3.6 Comparative Analysis between Office Lighting Designs

In Case Study 1, lighting design of an IT Office in is conducted using Suspended LED luminaires mounted on RCC Ceiling. Whereas in case study 2, lighting design of a real estate office is conducted using Recessed LED luminaires as the rooms in the office have gypsum ceiling. The detailed comparative analysis is shown below in Table 3.5. Also in case study 1, an eye catching continuous Y Shaped pattern is proposed in the workstation area using linear luminaires as shown in Figure 3.2 and Figure 3.9. And in case study 2, another innovative is pattern is proposed in the workstation area as shown in Figure 3.15. In both the case studies, application of linear LED luminaire is more because of task dependent areas. An average horizontal illuminance for task area, as per IS 3646 (Part I) is 300~500-750, depending on the criticality of the task, and the ambient conditions. So in major areas, lux level calculation is performed based on th BIS Standards. Uniformity of a room depends upon the mounting height. Large spatial variations in illuminances around the task area may lead to visual stress and discomfort. In the case study 1, since the mounting height is less, so to achieve good uniformity, the luminaire proposed in this project have wide beam angle, compared to the design conducted in case study 2, where the mounting height is 3.2 metres. So in case study 2, to achieve good uniformity, the luminaires proposed here have medium and narrow beam angle distribution. For both the case studies, maintenance factors were estimated based on the agreed unified schedule for the all rooms. It was decided that the environment was clean. Maintenance Factor is taken as 0.85 for simulation purpose.

Table 3.5: *Comparison Details*

Parameters	Case Study 1	Case Study 2
Design Type	IT Office	Real Estate Office
Ground Area	765 sq. meters	1000 sq. meters
Ceiling Type	RCC	Gypsum
Luminaire Type	Suspended	Recessed
Luminaire Mounting Height	2.8 m	3.2 m
Average lux level	*Refer to Table 3.2* (Recommended Value: 150 lux/ 200 lux, 300 lux)	*Refer to Table 3.4* (Recommended Value: 150 lux/ 200 lux, 300 lux)

Chapter 4

Lighting for Educational Complex

4.1 Introduction

The primary activity for a student studying in any educational institution is of reading and writing. These may range from easy tasks of reading clear and bold printed matter to more difficult ones like pencil writing, maps or graph sheet work. There may also be fine and detailed work such as art work, needle work, dissection activity in biology laboratory, etc. The difficult tasks would need higher levels of illumination. A student has to look at various objects with close attention for a long duration. There would be requirements of both nearby and far off viewing alternately. Where the eyes are required to adapt to vastly different luminance for short durations at frequent intervals one is likely to experience discomfort and fatigue. In order that such viewing is without discomfort, the visual environment should be good and hence good quality illumination is a necessity in educational complexes like schools, colleges, university etc.

4.2 Lighting Requirements

The illuminance required is governed by the size of the object to be seen, contrast and period of viewing. Generally horizontal illuminance level of 300 lux is considered adequate for teaching areas, 100 lux in corridors and 200 lux in gymnasiums. Higher illuminance should be provided for more exacting visual tasks by supplementary localised lighting. Where tasks with different requirements are to be performed at the same time in a space, the level of illuminance should satisfy the most demanding task. If this calls for excessive levels, then levels lower than those may be adopted, with localized supplementary lighting for specific tasks requiring higher levels. In lecture theatres in colleges, where the room sizes are larger compared to schools, attention should be given for unobstructed viewing and dimming of lights for the use of various visual aids. This dimming facility may be needed in large halls where visual aids are likely to be used, and also where practical experiments are conducted. In such situations, dimmable lumianaires comes into account.

4.3 Case Study

One of the major Educational Building Lighting Project Performed is a Senior Secondary Government School. This is a co educational government school and it consists of five floors.

4.3.1 Project Background

The government school consists of 1560 sq. metres of ground area and the typical height of the rooms is 3.3 metres. Majority of the rooms have RCC Ceiling. The basement floor consists of music room, sports room, chemistry lab and teacher room. The ground floor consists of some important rooms like principal office, waiting room, superintendent office, Secondary classroom, computer lab, physics lab and teacher room. The first floor consists of gent's staff room, upper primary classroom, Smart classroom and biology lab. The second floor consists of ladies staff room, pantry, SUPW room, maths lab, language lab, ICT, Sanskar room, geography lab and library. The third floor primarily consists of higher secondary classrooms. Dimensions of the rooms of all the five floors are represented in *Table 4.1, Table 4.2, Table 4.3, Table 4.4, Table 4.5* respectively.

Table 4.1: *Basement Floor Dimensions*

Room Name	Dimensions	Room Height
Music Room	4.19 m X 4.2 m	3.3 m
Sports Room	4.6 m X 4 m	3.3 m
Chemistry Lab	8.5 m X 12 m	3.3 m
Teacher Room	3.0 m X 8 m	3.3 m

Table 4.2: *Ground Floor Dimensions*

Room Name	Dimensions	Room Height
Principal Office	6 m X 8 m	3.3 m
Waiting Room	8 m X 9 m	3.3 m
Toilet	1.45 m X 2.5 m	3.3 m
Superintendant Office	7.0 m X 4.0 m	3.3 m
Secondary Classroom	8.4 m X 6.74 m	3.3 m
Entrance Foyer	3.0 m X 8 m	3.3 m
Computer Lab	10 m X 4 m	3.3 m
Physics Lab	10 m X 5 m	3.3 m
Teacher Room	5.45 m X 3.78 m	3.3 m
Corridor	20 m X 3 m	3.3 m

Table 4.3: *First Floor Dimensions*

Room Name	Dimensions	Room Height
Gents Staff Room	4.57 m X 6.18 m	3.3 m
Toilet	1.45 m X 2.45 m	3.3 m
Pantry	2.5 X 3.0 m	3.3 m
Corridor	20 m X 3 m	3.3 m
Upper Primary Classroom	8.4 m X 6.74 m	3.3 m
Smart Classroom	8.4 m X 6.74 m	3.3 m
Biology Lab	10 m X 5 m	3.3 m
Attendant Room	2.9 m X 3.5 m	3.3 m
Store	2.25 m X 3.1 m	3.3 m

Table 4.4: *Second Floor Dimensions*

Room Name	Dimensions	Room Height
Ladies Staff Room	4.57 m X 6.18 m	3.3 m
Pantry	2.5 X 3.0 m	3.3 m
Toilet	1.45 m X 2.45 m	3.3 m
Corridor	20 m X 3 m	3.3 m
Store	2.25 m X 3.1 m	3.3 m
SUPW Room	7.8 m X 3 m	3.3 m
Maths Lab	10 m X 5 m	3.3 m
Language Lab	10 m X 5 m	3.3 m
ICT Lab	10 m X 5 m	3.3 m
Sanskar Room	6.48 m X 5.56 m	3.3 m
Geography Lab	7.43 m X 8.86 m	3.3 m
Library	6.48 m X 5.56 m	3.3 m

Table 4.5: Third Floor Dimensions

Room Name	Dimensions	Room Height
Corridor	20 m X 3 m	3.3 m
Store	2.25 m X 3.1 m	3.3 m
Toilet	1.45 m X 2.45 m	3.3 m
Higher Secondary Classroom	8.4 m X 6.74 m	3.3 m
Higher Secondary Classroom	8.4 m X 6.74 m	3.3 m
Higher Secondary Classroom	8.4 m X 6.74 m	3.3 m
Higher Secondary Classroom	8.4 m X 6.74 m	3.3 m

4.3.2 Lighting Planning Layout

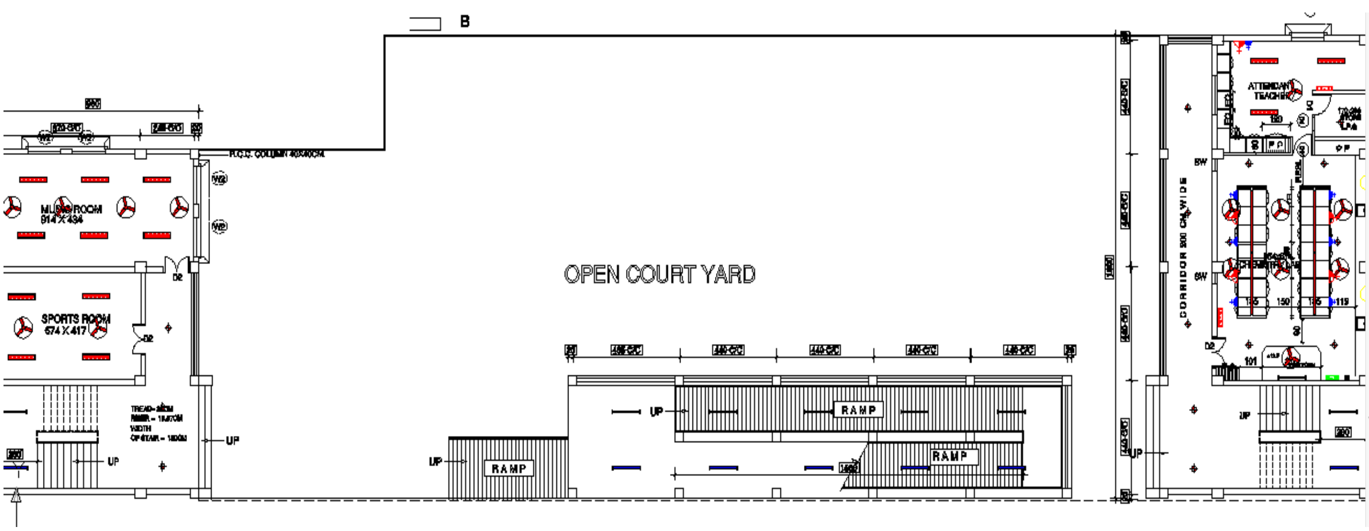


Figure 4.1: *Basement Lighting Layout*

Figure 4.2: *Ground Floor Lighting Layout*

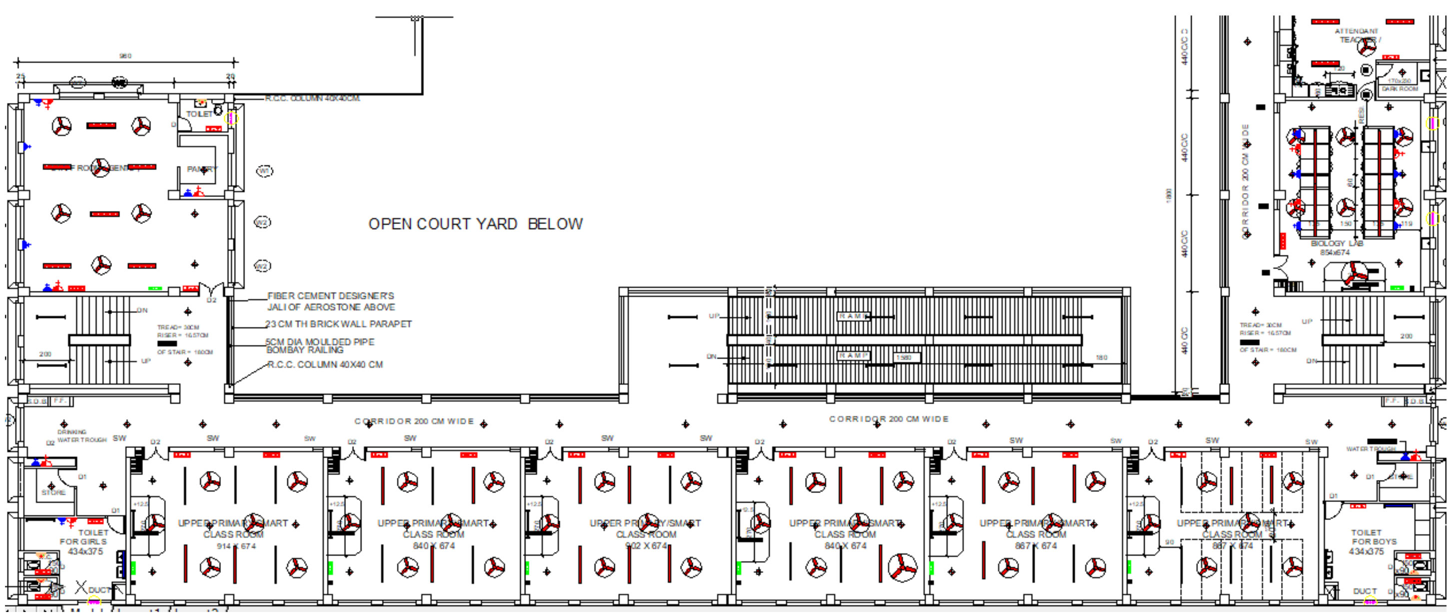


Figure 4.3: *First Floor Lighting Layout*

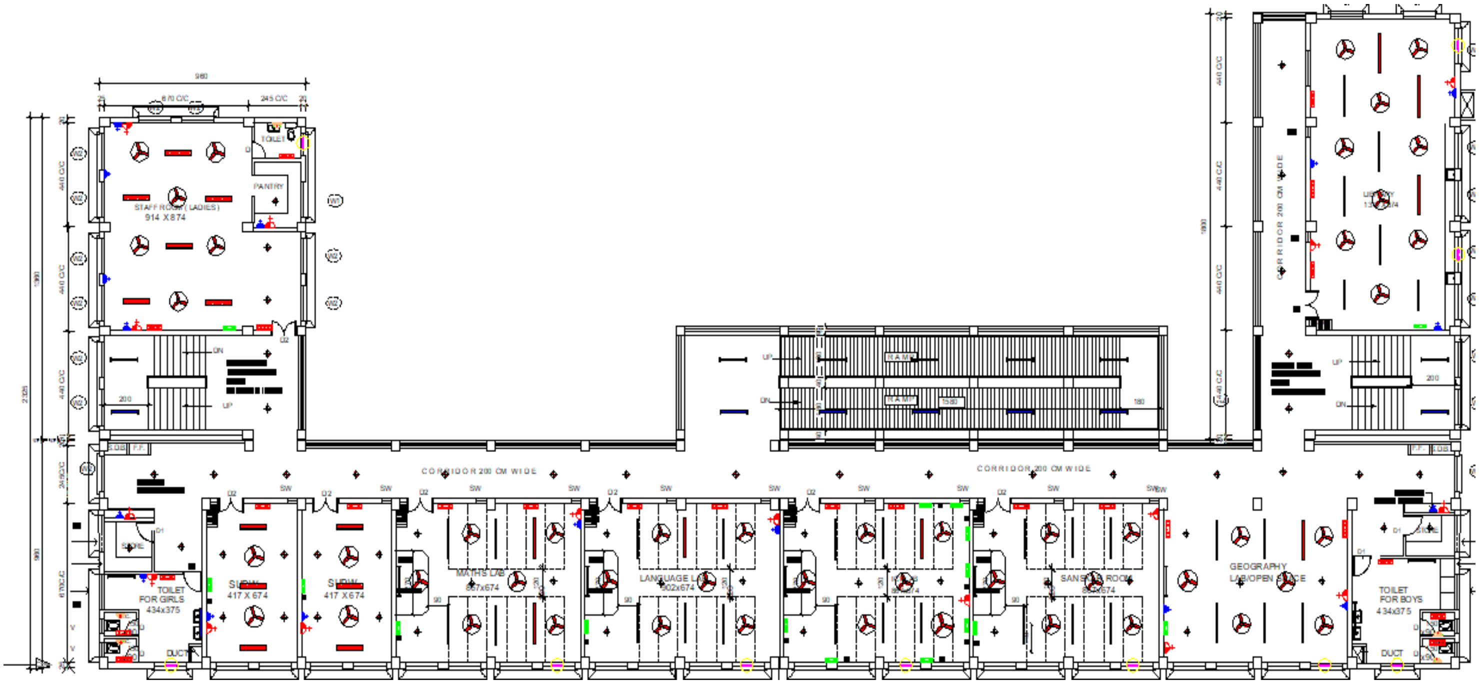


Figure 4.4: *Second Floor Lighting Layout*

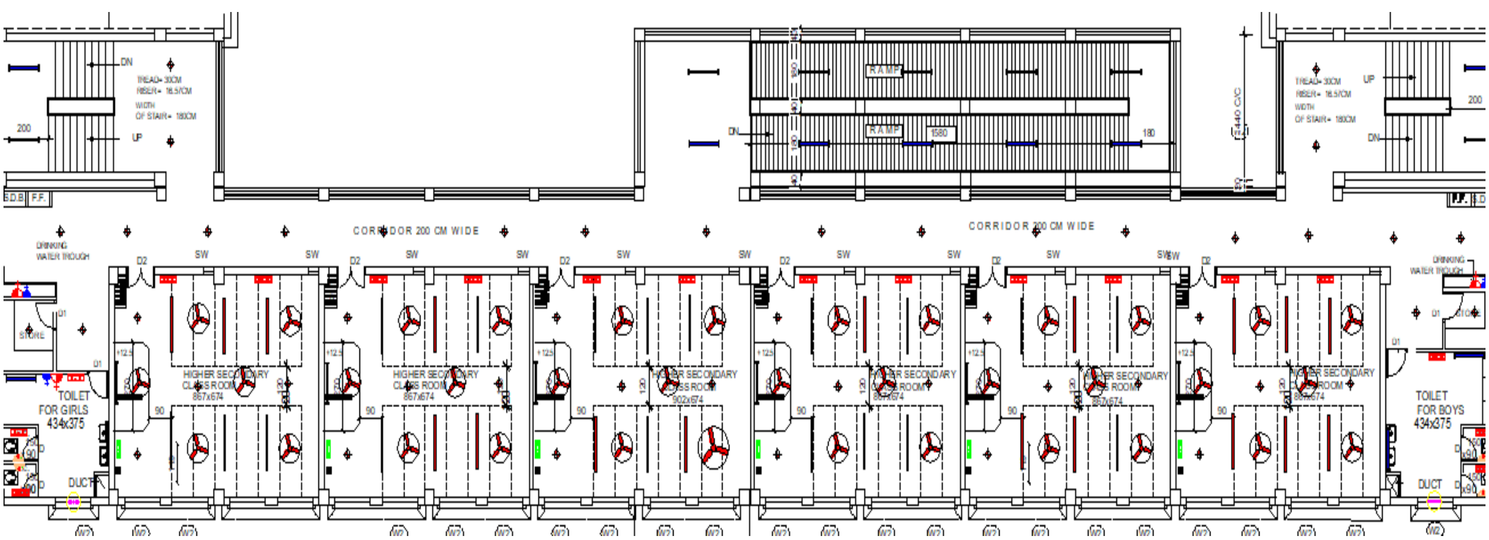


Figure 4.5: *Third Floor Lighting Layout*

The lighting layout and descriptive analysis of some of the major rooms are given as follows:

A. Library:

The library is an important area in an educational complex, which requires detailed consideration. General reading, both casual and sustained of a wide variety of printing types and styles, examination of drawings and maps, writing, etc, are among the more common visual tasks that will be encountered in a library. The lighting should be of very high quality since printed illustrative matter involves veiling reflections from overhead lighting and special care should be taken to use lighting equipment that will minimize the concentration of the light directly downward which in turn causes reduction of contrast. Particular attention should be paid to the avoidance of direct and indirect glare, and the use of decorations and furnishings with a non gloss finish is recommended. For lighting design of library, 40 watt 8 feet linear luminiare is used. Lighting layout of library is shown in *Figure 4.6.* For lighting design of library, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%.

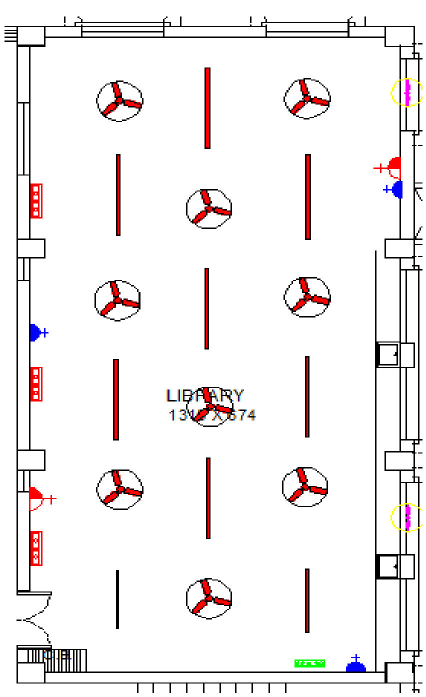


Figure 4.6: *Lighting Layout of library*

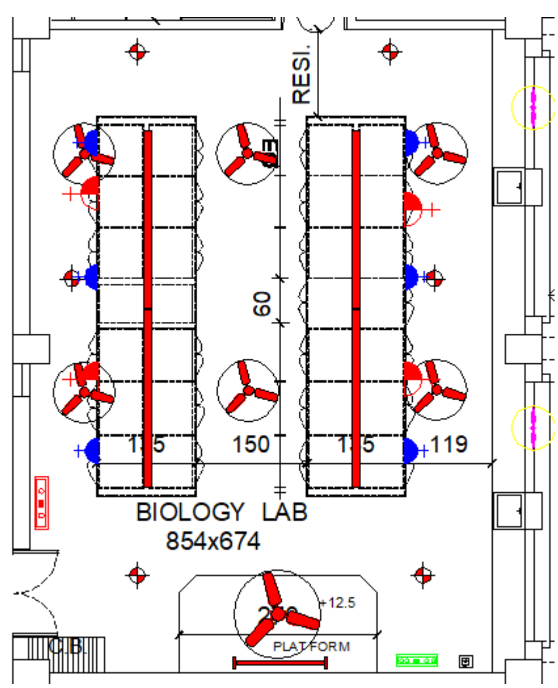


Figure 4.7: *Lighting Layout of Biology Lab*

B. Laboratories:

These involve laboratory tables or benches at which very detailed work is carried out in dissection, inspection of reactions, instrumentation and measurement. Good diffusion with some directional component and appropriate colour quality is required. For lighting design of laboratories, 40 Watt High lumen efficacy linear luminaire are used for the experiment table, 40 Watt batten is used for the experiment supervisor's platform and 15 Watt surface mounted downlighters are used to achieve the required uniformity. Lighting layout of Biology lab is shown in *Figure 4.7*. For lighting design of laboratories, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%.

C. Staff Rooms:

The staff room is a place where teachers assemble for discussions, study or rest during recess periods. These rooms should have general illumination for performing visual tasks like reading and writing. For lighting design of library, surface mounted 4 feet by 1 feet luminaire is used and the luminaire is of 36 Watt. Lighting layout of Gents Staff Room is shown in *Figure 4.8*. For lighting design of Staff Rooms, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%.

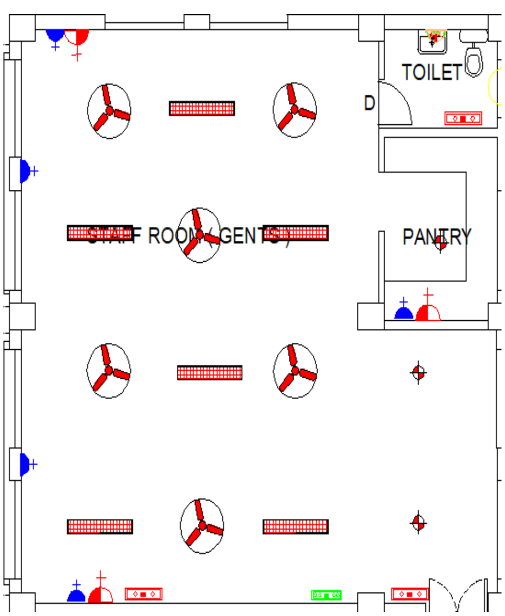


Figure 4.8: *Lighting Layout for Gents Staff Room*

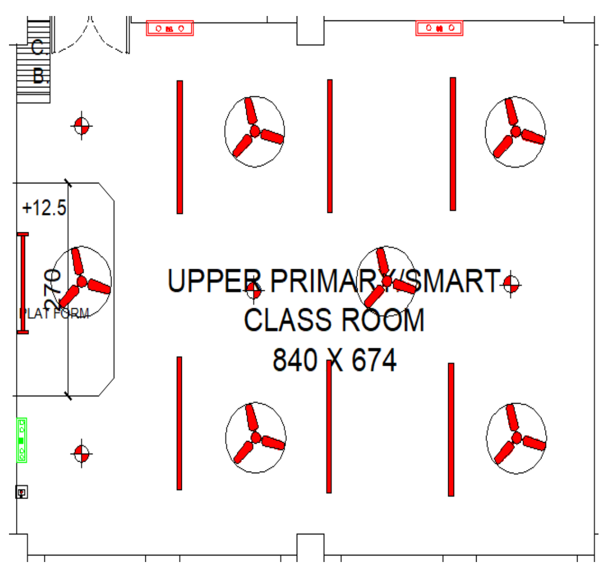


Figure 4.9: *Lighting Layout for Upper Primary Classroom*

D. Classrooms:

In classrooms, special attention should be given to designing for visual comfort. Direct glare from the lighting should be avoided, as students will often have to look across the room, as well as down at their desks. Luminaires should have a limited brightness from normal angles of views, and ceilings should be bright enough to allow the luminaires to be seen against a light background. A comfortable general system which is flexible enough to provide a moderately high level for general use and a subdued level for use during projection or special demonstrations should be provided for a typical lecture room. Special chalkboard lighting significantly improves visibility and attention powers. For lighting design of classrooms, 40 Watt linear luminaire are used for the student desks, 40 Watt batten is used for the teachers' platform and 15 Watt surface mounted downlighters are used to achieve the required uniformity. Lighting layout of classroom is shown in *Figure 4.9.* For lighting design of classrooms, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%.

E. Waiting Area:

Usually a restful, subdued atmosphere is desirable in the waiting area. The seating areas should be provided with well diffused comfortable illumination. From general lighting to supplementary illumination, care should be taken to provide good lighting which blend well with the architecture and at the same time should avoid veiling reflections. A rectangular pattern is created using linear fittings and L Connectors. Lighting layout of classroom is shown in *Figure 4.10.* L connectors are denoted with blue legend in the figure and 8 Feet 40 Watt linear fixture is marked with red colour and 4 Feet 20 Watt fixture is marked with Green legend in the figure. For lighting design of visitor waiting area, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%.

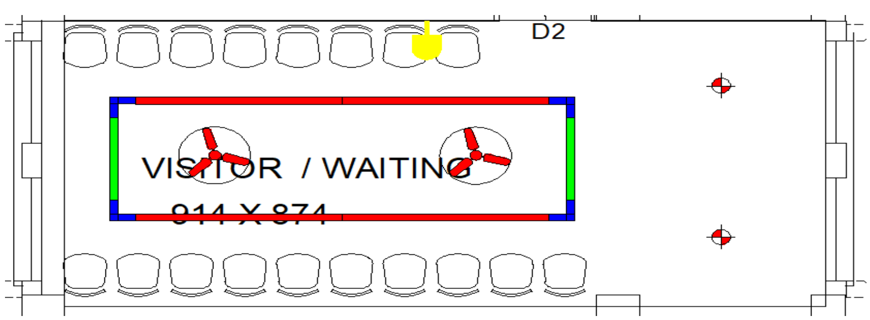


Figure 4.10: *Lighting Layout for Waiting Area*

4.3.3 Lighting Design

The luminaire selected for the design of classroom is 40 Watt suspended 4 feet linear LED luminaire. This luminaire is having a efficacy of 110 lumen/Watt and it is a linear lighting solution with extruded aluminium housing and high transmissivity HET and anti glare diffuser. The luminaire used for the design is shown in Figure 4.11. A pattern is created using linear fittings which not satisfy the required lux level but also improve ambience of the room. The reference picture of the created pattern is shown below in Figure 4.12. Luminaires selected for this design have CRI value of greater than 80. However, classroom lighting may also affect students' circadian systems, which may in turn affect test scores, attendance and behaviour. Also, it is necessary to select the reflectance of all the finishes of the room surfaces and equipment as well as control the luminance distribution of the lighting equipment. For this design, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%. And the maintenance factor is taken as 0.85.

