# A STUDY ON MODERN AUDITORIUM LIGHTING DESIGN

*A Thesis submitted towards partial fulfillment of the requirements of the degree of*

**Master of Technology in**
**Illumination Technology and Design**


Submitted by

**SAJAL GAYEN**

CLASS ROLL NO.:001631101007

EXAM ROLL NO.: M6ILT19010


Under the guidance of
**Dr. Saswati Mazumdar**
**&**
**Mr. Dipayan Nath**


Course affiliated to

**Faculty of Engineering and Technology, Jadavpur University**
**Kolkata –700032, India**


**2019**


School of Illumination Science, Engineering and Design, Jadavpur University

**Master of Technology in Illumination Technology and Design**
Course affiliated to
**Faculty of Interdisciplinary School of Law and Management**
**Jadavpur University, Kolkata, India**

---

## CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **A STUDY ON MODERN AUDITORIUM LIGHTING DESIGN,** is a bonafide work carried out by **SAJAL GAYEN** under our supervision and guidance for partial fulfillment of the requirement for **Master of Technology in Illumination Technology and Design** in School of Illumination Science, Engineering and Design, during the academic session 2016 -2019.

**..........................................................…**
**Dr. Saswati Mazumdar**
Professor, Electrical Engineering Department
Former Director, School of Illumination Science,Engineering & Design,
Jadavpur University, Kolkata-700032

**..........................................................…**
**Mr. Dipayan Nath**
Assistant Professor, Department of Electrical Engineering, Future Institute of Engineering and Management, Sonarpur Station Road, Kolkata – 700150.

**……………………………………………**
**Dr. Kamalika Ghosh**
Director, School of Illumination Science Engineering & Design,
Jadavpur University, Kolkata-700032

**…………………………………………….**
**DEAN**
**Prof.(Dr.) Pankaj Roy**
Faculty of Inter-disciplinary Studies, Law & Management (FISLM)
Jadavpur University, Kolkata-700 032

**Master of Technology in Illumination Technology and Design**
Course affiliated to
**Faculty of Interdisciplinary School of Law and Management**
**Jadavpur University, Kolkata, India**

---

## CERTIFICATE OF APPROVAL

This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented by **SAJAL GAYEN** (Exam Roll No**- M6ILT19010**) in a manner satisfactorily to warranty its acceptance as a pre-requisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn there in but approve the thesis only for purpose for which it has been submitted.

**FINAL EXAMINATION FOR EVALUATION OF THESIS**

**Board of Examiners**

**------------------------------------**

**------------------------------------**

**------------------------------------**

Date:

4th April, 2019

## To Whom It May Concern

We hereby certify that Sajal Gayen, M Tech student of Jadavpur University has successfully completed his internship program. His internship program was from 19th June, 2018 to 31st March, 2019 with Trilux Lighting India Pvt Ltd.. He was actively & diligently involved in the projects and tasks assigned to him.

During the span, we found him sincere and hardworking person. We wish him a bright future.

For **Trilux Lighting India Pvt Ltd.,**

**Anjali Singh**
**Dy. General Manager - Marketing**

## DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of the thesis for the degree of **Master of Technology in Illumination Technology and Design** studies during academic session 2016-2019.

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

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

NAME: SAJAL GAYEN

CLASS ROLL NUMBER: 001631101007

EXAM ROLL NUMBER: M6ILT19010

THESIS TITLE: **A STUDY ON MODERN AUDITORIUM LIGHTING DESIGN**

SIGNATURE: DATE:

## ACKNOWLEDGEMENT

I take this opportunity to express my deep sense of gratitude and indebtedness to **Dr. Saswati Mazumdar** Professor, Electrical Engineering Department; Former Director, School of Illumination Science Engineering & Design, Jadavpur University, for her constant guidance and supervision. I would also like to thank her for providing me valuable time and helpful suggestions.

I am also thankful to **Mr. Dipayan Nath** for his guidance and co-operation during my project work.

I would like to thank **Mrs Anjali Singh-** Dy. General Manager (Marketing), Trilux Lighting India Pvt Ltd**, Mr. Sreemanta Chakraborty-** Regional Sales Manager(East) of Trilux Lighting India Pvt Ltd**, Mr. Bibhuti Bhushan Nanda** - Regional Manager (N&E), Trilux Lighting India Pvt Ltd and **Mr. Sujeet Singh-** Lighting Designer, Trilux Lighting India Pvt Ltd. for providing me their support & guidance which helped me to gain valuable knowledge on lighting equipment, lighting control devices and lighting design etc.

Last but not the least, my special thanks to all my friends who helped me directly in completing my thesis successfully.

Date: ……………………………………

Jadavpur University **SAJAL GAYEN**

Kolkata- 32

# INDEX

**Content** **Page No.**

# Chapter-1:

# Introduction

## 1.1 Abstract

In this work the application of energy efficient light sources namely LED in a Proposed Auditorium building has been detailed with relevant theory. The total lighting design has been done by using software to estimate the entire lighting appearance, expected achieved light level by perfectly positioning the luminaires in the ceiling layout. The lighting design and simulations to follow in the subsequent chapters are done in Trilux Lighting India Pvt Ltd, Kolkata branch during the internship period of the author of this thesis.

## 1.2 Few words about Auditorium:

Auditorium is a large space with rows of seats and often a stage which is used for performances and for public events or meetings. The word Auditorium comes from the Latin word 'Auditorius' and the English word 'Auditory'; a large Outdoor or Indoor space where people gather to watch a performance, listen to a speech, etc is meant by the word Auditorium.

In Auditorium lighting the focus of the space is a speaker's podium in the center of the room, with white boards and retractable presentation screens on either side of the podium. Very little daylight enters the space, as there are only a few windows, which are very narrow in their design. Motorized blinds are utilized to control the light entering the space, as it is very important to prevent daylight from becoming a source of glare during presentations.

The aspect that makes the auditorium lighting design unique as the space is essentially used for multipurpose activities. Design implications require the space to be utilized for both as a classroom and as well as a presentation space which are related to functions of renowned university. Because of these implications, it requires the lighting design to be adaptive in terms of meeting all the lighting parameters of the occupants in the space. Hence the versatility of the auditorium lighting design is more challenging than the lighting design of a typical classroom. The auditorium will not be used solely by the students but also by the administration and possibly by the groups outside of the university as well.

Auditoriums are made for multiple uses, including theatrical plays, assemblies, and exhibits. With so much traffic, an auditorium must be constructed with all considerations in mind, including what lighting to use. This helps to literally illuminate auditoriums and their many events.

An auditorium can be used as an assembly hall. An assembly hall can be defined as an area where many people congregate, usually found in schools and colleges. Usually this kind of light is called recessed lighting, whereas lights retract back into the ceiling itself. Usually these lights are located in a spaced pattern throughout the ceiling.

# Chapter -2:

# Evolution of Auditorium through the Ages

## 2.1 Early Auditoriums

The first buildings used for theatrical performances in Britain were Amphitheaters introduced by the Romans, who copied theatres from ancient Greece. These were semi-circular structures, constructed of wood initially and later stone. They were open to the air with banked seating surrounding a raised stage.

Medieval theatre was presented on elaborate temporary stages inside great halls, barns, or in the open courtyards of galleried inns. It was from these that Elizabethan timber-framed open-air theatres took their form, such as the Globe in London. They were often multi-sided buildings, with a covered platform stage against one side. The audience sat or stood in covered galleries around the other sides or in the open courtyard. All the performances took place in daylight.