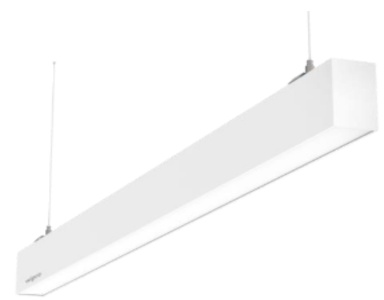


Figure 4.11: *Linear Suspended LED Luminaire*[1]

Figure 4.12: *Classroom Lighting Design with Linear Suspended LED Luminaire*

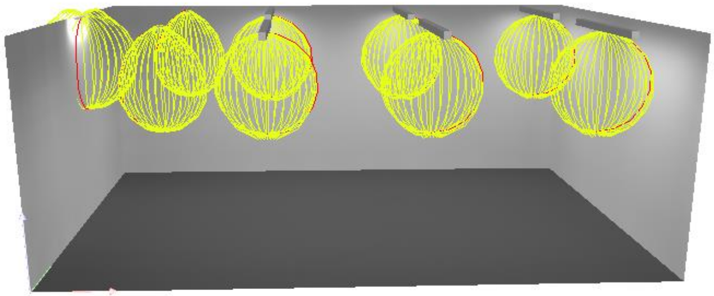


Figure 4.13: *3D View of Classroom in Dialux Software*

4.3.4 Results and Analysis

Table 4.6: *Lux Level Details of Basement Plan*

Room Name	Obtained lux level	Recommended lux level
Music Room	319	300
Sports Room	327	300
Chemistry Lab	459	400
Teacher Room	301	300

In case of preparation of simulation report some objects are in critical view, namely, boards, paper (books), etc, need special attention for visual comfort. In that case, vertical illumination should be taken into account. White chalk over black boards and dark marking pens over white boards, ensure a high contrast. Paper used in books, notebooks, etc, should be opaque and matt; shiny sheet surfaces should be avoided. Printed matter should have liberal spacing between lines, and print size should not be very small. All these aspects contribute to good seeing conditions. While designing school lighting, it is needed to take care of certain points like direct glare from the lighting should be avoided, as students will often have to look across the room, shifting their view from their desks at frequent intervals. Luminaires should have a limited brightness from normal angles of viewing. The ceiling should be bright enough to allow the luminaires to be seen against a comfortably bright background environment. All lux level details are represented in *Table 4.6.*

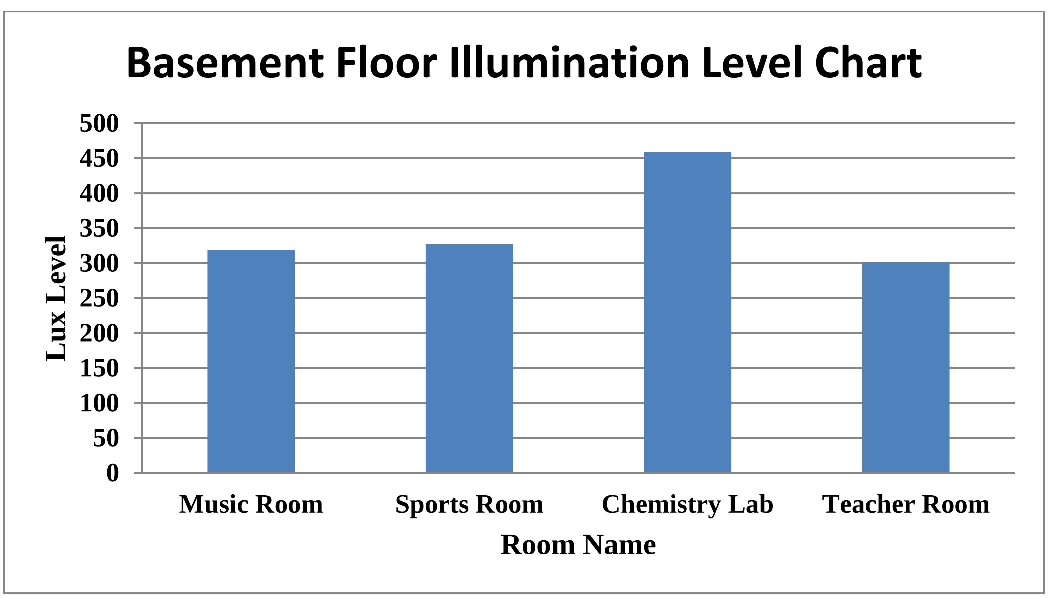


Figure 4.14: *Graphical Representation of Basement Floor Lux level Sheet*

The simulation results of all the five floors are in represented in tabular format in *Table 4.6, Table 4.7, Table 4.8, Table 4.9, Table 4.10.* The comparative analysis of the rooms needs to be highlighted for proper observation. The data obtained from simulation of the five floors are represented in graphical format in the lux level chart. The critical rooms in the school are classrooms, laboratories, principal office, where sufficient quantity of lux level is maintained with proper uniformity.

Table 4.7: *Lux Level Details of Ground Floor Plan*

Room Name	Obtained lux level	Recommended lux level
Principal Office	316	300
Waiting Room	209	200
Toilet	145	100
Superintendant Office	345	300
Secondary Classroom	306	300
Entrance Foyer	195	150
Computer Lab	399	400
Physics Lab	471	400
Teacher Room	305	300
Corridor	243	200

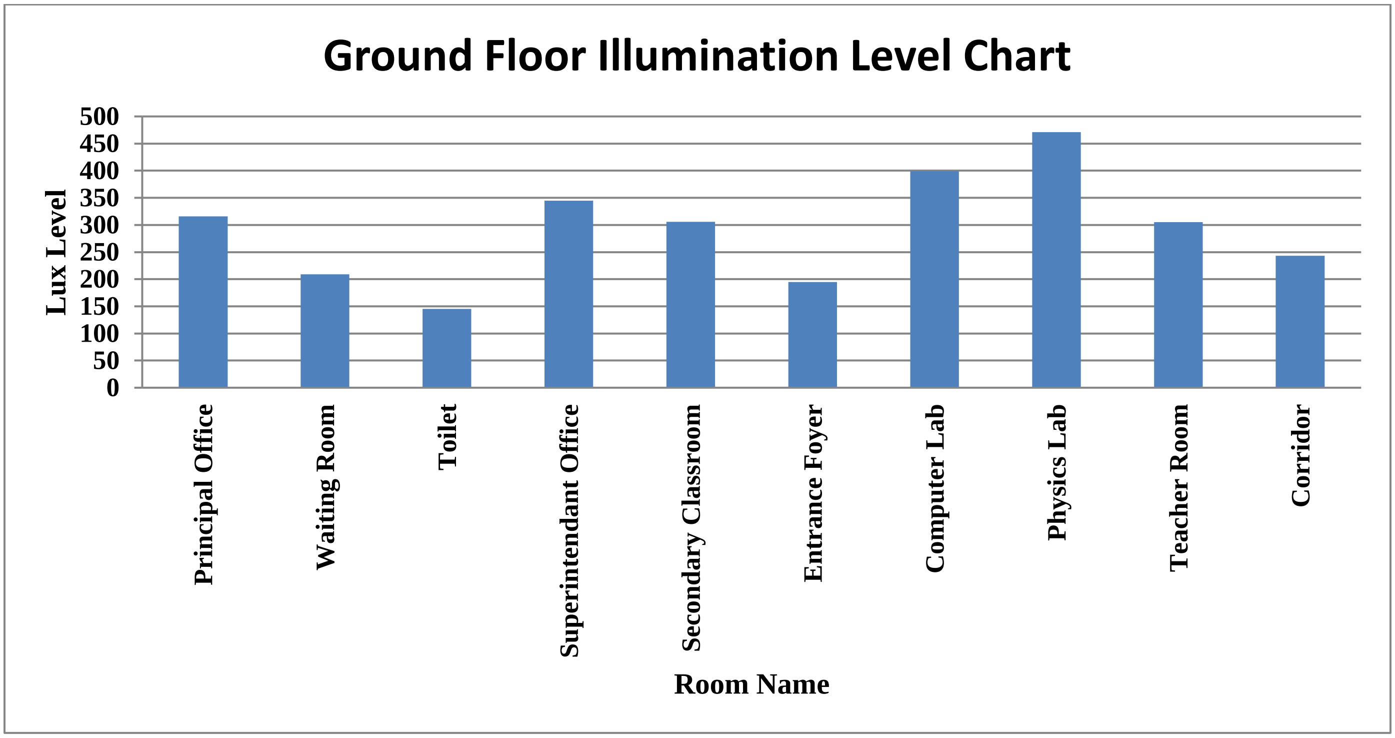


Figure 4.15: *Graphical Representation of Ground Floor Lux level Sheet*

Table 4.8: Lux Level Details of First Floor Plan

Room Name	Obtained lux level	Recommended lux level
Gents Staff Room	315	300
Toilet	113	100
Pantry	203	200
Corridor	229	200
Upper Primary Classroom	349	300
Smart Classroom	352	300
Biology Lab	414	400
Attendant Room	301	300
Store	222	200

Light in school buildings traditionally is from a combination of daylight and electric light to illuminate learning spaces (e.g. classrooms, labs, studios, etc.), hallways, cafeterias, offices and other interior areas. Light fixtures currently in use usually provide students and teachers with satisfactory visual performance, i.e., the ability to read a book, have lunch, or play basketball in a gymnasium. In classrooms of primary schools illumination levels on task areas shall not fall below 300 lux, depending on task or activity, UGR shall not exceed 19 and CRI shall not be lower than 80. In a typical polish classroom benches are located regularly, in two or three rows, covering all the floor area. Uniformity on the task area should be high, while the minimum to average illuminance shall not be lower than 0.7.

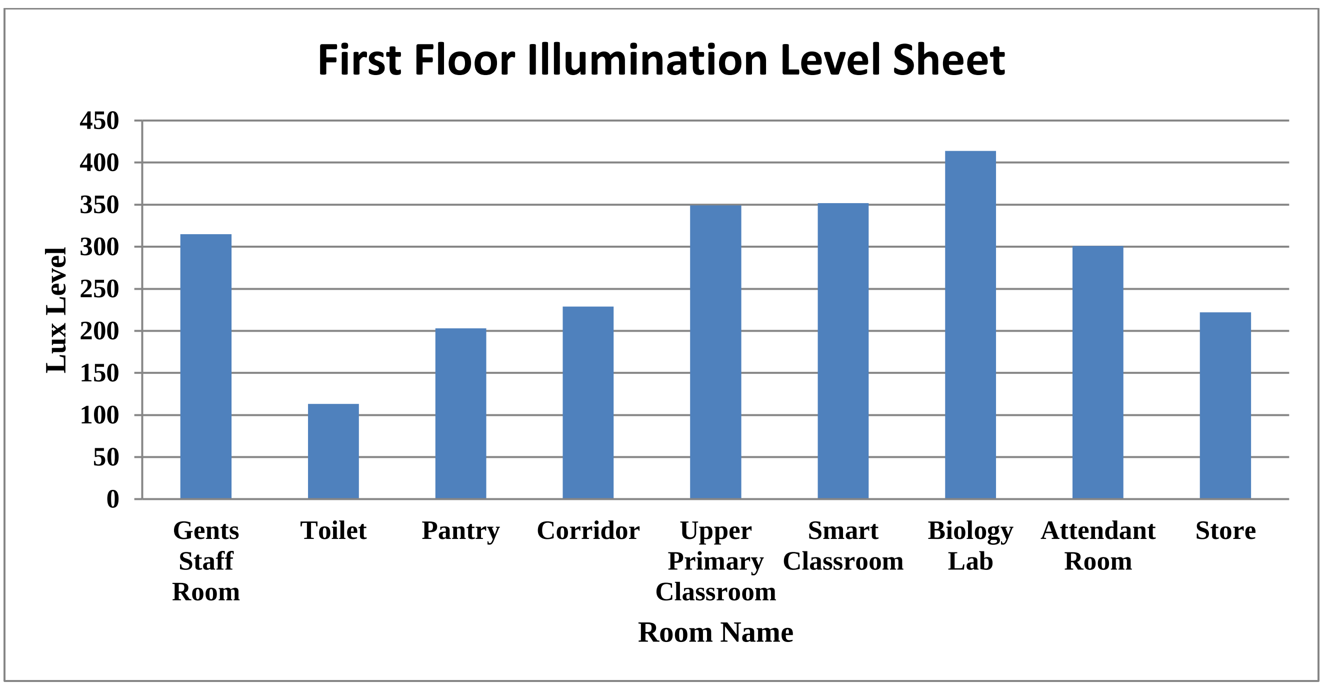


Figure 4.16: *Graphical Representation of First Floor Lux level Sheet*

Table 4.9: *Lux Level Details of Second Floor Plan*

Room Name	Obtained lux level	Recommended lux level
Ladies Staff Room	310	300
Pantry	206	200
Toilet	143	100
Corridor	236	200
Store	212	200
SUPW Room	389	300
Maths Lab	418	400
Language Lab	351	300
ICT Lab	397	400
Sanskar Room	349	300
Geography Lab	341	300
Library	316	300

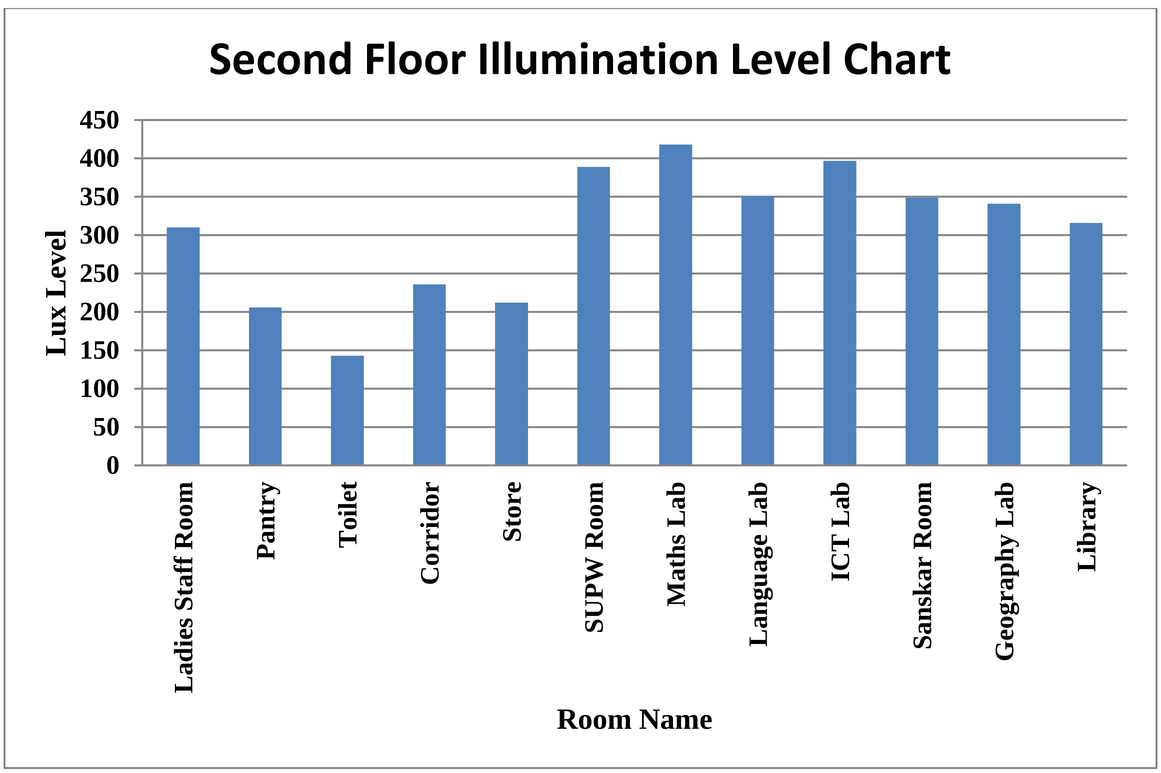


Figure 4.17: *Graphical Representation of Second Floor Lux level Sheet*

Table 4.10: *Lux Level Details of Third Floor Plan*

Room Name	Obtained lux level	Recommended lux level
Corridor	242	200
Store	219	200
Toilet	147	100
Higher Secondary Classroom	343	300
Higher Secondary Classroom	339	300
Higher Secondary Classroom	349	300
Higher Secondary Classroom	335	300

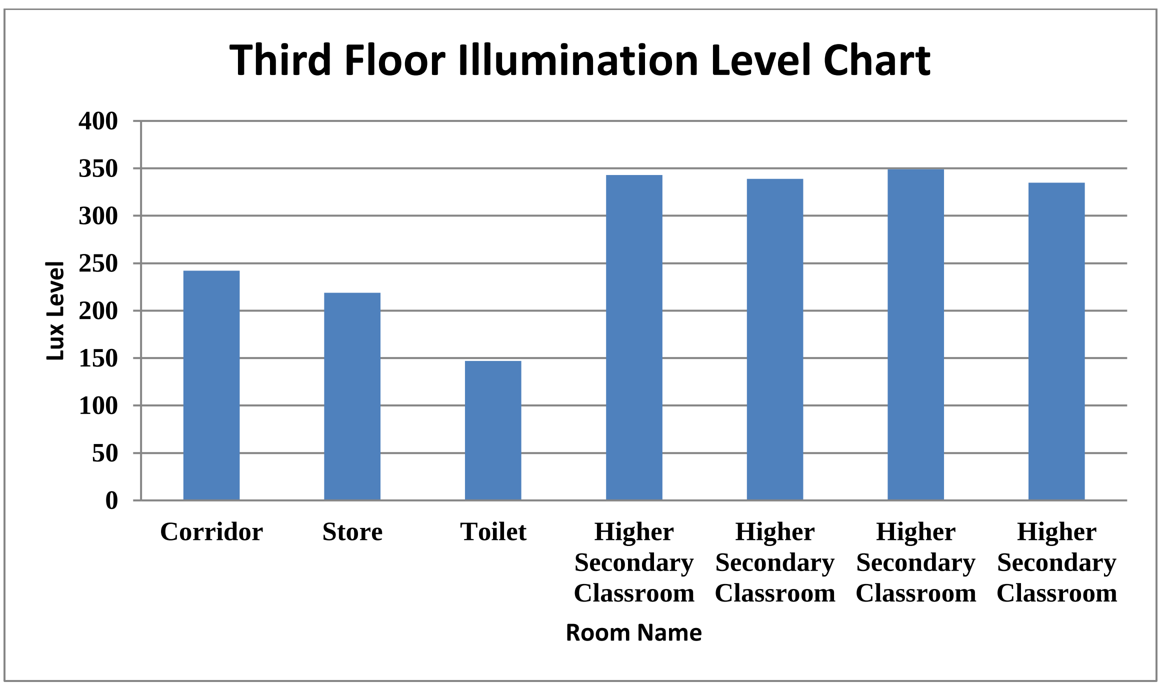


Figure 4.18: *Graphical Representation of Third Floor Lux level Sheet*

Chapter 5

Lighting for Cleanroom

5.1 Introduction

The Indian pharmaceuticals market is the third largest in terms of volume and thirteenth largest in terms of value in the global pharmaceuticals sector. The Indian pharma industry, which is expected to grow around 10% - 12% for next few years, will outperform the global pharma industry, which is set to grow at an annual rate of 5 percent between the same time frame. Post Covid 19, India to emerge as a major hub for Global pharma requirements. Government strongly promoting localization of Electronic manufacturing.

Inside of pharmaceutical industry where life-saving drugs are manufactured is a clinically clean room. It may also be called a sterile room. The hygienic requirements in the pharmaceutical industries are very stringent. The industry works with precise chemical compounds, worth hundreds of thousands of rupees per kilogram. Material contamination could gravely endanger patients and trace amounts of previously manufactured compounds or can easily destroy an entire production run. The work done in cleanrooms is sensitive to even invisible airborne particles and selection of lighting fixtures plays an important role in the contamination control. Of course, these products become even more critical, if these are used in the environments, where lifesaving drugs, food etc. are being processed. For example: pharmaceutical industries, food processing units.

Cleanroom requirements leave little room for error, so careful selection is very important. The lighting system in a cleanroom represents a very less percentage of the total budget; so cutting corners on fixture costs could be expensive cost avoidance. A few extra rupees saved can cost hundreds of thousands in disrupted operations or compromised processes.

5.2 Cleanroom Portfolio

Pharmaceutical industry is one of the largest users of cleanroom luminaires. Some of the major products manufactured in a pharmaceutical industry are Injectable Ampules, Disposable Syringes, Ointments, Capsules, Tablets, Syrups, Intra-venous Fluids, Bulk Drugs, and Suture Threads or Dressing Material. A cleanroom is an interior where inside conditions of temperature, air ventilation, humidity and dust levels are controlled to reduce the availability of airborne particulates to an acceptable level. The need for this level of cleanliness arose over 40 years ago when NASA created white rooms, which were designed to screen out dust during process of communication systems for aerospace. This is achieved through the creation of a shell including the floor, ceiling and walls, which are completely sealed off from the rest of the environment.

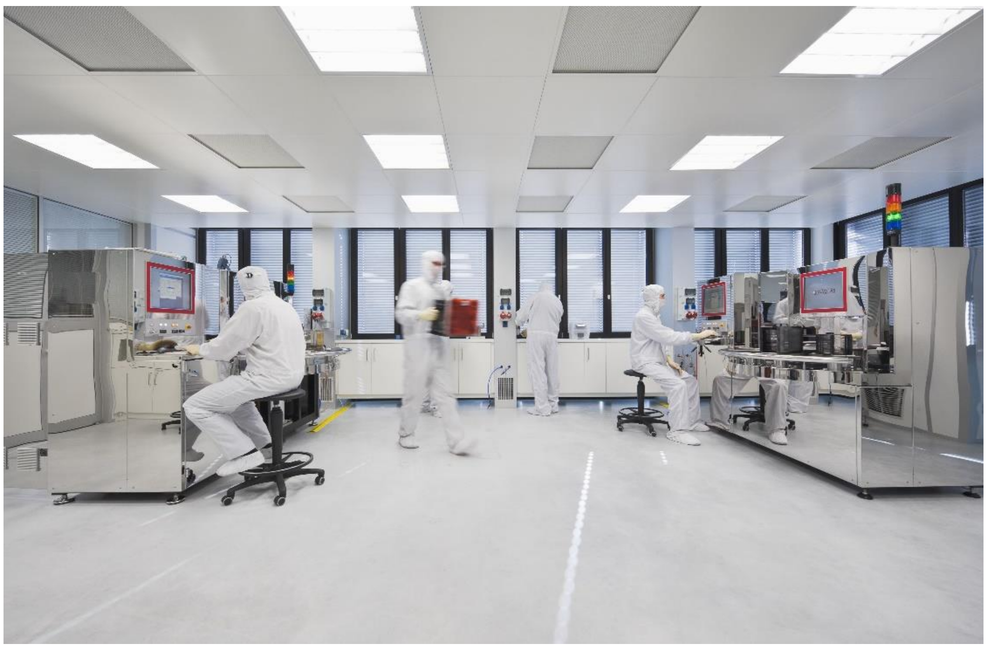


Figure 5.1: *A Typical Cleanroom Laboratory*

The air in this shell or cleanroom is then regulated by high-powered, advanced design H.V.A.C. (Heating, Ventilating, Air Conditioning) system. Air is exchanged as often as sixty times an hour, compared to six in the average office space. Everything in a cleanroom, including humidity, temperature, airflow and balance is monitored and all these parameters work together to create and maintain this cleanliness level.

All people who occupy the space wear special clothing designed to prevent accumulation of particles. They pass through an air shower to further remove any microscopic particles before entering a cleanroom.

The two types of basic clean spaces are as follows:

- **Clean zones** a modular or temporary construction having freestanding clear polymer soft walls. Clean zones are usually installed within a less clean space staging area holding work pieces to be processed within the clean zone. The area is positively pressurized by the HEPA units to keep the space cleaner than the surrounding environment.

Figure 5.2: *Clean Zone*

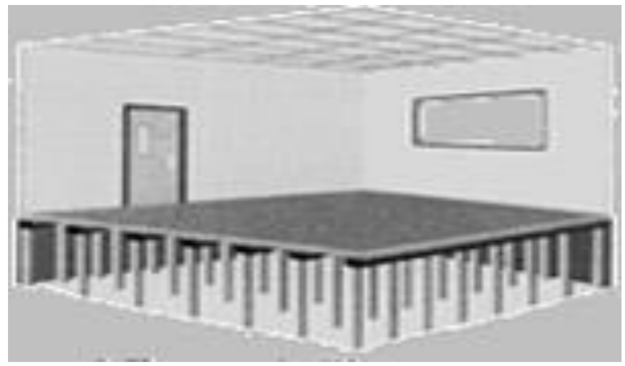


Figure 5.3: *Cleanroom*

- **Cleanrooms** are permanent constructions using some of the same materials and techniques used for clean zones. They are usually installed within a superstructure common to modern construction. Cleanrooms vary from basic stud and drywall construction, all the way to deluxe fabrications using high tech prefab mating-metal walls. Specialized gel-filled grid ceiling systems and exhaust air recapture mechanisms are sometimes required for high end users.

5.3 Cleanroom Standards and Classifications

Clean room classification is based on the count of micro particles of 0.5 microns and larger in a defined volume of air; the lower number of particles suspended in the air the more the clean room is purified. Although each industry or manufacturer determines the acceptable particulate levels for their processes. One of the measures is PARTICLE COUNT. This is normally done as per US FDA regulations (United States Food and Drugs Administration) by a measure called:

"No. Of Particles of Sizes < 0.5 Micron In A Cubic Foot Of Space"

The standard classes for cleanrooms are named for the maximum quantity of 0.5 micron or larger particles found within a cubic meter or cubic foot of air. A 0.5-micron particle is about 500 times smaller than the width of a human hair, and is invisible to the unaided eye. The class name is written as M3.5 (log 10) or Class 100 where 3,520 particles per cubic meter, or 100 particles per cubic foot, are found.

Table 5.1: *Cleanroom Stanards*

		Measured Particle Size									
		0.1 Micron		0.2 Micron		0.3 Micron		0.5 Micron		5 Micron	
Class Name		Volume Units		Volume Units		Volume Units		Volume Units		Volume Units	
SI	English	(M3)	(Ft3)	(M3)	(Ft3)	(M3)	(Ft3)	(M3)	(Ft3)	(M3)	(Ft3)
M1		350	9.91	75.7	2.14	30.9	0.875	10.0	.283		
M1.5	1	1240	35.0	265	7.50	106	3.00	35.3	1.00		
M2		3500	99.1	757	21.4	309	8.75	100	2.83		
M2.5	10	12,400	350	2650	75.0	1060	30.0	353	10.0		
M3		35,000	991	7570	214	3090	87.5	1000	28.3		
M3.5	100			26,500	750	10,600	300	3530	100		
M4				75,700	2140	30,900	875	10,000	283		
M4.5	1000							35,300	1000	247	7.00
M5								100,000	2830	618	17.5
M5.5	10,000							353,000	10,000	2470	70.0
M6								1,000,000	28,300	6180	175
M6.5	100,000							3,530,000	100,000	24,700	700
M7								10,000,000	283,000	61,800	1750

5.4 Critical Factors for Cleanroom Lighting

Some of the useful points that a lighting designer must keep in mind are as follows:

- The luminaire should be non corrosive and firm.
- Ensure IP protection is intact under high pressure & frequent jet cleaning and cleaning solvents across the service life.
- The luminaire should be suitable for both walkable and non walkable ceiling.

Table 5.2: *Different cleanroom areas in a pharma industry*

S. NO.	APPLICATION AREA	CLASS	LUX LEVEL	LUMINAIRE TYPE
1	Production Area		300 - 500	
a.	Tablets and Capsules	10,000 to 1,000		Recess mounted bottom opening clean room luminaire with Anti-corrosive bottom frame & option of Aluminium Reflector and Powder coated Reflector Same as above but Surface mounted construction Recess mounted top opening with Anti-corrosive integrate bottom frame/ housing with Pre-anodized reflector but without top frame & top cover. Same as above but with Top Frame and Top cover
b.	Injectable ampules and IV Fluids	1,000 to 1		Recess mounted top opening with Anti-corrosive integrate bottom frame/ housing with Powder coated reflector but without top frame & top cover Same as above but with Top Frame and Top cover
2	Packaging	10,000	300 - 500	-
3	Passage Area (Black and Grey rooms)	1,00,000	200 - 300	-
4	Office Area	-	200 - 500	-

5.5 Luminaires for Cleanroom Lighting

Cleanroom lighting is often an afterthought in cleanroom design, as the primary function of a cleanroom is to reduce contamination. So when identifying the type of light fitting to use, consideration needs to be given not just to the lux levels required for the process, but to how this choice of lighting may affect airflow and filtration. The environment, application and task must be carefully considered, with many choices to make depending on these variables. Arguably the greatest influence when choosing lighting is the ISO classification of the cleanroom. The luminaires designed for cleanroom applications must met all customer's requirements in area of product aesthesis, functional and modular design, such as product should be sleek, very less projection from the false ceiling, loss proof screws, anti-corrosive bottom frame and suits various false ceiling system, etc. The luminaire should provide optimum illumination with proper uniformity to achieve task based lux levels with glare free illumination. The two types of cleanroom luminiares are as follows:

Figure 5.4: *Bottom Openable Cleanroom Luminaire*[1]

Figure 5.5: *Top Openable Cleanroom Luminaire*[1]

- **<u>Bottom Opening Cleanroom Luminaire:</u>**

In the Bottom Opening Cleanroom Luminaires, the LED and control gear fixtures are accessible from the bottom side. These luminaires can be of both surface mounted and recess mounted form. Bottom opening cleanroom luminaires are suitable for class 1,00,000 to class 1,000. Luminaire consists of precisely manufactured CRCA powder coated Housing and CRCA Bottom frame. Bottom frame is fixed with captive (loss proof) screws. These luminaire have satin finish with high efficiency translucence (HET) diffuser is sealed with bottom frame and non-hygroscopic VHB gasket to ensure dust proofing. Bottom frame and diffuser, with gasket and pressure clamps, ensures dust proofing. Reference image of the lumianire is shown in *Figure 5.4*.

- **<u>Top Opening Cleanroom Luminaire:</u>**

In the Top Opening Cleanroom Luminaires, the lamp and the control gear tray are accessible from the top side i.e. from the bay area. These luminaires are used where entry in the clean space (working area) is restricted and luminaires can be accessed only from the bay area. These are can be of both surface mounted and recess mounted form.Housing and chamfered edge Bottom frame consists of CRCA powder coated in white colour.Top opening cleanroom luminaires are suitable for class 1,00,000 to class 100. These luminaire have integrated designed top cover and loop in loop out provision through pierce plug on top cover. Recommended for Industrial indoor environment such as Pharmaceutical plants, Micro electrical industries, Laboratories, Food processing industries, sterile areas, Operation theaters etc. These luminiares are designed for installation on Metallic walkable ceiling with through and through ceiling cutout. Reference image of the luminaire is shown in *Figure 5.5.*

5.6 Case Study

One of the major Cleanroom Lighting Project Performed is of a Pharmaceutical Export based Company. This company is a commercial business licensed to research, develop, market and/or distribute drugs, most commonly in the context of healthcare, and they deal in generic and brand medications. Lighting design of the ground floor and first floor is performed with the help of cleanroom luminiares.

5.6.1 Project Background

The pharma company comprises of ground floor and first floor. The majority of the production units are in the ground floor. The ground floor and the first floor section of the Pharmaceutical Company consist of 1092 sq. metres of ground area and its room height is 2.7 metres. The Pharmaceutical Company has several important zones where optimum lux level with proper uniformity is to be maintained, such as manufacturing cleanroom areas, admin areas, Passages, Airlocks, change rooms, Technical utility areas, packaging and warehouses areas, Technical and utility areas.

5.6.2 Lighting Planning Layout

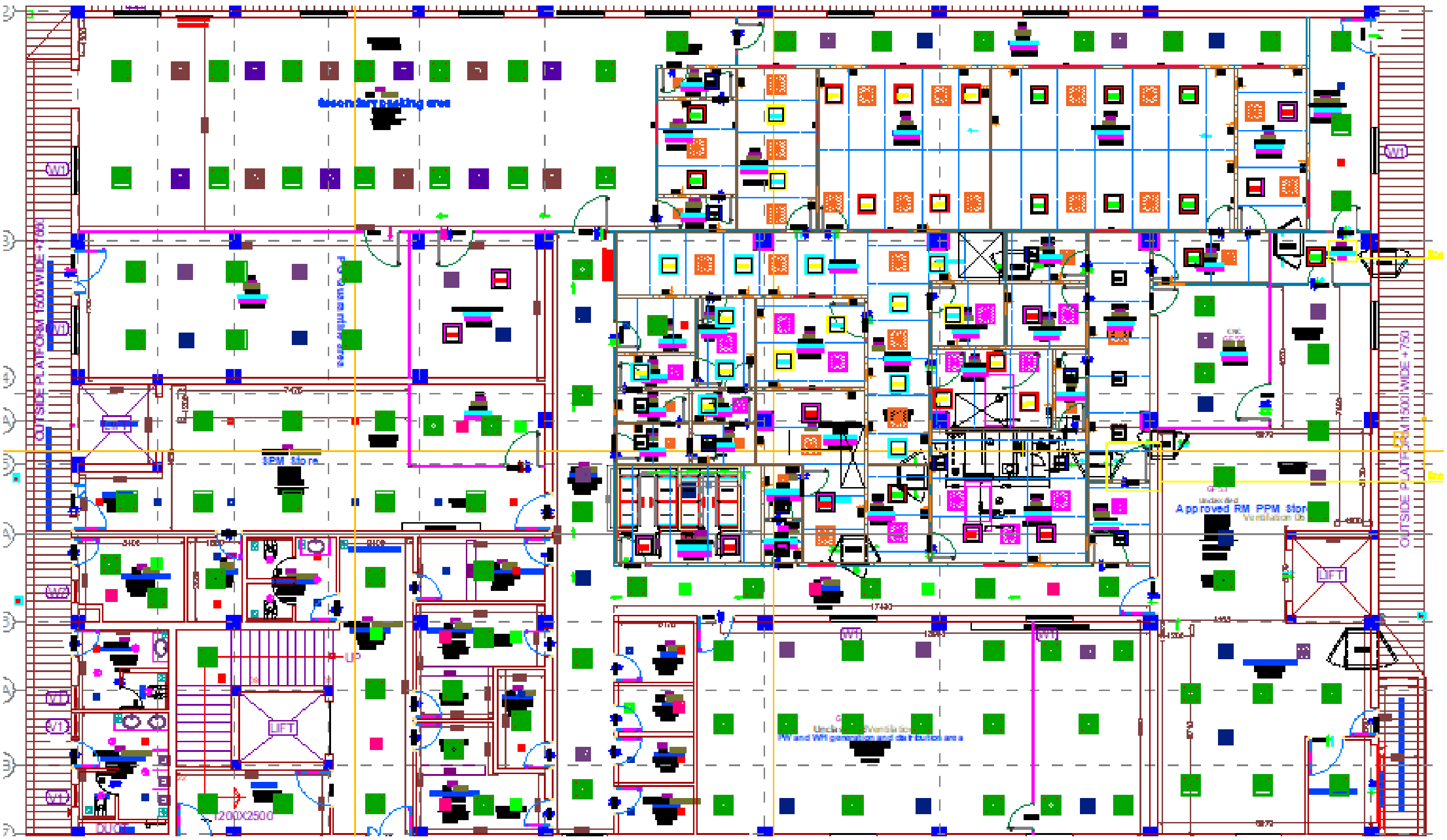


Figure 5.6: *Ground Floor Lighting Layout*

The complete lighting layout of Ground Floor and First Floor is shown in *Figure 5.6* and *Figure 5.7* respectively. In the figure, there are some cleanroom fixtures and non cleanroom fixtures. The IP20 rated normal 600mm by 600mm non cleanroom luminaire is of 36 Watt and it is having system lumen efficacy of 100 lumen/Watt and this luminiare is marked with green colour legend in the lighting layout. All other fixtures marked in the lighting layout are of IP65 rated Bottom openable and Top Openable cleanroom fixtures. The cleanroom fixtures are of 30 Watt, 42 Watt and 60 Watt and are having system lumen efficacy of 110 lumen/Watt. Wattages of cleanroom fixtures are proposed according to lux level calculations which are represented later *in Table 5.3*. Maintenance factors were estimated based on the agreed unified schedule for the all rooms. It was decided that the environment was clean. Maintenance Factor is taken as 0.85.

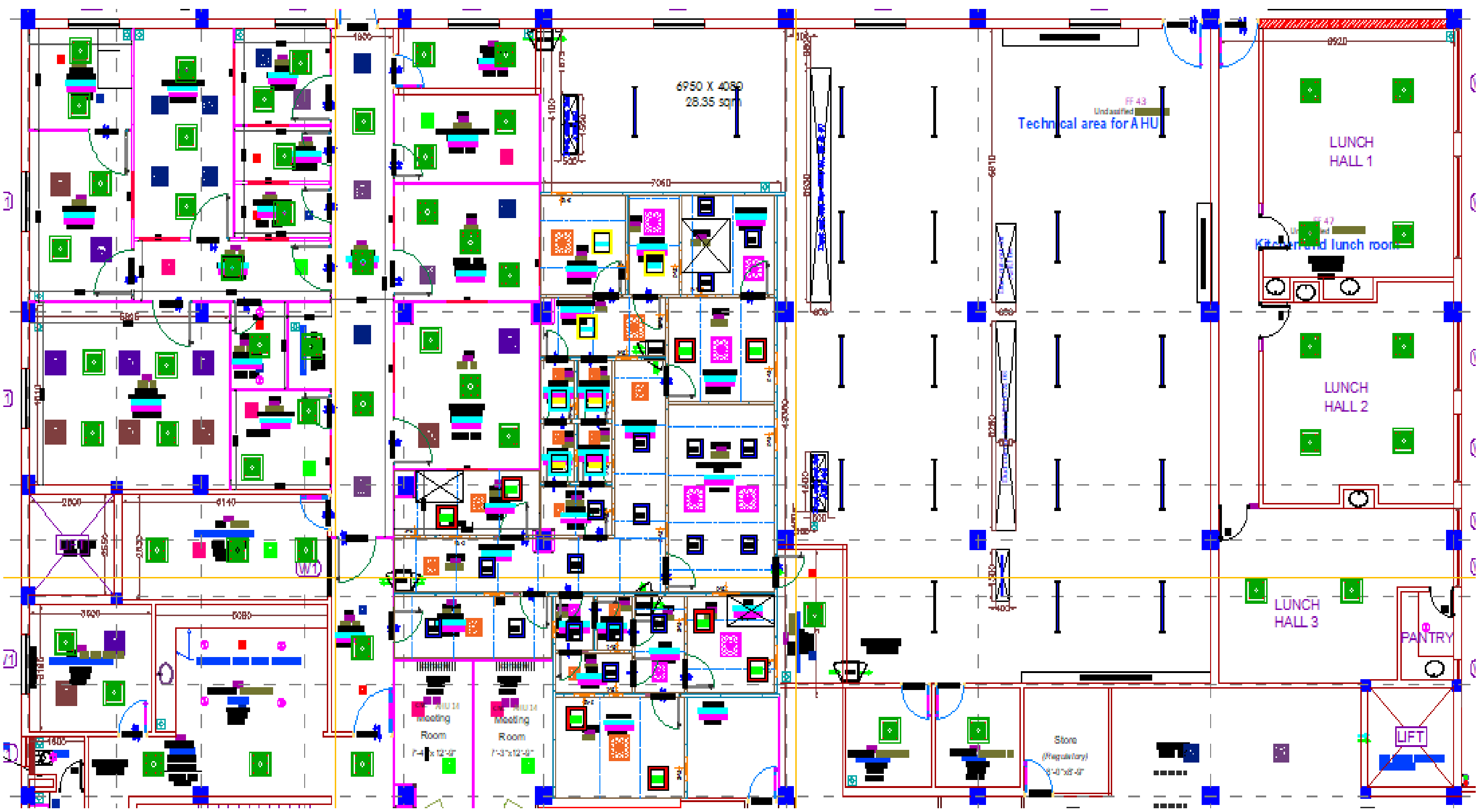


Figure 5.7: *First Floor Lighting Layout*

<u>Zone 1: Passages, Airlocks, Change Rooms</u>

These rooms fall under the category of cleanroom areas of Class 10000 & 100000. These are highly ingress protected areas and have controlled environment with laminar air flow. The recommended lux levels for these areas lie in between 200-250 lux. The lighting layout for Airlock and Change room is shown in *Figure 5.8* and *Figure 5.9* respectively. Also, it is necessary to select the reflectance of all the finishes of the room surfaces and equipment as well as control the luminance distribution of the lighting equipment. For this design, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%.

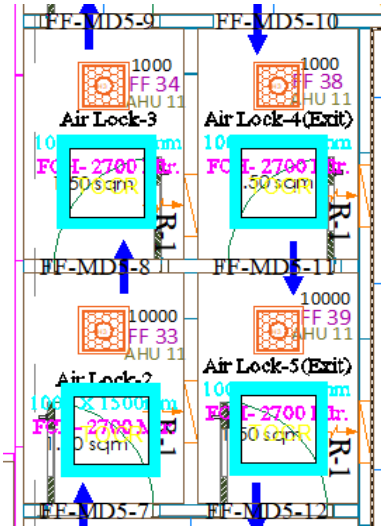


Figure 5.8: *Lighting Layout for Airlock*

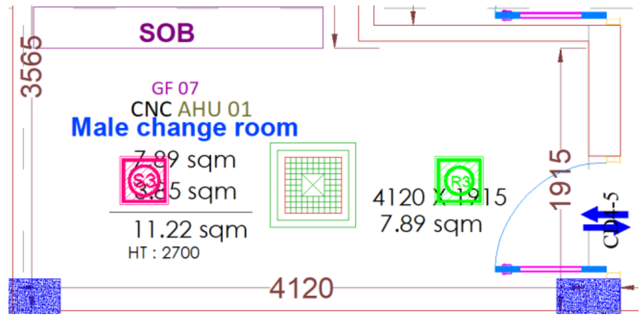


Figure 5.9: *Lighting Layout for Male Change Room*

Zone 2: Manufacturing Cleanroom Areas

These rooms fall under the category of cleanroom areas of Class 100 & 1000 or Class 10000 & 100000. These are highly ingress protected areas and have controlled environment with laminar air flow. These are areas with prevention for cross contamination. The recommended lux levels for these areas lie in between 350-400 lux. The lighting layout for manufacturing areas is shown in *Figure 5.10*. For this design, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%.

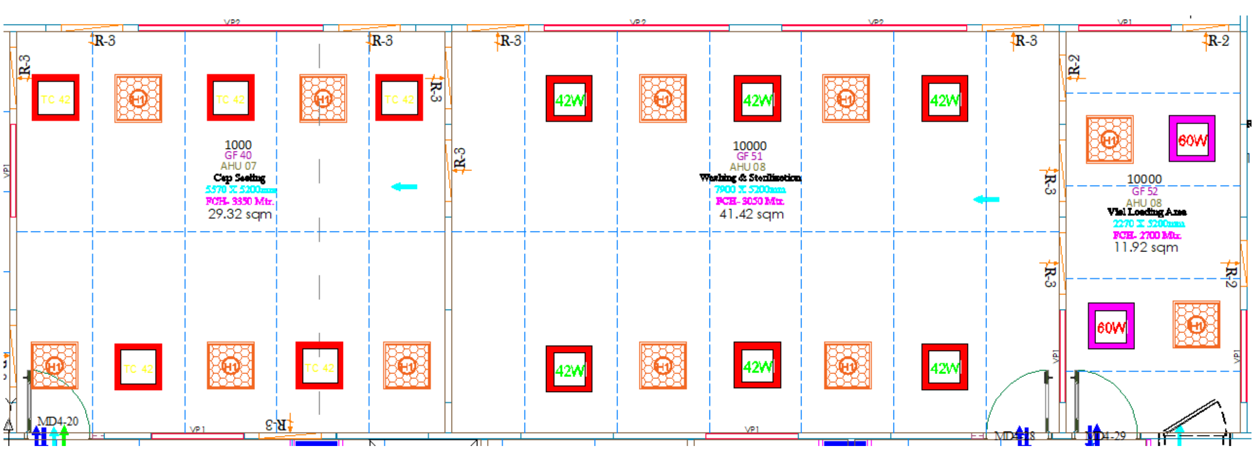


Figure 5.10: *Lighting Layout for Manufacturing Areas*

Zone 3 : Packaging & Warehouse Areas

These are contamination free areas with controlled temperature and are highly ingress protected. Packing rooms have racking system and have controlled environment with laminar air flow. The recommended lux levels for these areas lie in between 200-250 lux. The lighting layout for secondary packing area is shown in *Figure 5.11*. For this design, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%.

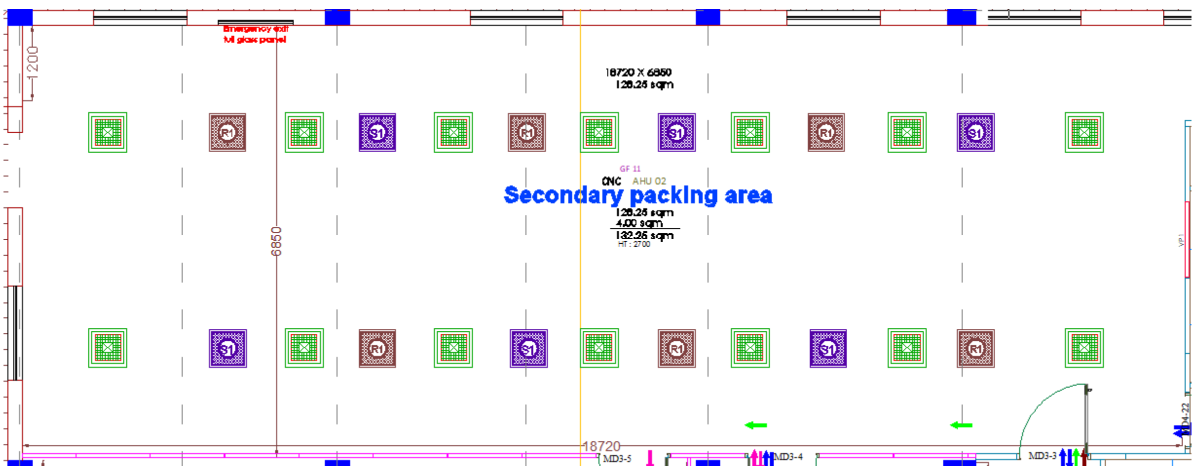


Figure 5.11: *Lighting Layout for Secondary Packing Area*

Zone 4 : Technical or Utility Area

Technical area for AHU is the utility area with high contamination from dust and moisture ingress and this area is prone to exposed environment. The recommended lux levels for these areas lie in between 200-250 lux. Lighting design for this area is planned with linear industrial batten. The lighting layout for Technical area is shown in *Figure 5.12*. The 40 Watt 4 feet long linear battens are marked with red colour legend in the figure. For this design, reflectance of the ceiling is considered as 50%, wall reflectance is considered as 30%, and Floor reflectance is considered as 20%.

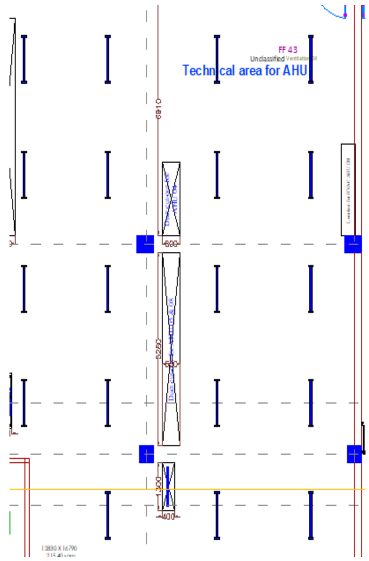


Figure 5.12: *Lighting Layout for Technical Area*

5.6.3 Lighting Design

Cleanroom lighting is often an afterthought in cleanroom design, as the primary function of a cleanroom is to reduce contamination. So when identifying the type of light fitting to use, consideration needs to be given not just to the lux levels required for the process, but to how this choice of lighting may affect airflow and filtration. Cleanroom lighting usually has to adhere to the Ingress Protection Code (IP Ratings) as defined by the IEC. An IP Rating is two digits, and the first digit refers to a light's protection against solids, like dust and particles, while the second refers to liquids. So, a 00 rating provides no protection from solids or liquids, a rating of 64 would protect against all dust and water splashing, etc. Lower IP Ratings are for indoor, less hazardous use. The scale goes from 0-6 for both solids and liquids, and will always see that two digit rating. For Class 10,000 & 100,000 cleanroom applications, IP54 Bottom opening cleanroom luminaire is used, and for class 1000 cleanroom applications IP65 Top opening cleanroom luminaire is used as TOCR suitable for walkable ceiling of various ceiling thickness. This comparison is illustrated below in *Figure 5.13* and *Figure 5.14*.

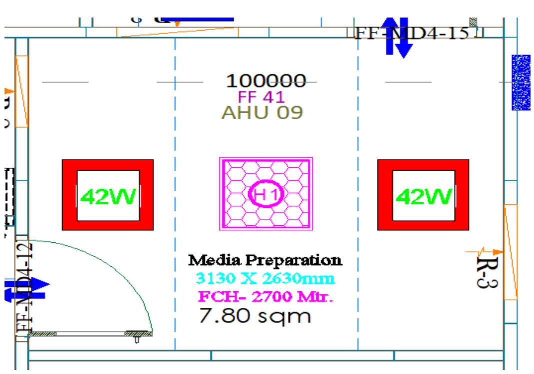


Figure 5.13: *Lighting Layout for Media Preparation Room with Bottom Opening Cleanroom Luminiare*

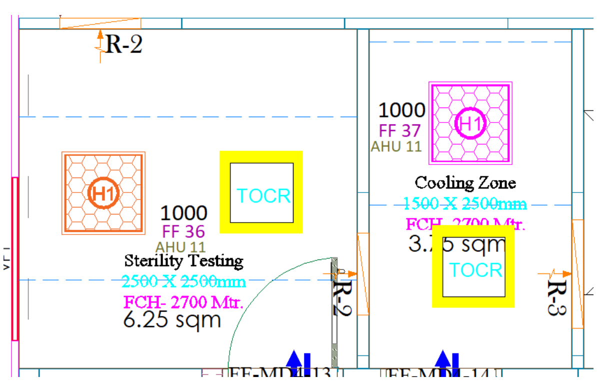


Figure 5.14: *Lighting Layout for Sterility Testing and Cooling Zone with Top Opening Cleanroom Luminaire*

Figure 5.15: *Luminaire Arrangement for Airlock*

Figure 5.16: *Luminaire Arrangement for Corridor*

Figure 5.17: *Luminaire Arrangement for Manufacturing Area*

Figure 5.18: *Luminaire Arrangement for Packing Area*

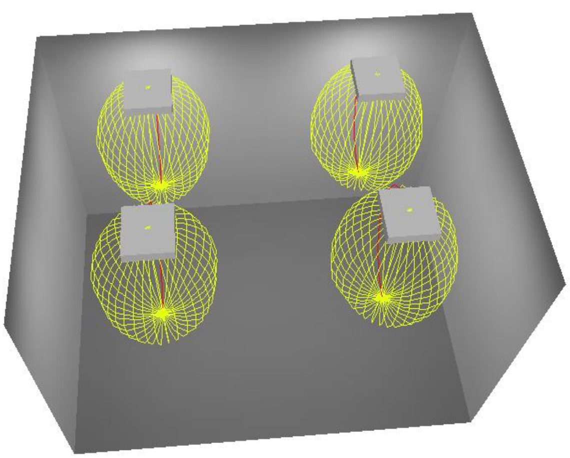


Figure 5.19: *3D View of Chemical Lab in Dialux Software*

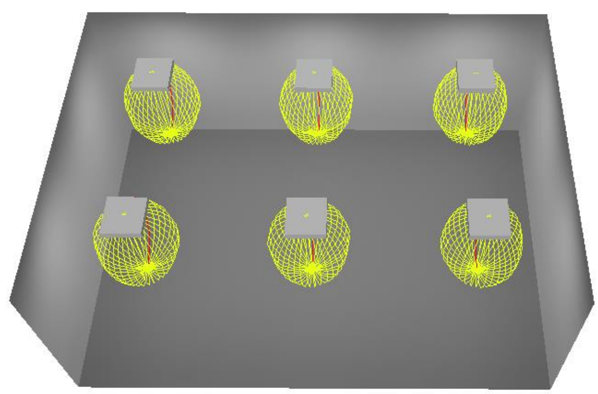


Figure 5.20: *3D View of Washing and Sterilisation Room in Dialux Software*

5.6.4 Results and Analysis

Table 5.3: *Lux Level Details*

Room Name	Obtained Lux Level	Recommended Lux Level
PW and WFI Generation	353	350
Distribution Area	360	350
Office	351	350
Garment Wash	295	250
Cooling Zone	369	350
Disinfectant Prep	392	350
Disinfectant & Filtration	392	350
Cap Sealing	326	300
Material Staging	337	300
F.G Quarantine	345	300
Instrument Lab-1	412	400
QC Manager Office	360	350
QC Staff	383	350
Quality Assurance Store	366	350
RM PPM Store	226	200
IPQC	356	350
Janitor Room	286	250
Garment Store	282	250
Vial Loading Area	391	350
Decatoning	344	350
Washing & Sterilisation	359	350
External Washing	298	250
Reject recall store	264	250

Room Name	Obtained Lux Level	Recommended Lux Level
Store Office	320	250
RM AC Store	278	250
Secondary Packing Area	375	350
PAL-1	241	200
Classified Corridor	240	200
Tool Room	300	250
Blendiing Room	399	350
Autoclave	418	400
Washing Area	281	250
Chemical Lab	325	300
Stability Chamber Room	367	350
Retain Sample Store	278	250
Filter Wash	260	250
Filter Store	265	250
Store	261	250
Culture Room	353	350
MLT	406	400
Wash and Discard Room	252	250
Unclassified Washing	249	250
Glassware & Chemical Store	327	250
Instrument Lab-2	395	350
Cooling Zone	405	350
Sterility Testing	367	350
Media Preperation	387	350
GC Lab	383	350
IR Room	381	350
Corridor	230	200
RM PPM Reject Store	245	200

Room Name	Obtained Lux Level	Recommended Lux Level
MAL-1	219	200
Sterile Corridor	241	200
Corridor	222	200
PAL-1	224	200
PAL-2	220	200
PAL-3	230	200
PAL-4	225	200
PAL-5	224	200
Entry Passage	250	200
Airlock	256	200
Label Store	269	250
Airlock	233	200
Linen Room	281	250
Male Change Room	241	200
Female Change Room	245	200
Visitor Change Room	214	200
Incubator Room	345	300
PAL-1	224	200
PAL-2	220	200
PAL	211	200
Change Room	234	200
Sterile Corridor	255	200
Airlock	233	200
Corridor	222	200
Incubator & Observation Room	345	300
Autoclave	361	350
Airlock-1	221	200
PAL-1	254	200

Room Name	Obtained Lux Level	Recommended Lux Level
PAL-2	229	200
PAL-3	230	200
PAL-4	251	200
Change Room	233	200
Classified Corridor	257	200
Sterility Buffer Zone	334	300
Hot Room	379	350
Passage	222	200
Weighing Room	355	350
PPM Testing	374	350
Safety Shower	391	350
BET Room	385	350
Sealing & Filling	377	350
Sterile Buffer Zone	367	350
Airlock-2	276	250
Airlock-3	276	250
Airlock-4	271	250
Airlock-5	275	250
Technical Area A.H.U	287	250

Chapter 6

Sports Lighting

6.1 Introduction

For designing of the lighting of a sports facility, careful consideration has to be given to the visual requirement and comfort of its principal users. Broadly, the users of a sports facility can be grouped as players and team officials allowed on the bench near the playing area. The players must be able to clearly see all that is going on in the playing area, so that they can deliver the best possible performance. Spectators in the stadium have to be able to follow the performances of the players and the developments of the game in an agreeable environment. The latter requirement means that they must be able to see their surroundings and immediate neighbors as well. The lighting should also help the spectators to safely enter and leave the sports facility. With large crowds this security aspect is very important. Also important in high end facilities is the ambience in the stadium.