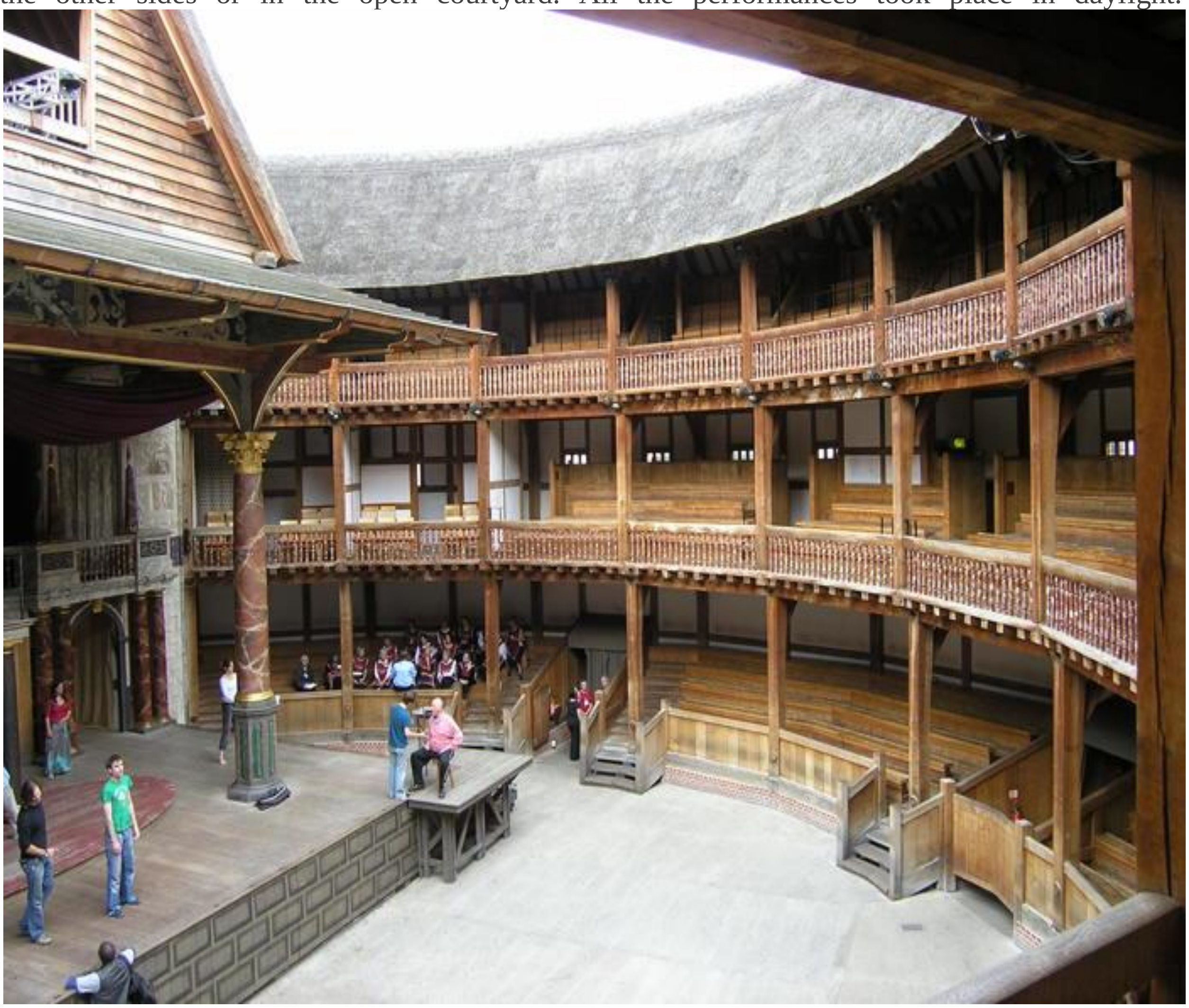


**Fig.2.1**: Image showing Shakespeare's Globe in London, a reconstruction of an Elizabethan theatre.

**2.2 Seventeenth-century theatres**

Interest in theatre increased during the Stuart period. Many rich courtiers and aristocrats hosted touring theatrical productions in their homes. Masques too were a popular form of recreation for the royal court and the very rich, often commissioned for celebrations. They would involve music, dance and elaborate costumes and scenery. The architect Inigo Jones devised the sets for several royal masques, and later went on to design theatre buildings. He had toured Italy and France and was heavily influenced by their designs. He is also attributed with introducing the first proscenium arch – a decorative architectural frame over a thrust stage.

After the execution of Charles I in 1642, theatrical performances were outlawed owing to the threat of civil unrest. Theatres closed and many were demolished.

Following the restoration of the monarchy twenty years later, interest in theatre resumed. In reward for their loyalty to the Crown, Charles II issued patents to two theatre companies in London, Davenant and Killigrew, to stage drama. They presented at various sites across the city before they set up permanent theatres in Drury Lane and Covent Garden. Later, the King issued limited patents to a few more theatres in London. However, by this time, theatre buildings began to change, influenced by those in Europe. They were now roofed, with stages for changeable scenery that was slid into position using grooves in their floors. Other scenery was flown in from above. To accommodate these elaborate stage sets more space was needed behind the stage. Fig;1 shows Shakespeare's Globe in London, a Theatre of that time period which is reconstructed later.

**2.3 Eighteenth-century theatres**

The Licensing Act of 1737 tightened censorship of drama, placing it under the control of the Lord Chamberlain. Only patent theatres were able to perform drama – known as legitimate theatre. Non-patent theatres performed melodrama, pantomime, ballet, opera and music hall (burlesque). As this involved music or musical interludes, they could not be classed as plays and were regarded as illegitimate theatre so were not subject to the Licensing Act.

Later, a series of royal patents were granted to cities outside London. These became known as “Theatres Royal”. Many still operate and were built in a restrained neo-classical style.

**Fig. 2.2**: Image showing the façade of the former Theatre Royal, Truro.

Also in the eighteenth century, companies of players began to travel on regular circuits between market towns. They set up their own theatres, called playhouses, which were similar in shape and size. This enabled stock scenery to be easily erected and reused, which made touring easier. Hundreds were built, of modest size and exterior. Their interiors were simple, consisting of a rectangular flat-floored room with a stage that projected into the audience. People sat on benched seating on the floor in front of the stage, or on balconies against the three remaining walls supported by columns or wooden posts. Any scenery was placed at the rear of the stage. The rich could pay a little more in order to sit on the stage, not only for better viewing, but also to be seen by the rest of the audience and the cast. These theatres were open for limited periods, and when not needed for performances could be used for other functions, for example as assembly rooms or ballrooms.Fig.2 shows the façade of the former Theatre Royal, Truro which was constructed at that time period.

Theatres had mainly wooden interiors which were always at risk of fire. In 1794 the Drury Lane Theatre, London introduced the first iron safety curtain, which would eventually become a statutory requirement in all large theatres. It also had a large water tank on its roof – a feature that was adopted by other theatres – to extinguish fire in the stage area. The theatre also began to make its scenery more fire-resistant.

By the end of the century the façades of many city theatres were built in the more imposing classical style. Some even had porticoes, similar to those seen on the front of large city homes or country houses. They were added mainly for show, but a few enabled the rich to descend from their carriages and enter the theatre without being exposed to any inclement weather.

## 2.4 Nineteenth-century theatres

In the early 1800s, theatre attendance lessened, owing partly to economic decline and poor standards of acting and production. Patronage by the middle classes also fell as a result of theatre's increasingly bad reputation and raucous nature. Consequently, many theatres closed or were converted to other uses.

The Industrial Revolution saw many people from the country migrate to the expanding industrial towns. This resulted in the decline of rural theatres, although some touring companies around the country continued to operate, but mainly from barn fit-ups. However, in the more populated urban centres there was a significant increase in theatre building.

In 1843, the Theatres Act removed the patent monopoly and allowed the Lord Chamberlain to grant a theatre license to any suitable person. This encouraged the building of new theatres, invariably by speculators seeking profit. However, the Lord Chamberlain's new licenses forbade the consumption of alcohol in the auditorium. This led to the closure of many small saloon theatres, which relied upon alcohol sales to stay in business.

Yet, the same legislation enabled magistrates to grant public houses licences to offer a variety of entertainment, which led to the creation of a new form of popular theatrical entertainment known as music hall. Very soon, concert or supper rooms were built onto public houses which could sell alcohol and serve meals during their musical productions. They were usually well-lit rooms with a flat floor and a simple open platform stage with little or no scenery. The audience would sit on benches or at tables in front of the stage, or on balconies against one or more of the walls. They could come and go freely during the evening and were not restricted to performance times.

Eventually a specific type of theatre building was developed to cater for this new form of entertainment, called a music hall. They had fewer tables in front of the stage, using the space for benched seating to accommodate more people. Hundreds were built-in working-class areas as money-making concerns.

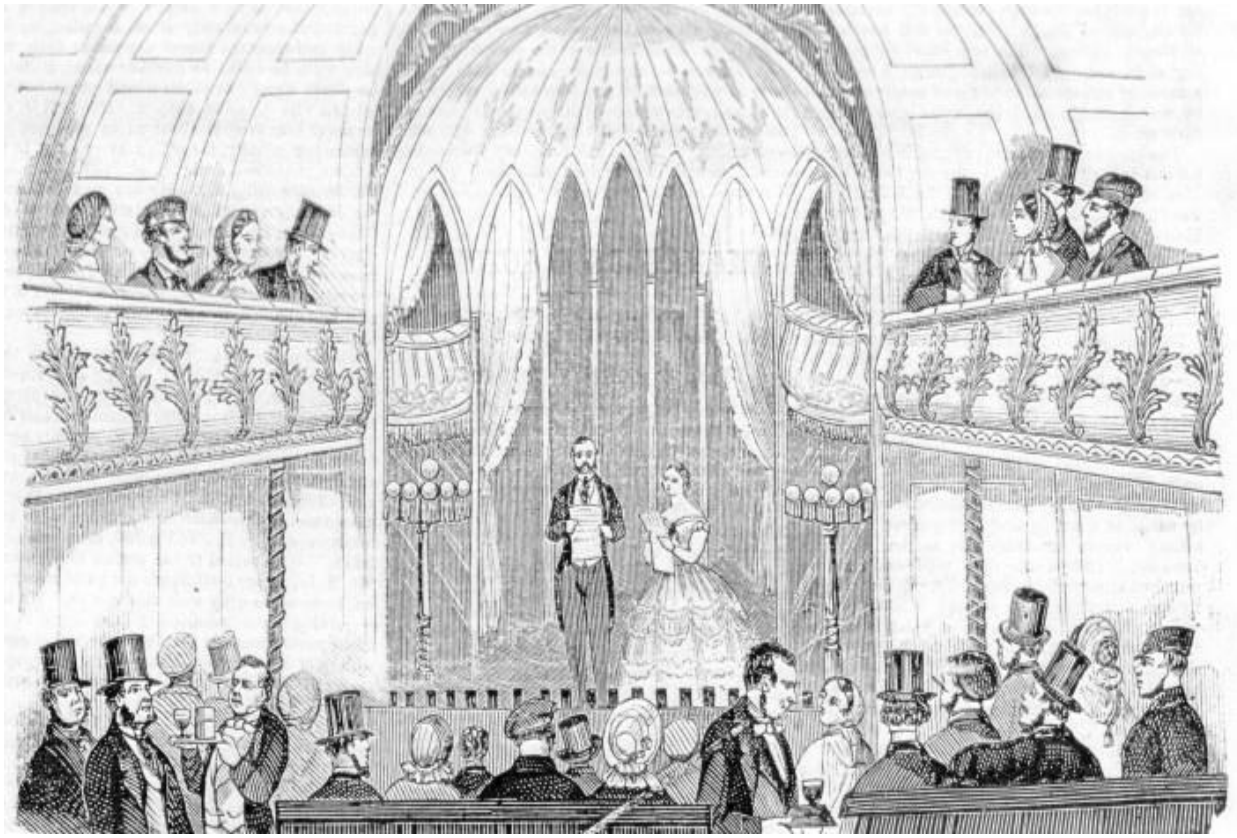


**Fig. 2.3**: Image showing Wilton's Music Hall, London.

By the middle of the nineteenth century theatre building was becoming a specialist architectural discipline, led by architects such as J. T. Robinson and C. J. Phipps. They were tasked with building even bigger theatres, with grander front of house arrangements and more luxurious social areas.

Often, older theatres were demolished and rebuilt to accommodate larger audiences. In the auditorium, rectangular galleries began to be replaced by horseshoe-shaped balconies that enveloped the stage and provided better viewing. Fig. 3 shows artist’s impression of Wilton's Music Hall, London.

The intention was to bring respectability to theatre-going and make it more socially acceptable for the middle classes. To achieve this, different classes were segregated: financially by the cost of the tickets; and physically by the requirement to use separate entrances and exits and circulation routes. The rich entered via illuminated entrances, with grand staircases and rich carpets: the cheaper seats via smaller side or rear entrances, with less grand staircases and public areas. Also, the benched pits in front of stages were replaced by more comfortable seats and carpeted aisles for the rich. The cheaper seats were now restricted to the rear stalls behind a wooden barrier, known as the ‘pit’, and the balcony or gallery.

Although theatre was enjoyed by much of the population, it was not always accessible throughout Britain. In rural areas of Wales the portable theatre was popular. These theatres toured the country and could be dismantled and moved easily. They were well supported in the small towns and villages which could not sustain permanent theatrical venues, and lasted until World War I.

### 2.5 Victorian invention and legislation

The Victorian period saw a number of innovations that impacted upon theatre design. Lighting changed from candle to gas and then later to electricity as a result of stringent health and safety legislation. Both emitted a more brilliant light that enabled directors to use lighting for theatrical effect.

Further legislation required that audiences seated at all levels could be evacuated quickly and safely in the event of fire or panic evacuations. Most theatre interiors used a lot of wood, including seats, balconies and structural supports. At that time the average life of theatres was just under twenty years owing to the risk of fire. Tragedies such as the fire at the Theatre Royal, Exeter in 1887, in which more than 190 people lost their lives, led to more careful planning of new theatres or the refurbishing of older ones. Fire exits and escape routes became a statutory requirement.