6.2 Criteria for Sports Lighting

The key considerations that sports lighting professionals need to take into account are as follows:

- **<u>Horizontal Illuminance:</u>**

  The illuminated playing surface takes up a major part of the field of view for anyone in a sporting venue, whether players, officials or spectators. Horizontal illuminance represents the illuminance on this horizontal plane at ground level. It serves primarily to create a stable visual background against which the eye can discern players and objects. For non-televised lighting classes, an average horizontal illuminance of between 50-100 lux and 750 lux is required, depending on the sport in question and on the lighting class. For televised competitions, the vertical illuminance level is more important than the horizontal illuminance level; to ensure that the television picture has a well-balanced brightness, the ratio between the average vertical and horizontal illuminance should match as closely as possible, but shouldn't exceed a 0.5 to 2 ratio. The horizontal illuminance shouldn’t be less than half the vertical illuminance or greater than twice the vertical illuminance.

- **Vertical Illuminance:**

The athletes in any particular sporting event, as well as the ball they’re using, can be understood as vertical surfaces. This means that we need to keep vertical illuminance primarily in mind when it is needed to lit them. To guarantee an optimal view and make it possible for the human eye to identify players from every direction, we should generally measure vertical illuminance at a height of 1.5 meters, which corresponds approximately to the faces of the players. There is an intimate relationship between vertical and horizontal illuminance. For sports with no specific vertical illuminance criteria, vertical illuminance will be sufficient if the required horizontal illuminance is achieved, and if the lighting design rules are followed. Televised events involve exceptions to this rule of thumb; vertical illuminance has a major influence on the quality of a final television or film picture. Television broadcasting generally calls for an average vertical illuminance of between approximately 1000 lux and 2000 lux.

- **Uniformity:**

Ensuring uniformity is important in avoiding adaptation problems for both players and spectators. If uniformity is inadequate, certain objects or player details might be difficult to see from certain positions. Uniformity is expressed as the ratio of the lowest to the average illuminance. In non-televised situations, the uniformity of the horizontal illuminance is generally specified as between 0.5 to 0.7 depending on sport and lighting class. In televised situations, high uniformity is necessary for smooth and natural-looking scenes, especially in this era of High definition television (HDTV); horizontal illuminance is generally 0.8, whereas vertical illuminance in the direction of fixed cameras requires a uniformity value of 0.7.

- **Glare Restriction:**

Glare is a subjective factor for which CIE has, on the basis of extensive field research, developed a practical evaluation system for use in outdoor sports applications (CIE 112 Glare evaluation system for use within outdoor sports and area lighting). CIE 112 defines a so-called glare rating factor (GR) ranging from 10 to 90 on the assessment scale. The lower the glare value, the better the glare perception for the players in a sporting event. A maximum GR value of 50 is generally specified for sports projects.

6.3 Sports Lighting Classifications and Standards

The dimensions of a sports area influence the quality requirement of the lighting (because different viewing distances are involved) and also the location possibilities of the luminaires. The overall dimensions of a sports area are determined by the type of sport or sports catered for and by the sort of spectator facilities provided, for example, no grandstand, grandstand at one side, grandstand totally enclosing the playing area, etc.

- **Principal Playing Area (PPA):**

  This is the actual playing area needed for the performance of a certain sport. Usually this means the actual marked out 'field' area for that sport (for instance, football), but in some cases this area comprises an extra playing area around the marked area (for example, tennis, volleyball and table tennis).

- **Total Playing Area (TPA):**

  Generally this area comprises the principal area (PA) plus an additional safety area outside the principal area.

The activity in any sports arena can be classified into class I, II and III, which are described as follows:

- **Lighting Class I:**

  Top level competitions such as international and national competitions which will generally involve large spectator capacities with long potential viewing distances. Top level training can also be included in this class.

- **Lighting Class II:**

  Mid level competitions such as regional or local club competitions which generally involve medium size spectator capacities with medium viewing distances. High level training can also be included in this class.

- **Lighting Class III:**

  Low level competition such as local or small club competition which generally do not involve spectators. General training, physical education, school sports and recreational activities will also come into this category.

6.4 Case Study: 1

One of the major Sports Lighting design Performed is of the Sports grounds of a reputed IIT campus. Lighting design of several sports sites like basketball court, lawn tennis court, cricket ground, football ground, hockey ground, volleyball are performed using specially design sport lighting floodlight luminaires. Once properly installed, the luminaires must be aimed. This can be done either with aids incorporated in the floodlights or, with special aiming devices.

6.4.1 Project Background

The dimensions of all the sports sites are given in *Table 6.1*.

Table 6.1: *Dimensions of the Sports Sites*

SL No.	Type of Sports Ground	Ground Dimensions
1	Basketball North Side	51 m X 49.90 m
2	Basketball South Side	18.85 m X 39.10 m
3	Cricket	128 m X 128 m
4	Football	93 m X 55 m
5	Hockey	110 m X 60 m
6	Tennis North Side Single Court	24.10 m X 34.80 m
7	Tennis North Side Two Court	40m X 39.80 m
8	Tennis South Side	20.85 m X 37.85 m
9	Volleyball South Side	34.20 m X 29.5 m

Figure 6.1: *Site Picture of the Cricket Ground*

Figure 6.2: *Site Picture of the Tennis Court*

Figure 6.3: *Site Picture of the Basketball Court*

Figure 6.4: *Site Picture of the Volleyball Court*

6.4.2 Lighting Design

As sports lighting design is a fairly complex process, it is important to gather the following field data as accurately as possible before the start of the process like detailed drawings of the stadium; Field dimensions; Feasibility of different luminaire arrangement. The luminaire selected for this design is cradle mounted LED Floodlight having system luminous efficacy of 110 lumen/Watt. The beam angle of luminaires are selected on the basis of mounting height and dimensions of the sports ground. The luminaire used for the design is shown in *Figure 6.5.*

Figure 6.5: *Floodlight Luminaire for Sports Lighting*[1]

The design analysis of all the Sports Sites is explained as follows:

A. Basketball Court North Side:

Lighting design for basketball court of North Side is performed according to Class II sports lighting BIS standards as per the guidelines mentioned in National Lighting Code 2010. Total 40 luminaires of 250 Watt having beam angle of 60° are used to achieve to average lux level of 263 with uniformity of 0.72. Total 6 Poles are used and height of the pole used for the design is 16 metres. The luminaire aiming diagram is given in Figure *6.6.* Maintenance Factor is taken as 0.8.

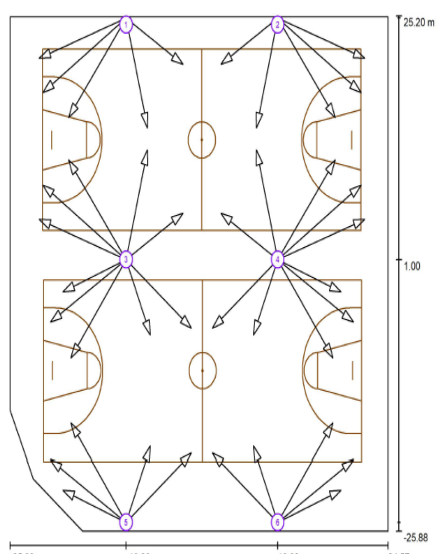


Figure 6.6: *Luminaire Aiming for Basketball Court North Side*

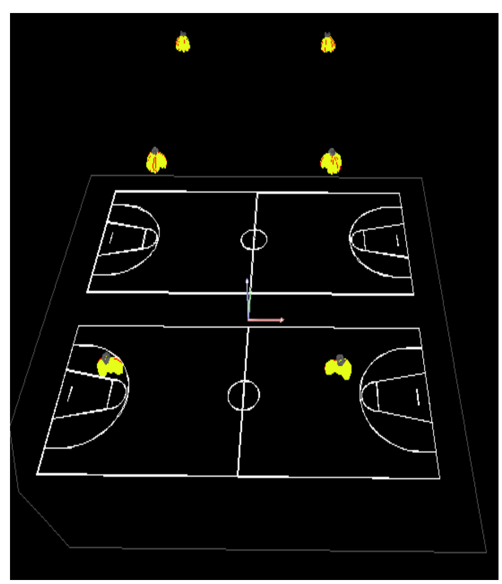


Figure 6.7: *3D View in Dialux 4.13 Software*

B. Basketball Court South Side:

Lighting design for basketball court of South Side is performed according to BIS standards as per the guidelines mentioned in National Lighting Code 2010. Total 16 luminaires of 250 Watt having beam angle of 60° are used to achieve to average lux level of 275 with uniformity of 0.7. Total 4 Poles are used and height of the pole used for the design is 16 metres. Each pole has 4 luminaires. The luminaire aiming diagram is given in Figure *6.8.* Maintenance Factor is taken as 0.8.

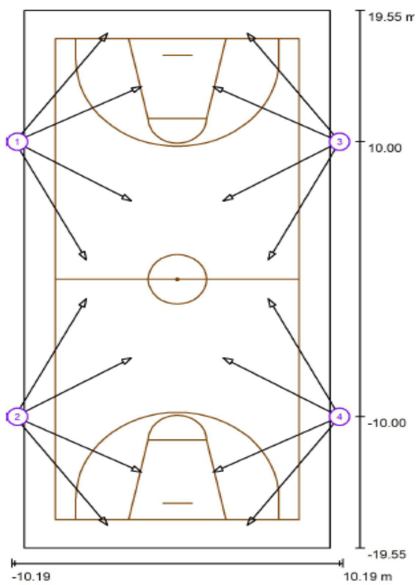


Figure 6.8: *Luminaire Aiming for Basketball South Side*

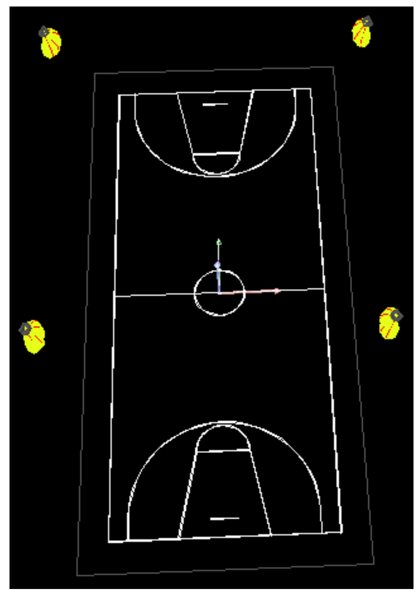


Figure 6.9: *3D View in Dialux 4.13 Software*

C. Cricket:

Lighting design for Cricket ground is performed according to Class II sports lighting BIS standards as per the guidelines mentioned in National Lighting Code 2010. Total 116 luminaires of 1000 Watt are used to achieve to average lux level of 524 with uniformity of 0.73. Total 4 poles are used and height of the pole used for the design is 30 metres. The luminaire aiming diagram is given in Figure *6.10.* Maintenance Factor is taken as 0.8.

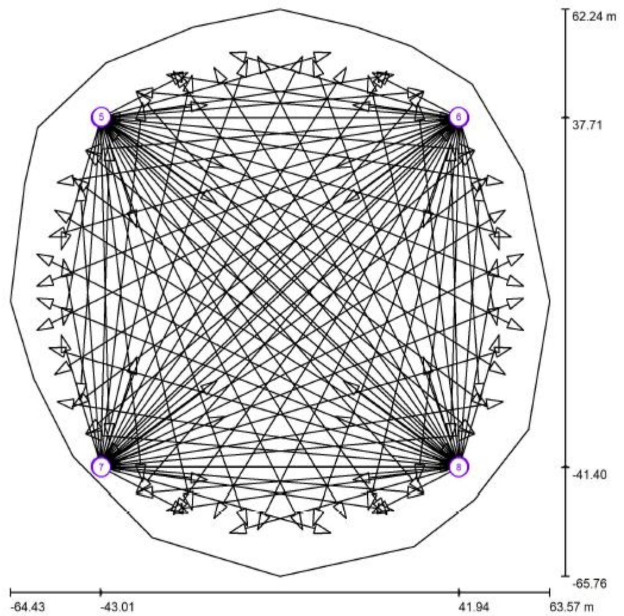


Figure 6.10: *Luminaire Aiming for Cricket Ground*

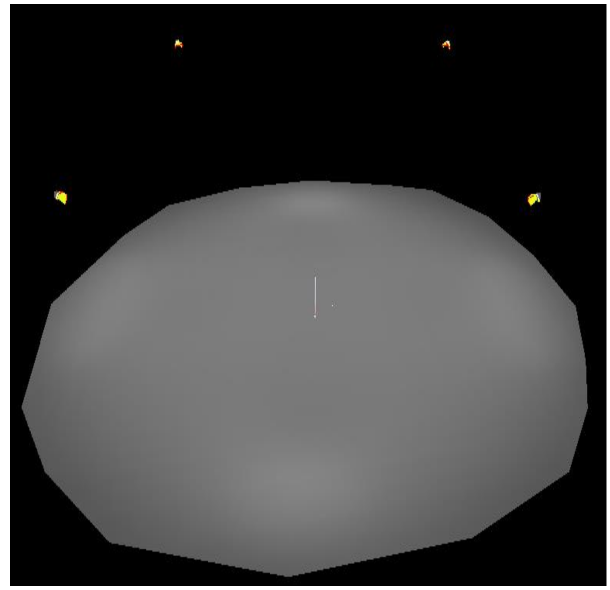


Figure 6.11: *3D View in Dialux 4.13 Software*

D. Football:

Lighting design for Football ground is performed according to Class II sports lighting BIS standards as per the guidelines mentioned in National Lighting Code 2010. Total 64 luminaires of 250 Watt are used to achieve to average lux level of 241 with uniformity of 0.66. Total 8 poles are used and height of the pole used for the design is 30 metres. Each pole has 8 luminaires. The luminaire aiming diagram is given in Figure *6.12*. Maintenance Factor is taken as 0.8.

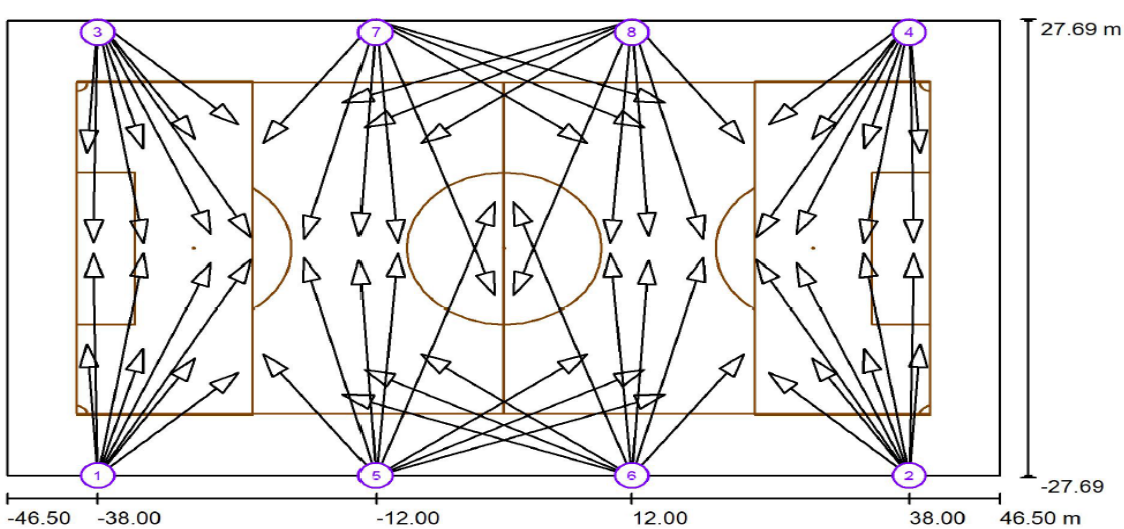


Figure 6.12: *Luminaire Aiming for Football Ground*

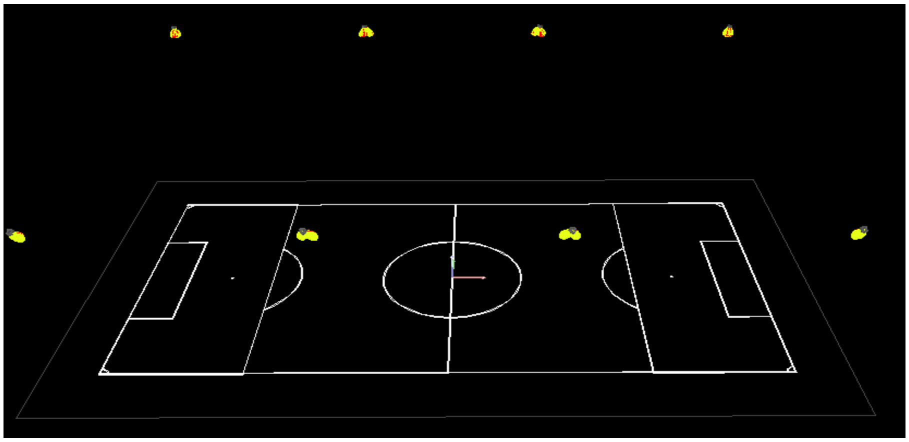


Figure 6.13: *3D View in Dialux 4.13 Software*

E. Hockey:

Lighting design for Hockey ground is performed according to Class II sports lighting BIS standards as per the guidelines mentioned in National Lighting Code 2010. Total 88 luminaires of 500 Watt are used to achieve to average lux level of 546 with uniformity of 0.7. Total 8 poles are used and height of the pole used for the design is 30 metres. Each pole has 8 luminaires. The luminaire aiming diagram is given in Figure *6.14*. Maintenance Factor is taken as 0.8.

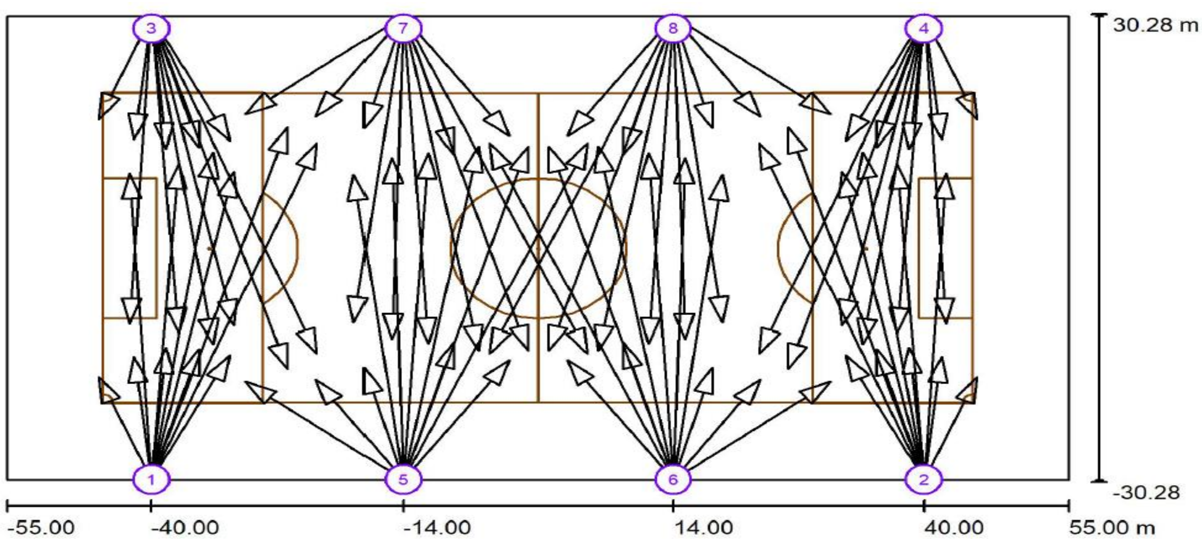


Figure 6.14: *Luminaire Aiming for Hockey Ground*

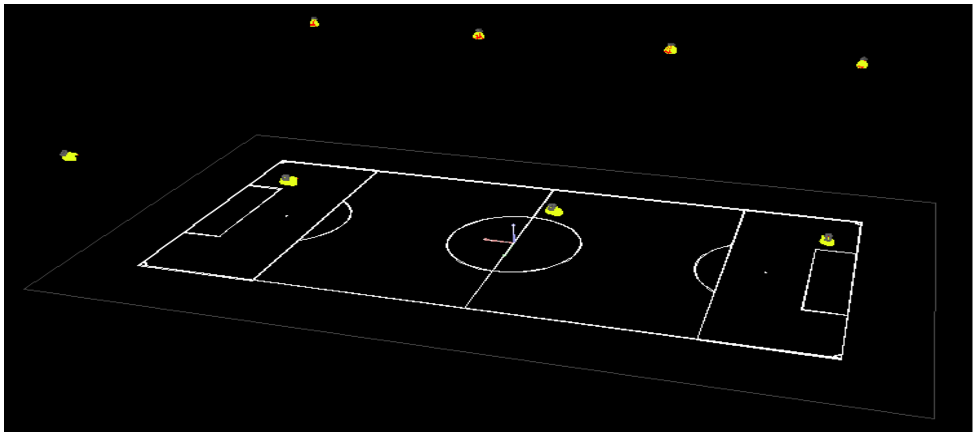


Figure 6.15: *3D View in Dialux 4.13 Software*

F. Tennis North Side Single Court:

Lighting design for Tennis Court of North Side is performed according to Class II sports lighting BIS standards as per the guidelines mentioned in National Lighting Code 2010. Total 20 luminaires of 250 Watt are used to achieve to average lux level of 328 with uniformity of 0.73. Total 4 poles are used and height of the pole used for the design is 16 metres. Each pole has 5 luminaires. The luminaire aiming diagram is given in Figure *6.16.* Maintenance Factor is taken as 0.8.

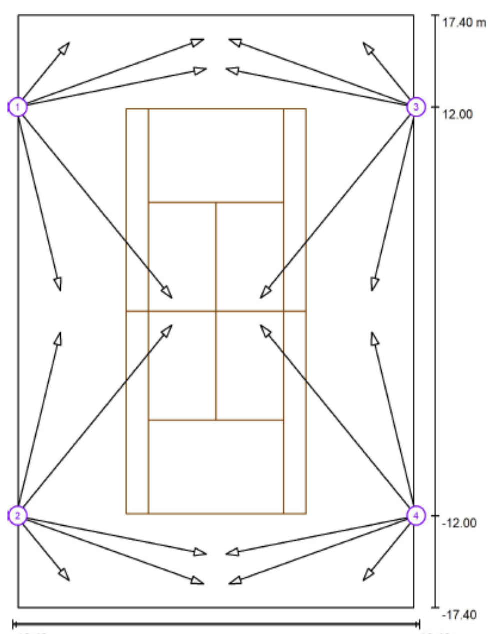


Figure 6.16: *Luminaire Aiming for Tennis North Side Single Court*

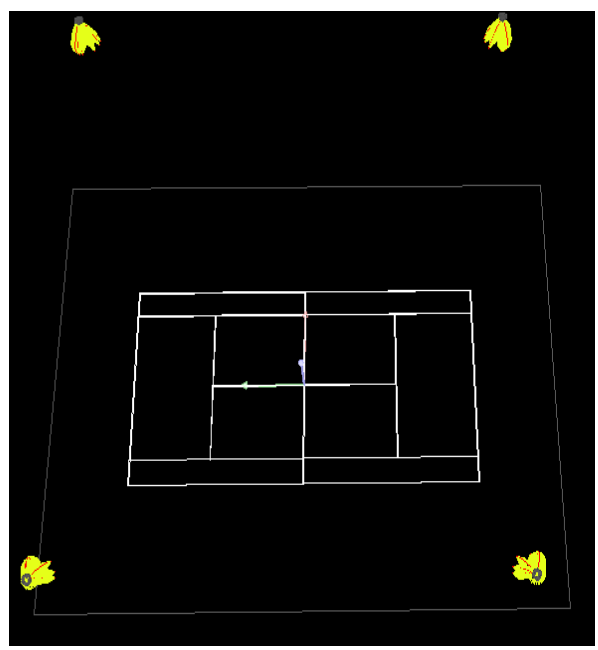


Figure 6.17: *3D View in Dialux 4.13 Software*

G. Tennis Court North Side Two Court:

Lighting design for Tennis Court of North Side is performed according to Class II sports lighting BIS standards as per the guidelines mentioned in National Lighting Code 2010. Total 32 luminaires of 250 Watt are used to achieve to average lux level of 358 with uniformity of 0.74. Total 6 poles are used and height of the pole used for the design is 16 metres. The luminaire aiming diagram is given in Figure *6.18.* Maintenance Factor is taken as 0.8.

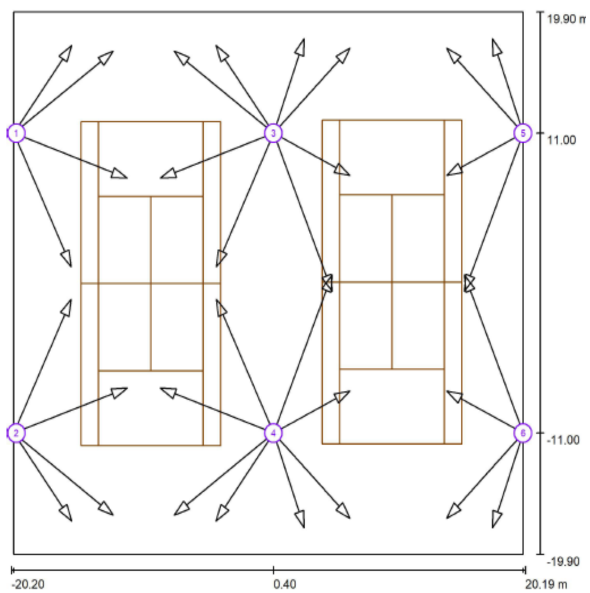


Figure 6.18: *Luminaire Aiming for Tennis Court North Side Two Court*

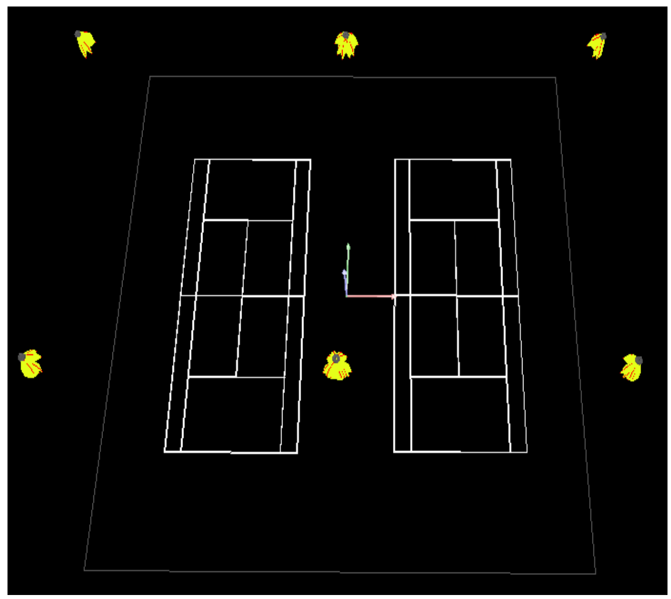


Figure 6.19: *3D View in Dialux 4.13 Software*

H. Tennis Court South Side:

Lighting design for Tennis Court of South Side is performed according to Class II sports lighting BIS standards as per the guidelines mentioned in National Lighting Code 2010. Total 20 luminaires of 250 Watt are used to achieve to average lux level of 346 with uniformity of 0.73. Total 4 poles are used and height of the pole used for the design is 16 metres. Each pole has 5 luminaires. The luminaire aiming diagram is given in Figure *6.20.* Maintenance Factor is taken as 0.8.