**Fig. 2.4**: Image showing the 1867 fire at Her Majesty's Theatre, London.

The development of cantilevered balconies was another innovation. These steel-framed structures covered with concrete did not need supporting columns that impede the audience's view of the stage. Concrete soon became a popular material for theatre interiors, not only for its resistance to fire, but also because it could be moulded into elaborate curved forms. Fig. 4: shows the fire at Her Majesty's Theatre, London during 1867.

## 2.6 Seaside and circuses

The expansion of the railways in the nineteenth century enabled urban populations to travel to the coast. These visitors liked to take in the sea air, promenading along the sea front and the lengthy piers that stretched ever further into the sea and which were being built in greater numbers from the 1860s.

Several of these commercial enterprises had theatres or variety halls built on them, and became an important element of the local seaside economy. Following the outbreak of World War II, though, many began to be neglected, and by the 1960s changing holiday patterns and rising costs led to many being closed, to be replaced by lucrative amusement arcades.

Hippodromes or circuses, too, were a popular form of entertainment in the Victorian period and developed from the interest in equestrian entertainment in the late-eighteenth century, which took place in circular enclosures. They were built in major cities and seaside resorts in theatre-like buildings to present live animal acts, though their shows would often include human acts.

**Fig. 2.5**: Image showing the Tower Circus, Blackpool

Some hippodromes could even be flooded for spectacular water shows. Very few remain in use today, most converted to other uses or demolished, but they can often be recognised by the use of animal forms in their decoration. Fig. 5: shows the Tower Circus, Blackpool, a typical circular enclosure theatre.

### 2.7 Theatre-building's heyday

The period from the 1880s to World War I was the greatest era of theatre building. Over 1000 professional theatres were operating in Britain then, some built by syndicates, who created chains of touring houses. New architects such as W. G. R. Sprague and T. Verity became renowned for their work and could design theatres according to the changing stringent building regulations.

Probably the most prolific was Frank Matcham, who designed or renovated over 120 theatres. He was noted for his excellent planning and opulent interiors.


**Fig. 2.6**: Image showing Frank Matcham's Grand Opera House, Belfast.

The development of hydraulic (water powered) stage machinery enabled more spectacular productions to be presented. Shows with increasingly ambitious special effects were devised to attract and retain audiences. However, this required more backstage space for storage and operation.

Music halls were still very popular places of entertainment, but were usually called variety theatres, owing to the variety of the acts in their shows. To make them more suitable for families the consumption of alcohol was banned in the auditorium, though it could still be consumed in bars at intervals or before and after performances. Internally, they became more like conventional theatres. Admission was by payment for designated seats, as had been the case with theatres showing drama, and which ensured that families could sit together. Fig.6 shows Frank Matcham's Grand Opera House, Belfast, a famous opera house of that times.

## 2.8 Early twentieth-century theatres

The beginning of the twentieth century saw the introduction of a new component in variety bills that would eventually lead to the closure of hundreds of theatres and music halls. This was the bioscope, a forerunner of the cinema. It was so popular that new or refurbished theatres often included provision for screening films.

The films were silent, but accompanied by music, usually an organ. These theatres became known as ciné-varieties, because of their mixture of variety theatre and cinema. Some foresighted architects included a separate projection room in their plans. This ensured the survival of some theatres as future fire safety legislation required any building showing a film to have a separate projection room. However theatres which relied on cinema for their commercial survival, soon closed if they failed to meet new regulations.

World War I suspended theatre building, but by then it had reached a peak and demand was satisfied. By then, large towns might have two or three theatres while cities could have up to a dozen. The Depression further affected theatre-going and theatre-building. However, it was the emerging popularity of film that concerned theatre owners. Super-cinemas were springing up rapidly, many designed in a radical new artistic style, known as art deco or ‘the Hollywood style’. This in turn influenced the refurbishing of some new theatres, which aspired to a more modern appeal, that of glamour and glitz.

Either side of World War I there were some significant new developments in theatre. Club theatres were set up in response to the conservative nature of commercial theatre. In order to escape censorship by the Lord Chamberlain they operated as private clubs with ‘members’ paying a subscription fee rather than an entrance fee. These theatres were tiny and showed specialist, political and experimental theatre, as well as showcasing the work of foreign writers.

Also, the emerging Labour Party sought to raise the educational level and opportunities of the working classes through cultural activities. This led to the creation of theatres such as the People’s Theatre, in Newcastle upon Tyne, in 1911.

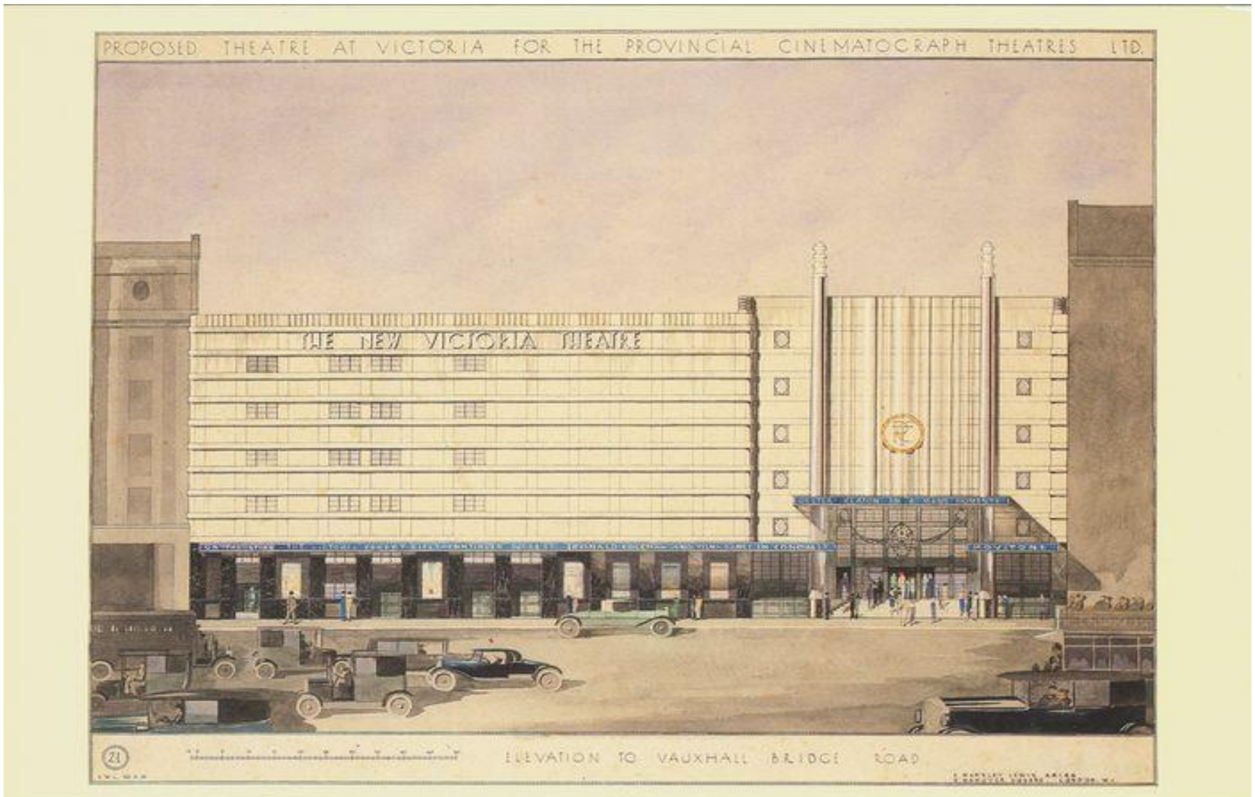



**Fig. 2.7**: Image showing proposals for the New Victoria Theatre (now the Apollo Victoria) in London, 1928.

The period between the two world wars was one of social discontent, and saw the rise of the Workers Theatre Movement. It used theatre as a way to advocate social change and educate the masses. One of its achievements was the opening of the Unity Theatre in London in 1936, in a reused chapel.

A further initiative at the time was Repertory theatre, or ‘rep’. It evolved in the regions and was sponsored by rich theatrical benefactors seeking to introduce audiences to a wide variety of theatre at a price they could afford. These sponsors also sought to support local writers and help train young regional actors. Some ‘rep’ companies took over existing theatres, with assistance from their sponsors**.** Fig.2.7 shows proposals for the New Victoria Theatre (now the Apollo Victoria) in London, 1928 from early eighteenth century.

## 2.9 World War II and after

During World War II, CEMA (Council for the Encouragement of Music and the Arts) was set up to provide entertainment for the civilian and military population, often in community or church halls or in makeshift theatres in camps. This initiative, and subsequent interest in the arts as a whole, led to the formation of the Arts Council in 1946 which enabled public money to be used to support theatre in the regions, including the construction of new theatres. The Belgrade in Coventry was the first purpose-built theatre after the war.


**Fig. 2.8**: Image showing the Belgrade Theatre, Coventry.

After World War II, it was television that led to the demise of theatre-going. By then many older theatres were seen as old-fashioned and did not appeal to the modern lifestyle of the working classes. Falling audiences and increasing maintenance costs resulted in the demolition of many theatres, especially if they were situated in bomb-damaged town centres that were targeted for redevelopment. Others were converted to different uses, such as bingo halls or nightclubs. Fig.2.8 shows the Belgrade Theatre, Coventry, a theatre built after WW-II.

In the 1960s and 70s, local councils were the main builders of new theatres, usually as part of their cultural and leisure programmes. Any new or replacement theatres were often integrated into multi-purpose civic complexes that included other amenities such as libraries, museums, sports halls, swimming pools and shopping areas.

These new ‘civic theatres’ were frequently designed for multi-purpose use and built in a more functional architectural style. They presented opportunities to experiment with different auditoria arrangements, with some being built in the less traditional arrangements, such as theatre-in-the-round, courtyard-style or with a wide single rake of seating and open stage.

In 1968 censorship ended, and performances usually seen in club theatres could now be staged in mainstream theatres. There was also an explosion of fringe and alternative theatre. Some companies acquired and adapted redundant buildings for rehearsal and presenting.Concern over the number of older theatres being lost led to moves to preserve, restore and re-use theatre buildings. Finally, some were listed during the 1970s for their architectural or historical interest.

Then, in 1976, the Theatres Trust Act was passed, founding a new organisation, Theatres Trust, the National Advisory Public Body for Theatres, tasked with protecting theatres and theatre use, and with a statutory role to advise on all planning applications affecting land on which there is a theatre.

Further good news for theatres came in 1994, with the creation of the National Lottery. Its proceeds fund substantial 'good causes', including the restoration, refurbishment and redevelopment of theatres. Then, as the millennium approached, towns and cities were looking at ways to celebrate the new millennium. Many opted for cultural initiatives, creating new performing arts venues, drawing on the financial opportunities offered at the time. This new breed of cultural centres provided the focus of much-needed urban regeneration schemes, creating accessible 'landmark' buildings for everybody's use and enjoyment.

### 2.10 Black-box or Studio theatres

The black box is a relatively recent innovation in theatre These are flexible performance spaces which when stripped to their basics are a single room painted black, the floor of the stage at the same level as the first audience row. Usually these spaces allow for the temporary setup of seating in a number of different configurations to enable a wide variety of productions to be presented.

The simplicity of the space is used to create a flexible stage (as shown in Fig2.10) and audience interaction. This is gradually getting popular in recent times.

**Fig 2.9** Inside of a Black Box Theatre

# Chapter-3:

# General Lighting Parameters

## 3.1 TERMINOLOGY

For the purpose of this study, the following definitions shall apply.

### 3.1.1 Adaptation

The process by which the properties of the organ of vision are modified according to the luminance or the colour stimuli presented to it. The term is also used, usually qualified, to denote the final state of this process. For example, 'dark adaptation' denotes the state of the visual system when it has become adapted to a very low luminance.

### 3.1.2 The Candela

A candela represents a base unit of luminous intensity, which is defined in the Merriam-Webster online dictionary as being equal to the luminous intensity in a given direction of a source which emits monochromatic radiation of frequency 540 x 1012 hertz and has a radiant intensity in that direction of watt per unit solid angle. This definition of the candela represents a luminous intensity in a given direction at a precise frequency. In addition, as we will note later in this chapter, the candela is also defined as having a radiant intensity of 1/683 watts per steradian (W/sr). The frequency selected for the definition of the candela corresponds to a wavelength of approximately 555 nm, which represents the visible spectrum of light near the color green. The selection of this point was based on the fact that the human eye is most sensitive to the selected. [1]

frequency when adapted for bright conditions. At other frequencies, additional radiant intensity is needed to obtain the same level of luminous intensity when viewed via the human eye. The relationship between the luminous intensity in candelas $Iv(\lambda)$ of a particular wavelength$(\lambda)$ is given by the following formula:

$$I_v(\lambda) = 683.00\, y(\lambda)\, I(\lambda)$$

where

$Iv(\lambda)$ = the luminous intensity in candelas

$I(\lambda)$ = the radiant intensity in watts per steradian

$y(\lambda)$ = the standard luminosity function if more than one wavelength is present, which then requires the sum over the spectrum of wavelengths present to obtain the total luminous intensity

### 3.1.3 Colour Rendering [1]

A general expression for the appearance of surface colours when illuminated by light from a given source compared, consciously or unconsciously, with their appearance under light from some reference source. Good colour rendering' implies similarity of appearance to that under an acceptable light source, such as daylight.

### 3.1.4 Colour Temperature ( K )

The temperature of the black body that emits radiation of the same chromaticity as the radiation considered.

### 3.1.5 Contrast

A term that is used subjectively and objectively. Subjectively, it describes the difference in appearance of two parts of a visual field seen simultaneously or successively. The difference may be one of brightness or colour, or both. Objectively, the term expresses the luminance difference between the two parts of the field by such relationship as: -

$$\text{Contrast} = ( L_O - L_b) / L_b$$

$L_b$ is the dominant or background,
$L_o$ is the task luminance. luminance.

Quantitatively, the sign of the contrast is ignored.

### 3.1.6 Contrast Rendering Factor ( CRF )

The ratio of the contrast of a task under a given lighting installation to its contrast under reference lighting conditions.

### 3.1.7 Contrast Sensitivity

The reciprocal of the minimum perceptible contrast.

### 3.1.8 Correlated Colour Temperature ( Unit : K )

The temperature of a block body which emits radiation having a chromaticity nearest to that of the light source being considered, for example, the colour of a full radiator at 3500 K is the nearest match to that of a White tubular fluorescent lamp.

### 3.1.9 Diffuse Reflection

Diffusion by reflection in which, on the macroscopic scale, there is no regular reflection.