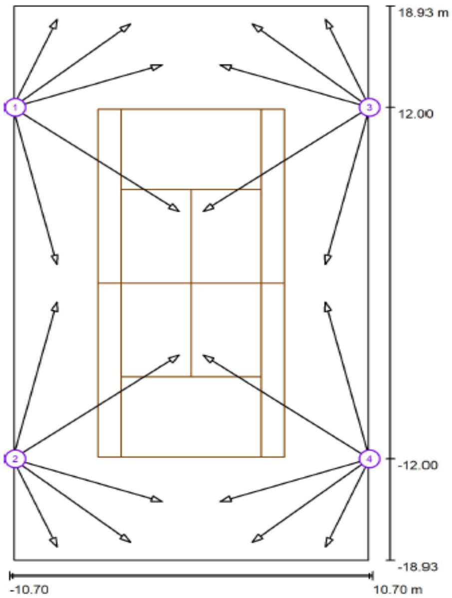


Figure 6.20: *Luminaire Aiming for Tennis South Side*

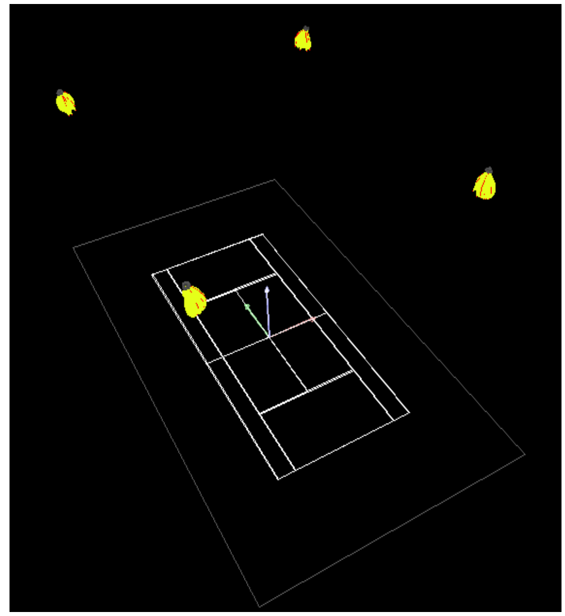


Figure 6.21: *3D View in Dialux 4.13 Software*

I. Volleyball:

Lighting design for Volleyball Court is performed according to Class II sports lighting BIS standards as per the guidelines mentioned in National Lighting Code 2010. Total 12 luminaires of 250 Watt having beam angle of 30° are used to achieve to average lux level of 255 with uniformity of 0.61. Total 3 poles are used and height of the pole used for the design is 12 metres. The luminaire aiming diagram is given in Figure *6.22*. Maintenance Factor is taken as 0.8.

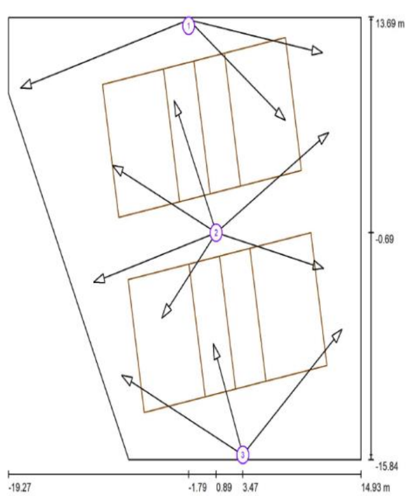


Figure 6.22: *Luminaire Aiming for Volleyball Court*

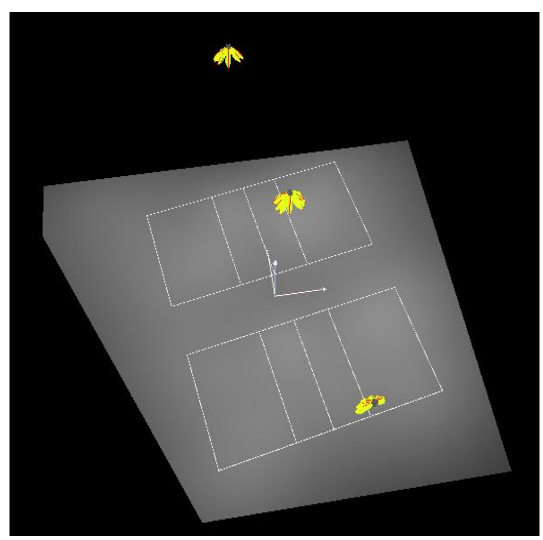


Figure 6.23: *3D View in Dialux 4.13 Software*

6.4.3 Results and Analysis

The Simulation results of all the sports sites are represented below in *Table 6.2.* The activity in any sports arena can be classified into class I, II and III. Class I represents top level competitions such as international and national competitions which will generally involve large spectator capacities with long potential viewing distances. Top level training can also be included in this class. Class II represents mid level competitions such as regional or local club competitions which generally involve medium size spectator capacities with medium viewing distances. High level training can also be included in this class. Class III represents low level competition such as local or small club competition which generally does not involve spectators. General training, physical education, school sports and recreational activities will also come into this category. The simulation analysis is prepared according to Class II sports lighting standards, as all the sports sites will have regional college or university level competitions.

Table 6.2: *Lux Level Details*

SL No.	Type of Sports Ground	Sports Lighting Class	Mounting Height	Obtained lux level	Recommended lux level	Obtained Uniformity	Recommended Uniformity
1	Basketball North Side	Class II	16 m	263	200	0.72	0.7
2	Basketball South Side	Class II	16 m	275	200	0.7	0.7
3	Cricket	Class II	30 m	524	500	0.73	0.7
4	Football	Class II	30 m	241	200	0.66	0.6
5	Hockey	Class II	30 m	526	500	0.7	0.7
6	Tennis North Side Single Court	Class II	16 m	328	300	0.73	0.7
7	Tennis North Side Two Court	Class II	16 m	358	300	0.74	0.7
8	Tennis South Side	Class II	16 m	346	300	0.73	0.7
9	Volleyball South Side	Class II	12 m	255	200	0.61	0.6

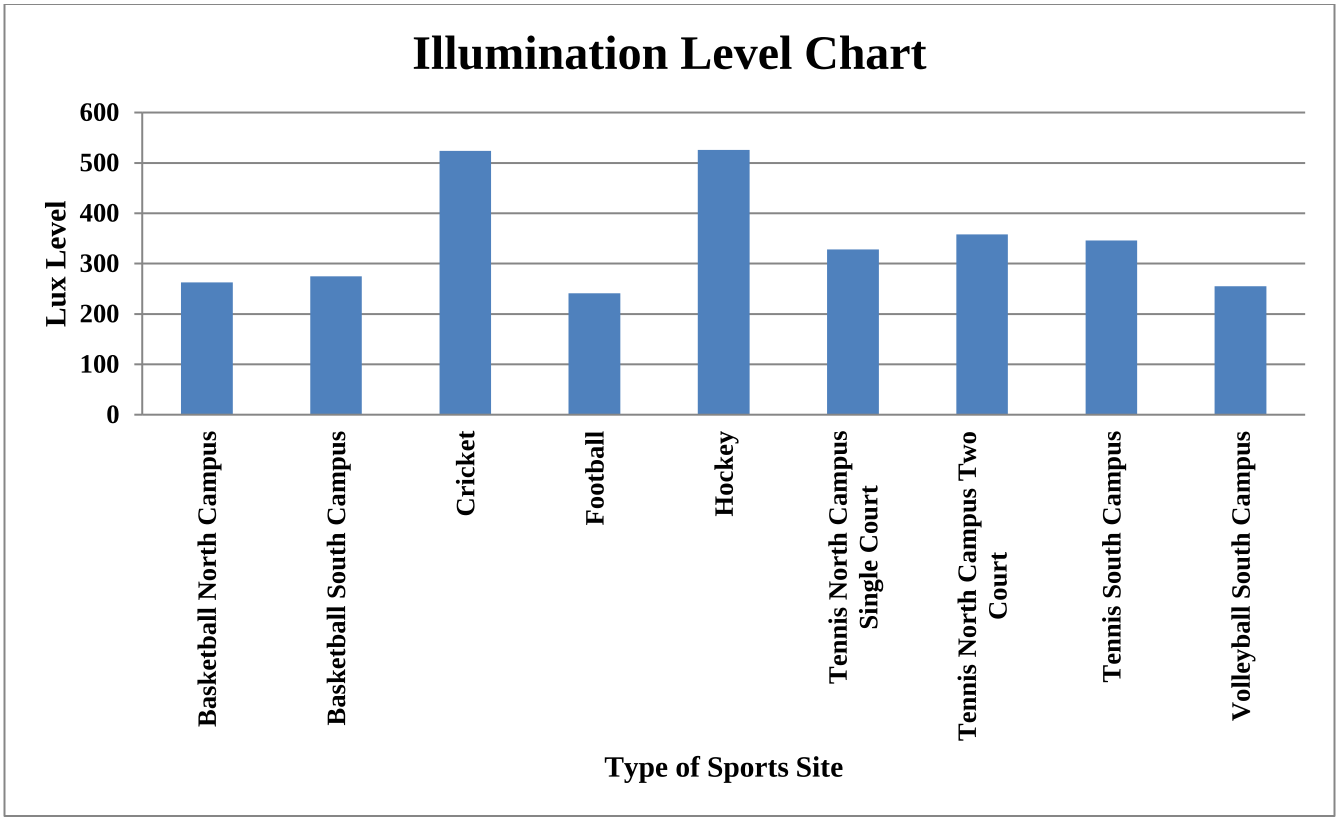


Figure 6.24: *Graphical Representation of Lux Level Sheet*

6.5 Case Study: 2

In this section, the detailed description of an Indoor Sports Lighting design is mentioned. This design is of a shooting hall in the basement floor of a government boarding school. In this design both horizontal and vertical illumination is taken into account.

Figure 6.25: *Site Picture of the school where lighting design of the shooting hall is performed*

6.5.1 Project Background

In this shooting hall, there are two target zones, one is 10 metre target zone and another is 25 metre target zone. Also there are three shooting platforms, at 10 metres distance, at 25 metres distance and 50 metres distance. All the shooting platforms are simulated using horizontal calculation surface and the two target zones are simulated using vertical calculation surface. The dimensions of the shooting hall are given in *Table 6.3*.

***Table 6.3:** Dimensions of the Shooting Hall*

SL No.	Area	Dimensions
1	Main Hall	62.55 m X 26.73 m
2	10 m Firing Platform	20.60 m X 1 m
3	25 m Firing Platform	16 m X 1 m
4	50 m Firing Platform	10 m X 1 m

6.5.2 Lighting Layout

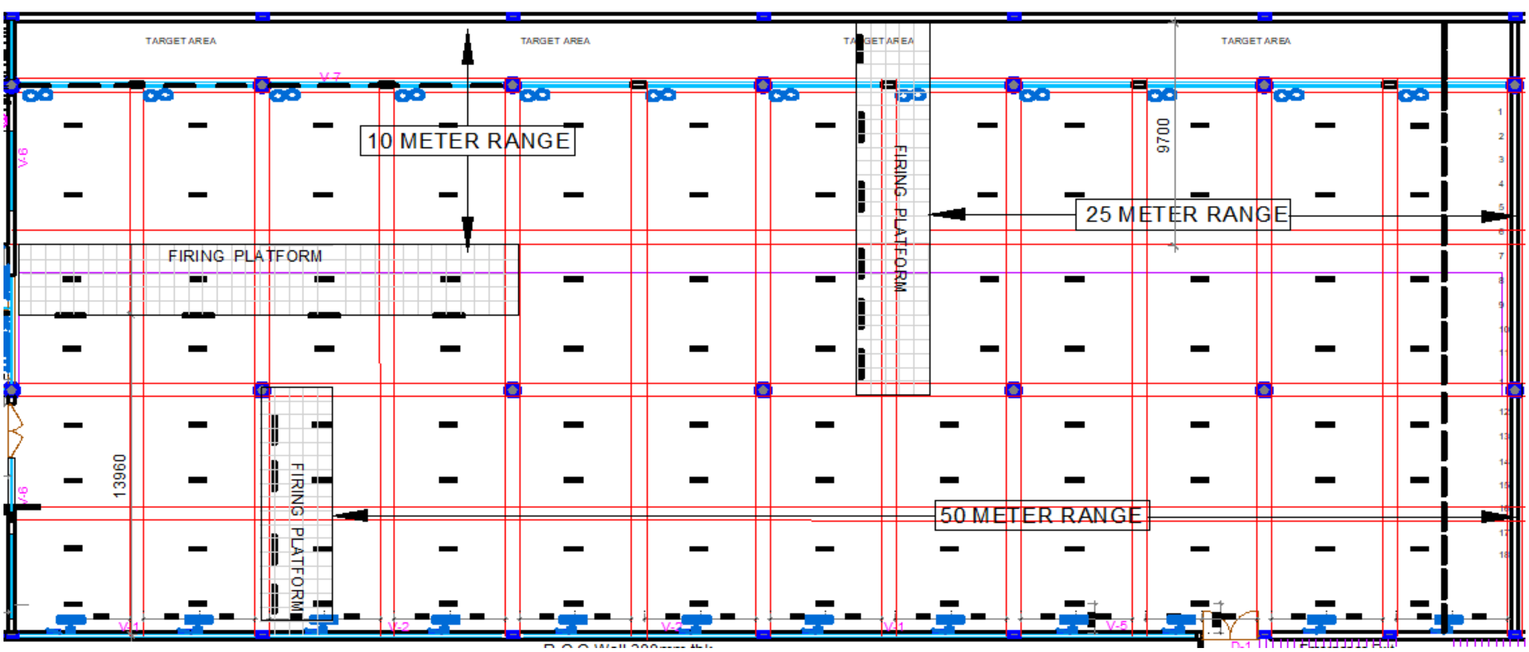


***Figure 6.26:** Complete Lighting Layout of Shooting Hall*

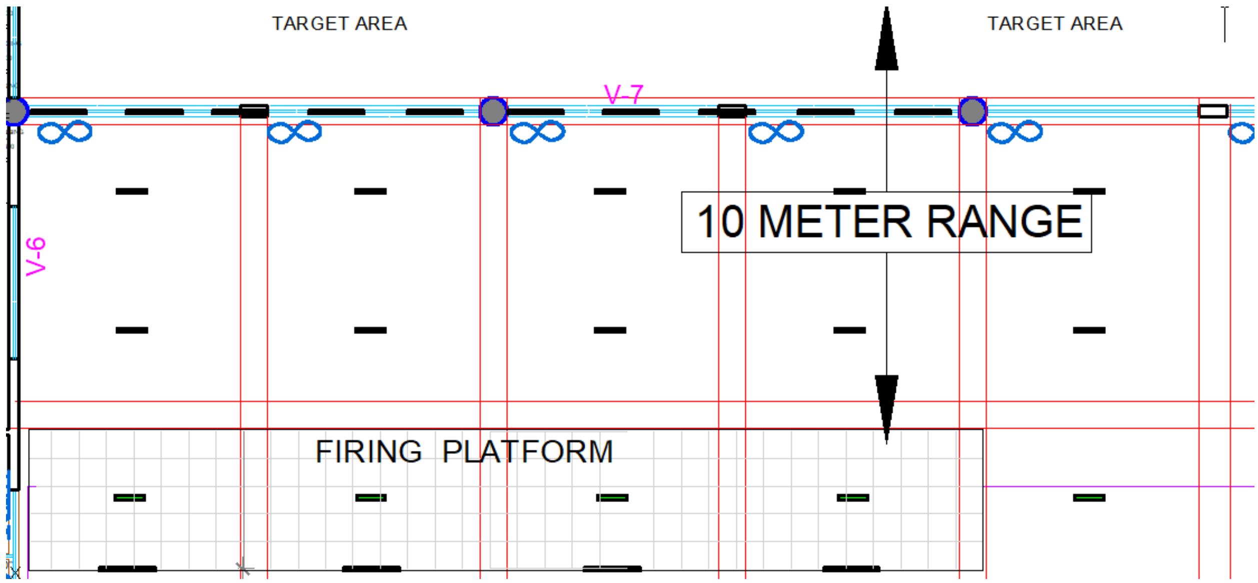


Figure 6.27: *Complete Lighting Layout for Firing Platform and Target Area*

6.5.3 Lighting Design

Critical Parameters of Indoor Shooting Hall lighting design are as follows:

- Glare – Too-harsh lighting creates serious visibility and safety issues for shooters.
- Even Lighting – For professional and indoor competitive shooters, starting off on equal footing with the shooter next is mandatory. It is crucial to maintain even lighting downrange and in each shooting lane to ensure accuracy and uniformity.
- Dust-proof – Discharged ammunition generates lead dust. While there are always ventilation systems in place to prevent harmful lead build up in any reputable indoor shooting range, some of this dust can eventually infiltrate light fixtures and make them less effective.
- Correlated Color Temperature (CCT) – It is recommended that CCT value in indoor shooting ranges should not be too warm or too cool.

The luminaire selected for this design is 80 Watt Linear Highbay. This highbay luminaire is suitable for indoor sports lighting application having high luminous efficacy of 145 lm/Watt and this 80 Watt product is having wide beam angle of 120°. The luminaire used for the design is shown in *Figure 6.28.* Maintenance Factor is taken as 0.8

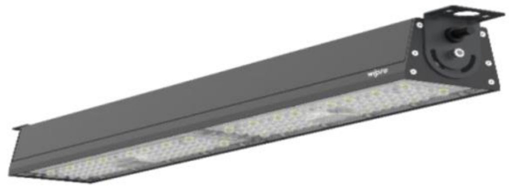


Figure 6.28: *Linear LED Highbay Luminaire*[1]

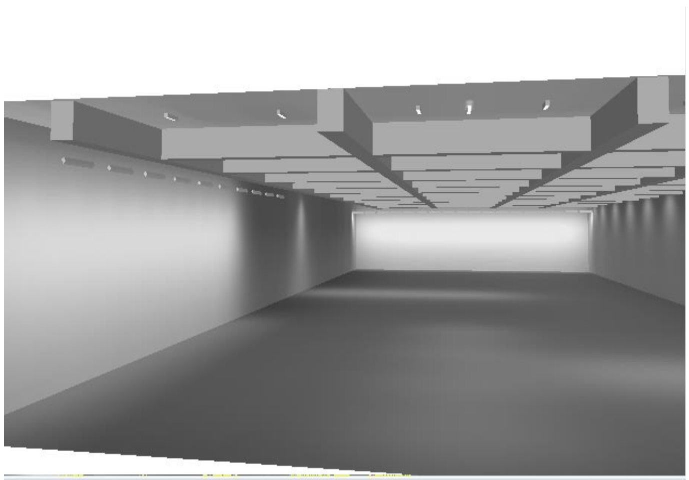


Figure 6.29: *3D View of the Shooting Hall in Dialux Software*

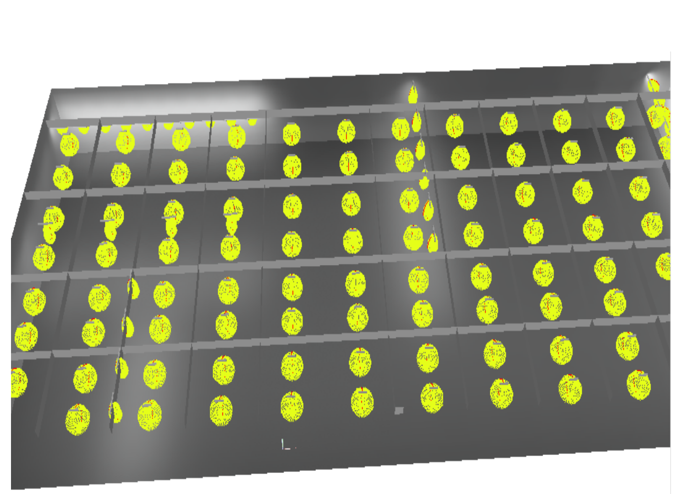


Figure 6.30: *3D View of the Shooting Hall in Dialux Software with Flux Lines*

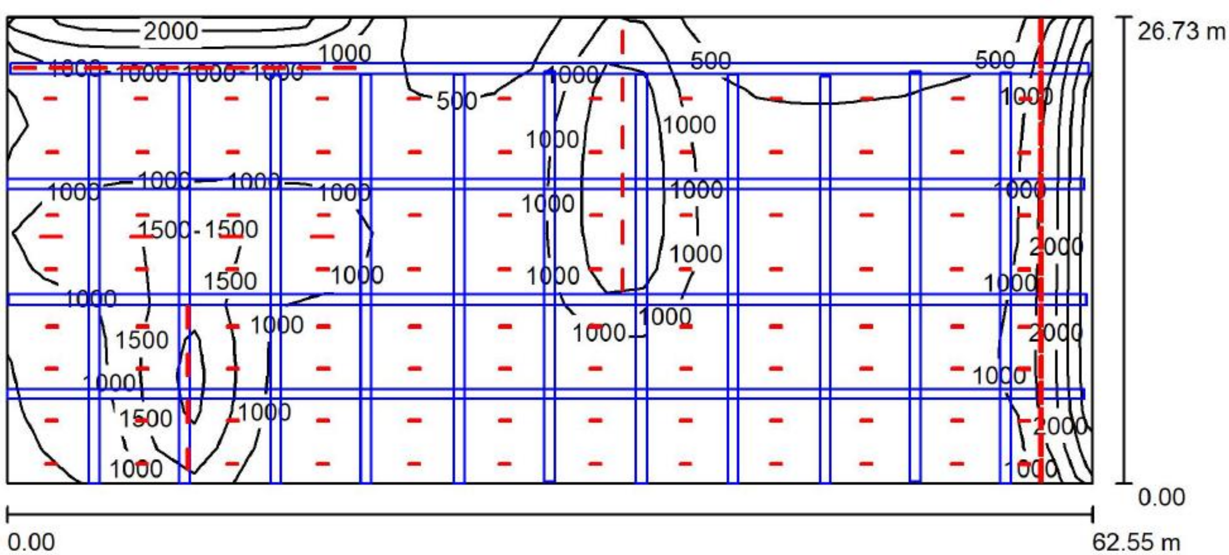


Figure 6.31: *Isolines Representation of the Entire Shooting Hall*

6.5.4 Results and Analysis

The entire shooting hall is planned with 80 Watt Linear Highbay for general lighting. For task lighting that is at target zones and shooting platforms, additional lighting is proposed with 200 Watt linear highbay. In this shooting hall, there are two target zones, one is 10 metre target zone and another is 25 metre target zone. Also there are three shooting platforms, at 10 metres distance, at 25 metres distance and 50 metres distance. In the target areas, the 200 Watt Linear highbay is planned with tilt angle of 15°, as in the target zones, calculation of vertical lux level is required.

Table 6.4: *Lux Level Details*

SL No.	Area	Obtained Average Lux level	Recommended Lux level	Obtained Uniformity
1	Main Hall	947 (Horizontal)	800	0.444
2	10 m Firing Platform	1509 (Horizontal)	1500	0.612
3	25 m Firing Platform	2067 (Horizontal)	2000	0.523
4	50 m Firing Platform	2145 (Horizontal)	2000	0.586
5	Target at 10 m	1826 (Vertical)	1800	0.71
6	Target at 25 and 50 m	2608 (Vertical)	2500	0.76

6.6 Comparative Analysis between Sports Lighting Designs

A great lighting system does more than just illuminate the field of play. Among other things, it also makes stadium visitors generally comfortable in their surroundings and ensures a successful television broadcast for spectators watching at home. The right sports lighting system answers a range of needs: to ensure broadcast quality, to keep spectators and players safe, to guarantee great playing conditions, to minimize unwanted effects for area residents, and more. In Case Study 1, an outdoor sports lighting design is conducted using Floodlight luminaires mounted on high masts. The luminaire selected for this design is Cradle Mounted LED Floodlight having system luminous efficacy of 110 lumen/Watt. The beam angle of luminaires are selected on the basis of mounting height and dimensions of the sports ground. Whereas in case study 2, since it is an indoor shooting hall, so it is performed with higher efficacy, tiltlable and anti-glare linear highbay luminaire. In Case Study 1, only average horizontal lux level is taken into account, whereas in case study 2, both horizontal and vertical illuminance is considered. In case study 2, The luminaire selected for this design is 80 Watt Linear Highbay. This highbay luminaire is suitable for indoor sports lighting application having high luminous efficacy of 145 lm/Watt and this 80 Watt product is having wide beam angle of 120°. For the shooting platform area and target area, where high amount of lux level is needed, 200 Watt linear highbay is proposed which is also having high lumen efficacy of 145 lm/Watt. This 200 Watt linear highbay is having beam angle of 60°. A tabular representation of comparative analysis is prepared below in ***Table 6.5.***

Table 6.5: *Comparison Details*

Parameters	**Case Study 1**	**Case Study 2**
Design Type	Outdoor Sports Lighting	Indoor Sports Lighting
Luminaire Used	Floodlights	Linear Highbay
Luminaire Mounting Height	16 metres	5.65 metres
Lumianire Wattage	250 Watt	80 Watt/200 Watt
Luminaire Efficacy	110 lumen/Watt	145 lumen/Watt
Average lux level	Based on Sports Lighting Class II Standards (*Refer to Table 6.2*)	947 lux

Chapter 7

Road Lighting

7.1 Purpose of Road Lighting

The main objectives of road lighting design scheme are as follows:

- Perfect visual sensation for safety and security of both driver and pedestrian. Lighting should permit users of the road at night to move about with the greatest possible safety and comfort so that the traffic capacity of the road at night is as much equal to that planned for the daytime as possible.
- Illuminated environment for quick movement of the vehicles. The driver should be able to see distinctly without the use of driving headlights and locate with certainty and in time, all significant details notably the alignment of the road, any traffic signs and possible obstacles. Moreover, driver should be made aware of any dangerous situation without the use of his headlight beams, either driving or passing.
- Clear view of objects for comfortable movement of the road users.
- Uniformity and consistency in lighting designs throughout the province while meeting the industry standards.
- Take into account the initial capital cost of the installation as well as long term maintenance. The cheapest cost up front may not be the cheapest over the life of the luminaire.

Guidelines and standards for road lighting are provided to help designers achieve these purposes, and to do so, they provide quantitative recommendations for the appropriate level (luminance or illuminance), colour (or other characteristic derived from the spectral power distribution) and spatial distribution of light.

7.2 Quality Criteria for Road Lighting

The factors which contribute to the fundamental criteria of quality of road lighting are as follows:

- Level of Luminance
- Level of Illuminance
- Uniformity
- Limitation of Glare
- Visual guidance

Level of Luminance:

The most generally used approach to selecting quality criteria for lighting roads for motorized traffic is based on the luminance concept. This is minimum value to be maintained throughout the life of the installation. It is dependent on the light distribution of the luminaires, the luminous flux of the lamps, the geometry of the installation and on the reflection properties of the road surface.

The level of luminance should be adequate to provide visibility which will guarantee for the user a maximum of safety and sufficient visual comfort. It is obvious that it is the road surface luminance rather than the illumination level which provides the more accurate measure of the effective light in a street lighting installation. However, in the present state of the technique and the knowledge of reflection properties of road surfaces, the calculation and measurement of luminance are likely to present difficulties. Most road lighting installations have lighting levels corresponding to mesopic vision.

Level of Illuminance:

For road lighting specifically meant for non-motorized road users, the concentration is mainly on the illuminance as the basic lighting parameter. The illuminance level for road lighting in India is governed by IS 1944 (Parts 1 and 2). These values must of course satisfy the basic principles of vision, criteria of quality etc. and are classified as per the different types of roads. The lighting levels as specified are average values.

Uniformity:

Uniformity is required to provide visual comfort for the driver. It should be noted that the requirements are more stringent than those which are demanded merely by questions of visibility.