### 3.1.10 Diffused Lighting

Lighting in which the light on the working plane on an object is not incident predominantly from any particular direction.

### 3.1.11 Direct Lighting

Lighting by means of luminaires with a light. distribution such that 90 to 100 percent of the emitted luminous flux reaches the working plane directly, assuming that this plane is unbounded.

### 3.1.12 Directional Lighting

Lighting in which the light on the working plane or on an object is incident predominantly from a particular direction.

### 3.1.13 Disability Glare

Glare which impairs the vision of objects without necessarily causing discomfort.

### 3.1.14 Discomfort Glare

Glare which causes discomfort without necessary impairing the vision of objects.

### 3.1.15 Emergency Lighting

Lighting intended to allow the public to find the exists from a building with ease and. certainty in the case of failure of the normal lighting system.

### 3.1.16 Flicker

Impression of fluctuating luminance or colour.

### 3.1.17 General Lighting

Lighting designed to illuminate the whole of an area uniformly, without provision for special local requirements.

### 3.1.18 Glare

Condition of vision in which there is discomfort or a reduction in the ability to see significant objects, or both, due to an unsuitable distribution or range of luminance or to extreme contrasts in space or time.

### 3.1.19 Illumioance ( E )

At a point of surface, quotient of the luminous flux incident on an element of the surface containing the point by the area of that element. (Unit : Lux, lx).

### 3.1.20 Illumination

The application of visible radiation to an object.

### 3.1.21 Indirect Lighting

Lighting by means of luminaires with a light distribution such that not more than 10 percent of the emitted luminous flux reaches the working plane directly, assuming that this plane is unbounded.

**3.1.22 Light Loss Factor**

Ratio of the average illuminance on the working plane after a specified period of use of a lighting installation to the average illuminance obtained under the same conditions for a new installation.

**3.1.23 Local Lighting**

Lighting designed to illuminate a particular small area which usually does not extend far from the visual task, for example, a desk.

**3.1.24 Localized Lighting**

Lighting designed to illuminate an interior and at the same time to provide higher illuminance over a particular part or parts of the interior.

**3.1.25 Lumen ( lm )**

Luminous flux emitted within unit solid angle ( one steradian ) by a point source having a uniform luminous intensity of 1 candela.

**3.1.26 Luminaire**

Apparatus that distributes, filters or transforms the light given by a lamp or lamps and which includes all the items necessary for fixing and protecting these lamps and for connecting them to the supply circuit.

**3.1.27 Luminance ( L )**

In a given direction, at a point on the surface of the source or a receptor or at a point on the path of a beam. Quotient of the luminous flux leaving, arriving at, or passing through an element of surface at this point and propagated in direction defined by an elementary cone containing the given direction and the product of the solid angle of the cone and the area of the orthogonal projection of the element surface on a plane perpendicular to the given direction (Unit : Candela per square metre, cd/ma ). [2]

**3.1.28 Luminous Efficacy ( Unit : lm/W )**

The ratio of luminous flux emitted by a lamp to the power consumed by the lamp. When - the power consumed by control gear is taken into acco nt, this term is sometime known as lamp circui Y luminous efficacy and is expressed in. lumens/circuit watt.

### 3.1.29 Luminous Flux

The quantity derived from radiant flux by evaluating the radiation according to its action upon a selective receptor, the spectral sensitivity of which is defined by the standard spectral luminous efficiencies ( Unit : lumen ).

### 3.1.30 Luminous Intensity ( I ) ( Of a source in a given .direction )

Quotient of the luminous flux leaving the source propagated in an element of solid angle containing the given direction, by the element of solid angle ( Unit : candela, cd ).

### 3.1.31 Lux ( lx ), Lumen Per Squtie 'Metre

( SI Unit of Illuminance ) Illuminance produced by a luminous flux- of one lm uniformly distributed over a surface of area one square metre.

### 3.1.32 Reflectance ( Reflection Factor )

Ratio of the reflected radiant or luminous flux to the incident flux.

### 3.1.33 Service Illuminance

The mean illuminance throughout the maintenance cycle of an installation, averaged over the relevant area. The area may be the whole of the working plane or just the area of the visual task and its immediate surround, depending on the lighting approach used.

### 3.1.34 Specular Reflection

Regular Reflection Reflection without diffusion in accordance with the laws of optical reflection as in a mirror.

### 3.1.35 Stroboscopic Effect

Apparent change of motion or immobilization of an object, when the object is illuminated by a periodically varying light of appropriate frequency.

### 3.1.36 Uniformity Ratio

The ratio of the minimum illuminance to the average illuminance. In some instances, the ratio of the minimum to the maximum illuminance is quoted. The ratio usually applies to values on the working plane over the working area.

### 3.1.37 Visual Environment

The environment either indoors or outdoors as seen by an observer.

### 3.1.38 Visual Field

The full extent in space of what can be seen when looking in a given direction.

## 3.2 FUNCTIONS OF LIGHTING

The lighting of an interior should fulfill three functions. It should -

(a) ensure the safety of people in the interior,

(b) facilitate performance of visual tasks, and

(c) aid the creation of an appropriate visual environment.

Safety is always important but the emphasis given to task performance and the appearance of the interior will depend on the nature of the interior. For example, the lighting considered suitable for a factory toolroom will place more emphasis on lighting the task than on the appearance of the room, but in a hotel lounge the priorties will be reversed. This variation in emphasis should not be taken to imply that either task performance or visual appearance can be completely neglected. In almost all situations the designer should give consideration to both these aspects of lighting.

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.

## 3.3 LIGHTING REQUIREMENTS

### 3.3.1 General Lighting Engineering Criteria

Lighting requirements are based on the following lighting engineering criteria:

- Lighting level,

- Luminance distribution,

- Glare restriction,

- Direction of incidence of light and shadow effect, and

- Colour appearance and colour rendering.

A lighting installation can satisfy the requirements laid down, only if all !he quality criteria are complied with; one or other quality criterion may be given priority, depending on the nature and difficulty of the visual task or on the type of room.

### 3.3.2 Visual Tasks

The size of the critical details of the task:

- Their contrast with the background,

- The speed at which these details have to be perceived,

- The desired reliability of recognition, and

- The duration of the visual work.

The quality requirements of the lighting increase with the difficulty of the visual task.

### 3.3.3 Economic Aspect

The selection of nominal illuminance for particular activities has to take into account economic aspects too. Although a higher level of lighting involves greater overall costs, these may be more than out-weighed by increased productivity and lower accident rate. A compromise has often to be made between desirable illuminance levels and those which are possible due to the economic climate prevailing. In consequence, it may be necessary to accept a lower standard of. lighting than that which' would be required from the performance point of view. The overall costs of a lighting installation can be reduced by using lamps having a high luminous efficacy and luminaires having a high efficiency and suitable light distribution.

### 3.3.4 Lighting Levels

***Illuminance***

The lighting level produced by a lighting installation is usually qualified by the illuminance produced on a specified, plane. In most cases, this plane is the major plane of the tasks in the interior and is commonly called the working plane. The illuminance provided by an installation affects both the performance of the tasks and the appearance of the space.