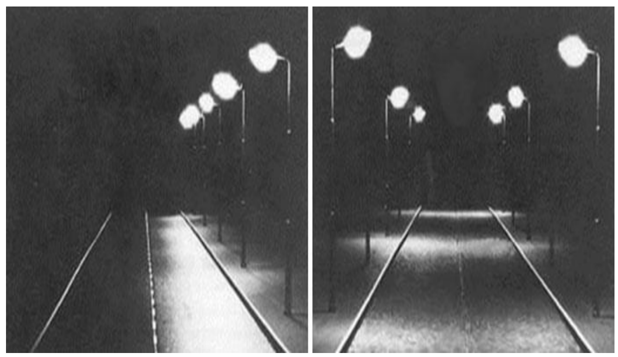


Figure 7.1*: Photograph of a Road illustrating Bad Uniformity*[2]

In the case of a luminance pattern on the road in which there is a large difference between the luminance value of the darkest part and the value of the average road surface luminance, it may become difficult to detect objects against that darkest part because the eye adapts itself to the higher average luminance. It is for this reason that the concept of overall uniformity has been introduced. Overall Uniformity is defined as the ratio of the minimum to the average road-surface luminance, $L_{min}/ L_{avg.}$ A good overall uniformity ensures that all spots and objects on the road are sufficiently lit and visible to the motorist. A continuous sequence of bright and dark spots on the road in front of a driver can be extremely discomforting. This discomfort aspect of a road lighting installation can be limited by specifying a minimum value for the longitudinal uniformity. Longitudinal Uniformity is defined as the ratio of the minimum to the maximum road-surface luminance, L_{min}/ L_{max} along the centre line of a lane within the calculation area. A good level of longitudinal uniformity ensures comfortable driving conditions by reducing the pattern of high and low luminance levels on a road (i.e. Zebra effect, as shown in *Figure 7.2*).

Figure 7.2*: Zebra Effect*[2]

Limitation of Glare:

The glare due to luminaires should be controlled at a value which keeps the visual discomfort to which the driver is subjected below an acceptable level. Luminaires have been classified, according to the form of their light distribution, into three categories and limits have been set to their employment from the point of view of glare. Glare, as shown in *Figure 7.3* is caused due to the sudden presence of a very bright source in the visual field. Glare in road lighting is caused by luminaires. There are two types of glare namely, disability glare which impairs vision and discomfort glare which creates unpleasant viewing conditions.

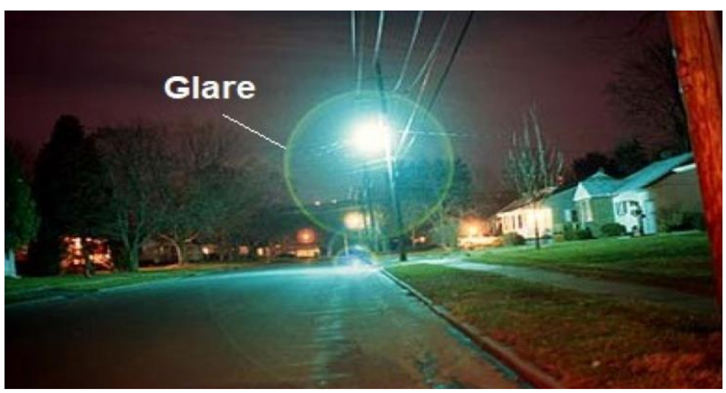


Figure 7.3*: Illustration of Glare*[2]

Visual Guidance:

A good visual guidance is required especially on long stretches of lighted roads and even more on complicated intersections, roundabouts, etc. The primary importance with regard to visual guidance are the design of the road, the road markings, and the guidance provided by the run of possible crash barriers. The guidance so provided should be strengthened by the lighting.

Figure 7.4: *Good visual guidance obtained by the alignment of the luminaires*[2]

A lighting installation can be made to provide good visual guidance, during the day as well as by night, by paying special attention to the alignment and arrangement of the masts with luminaires, as shown in *Figure 7.4*. These should clearly indicate any changes important to a driver in the situation ahead. This type of visual guidance gives information over a much greater distance.

7.3 Geometry in Road Lighting System

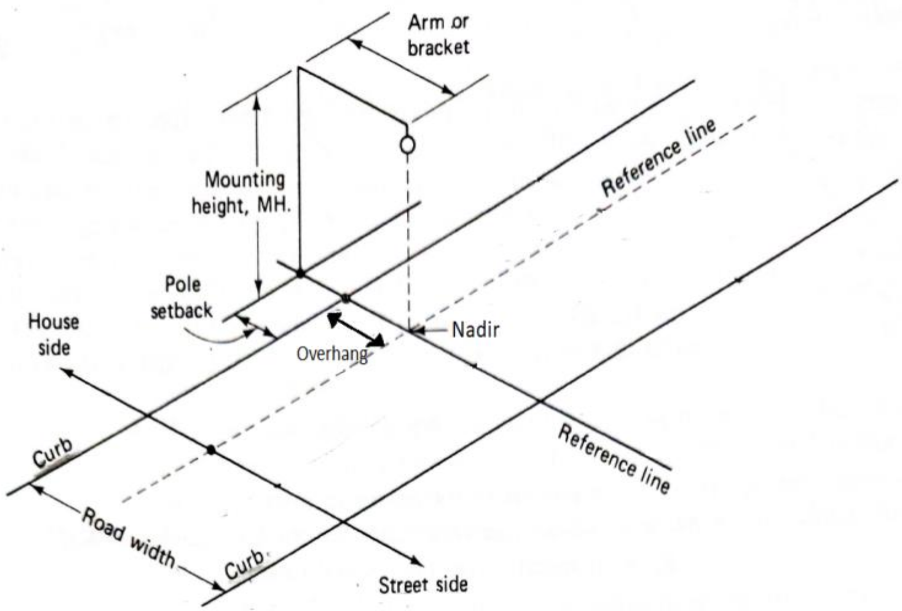


Figure 7.5: *Road Lighting Configurations* [2]

Pole Setback: Pole Setback is the horizontal distance between the face of a light pole and the edge of travelled way.

Overhang: The distance measured horizontally between the centre of a luminaire mounted on a bracket and the adjacent edge of the road.

Curb: A border of stone, concrete or other rigid material formed at the edge of a street.

Nadir: The point vertically below a luminaire's lamp source center with the luminaire mounted in standard position with zero tilt or roll.

Mounting Height: The vertical distance between the centre of the luminaire and surface of a road.

Span: The part of the highway lying between successive luminaires in an installation.

7.4 Road Lighting Standards and Recommendations

According to the Bureau of Indian Standards (BIS), lighting recommendations for different road types are specified in IS: 1944 (Parts I and II) – 1970: CODE OF PRACTICE FOR LIGHTING OF PUBLIC THOROUGHFARES, as illustrated in *Table 7.1* and *Table 7.2*.

***Table 7.1**: Lighting Classes for Different Road Types* [2]

Description of Road	Lighting Class
Important traffic routes carrying fast traffic	A1
Other main roads carrying mixed traffic, like main city streets, arterial roads, throughways, etc.	A2
Secondary roads with considerable traffic like principal local traffic routes, shopping streets, etc.	B1
Secondary roads with light traffic	B2

__Table 7.2__: IS: 1944 Recommended Levels of Illuminance [2]

Classification of lighting Installation	**Average Level of Illumination on Road Surface**	**Uniformity Ratio (E_{min}/E_{avg})**	**Transverse Uniformity (E_{min}/E_{max})**
Group A1	30 lux	0.4	0.33
Group A2	15 lux	0.4	0.33
Group B1	8 lux	0.3	0.2
Group B2	4 lux	0.3	0.2

7.5 Case Study: 1

One of the major Road Lighting Project Performed was of a famous road in India. This design is performed using solar street lights. Solar street lights are raised light sources which are powered by solar panels generally mounted on the lighting structure or integrated into the pole itself. The solar panels charge a rechargeable battery, which powers LED during the night. Most solar lights turn on and turn off automatically by sensing outdoor light using solar panel voltage. Solar streetlights are designed to work throughout the night. Many can stay lit for more than one night if the sun is not in the sky for an extended period of time. Solar lights installed in windy regions are generally equipped with flat panels to better cope with the winds.

Figure 7.6: *Pictorial Representation of Road during Day time*

7.5.1 Project Background

This road lighting design is a type of retrofitting design where existing lighting poles are to be replaced with solar street lighting poles. For this purpose, it is therefore needed to analyse the existing design parameters before starting the design. During the actual lighting design phase of a lighting project, the lighting designer has to perform lighting calculations in order to arrive at solutions that will satisfy the relevant lighting requirements. Existing lux level details are taken at site using lux meter using grid points. Existing lux level details are illustrated in *Table 7.4.* 120 LED Fixtures are to be replaced with Hybrid Solar Streetlight. Existing lighting poles are arranged in Twin Central arrangement in Median. On either side of the median road width are of 11 metres and the width of median is 1 meter. Tabular representation of existing design parameters is represented below in *Table 7.3.*

Table 7.3: *Existing Design Parameters*

Design Parameters	Value
Road Width	11 m
Mounting Height	10 m
Pole to Pole Spacing	30 m
Boom Length	1.5 m
Boom Angle	15 degree
Luminaire Details	LED Fixture 120 Watt
Luminaire Arrangement	Twin Central

Table 7.4: *Existing lux level Details*

Design Parameters	Value
Average Lux Level (Eav)	14 lux
Minimum Lux level (Emin)	9 lux
Maximum Lux level (Emax)	23 lux
Overall Uniformity	0.62
Transverse Uniformity	0.391

7.5.2 Lighting Design

While planning a road lighting design, certain parameters are needed to take into account like mounting height, pole to pole spacing, boom length, boom angle, luminaire arrangement. This design is performed using Twin Central arrangement. In Twin central arrangement the luminaries are mounted on T-shaped masts in the middle of the centre island of the road. The central reserve is not too wide; both luminaires can contribute to the luminance of the road surface on either lane. Solar street lighting system uses the photovoltaic technology to convert the sunlight into DC electricity through solar cells. The generated electricity can either be used directly during the day or may be stored in the batteries for use during night hours.

The solar street lighting system comprises of

1. Solar photovoltaic module
2. Battery box
3. Lamp with charge controller
4. Lamp post

The luminaire selected for the design is 90 Watt and 120 Watt Solar Street Lighting LED luminaire. This luminaire is having efficacy of 150 lumen/Watt. The luminaire used for the design is shown in *Figure 7.7*. According to BIS standards as shown in *Table 7.1* and *Table 7.2*, this road falls under A2 road lighting class where minimum average lux level to be maintained is 15 lux.

Figure 7.7: *Hybrid All in one Solar Streetlight*[1]

Figure 7.8: *2D Representation of the Road in Dialux 4.13 Software*

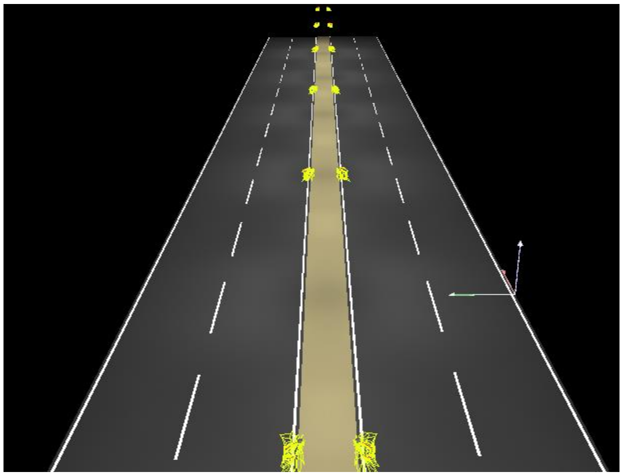


Figure 7.9: 3D Representation of the Road in Dialux 4.13 Software

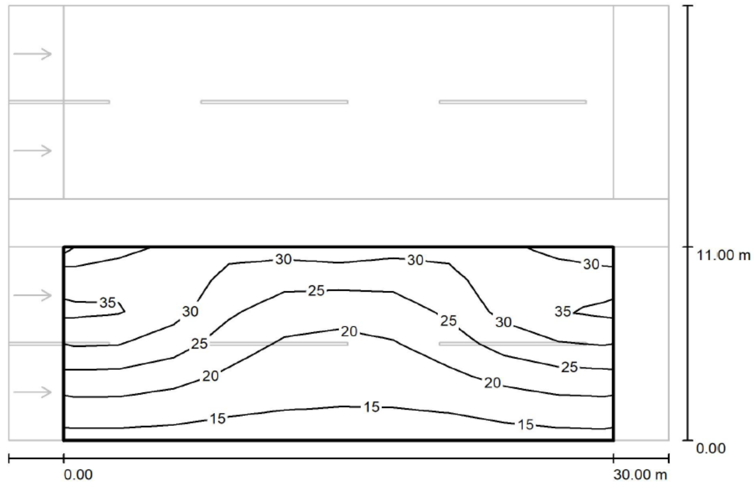


Figure 7.10: Isolines Representation of Roadway

7.5.3 Results and Analysis

Table 7.5: Simulation Details

Design Parameters	120W Hybrid Solar Led Street Light	90W Hybrid Solar LED Street Light
Road Width	11 m	11 m
Mounting Height	10 m	10 m
Pole to Pole Spacing	30 m	30 m
Boom Length	0.8 m	0.8 m
Luminaire Arrangement	Twin Central	Twin Central
Average lux level	32	24
Overall Uniformity	0.547	0.547
Transverse Uniformity	0.349	0.349

While designing Road Lighting, it is also necessary to analyse the Economic Scenario. According to a latest economic survey, Road lighting infrastructure in most parts of India is out-dated and its inefficient operation places a heavy burden not only on municipal budgets but also on utility grid capacity and reliability. According to a financial year 2013 report, road lighting in India consumes about 8,478 GWh of electricity, about 1.5% of total electricity consumption. That figure can be reduced by 40-60% through use of energy efficient LED technologies. For instance, retrofitting the entire conventional streetlights with LEDs in the country could result in a potential annual savings of 4,300 million KWh, which is about 50% of total energy consumed. In addition, operational optimization, such as the use of twilight switching controls and dimming and voltage optimization, could lead to an additional energy savings of 15-20%. The total opportunity of energy savings at the national level could increase from 4,300 million KWh to about 5,000 million KWh annually. Assuming a power cost of Rs.5 per KWh, this translates to an annual cost savings of Rs.2500 crores. So, a savings sheet is prepared to analyse the economic side of this design. The saving sheet as shown in *Table 7.6* is prepared in terms of the existing design versus proposed design. The saving calculation is performed by taking 3 months period in a calendar year as operational on A.C Supply.

Table 7.6: *Savings Calculation Details*

SAVINGS CALCULATION -LED Street Light VS Hybrid AIO Solar LED Street Light			
Type	**120W LED Street Light**	**120W Hybrid Solar Led Street Light**	**90W Hybrid Solar LED Street Light**
Wattage(W)	120	120	90
Quantity	73	73	73
Efficacy(lm/W)	100	150	150
Lux Level(Lux)	14	32	24
Total Wattage inKW	8.76	8.76	6.57
No of Days of operation per annum from Grid Supply	365	90	90
Total Hours of operation Per annum from Grid Supply	4380	1080	1080
Total KWhr	38368.8	9460.8	7095.6
Savings in KWhr.		28908	31273.2
% Savings		75%	82%
Electricity Charges Per Unit(INR.)	11	11	11
Total Electricity Charges Per Annum(INR.)	422057	104069	78052
Total Savings in Electricity Charges Per annum(INR.)		317988	344005
% Savings in Electricity Cost p.a		75%	82%
Total Savings in Electricity Charges in 5years(INR.)		1589940	1720026

7.6 Case Study: 2

Another major Road Lighting Project Performed was of a famous road in India. This design was performed using LED Street lighting luminaire. The road in this design is secondary road, which lie between two building blocks.

7.6.1 Project Background

In this road lighting project, majority of the roads are secondary roads which fall under Group B category roads. This design is performed using LED Street light luminaires. An LED Street light is an integrated light that uses light emitting diodes (LED) as its light source. These are considered integrated lights because, in most cases, the luminaire and the fixture are not separate parts. In manufacturing, the LED light cluster is sealed on a panel and then assembled to the LED panel with a heat sink to become an integrated lighting fixture. Different designs have been created that incorporate various types of LEDs into a light fixture. Either few high-power LEDs or many low-power LEDs may be used. The shape of the LED Street light depends on several factors, including LED configuration, the heat sink used with the LEDs and aesthetic design preference.

7.6.2 Lighting Layout

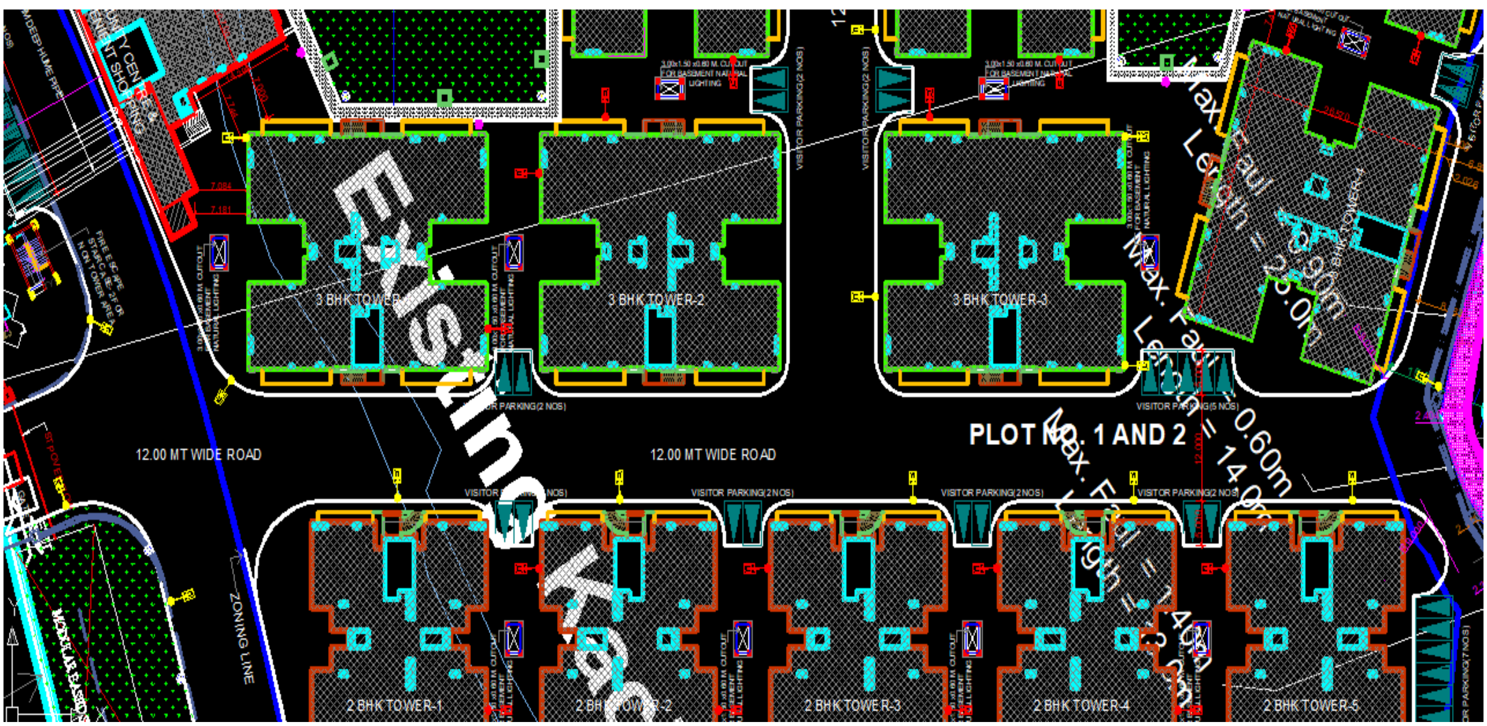


Figure 7.11: *Lighting of a Typical Section*

7.6.3 Lighting Design

The luminaire selected for the design is 70 Watt IP66 Protected LED Street luminaire. This luminaire is having a efficacy of 110 lumen/Watt with aluminium die cast housing with high PC lens diffuser. The luminaire used for the design is shown in *Figure 7.12*. Boom length must be between 0.5 to 2 metres and the boom angle must be between 5° to 15°. Here boom length is taken as 0.8 m and boom angle is taken as 10°. According to BIS standards as shown in *Table 7.1* and *Table 7.2*, this road falls under B1 road lighting class where minimum average lux level to be maintained is 8 lux. Boom angle is taken as 10° in this design so as to achieve the recommended transverse uniformity of 0.2.

Figure 7.12: *70 Watt Road Lighting Luminaire*[1]

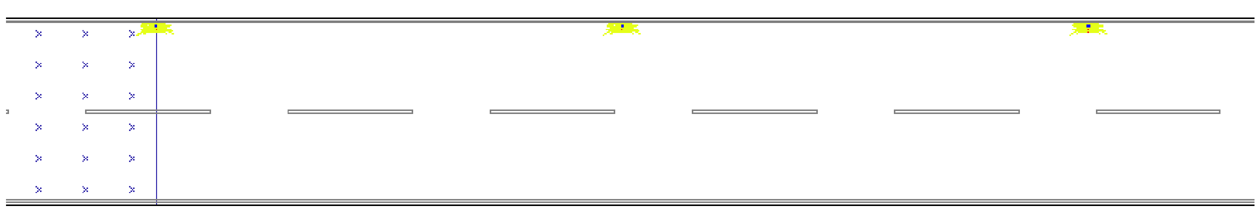
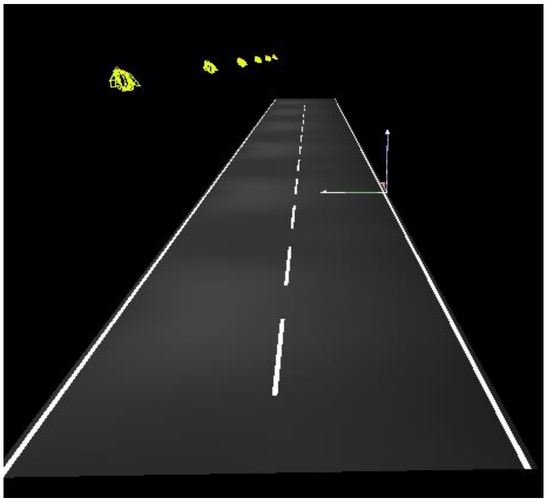


Figure 7.13: *2D Representation of the Road in Dialux 4.13 Software*



' ***Figure 7.14:*** *3D Representation of the Road in Dialux 4.13 Software*

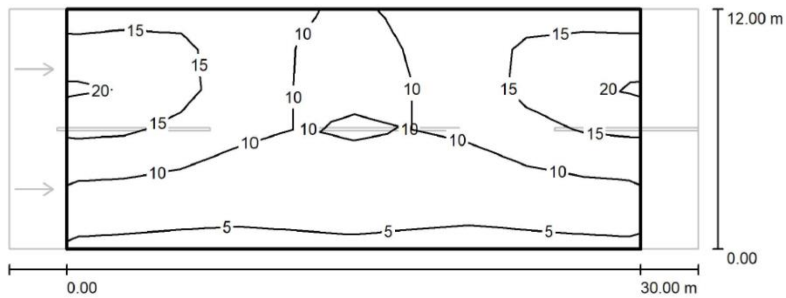


Figure 7.15: *Isolines Representation of Roadway*

7.6.4 Results and Analysis

Table 7.7: *Simulation Details*

Design Parameters	Road Width 12 m	Road Width 9 m
Mounting Height	9 m	9 m
Pole to Pole Spacing	30 m	30 m
Boom Length	0.8 m	0.8 m
Boom Angle	10°	10°
Luminaire Wattage	70 Watt	70 Watt
Luminaire Arrangement	Single Side	Single Side
Average lux level	11 lux	13 lux
Overall Uniformity	0.419	0.643
Transverse Uniformity	0.214	0.378

While planning a road lighting design, certain parameters are needed to take into account like mounting height, pole to pole spacing, boom length, boom angle, luminaire arrangement. This design is performed with single side arrangement. In single side arrangement all the luminaires are on one side of the road. It is recommended only when the width of the road is equal to or less than the mounting height. The illumination on the road surface on the side remote from the luminaires is inevitably lower than that on the same side as the luminaires. This road falls under B1 road lighting class where 8 lux is recommended, so both the 12 m and 9 m wide roads are designed with 70 Watt LED Streetlight.

7.7 Comparative Analysis between Road Lighting Designs

A Comparative analysis between the road lighting designs is given below in *Table 7.8*. In Case Study 1, a solar street lighting design is described and in Case Study 2, the design is performed with LED street light luminiare. In case study1, according to BIS standards as shown in *Table 7.1* and *Table 7.2*, this road falls under A2 road lighting class where minimum average lux level to be maintained is 15 lux. In case study 2, according to BIS standards this road falls under B1 road lighting class where minimum average lux level to be maintained is 8 lux. In both the case studies, boom length is taken 0.8 metres and boom angle is taken as 10° in both case study 1 and case study 2. In both road lighting designs, pole setback or pole distance to roadway is taken as 0.5 metres. Since in case study 1, the design is performed using hybrid solar streetlights, so it can be operated using both ON Grid and OFF grid supply. Whereas in case study 2, the design is performed using normal LED Streetlight, so it can be operated using only ON Grid supply. The Hybrid All-in-one solar streetlight luminaire is having a high system lumen efficacy of 150 lumen/Watt and have a have battery backup capability of 30 Hours without having grid supply. And in case study 2 where LED streetlight is proposed, the fixture is having system lumen efficacy of 120 lumen/Watt.

Table 7.8: *Comparison Details*

Parameters	**Case Study 1**	**Case Study 2**
Design Type	Hybrid Solar LED Street Lighting	LED Street Lighting
Luminaire Used	Hybrid AIO Solar Streetlight	LED Street Light
Luminaire Mounting Height	10 m	9 m
Lumianire Wattage	90 Watt / 120 Watt	70 Watt
Luminaire Arrangement	Twin Central	Single Side
Luminaire Efficacy	150 lumen/Watt	110 lumen/Watt
Average lux level	32	11
Overall Uniformity	0.547	0.419
Transverse Uniformity	0.349	0.214

Chapter 8

Road Lighting Visibility Analysis

8.1 Introduction

Roads make a crucial contribution to economic development and growth and bring important social benefits. They are of vital importance in order to make a nation grow and develop. In addition, providing access to employment, social, health and education services makes a road network crucial in fighting against poverty. Road lighting in most parts of India is in need of upgrades and suffers from inefficient operation and maintenance. In an effort to improve the street lighting situation, some urban local bodies have embarked on energy efficiency projects in street lighting. Road lighting infrastructure in most parts of India is out-dated and its inefficient operation places a heavy burden not only on municipal budgets but also on utility grid capacity and reliability. A well designed, energy efficient lighting system should permit users to travel at night with good visibility, in safety and comfort, while reducing energy use and costs. Conversely, poorly designed road lighting systems can lead to poor visibility or light pollution, or both of the problems. Road lighting has significant impact on road traffic comfort and safety. All participants of the traffic, drivers, and pedestrians should benefit from vision conditions that facilitate the completion of visual tasks.

8.2 Effect of Road Surface

The road surface plays a very important part in road lighting. The same illuminance may result in a different visual scene because of a difference in the road surface. As shown in *Figure 8.1*, the illuminance pattern on the road is the same in each photograph because the road lighting luminaires and their configuration are the same. It is the changes in the reflection properties of the road surface which results in changes in the luminance pattern and, in turn, in differences in brightness. Since brightness is finally determined not by illuminance but by luminance, the visual performance and visual comfort of a road user are directly influenced by the complex pattern of luminances existing in his view of the road ahead. The refection properties of cars, bicycles, pedestrians, obstacles and other objects in the field of view vary widely.