## 3.4 RECOMMENDATION ON ILLUMINANCE

### 3.4.1 Scale of illuminance

In order to be able just to discern features of the human face, a luminance of approximately 1cd/m$^2$ is necessary. This can be achieved under normal lighting conditions with a horizontal illuminance of approximately 20 lux. So 20 lux is regarded as the minimum illuminance for all non-working interiors. A factor of approximately 1.5 represents the smallest significant difference in subjective effect of illuminances.

Therefore, the following scale of illuminances is recommended.

20-30-50-75-100-150-200-300-500-750-1000-1500-2000, etc, lux.

### 3.4.2 Illuminance ranges

Because circumstances may be significantly different for different interiors used for the same application or for different conditions for the same kind of activity, a range of illuminances is recommended(as per IS 3646 Part II) for each type of interior or activity intended ,of a single value of illuminance. Each range consists of three successive steps of the recommended scale of illuminances. For working interiors the middle value of each range represents the recommended service illuminance that would be used unless one or more of the factors mentioned below apply. The higher value of the range should be used when:

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

The lower value of the range may be used when:

- Reflectance or contrasts are unusually high;
- Speed and accuracy is not important; and
- The task is executed only occasionally.

### 3.4.5 Luminance Distribution on Major Room Surfaces

The distribution of luminance should be regarded as complementary to the design on the illuminant in the interior. It should take into account the following aspects:

- Luminance of the task and its immediate surroundings;
- luminance of ceiling, walls and floor;

- Avoidance of glare by limiting the luminance of luminaires and windows.

### 3.4.6 Luminance Distribution in the Task Area

The luminance of the immediate surroundings of the task should, if possible, be lower than the task luminance, preferably not less than l/3 of this, value. This implies that the ratio of the reflectance of the immediate background of a task to that of the task itself should preferably be in the range 0.3 to 0.5.

### 3.4.7 Luminance of Ceilings, Walls and Floors

The average luminance in the peripheral field of view should, if possible, be not lower than 1/10th of the task luminance.

### 3.4.8 Reflectances and illuminances

In working interior, in order to reduce the contrast between luminaires and surrounding ceiling, the ceiling reflectance should be as high as possible. In order to avoid that the ceiling may otherwise appear too dark, the ceiling illuminance should not be lower than l/l0th of the task illuminance. In order to obtain a well balanced luminance distribution, the ratio of the minimum to the average illuminance should not be less than 0.8. The average illuminance of the general areas of a working interior should normally not be less than l/3 of the average illuminance of the task area(s). The average illuminance of adjacent interiors should not vary from each other by a ratio exceeding 5 : 1.

### 3.4.10 Restriction of Glare

General Glare may be caused by lamps, luminaires and windows ( direct glare ) or by the reflection of bright sources from surface with high reflectance ( reflected glare ). In interior lighting, discomfort glare from lamps and luminaires is likely to be more of a problem than disability glare.

# Chapter- 4:

# Parameters and Guidelines for Auditorium lighting

## 4.1 AUDITORIUM LIGHTING AS DESCRIBED IN ILLUMINATION ENGINEERING SOCIETY OF NORTH AMERICA (IESNA) 10th EDITION: [3]

For theatre, television, and film, the lighting system design and luminaire choices are based on production plans. The size and complexity of the system are based on production needs, from elementary training facilities to professional facilities. In all facilities, however, the budget usually determines the degree of complexity. Theatre design requires information concerning the types of programs (opera, orchestra, choral, dance, drama, variety) that are produced by resident groups or touring companies.

Television design requires information concerning types of productions (variety shows, dramas, news, soap operas, panel shows) that will be produced for network or local broadcasting or for closed-circuit or syndication release. The actual illuminance levels for television vary from under 1000 lx (100 fc) to several thousand lx (several hundred fc), depending on the type of camera used. In lighting for film, both still and motion picture, the function of the lighting is to produce the photochemical changes on the film required to produce the image. Thus, the illuminance required is determined largely by the sensitivity of the film.

## 4.2 LUMINAIRES, LAMPS, AND CONTROL SYSTEMS:

### Luminaires for Theatre:

In theatre, television, and photographic (film) lighting, different types of luminaires are used to produce qualities of light that fall within three basic categories:

1. Key light is illumination with defined margins. Its output produces defined but soft-edged shadows and highlights. (A typical luminaire is the Fresnel spotlight.)
2. Soft-edged light, sometimes referred to as "fill light," is diffuse illumination with indefinite margins. Its output produces poorly defined shadows, and it softens and fills the shadows produced by key light. (A typical luminaire is the soft light.)
3. Hard-edged light is illumination that produces sharply defined, geometrically precise shadows. (A typical luminaire is the ellipsoidal spotlight.)

The basic types of luminaires used in theatre, television, and film production have a variety of optical characteristics. Most luminaires conta.in provisions for color filters or diffusion materials. Different type of stage lighting equipments are shown in Fig-9. Some special luminaires, or accessory devices, have the ability to remotely control aiming, focus, or color.

**Non-lens Luminaires.** The non-lens luminaire (primarily used in film location applications) embodies a lamp, a reflector, and frequently a focus mechanism to change the field and beam angles, corresponding to 10% and 50% of maximum intensity, respectively. The spectral quality of the illumination produced by a non-lens luminaire can vary depending on lamp type, reflector finish, heat filters, daylight correction filters, and color frames. [4]