Figure 8.1*: The influence of road surface reflectance on perceived brightness, with illuminances constant:* ***a*** *smooth dry surface;* ***b*** *smooth wet surface;* ***c*** *rough dry surface;* ***d*** *rough wet surface.*[2]

The reflection properties of a road surface cannot be given by a single value. The amount of light reflected from the road surface is dependent on the position of the observer, the position of the point on the surface that the observer is looking at, and the direction of light incidence at that point. The reflection characteristic of a road surface is specified by a set of luminance coefficients. The luminance coefficient (q) is defined as the ratio of the luminance (L) at an element on the road surface to the illuminance (E) at the same element, as given by a single light source.

$$q = \frac{L}{E}$$

The luminance coefficient depends upon the nature of the road surface material and upon the positions of the light source and the observer relative to the element under consideration, as defined by the three angles α, β, and γ as shown below in *Figure 8.2*.

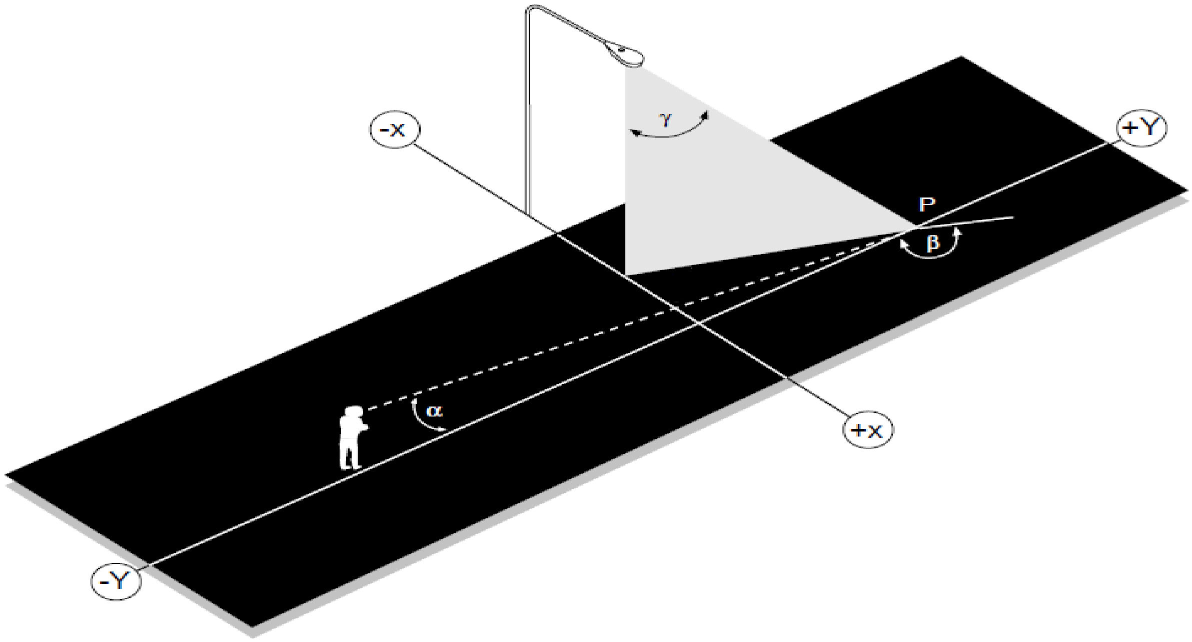


Figure 8.2: *The luminance coefficient (q) of a road surface is dependent upon the angle of observation (α) , the angle between plane of light incidence and plane of observation (β) and the angle of light incidence (γ)* [5]

For the conditions of observation related to motorists, the luminance coefficient of a road surface is dependent mainly on angles, β and γ.

$$q = q\ (\beta\ , \gamma)$$

The complete reflection characteristics of a road surface are represented by table in which the luminance coefficient values are specified for a number of β- γ combinations. The calculation of luminance is made easier by the use of reduced luminance coefficient (r) values in place of q which is represented as follows:

$$r = q \cos^3 \gamma$$

where, r = reduced luminance coefficient of an element on the road surface ($cd/m^2/lux$)

In a reduced luminance coefficient table (also called reflection table or *r*-table), each coordinate of r value are represented as β and tan γ, which is mathematically represented as $r(\beta\ , \tan \gamma)$. The choice of parameters used to describe the reflection characteristics of a road surface is based on the fact that most surfaces are described in terms of two basic qualities, their lightness (degree of grayscale from white to black), and their specularity (shininess). The parameters used to describe these are Q_0(average luminance coefficient) , for the lightness and S1(specular factor) for the specularity. Low Q_0 value represents a dark road surface and high Q_0 value indicates a light surface. Low S1 value represents a diffuse surface (low glossiness) and a high value indicates a more shiny surface (high specularity).The parameter values can be calculated from the *r*-table. The parameters are mathematically represented as follows:

$$Q_0 = \frac{1}{\Omega} \iint_0^{\Omega} q \, d\beta \, d\gamma$$

$$S1 = \frac{r\,(0,2)}{r\,(0,0)}$$

where, Ω = solid angle measured from the point on the surface containing all those directions from which light is incident and contributes to reflection.

Table 8.1: *Classification of Road Surface*[2]

Class	Q_0	Description	Reflectance Mode
R1	0.10	Portland cement concrete road surface. Asphalt road surface with a minimum of 12% of the aggregates composed of artificial brightener (Synopal) aggregates (e.g., labradorite, quartzite).	Mostly Diffuse
R2	0.07	Asphalt road surface with an aggregate composed of a minimum 60% gravel (size greater than 1 cm). Asphalt road surface with 10-15% artificial brightener in aggregate mix.	Mixed (diffuse and specular)
R3	0.07	Asphalt road surface with dark aggregates; rough texture after some months of use (typical highways)	Slightly Specular
R4	0.08	Asphalt road surface with very smooth texture.	Mostly Specular

8.3 Analysis of Visual Performance of Road Users

An observer's visual performance can be assessed using a number of different performance criteria. The visibility of static objects and the visibility of changes in the visual scene and the detection of relative movement are examples of important criteria. In order to be able to draw conclusions as to what lighting quality is needed under different situations, the individual relationships between photometric lighting parameters and the different performance criteria, such as visibility level, small target visibility and relative visual performance, are needed.

8.3.1 Object Contrast

An object has a luminance contrast (C) defined by:

$$C = (L_t - L_b) / L_b$$

Where L_t = Luminance of the target object,

L_b = Luminance of the background of the object

An observer can spot an object in the road or in its background only if the contrast the object creates with the background is above the threshold value of the contrast. If the object's luminance is higher than the luminance of the background the contrast is positive, otherwise the contrast is negative and the object will be seen in silhouette.

8.3.2 Visibility Level

Visibility level, VL, is a measure that indicates how far the visibility of an object of defined size, shape and reflectance, is above the threshold of visibility. The Visibility Level (VL) is defined as the relation of contrast of an object to background, to the object's threshold contrast in threshold conditions, with the same background luminance.

$$VL = C_{actual} / C_{th}$$

Where, C_{actual} = real contrast between the object on the road and its background

C_{th} = contrast threshold needed between the object and its background for it to be just visible.

If the visibility level equals 1 the object is exactly at the threshold of vision as defined for laboratory conditions. If the visibility level equals 3 it is at the threshold of vision taking a field factor of 3 into account corresponding to realistic driving conditions. Negative visibility level indicates that the object is darker than its background as shown in ***Figure 8.3***. Visibility Level is a ratio and has no units.

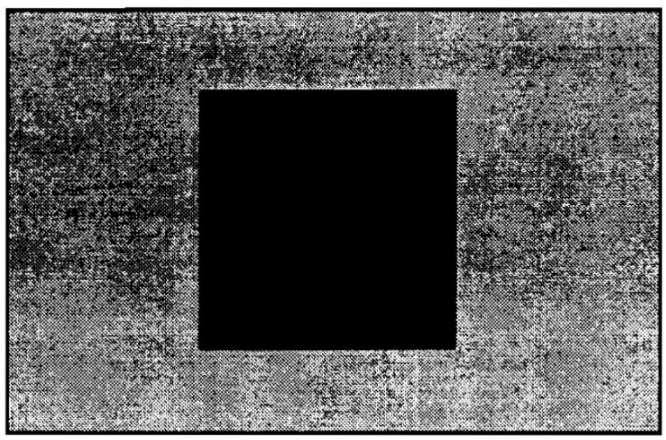


Figure 8.3: *A flat target with negative visibility level* [2]

Table 8.2: *Visibility Assessment Rating Scale* [2]

Visibility Level (VL)	**Visibility Rating**
0	Not Visible
1	Weak Visibility
2	Passive Visibility
3	Satisfactory Visibility
4	Good Visibility

2.3.3 Small Target Visibility

The visibility of a single target has little or no meaning. If the visibilities of many targets symmetrically arranged over the roadway are calculated, their combined visibility has great importance. The American Standard Practice for Roadway Lighting (RP-8-00) includes three criteria for designing continuous lighting systems for roadways. These are illuminance, luminance, and Small Target Visibility (STV). Small Target Visibility is a visibility metric, which is used to determine the visibility of an array of targets on the roadway.

The method of calculating STV described in the American National Standard Practice for Roadway Lighting makes it possible to assess visibility in a relatively simple, step-by-step method. This method, however, has been created for design purposes based on American standards. The visibility criterion is not used for design purposes in Europe. According to the CIE standards, the direct takeover of STV as employed in USA for European requirements and recommendations is a difficult task. Despite the fact that the visibility criterion is not taken into account in Europe for road design, CIE presented suggested values for Visibility Level (VL) for illumination classes from M1 to M5. There are several differences between the American and European design requirements and recommendations.

For computation of visibility level, the target luminance and background luminance of the object should have to be measured. Target luminance (L_t) is calculated for point at the centre of target. Background luminance (L_b) is calculated as the average value of two background luminance, L_{b1} and L_{b2}. Background luminance (L_{b1}) is calculated at a point adjacent to the centre of the bottom of the target, that is, the target's position on the roadway. Background luminance (L_{b2}) is calculated at a point 11.77 meters beyond the target, at a point on a line projected from the observer's point of view through the point at the centre of the top of the target.

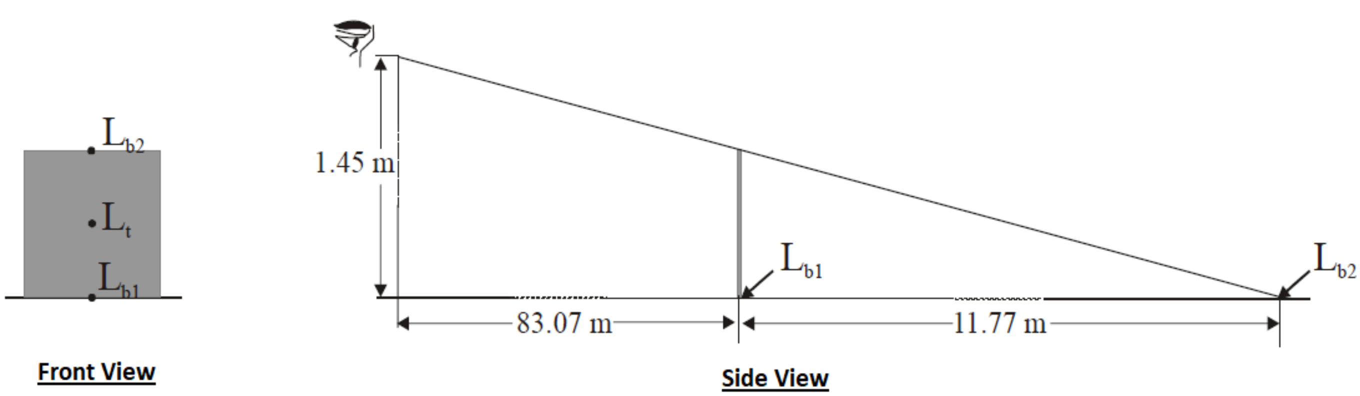


Figure 8.4: *Determination of target luminance and background luminance* [6]

Mathematically, background luminance (L_b) is defined as:

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

Where, L_{b1} = Background luminance at the lower boundary of the target as shown in Figure 2

L_{b2} = Background luminance at the upper boundary of the target as shown in Figure 2

According to ANSI/IESNA: RP-8-00, for luminance measurements, there should be two grid lines per lane located on quarter (1/4) of the width of the lane from the edge of each lane. In the longitudinal direction the distance between grid lines shall be one tenth (1/10) of the spacing between luminaires, or 5 meters, whichever is smaller. The starting point for grid lines should not be located directly under the luminaire, but the grid should start at a point one half (1/2) of the grid cell size from the luminaire. The area of all grid cells is identical. The observer moves with points parallel to the roadway [observer height = 1.45 meters; line of sight = 1° down over a longitudinal distance of 83 meters]. The installation should include a minimum of three luminaire cycles beyond the test area and one cycle in front of the test area.

Table 8.3: *Differences in observer and target specifications* [6]

PARAMETERS	**AMERICAN (IESNA) RECOMMENDATIONS (RP-8-00 : 2000)**	**EUROPEAN (CIE) RECOMMENDATIONS (CIE 140 : 2000)**
Size of the object	Flat Target of 18 cm by 18 cm	Flat Target of 20 cm by 20 cm
Reflectance of the object	50 %	20%
Observation Height	1.45 m	1.50 m
Distance of observer from the target	83.07 m	60 m
Observer Position	Varies with the target location	Fixed
Observer Age	60 Years	23 Years

Besides the comparisons shown above, there are also certain differences in the computational grid. According to American standards, the calculation field is limited by placing two consecutive luminaires in the same row. The location of calculation points in longitudinal direction is equal to (1/10) of the distance between luminaires, but not more than 5 m. The lines of the first and last calculation points in longitudinal direction to the road are located halfway between points in this direction. Crosswise, the points are located on each traffic lane, at a quarter of the width of the lane from each border of the traffic lane. Now according to European standards, the computational grid is also limited to two consecutive luminaires in one line, and the location of calculation points in longitudinal direction is equal to (1/10) of the distance between luminaires, but not more than 3 m. The first and the last calculation points in longitudinal direction to the road are located halfway between points in this direction. Crosswise, the distance between calculation points is (1/3) of the width of the roadway.

8.3.4 Visibility Level Calculation Procedure

Step 1: Determination of Adaptation Luminance (L_a)

In the case of disability glare, the adaptation luminance (L_a) around location of the target on the retina is composed of the background luminance (L_b) and veiling luminance (L_v), which is given by:

$$L_a = L_b + L_v$$

Without considering the disability glare in road lighting, the adaptation luminance is equivalent to the background luminance.

Mathematically neglected glare, adaptation luminance is expressed as:

$$L_a = L_b$$

Step 2: Determination of sensitivity of the visual system- Functions ‘F’ and ‘L’

If $L_a \geq 0.6$

$$F = [\log_{10}(4.2841.L_a^{0.1556}) + (0.1684.L_a^{0.5867})]^2$$

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

If $L_a \geq 0.00418$ and $L_a < 0.6$

$$F = 10^{\left\{2\cdot\left[\left(0.0866\cdot(\log_{10}(L_a))^2 + (0.3372\cdot\log_{10}(L_a)) - 0.072\right)\right]\right\}}$$

$$L = 10^{\left[2\cdot(0.319\cdot\log_{10}(L_a) - 1.256)\right]}$$

If $L_a < 0.00418$

$$F = 10^{(0.346\cdot(\log_{10}(L_a)) + 0.056)}$$

$$L = 10^{\left[0.0454\cdot(\log_{10}(L_a))^2 + 1.055\cdot\log_{10}(L_a) - 1.782\right]}$$

Step 3: Calculation of functions B, C, AA, AL, AZ and DL_1

$$B = \log_{10}(A) + 0.523$$

Where, A = Angular size of object = 7.45 minutes = 0.124°

$$C = \log_{10}(L_a) + 6$$

$$AA = 0.360 - \frac{0.0972\cdot B^2}{B^2 - (2.513\cdot B) + 2.789}$$

$$AL = 0.355 - \frac{0.1217\cdot C^2}{C^2 - 10.40\cdot C + 52.28}$$

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

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

Step 4: Determination of Negative Contrast Factor (FCP)

Negative Contrast Factor (FCP) is defined as the ratio of luminance difference threshold for negative contrast to luminance difference threshold for positive contrast. Calculation of FCP depends upon two functions: M and TGB.

If $-2.4 < \log_{10}(L_a) < -1$

$$M = 10^{-10^{-\left[0.075\cdot(\log_{10}(L_a)+1)^2 + 0.0245\right]}}$$

If $\log_{10}(L_a) \geq -1$

$$M = 10^{-10^{-[0.125\cdot(\log_{10}(L_a)+1)^2 + 0.0245]}}$$

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

$$FCP = 1 - \left[\frac{(M)\cdot(A)^{TGB}}{1.2\cdot(DL_1)(AZ+2)}\right]$$

If $\log_{10}(L_a) \leq -2.4$

$$FCP = 0.5$$

Step 4: Determination of Age Factor (AF)

If age= 23 AF =1

If $23 < \text{age} \leq 64$ AF = $\left[\dfrac{(\text{age}-19)^2}{2160}\right] + 0.99$

Step 5: Calculation of functions DL_2, DL_3, DL_4

$$DL_2 = DL_1 \cdot \frac{AZ + t}{t}$$

Where t = Observation time = 0.2 seconds

$$DL_3 = DL_2 \, . \, AF$$

If $L_t > L_b$ $DL_4 = DL_3$

If $L_t < L_b$ $DL_4 = DL_3 \, . \, FCP$

Step 6: Computation of Visibility Level (VL)

$$VL = \frac{L_t - L_b}{DL_4}$$

Table 8.4: *Recommended STV Values* [2]

Road and Pedestrian Conflict Area		**STV Criteria**	**Luminance Criteria**		
Road	Pedestrian Conflict Area	**Weighted Average Visibility Level**	**L_{av} (cd/m^2) Median <7.3 m**	**L_{av} (cd/m^2) Median ≥ 7.3 m**	**Uniformity Ratio (L_{max} / L_{min}) (Max)**
Freeway Class A		3.2	0.5	0.4	6.0
Freeway Class B		2.6	0.4	0.3	6.0
Expressway		3.8	0.5	0.4	6.0
Major	High	4.9	1.0	0.8	6.0
	Medium	4.0	0.8	0.7	6.0
	Low	3.2	0.6	0.6	6.0
Collector	High	3.8	0.6	0.5	6.0
	Medium	3.2	0.5	0.4	6.0
	Low	2.7	0.4	0.4	6.0
Local	High	2.7	0.5	0.4	10.0
	Medium	2.2	0.4	0.3	10.0
	Low	1.6	0.3	0.3	10.0

8.4 Experiments Performed

This analysis follows an experiment carried out at the road beside department of Electrical Engineering, Jadavpur University. The experiment is conducted within a span of road lighting luminaires. The road width is measured with the help of a distance meter and the pole to pole spacing, pole setback are measured with the help of a measuring tape (0-30 m). Picture of the road and the layout plan of the road are illustrated in *Figure 8.5* and *Figure 8.6* respectively. Then simulation of the road is conducted in Dialux 4.13 software and the photometric results are recorded.

Figure 8.5: *Road beside Department of Electrical Engineering, Jadavpur University*

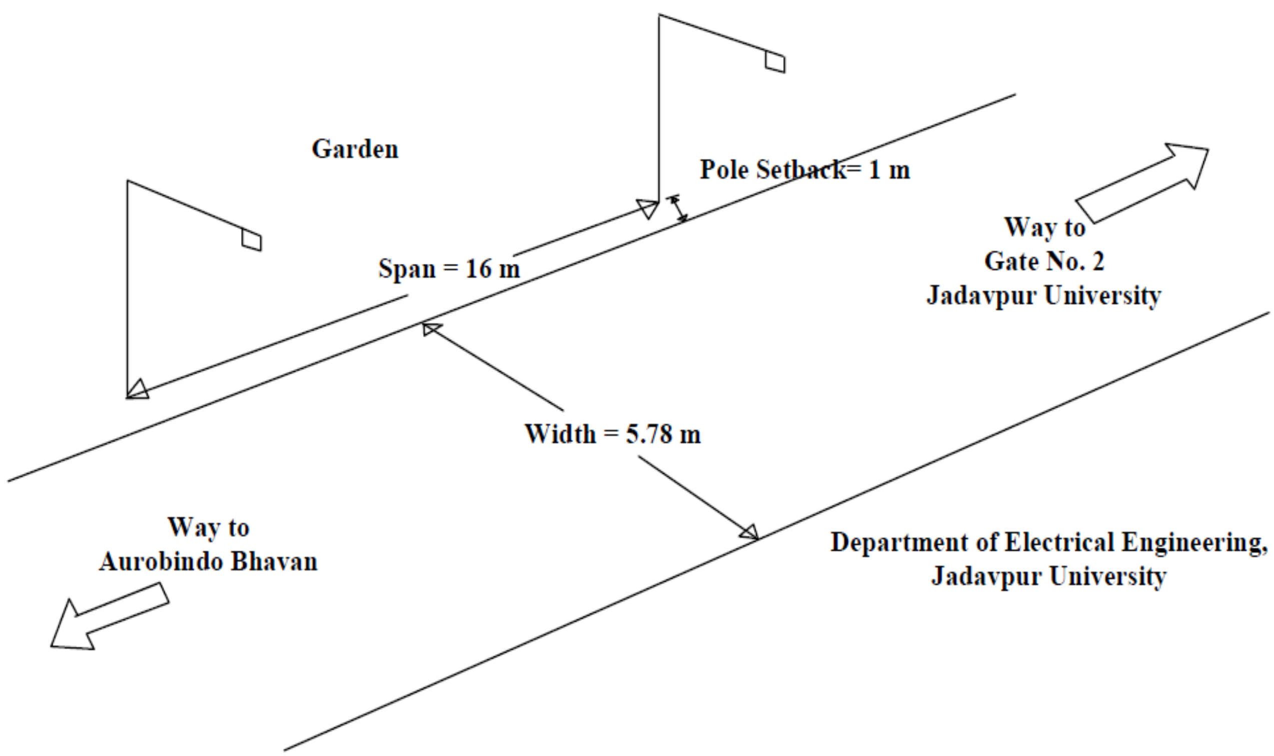


Figure 8.6: *Layout Plan of the Road beside Department of Electrical Engineering, Jadavpur University*

8.4.1 Simulation Parameters

Table 8.5: *Road and Luminaire Specifications*

Parameters	Values
Road Width	5.78 m **[Measured]**
Pole to Pole Spacing	16 m **[Measured]**
Pole Setback	1 m **[Measured]**
Arrangement Type	Single Side Arrangement
Luminaire Type	Roadway 150 Watt LED Luminaire with Protector
Boom Length	1.5 m
Boom Angle	0°
Overhang	0.5 m

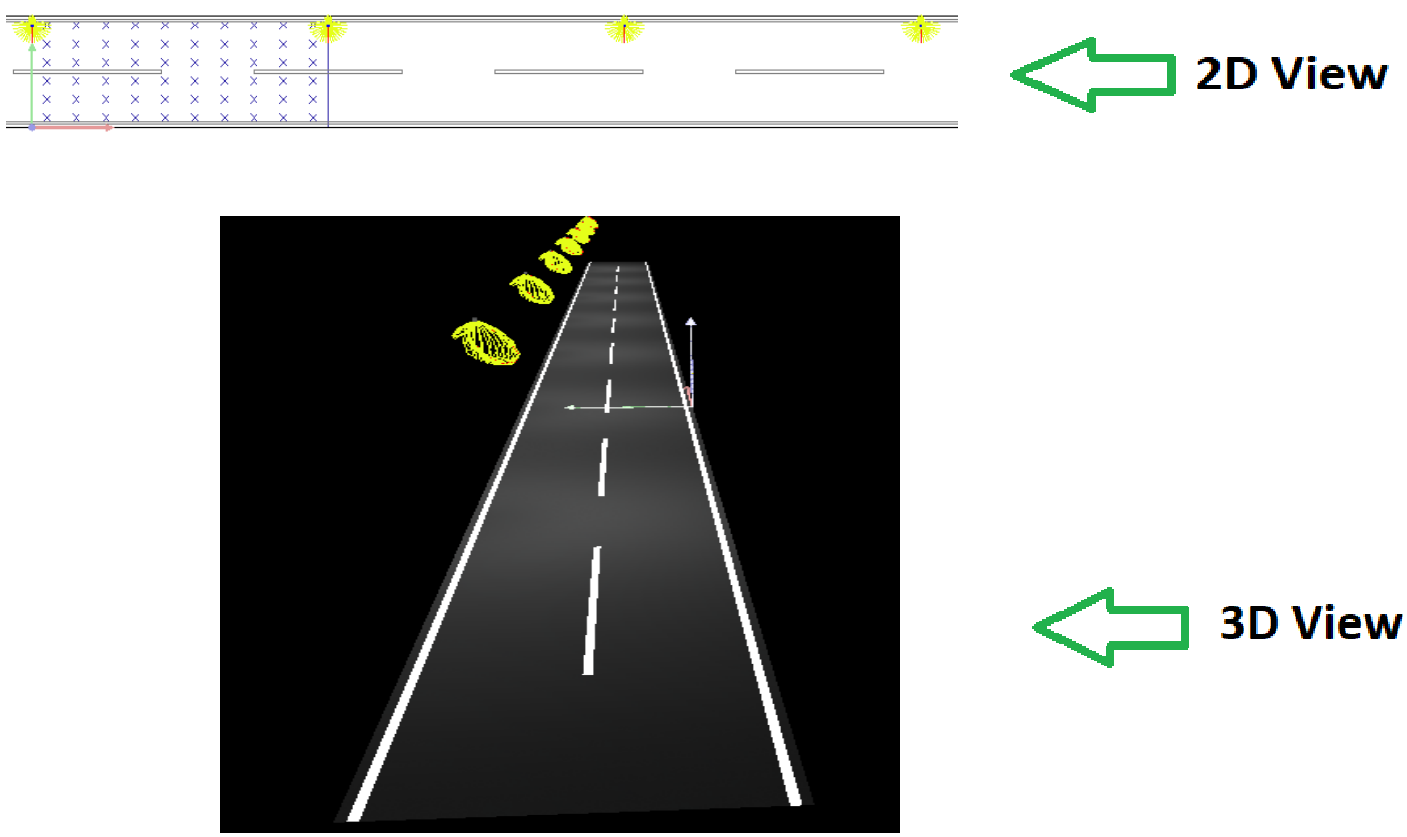


Figure 8.7: *Light Distribution Display of the Luminaire in Dialux Software*

__Table 8.6:__ Luminaire Details

Luminaire Used	Lumimaire Wattage (Measured)	Duty Cycle (Cool White)	Duty Cycle (Warm White)	Lamp Lumen (lm)	Luminaire Lumen (lm)	Light Output Ratio LOR
100 lux ON	35 W	0.00%	21.70%	6500	2167	33%
100 lux ON Edit	35 W	0.00%	21.70%	6500	6500	100%
100 lux ON3	35 W	18.75%	10.60%	6492	2164	33%
100 lux ON3 Edt	35 W	18.75%	10.60%	6492	6492	100%
100 lux ON5	35 W	31.25%	4.40%	6461	2154	33%
100 lux ON5 Edit	35 W	31.25%	4.40%	6460	6460	100%
100 lux ON18	35 W	26.50%	6.25%	6327	2109	33%
100 lux ON18 Edit	35 W	26.50%	6.25%	6326	6326	100%
100 lux ON19	35 W	14.16%	12.50%	6360	2120	33%
100 lux ON19 Edit	35 W	14.16%	12.50%	6360	6360	100%
200 lux ON Edit	60 W	0.00%	48.10%	12674	12674	100%
200 lux ON Edit	60 W	0.00%	48.10%	12674	12674	100%
200 lux ON8 Edit	60 W	50.00%	19.14%	12344	12344	100%
200 lux ON15 Edit	60 W	93.75%	1.56%	10666	10666	100%
200 lux ON17 Edit	60 W	79.20%	6.25%	11740	11740	100%
200 lux ON20 Edit	60 W	37.10%	25.00%	12466	12466	100%
200 lux ON23 Edit	60 W	6.15%	43.75%	12086	12086	100%
300 lux ON Edit	90 W	0.00 %	65.1 %	16554	16554	100%
400 lux ON Edit	110 W	18.75%	99.02%	22434	22434	100%
400 lux ON7 Edit	110 W	62.50%	65.33%	20660	20660	100%
400 lux ON13 Edit	110 W	100.00%	49.50%	20864	20864	100%
400 lux ON17 Edit	110 W	86.33%	56.25%	21123	21123	100%
400 lux ON21 Edit	110 W	42.58%	81.25%	21337	21337	100%
400 lux ON24 Edt	110 W	16.60%	100.00%	21395	21395	100%
500 lux ON Edt	130 W	75.00%	95.80%	26632	26632	100%
500 lux ON2 Edt	130 W	87.50%	88.38%	25439	25439	100%
500 lux ON4 Edt	130 W	100.00%	80.86%	25305	25305	100%
500 lux ON17 Edt	130 W	88.87%	87.50%	25180	25180	100%

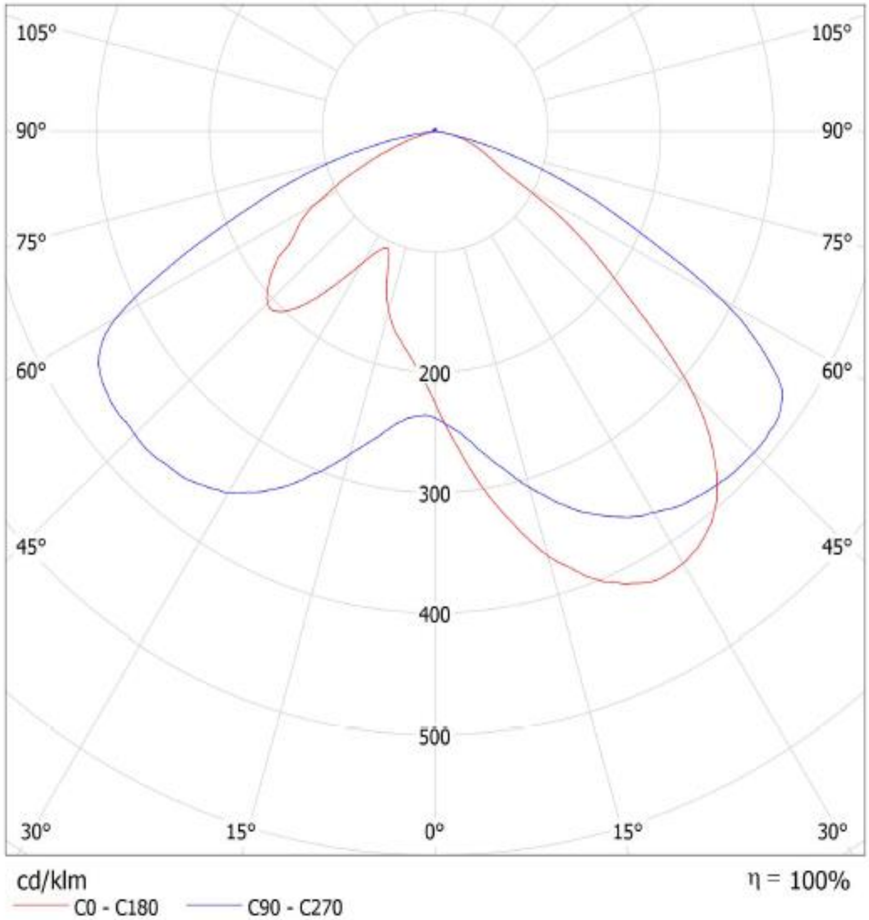


Figure 8.8: *Light Distribution Curve (Polar)*

Using the luminaire IES files as shown in *Table 8.6*, the simulation results are recorded, with two types of surfaces, concrete surface and bitumen surface. The obtained results are shown in *Table 8.7* and *Table 8.8*.

8.4.2 Observation Table

Table 8.7: *Luminance Based Results*

Luminaire Used	Road Surface Type	Mounting Height (m)	Average Luminance L_{av} (cd/m^2)		Overall Uniformity U_0		Longitudinal Uniformity U_L		Threshold Increment TI (%)		Surround Ratio SR	
			Output Values	Recommended Value (Minimum) [According to Lighting class ME4a]	Output Values	Recommended Value (Minimum)	Output Values	Recommended Value (Minimum)	Output Values	Recommended Value (Maximum)	Output Values	Recommended Value (Minimum)
100 lux ON	Bitumen	6.5 m	0.51	0.75	0.47	0.4	0.8	0.6	4	15	0.54	0.5
100 lux ON	Concrete	6.5 m	0.81	0.75	0.54	0.4	0.61	0.6	3	15	0.54	0.5
100 lux ON Edit	Bitumen	6.5 m	1.52	0.75	0.47	0.4	0.8	0.6	5	15	0.54	0.5
100 lux ON Edit	Concrete	6.5 m	2.42	0.75	0.54	0.4	0.61	0.6	3	15	0.54	0.5
100 lux ON3	Bitumen	6.5 m	0.51	0.75	0.47	0.4	0.79	0.6	4	15	0.53	0.5
100 lux ON3	Concrete	6.5 m	0.81	0.75	0.54	0.4	0.6	0.6	3	15	0.53	0.5
100 lux ON3 Edt	Bitumen	6.5 m	1.53	0.75	0.47	0.4	0.79	0.6	5	15	0.53	0.5
100 lux ON3 Edt	Concrete	6.5 m	2.43	0.75	0.54	0.4	0.6	0.6	3	15	0.53	0.5
100 lux ON5	Bitumen	6.5 m	0.51	0.75	0.46	0.4	0.79	0.6	4	15	0.53	0.5
100 lux ON5	Concrete	6.5 m	0.81	0.75	0.54	0.4	0.6	0.6	3	15	0.53	0.5
100 lux ON5 Edit	Bitumen	6.5 m	1.53	0.75	0.46	0.4	0.79	0.6	5	15	0.53	0.5
100 lux ON5 Edit	Concrete	6.5 m	2.42	0.75	0.54	0.4	0.6	0.6	4	15	0.53	0.5
100 lux ON18	Bitumen	6.5 m	0.49	0.75	0.47	0.4	0.78	0.6	4	15	0.53	0.5
100 lux ON18	Concrete	6.5 m	0.79	0.75	0.55	0.4	0.6	0.6	3	15	0.53	0.5
100 lux ON18 Edit	Bitumen	6.5 m	1.47	0.75	0.47	0.4	0.78	0.6	5	15	0.53	0.5
100 lux ON18 Edit	Concrete	6.5 m	2.36	0.75	0.55	0.4	0.6	0.6	3	15	0.53	0.5
100 lux ON19	Bitumen	6.5 m	0.5	0.75	0.47	0.4	0.79	0.6	4	15	0.53	0.5
100 lux ON19	Concrete	6.5 m	0.79	0.75	0.54	0.4	0.6	0.6	3	15	0.53	0.5
100 lux ON19 Edit	Bitumen	6.5 m	1.49	0.75	0.47	0.4	0.79	0.6	5	15	0.53	0.5
100 lux ON19 Edit	Concrete	6.5 m	2.38	0.75	0.54	0.4	0.6	0.6	3	15	0.53	0.5
200 lux ON Edit	Bitumen	6.5 m	2.8	0.75	0.49	0.4	0.77	0.6	5	15	0.54	0.5
200 lux ON Edit	Concrete	6.5 m	4.63	0.75	0.55	0.4	0.58	0.6	3	15	0.54	0.5
200 lux ON8 Edit	Bitumen	6.5 m	2.93	0.75	0.47	0.4	0.79	0.6	6	15	0.52	0.5
200 lux ON8 Edit	Concrete	6.5 m	4.66	0.75	0.54	0.4	0.61	0.6	4	15	0.52	0.5
200 lux ON15 Edit	Bitumen	6.5 m	2.5	0.75	0.47	0.4	0.77	0.6	5	15	0.52	0.5

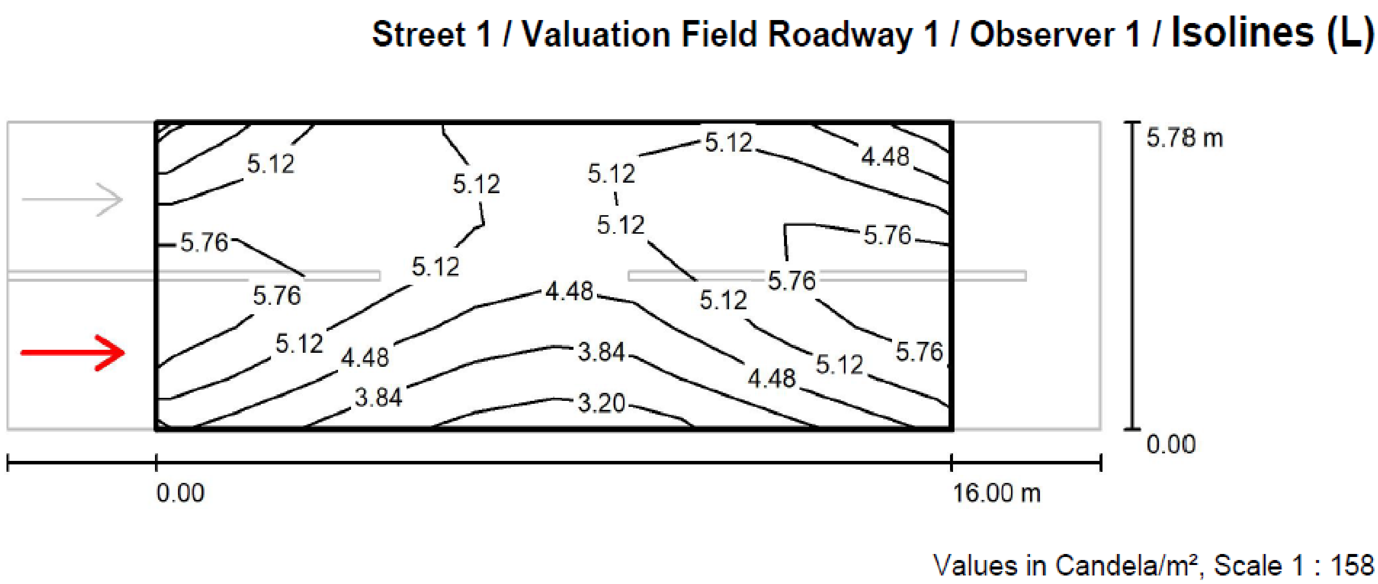
Luminaire Used	Road Surface Type	Mounting Height (m)	Average Luminance L_{av} (cd/m^2)		Overall Uniformity U_0		Longitudinal Uniformity U_L		Threshold Increment TI (%)		Surround Ratio SR	
			Output Values	Recommended Value (Minimum) [According to Lighting class ME4a]	Output Values	Recommended Value (Minimum)	Output Values	Recommended Value (Minimum)	Output Values	Recommended Value (Maximum)	Output Values	Recommended Value (Minimum)
200 lux ON15 Edit	Concrete	6.5 m	4.02	0.75	0.54	0.4	0.59	0.6	4	15	0.52	0.5
200 lux ON17 Edit	Bitumen	6.5 m	2.75	0.75	0.47	0.4	0.78	0.6	5	15	0.52	0.5
200 lux ON17 Edit	Concrete	6.5 m	4.41	0.75	0.54	0.4	0.6	0.6	4	15	0.52	0.5
200 lux ON20 Edit	Bitumen	6.5 m	2.82	0.75	0.49	0.4	0.78	0.6	5	15	0.53	0.5
200 lux ON20 Edit	Concrete	6.5 m	4.63	0.75	0.55	0.4	0.57	0.6	3	15	0.53	0.5
200 lux ON23 Edit	Bitumen	6.5 m	2.77	0.75	0.48	0.4	0.79	0.6	5	15	0.53	0.5
200 lux ON23 Edit	Concrete	6.5 m	4.5	0.75	0.55	0.4	0.61	0.6	3	15	0.53	0.5
300 lux ON Edit	Bitumen	6.5m	3.78	0.75	0.48	0.4	0.78	0.6	5	15	0.53	0.5
300 lux ON Edit	Concrete	6.5m	6.15	0.75	0.55	0.4	0.61	0.6	Nil	15	0.53	0.5
400 lux ON Edit	Bitumen	6.5 m	5.32	0.75	0.47	0.4	0.76	0.6	Nil	15	0.53	0.5
400 lux ON Edit	Concrete	6.5 m	8.48	0.75	0.54	0.4	0.62	0.6	Nil	15	0.53	0.5
400 lux ON7 Edit	Bitumen	6.5 m	4.75	0.75	0.48	0.4	0.79	0.6	6	15	0.53	0.5
400 lux ON7 Edit	Concrete	6.5 m	7.69	0.75	0.55	0.4	0.6	0.6	Nil	15	0.53	0.5
400 lux ON13 Edit	Bitumen	6.5 m	4.82	0.75	0.48	0.4	0.79	0.6	6	15	0.53	0.5
400 lux ON13 Edit	Concrete	6.5 m	7.79	0.75	0.55	0.4	0.6	0.6	Nil	15	0.53	0.5
400 lux ON17 Edit	Bitumen	6.5 m	4.9	0.75	0.48	0.4	0.79	0.6	6	15	0.53	0.5
400 lux ON17 Edit	Concrete	6.5 m	7.9	0.75	0.55	0.4	0.61	0.6	Nil	15	0.53	0.5
400 lux ON21 Edit	Bitumen	6.5 m	4.9	0.75	0.48	0.4	0.79	0.6	6	15	0.53	0.5
400 lux ON21 Edit	Concrete	6.5 m	7.94	0.75	0.55	0.4	0.61	0.6	Nil	15	0.53	0.5
400 lux ON24 Edt	Bitumen	6.5 m	4.89	0.75	0.48	0.4	0.79	0.6	5	15	0.53	0.5
400 lux ON24 Edt	Concrete	6.5 m	7.96	0.75	0.55	0.4	0.61	0.6	Nil	15	0.53	0.5
500 lux ON Edt	Bitumen	6.5 m	6.35	0.75	0.47	0.4	0.77	0.6	Nil	15	0.52	0.5
500 lux ON Edt	Concrete	6.5 m	10.0	0.75	0.54	0.4	0.62	0.6	Nil	15	0.52	0.5
500 lux ON2 Edt	Bitumen	6.5 m	5.9	0.75	0.48	0.4	0.79	0.6	Nil	15	0.53	0.5
500 lux ON2 Edt	Concrete	6.5 m	9.52	0.75	0.55	0.4	0.61	0.6	Nil	15	0.53	0.5
500 lux ON4 Edt	Bitumen	6.5 m	5.91	0.75	0.47	0.4	0.79	0.6	Nil	15	0.53	0.5
500 lux ON4 Edt	Concrete	6.5 m	9.49	0.75	0.54	0.4	0.61	0.6	Nil	15	0.53	0.5
500 lux ON17 Edt	Bitumen	6.5 m	5.8	0.75	0.48	0.4	0.79	0.6	Nil	15	0.53	0.5
500 lux ON17 Edt	Concrete	6.5 m	9.39	0.75	0.55	0.4	0.6	0.6	Nil	15	0.53	0.5

Table 8.8: *Illumnijnance Based Results*

Luminaire Used	Road Surface Type	Mounting Height (m)	Average Illuminace E_{av} (lux)		Overall Uniformity (Emin/Eav)		Transverse Uniformity (Emin/Emax)	
			Output Values	Recommended Value (Minimum)	Output Values	Recommended Value (Minimum)	Output Values	Recommended Value (Minimum)
100 lux ON	Bitumen	6.5 m	9.68	4	0.512	0.3	0.336	0.2
100 lux ON	Concrete	6.5 m	9.68	4	0.512	0.3	0.336	0.2
100 lux ON Edit	Bitumen	6.5 m	29	4	0.512	0.3	0.336	0.2
100 lux ON Edit	Concrete	6.5 m	29	4	0.512	0.3	0.336	0.2
100 lux ON3	Bitumen	6.5 m	9.66	4	0.513	0.3	0.337	0.2
100 lux ON3	Concrete	6.5 m	9.66	4	0.513	0.3	0.337	0.2
100 lux ON3 Edt	Bitumen	6.5 m	29	4	0.513	0.3	0.337	0.2
100 lux ON3 Edt	Concrete	6.5 m	29	4	0.513	0.3	0.337	0.2
100 lux ON5	Bitumen	6.5 m	9.61	4	0.514	0.3	0.336	0.2
100 lux ON5	Concrete	6.5 m	9.61	4	0.514	0.3	0.336	0.2
100 lux ON5 Edit	Bitumen	6.5 m	29	4	0.514	0.3	0.336	0.2
100 lux ON5 Edit	Concrete	6.5 m	29	4	0.514	0.3	0.336	0.2
100 lux ON18	Bitumen	6.5 m	9.4	4	0.519	0.3	0.342	0.2
100 lux ON18	Concrete	6.5 m	9.4	4	0.519	0.3	0.342	0.2
100 lux ON18 Edit	Bitumen	6.5 m	28	4	0.519	0.3	0.342	0.2
100 lux ON18 Edit	Concrete	6.5 m	28	4	0.519	0.3	0.342	0.2
100 lux ON19	Bitumen	6.5 m	9.46	4	0.513	0.3	0.336	0.2
100 lux ON19	Concrete	6.5 m	9.46	4	0.513	0.3	0.336	0.2
100 lux ON19 Edit	Bitumen	6.5 m	28	4	0.514	0.3	0.336	0.2
100 lux ON19 Edit	Concrete	6.5 m	28	4	0.514	0.3	0.336	0.2
200 lux ON Edit	Bitumen	6.5 m	56	4	0.514	0.3	0.324	0.2
200 lux ON Edit	Concrete	6.5 m	56	4	0.514	0.3	0.324	0.2
200 lux ON8 Edit	Bitumen	6.5 m	55	4	0.513	0.3	0.342	0.2
200 lux ON8 Edit	Concrete	6.5 m	55	4	0.513	0.3	0.342	0.2
200 lux ON15 Edit	Bitumen	6.5 m	48	4	0.511	0.3	0.34	0.2
200 lux ON15 Edit	Concrete	6.5 m	48	4	0.511	0.3	0.34	0.2
200 lux ON17 Edit	Bitumen	6.5 m	52	4	0.517	0.3	0.343	0.2
200 lux ON17 Edit	Concrete	6.5 m	52	4	0.517	0.3	0.343	0.2
200 lux ON20 Edit	Bitumen	6.5 m	55	4	0.517	0.3	0.325	0.2

Luminaire Used	Road Surface Type	Mounting Height (m)	Average Illuminace E_{av} (lux)		Overall Uniformity (Emin/Eav)		Transverse Uniformity (Emin/Emax)	
			Output Values	Recommended Value (Minimum)	Output Values	Recommended Value (Minimum)	Output Values	Recommended Value (Minimum)
200 lux ON20 Edit	Concrete	6.5 m	55	4	0.517	0.3	0.325	0.2
200 lux ON23 Edit	Bitumen	6.5 m	54	4	0.519	0.3	0.341	0.2
200 lux ON23 Edit	Concrete	6.5 m	54	4	0.519	0.3	0.341	0.2
300 lux ON Edit	Bitumen	6.5m	74	4	0.52	0.3	0.342	0.2
300 lux ON Edit	Concrete	6.5m	74	4	0.52	0.3	0.342	0.2
400 lux ON Edit	Bitumen	6.5 m	101	4	0.508	0.3	0.342	0.2
400 lux ON Edit	Concrete	6.5 m	101	4	0.508	0.3	0.342	0.2
400 lux ON7 Edit	Bitumen	6.5 m	92	4	0.519	0.3	0.341	0.2
400 lux ON7 Edit	Concrete	6.5 m	92	4	0.519	0.3	0.341	0.2
400 lux ON13 Edit	Bitumen	6.5 m	93	4	0.519	0.3	0.342	0.2
400 lux ON13 Edit	Concrete	6.5 m	93	4	0.519	0.3	0.342	0.2
400 lux ON17 Edit	Bitumen	6.5 m	94	4	0.518	0.3	0.342	0.2
400 lux ON17 Edit	Concrete	6.5 m	94	4	0.518	0.3	0.342	0.2
400 lux ON21 Edit	Bitumen	6.5 m	95	4	0.52	0.3	0.342	0.2
400 lux ON21 Edit	Concrete	6.5 m	95	4	0.52	0.3	0.342	0.2
400 lux ON24 Edt	Bitumen	6.5 m	96	4	0.519	0.3	0.342	0.2
400 lux ON24 Edt	Concrete	6.5 m	96	4	0.519	0.3	0.342	0.2
500 lux ON Edt	Bitumen	6.5 m	120	4	0.508	0.3	0.341	0.2
500 lux ON Edt	Concrete	6.5 m	120	4	0.508	0.3	0.341	0.2
500 lux ON2 Edt	Bitumen	6.5 m	114	4	0.517	0.3	0.341	0.2
500 lux ON2 Edt	Concrete	6.5 m	114	4	0.517	0.3	0.341	0.2
500 lux ON4 Edt	Bitumen	6.5 m	113	4	0.516	0.3	0.339	0.2
500 lux ON4 Edt	Concrete	6.5 m	113	4	0.516	0.3	0.339	0.2
500 lux ON17 Edt	Bitumen	6.5 m	112	4	0.518	0.3	0.341	0.2
500 lux ON17 Edt	Concrete	6.5 m	112	4	0.518	0.3	0.341	0.2

It can be observed from the observation tables, as shown in *Table 8.7* and *Table 8.8*, that the values of average luminance in concrete road surface are greater compared to bitumen road surface. Also by using the edited IES files, where the Light Output Ratio (LOR) is improved from 33% to 100%, the obtained average luminance values are almost 3 times greater compared to the values obtained from using unedited IES files.



Grid: 10 x 6 Points
Observer Position: (-60.000 m, 1.445 m, 1.500 m)
tarmac: R1, q0: 0.100

	L_{av} [cd/m²]	U0	Ul	TI [%]
Calculated values:	4.97	0.62	0.65	2
Required values according to class ME4a:	≥ 0.75	≥ 0.40	≥ 0.60	≤ 15
Fulfilled/Not fulfilled:	✓	✓	✓	✓

Figure 8.9: *Isoline diagram for a 23 year old observer positioned at a distance of 60m from the road with observation height of 1.5m*

8.4.3 Graphical Representation

Based on the photometric results shown earlier, the variations in the values of average luminance are displayed in the form of a graphical representation, as shown below in *Figure 8.10*. With the luminaire IES files as shown in *Table 8.6*, the simulation results are recorded, with two types of surfaces, concrete surface and bitumen surface. The obtained results are shown in *Table 8.7* and *Table 8.8*. In the graph shown below, the data collected using the IES flies are plotted with a comparative analysis. X-Axis represents the lux level of IES files and Y- Axis represents the luminance data collected from simulation of these IES files from bitumen road surface and concrete road surface. This represents that road having concrete surface have greater luminance value compared to those of the bitumen surface.

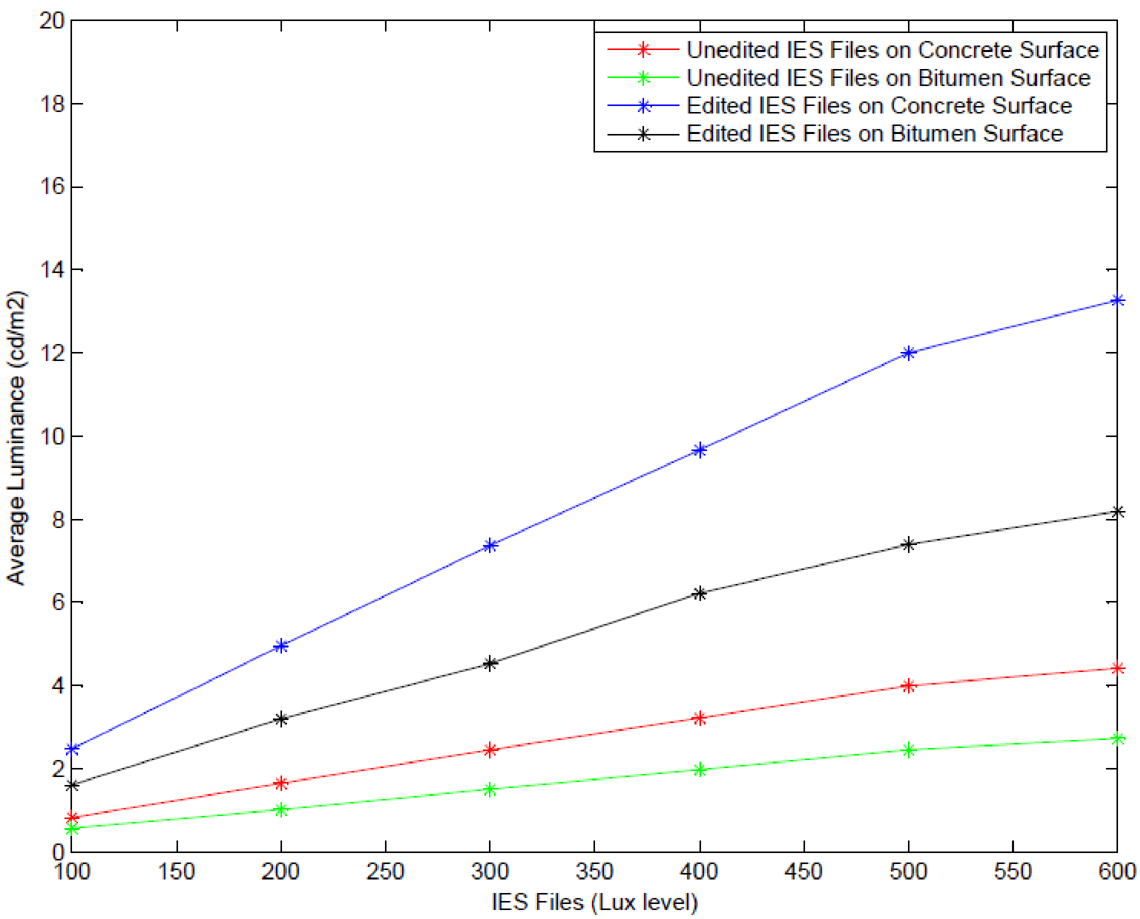


Figure 8.10*: Graphical representation of variation of Average Luminance*

Chapter 9

Conclusion

9.1 Conclusion

Lighting influences human health and nature. Effective lighting decreases depression and improve mood, energy, and alertness. Lighting is not just a high priority when considering any indoor or outdoor space design, but it should also be a high return, low-risk investment. This thesis primarily explained the role and need of efficient lighting systems. Efficient lighting reduces energy wastage and light pollution. End users and consumers do not always have access to accurate and reliable information on what represents a safe, reliable and efficient lighting system. Economic development over the last few years has shown a major boost in the demand of lighting equipment. The average illuminance over an appropriate area on an appropriate plane is the most common quantitative criterion used for the amount of light to be provided, with visual task performance as the primary determinant. This thesis also contains some refurbishment projects. These designs explain how modern lighting design techniques can be used for betterment in terms of design, lighting and economy. Putting in place the best available technology, proper design, planning and selection of luminaires and other necessary equipment for the lighting in industrial, commercial, public and utility areas and residential applications with special emphasis on energy conservation is the primary responsibility of a lighting designer.

9.2 Future Scope

All the lighting design solutions proposed in this thesis can be promoted into next level through smart lighting. Smart lighting continues to gain popularity due to its amazing features like scheduling, dimming and wireless control. The ability to remotely control the lighting and influence the atmosphere of indoor spaces with a single click is the major benefit of smart lighting. Smart Lighting involves Digital Addressable Lighting Interface (DALI) and Analogue Dimmable luminaires for easy integration with wired or wireless lighting management systems. Smart LED luminaires contain software that connects to an application or other smart accessory so that automation can be performed, eliminating the need for traditional wall switches. Also by variation of CCT of luminaires, colour tuning can be performed. Colour tuning is the technique of adjusting of the colour of luminaires in a space. Colour tuning further enhances the ability of lighting to dramatically change the look of a lighted space.

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