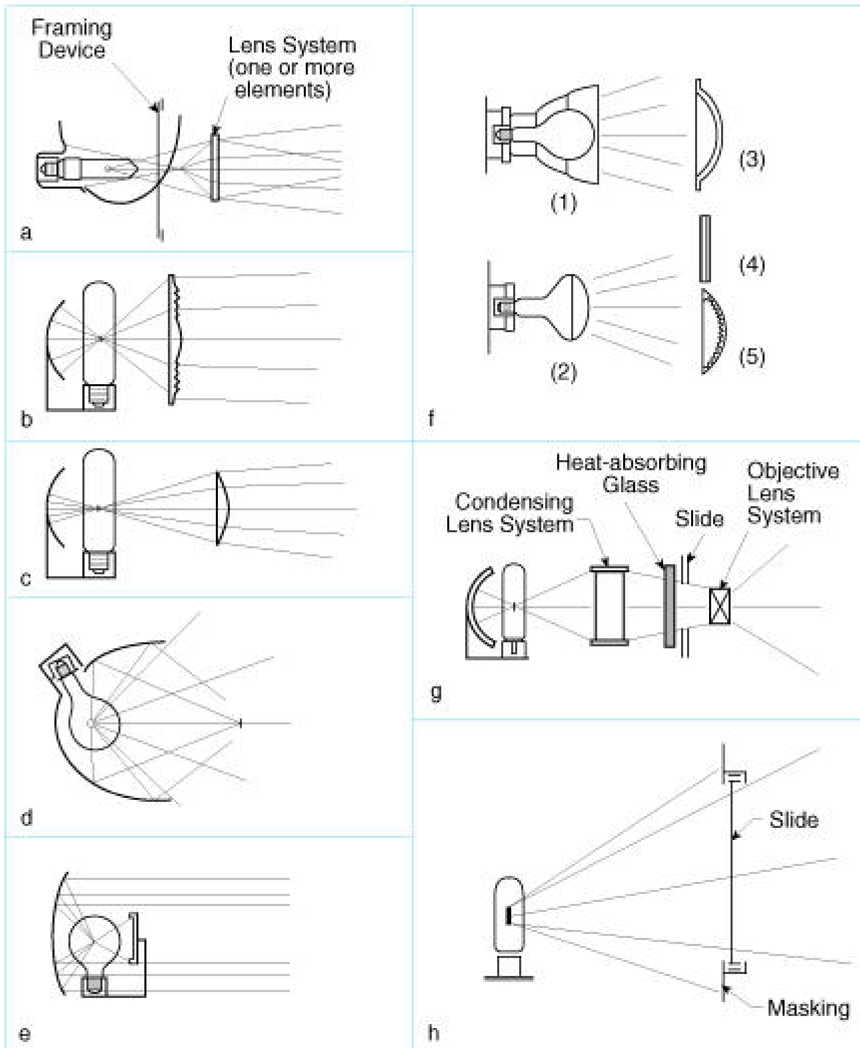



**Figure 4.1.** Optical characteristics of stage lighting equipment. (a) Ellipsoidal reflector spotlight. (b) Fresnel-lens spotlight. (c) Plano-convex lens spotlight. (d) Scoop-type floodlight. (e) parabolic-reflector floodlight. (f) Striplight: (1) reflector with general service lamp; (2) reflector lamp; (3) glass roundel; (4) sheet color medium; (5) spread lens roundel, plain or colored. (g) Lens-type scenic slide projector. (h) Nonlens-type scenic slide project (Linnebach type). The luminaires shown in c and e are used primarily in Europe.

There are many different types of nonlens luminaires that can be considered as spotlights or floodlights. They utilize tungsten-halogen lamps from 100 to 2000 W, and discharge sources from 200 to 4000 W. Nonlens luminaires include a variety of light distributions. Barn doors are swinging flaps attached to the front of a luminaire to control the shape and spread of light; however, the degree of control afforded with barn doors is limited. Scoops are floodlights consisting of a lampholder, lamp, and reflector with a matte or brushed finish. The lamp and reflector can have a fixed or variable relationship.

Scoops are equipped with front clips to hold a color frame containing either color media or diffusion material. The scoop produces illumination having a field angle of 90 to 180°. The quality of the illumination is considered soft, and the shadow sharpness depends primarily on the texture of the reflector. Scoops are available from 250 to 450 mm (10 to 18 in.) in diameter and are usually equipped with incandescent pear-shaped (PS) or tungsten-halogen lamps from 400 to 2000 W. The lamps are usually frosted for further softening of illumination. In general, the larger the diameter of the scoop, the softer the light output. There are variable-focus scoops. Parabolic (reflector) spotlights consist of a lamp and a parabolic specular reflector. Some luminaires have a reflector in front of the lamp to redirect light into the main reflector.

Other luminaires are equipped with spill rings to minimize spill light and glare. In most types of parabolic spotlights, the lamp and reflector are adjustable to produce a wide or a narrow beam of light; the closer the lamp is to the reflector, the wider the beam. This luminaire produces a hard-edged beam that cannot be easily controlled, except, in part, by spill rings. A parabolic spotlight is also known as a sun spot or beam projector. Parabolic spotlights have not enjoyed great interest in North America, but they are becoming more popular.

Soft light luminaires are well-diffused, almost shadow-free, light sources used in special applications. All of the light in these units is reflected off a matte-finish reflector before reaching the subject, and due to this design, they are not efficient sources of illumination. The soft light is the most common fill light chosen for television studio applications. Soft lights are available from 500 to 8000 W and are used where either shadows or reflections must be minimized.
Broads are small, rectangular floodlights used primarily in television for a very wide, soft lighting effect and fill light.

Broads are available in ratings up to 1500 W and are generally designed to use double-ended tungsten halogen lamps. They commonly have different distributions in the horizontal and vertical directions. Horizontal spreads of over 100° and vertical distributions of near 90° are common. Cyclorama, or cyc, lights provide an overall wash of illumination over the cyclorama curtain for background. There are two types of cyc, lights: strip cyc lights, which are compartmentalized luminaires with lamps on 200 to 300 mm (8 to 12 in.) centers, and cluster lights, mounted on 1.8 to 2.4 m (6 to 8 ft) centers.

Strip cyc lights, when mounted either from above or on the floor, can generally light a cyclorama which is 3.6 to 6.0 m (12 to 20 ft) high. If lights are used on both top and bottom, or if they have an asymmetrical reflector to improve the beam distribution, even higher surfaces can be suitably illuminated. Normally a single group, either suspended from above or floor mounted, has an illuminance falloff greater than 50% from the top of the space to the bottom. Lamps for these luminaires are available from 300 to 2000 W. Striplights have the advantage of much closer mounting to the cyclorama than the cluster lights. This can be critical in those theatres where stage space is limited.

Cluster lights can light a cyclorama up to 9 m (30 ft) high by lighting from the top only, and the illuminance falloff is less than 5%. Since these lights are mounted on 1.8 to 2.4 m (6 to 8 ft) centers, rather than the 300 mm (12 in.) centers for striplights, the power savings is substantial. This type of cyc light usually requires greater stage depth than striplights. Striplights for two-color luminaires use 3300 W/m (1000 W/ft), whereas cluster lights use 820 W/m (250 W/ft) for the same two-color coverage.

**Lens Luminaires**. The lens luminaire used in theatre, film, and television embodies a lamp, a reflector, a system of one or more lenses, and, frequently, a focus mechanism to change the light output by varying the field and beam angles. The quality of the illumination produced by a lens luminaire can vary from soft to hard, depending on lamp type and reflector finish. External beam control is possible with barn doors, gobos (devices that allow patterns to be projected onto the stage or curtain, usually cut into a flat metal sheet), irises, shutters, color frames, and in some cases adjustable-focal-length arrangements to permit zoom control.

There are many different types of lens luminaires that can be considered as spotlights or floodlights. They utilize tungsten-halogen lamps in the range of 100 to 6000 W. Among those luminaires considered "lens" are Fresnel and ellipsoidal spotlights, parabolic aluminized reflector (PAR) luminaires, striplights, and follow spots. Plano-convex spotlights also fall into this category; however, while they are popular in other parts of the world, they get little use in North America, and for that reason they are not discussed here.

***Fresnel Spotlight.*** The Fresnel spotlight is a luminaire that embodies a lamp, a Fresnel lens, and generally a spherical reflector behind the lamp. The field and beam angles can be varied by changing the distance between the lamp and the lens. The distance between the lamp and the reflector is defined by the optical design and cannot be changed. The quality of illumination produced by a Fresnel spotlight tends to be intermediate or hard, and the beam angle is soft-edged. The illumination varies considerably depending on the optics of the luminaire. Typical luminaires of this type have a beam angle of 10 to 50°, depending on the relative position of the lamp and lens. Fresnel spotlights are generally equipped with tungsten-halogen lamps with C-13 or C-13D planar filaments.

Many Fresnel spotlights are now available using a compact-source metal halide lamp as well. In order to shape the light beam, barn doors are used, as well as snoots. Snoots are metal tubes mounted on the front of spotlights to control stray light. They are also called funnels, top hats, or high hats. The light beam may also be colored or diffused by means of materials placed in its color frame. Fresnel spotlights are manufactured in lens diameters from 75 to 610 mm (3 to 24 in.) and in wattages from 75 to 12,000 W. Remote operation (pan, tilt, focusing, on/off) is available on some luminaires. Remote operation of these units can be achieved manually by using a pole, or electrically by use of servomotor-equipped units. These units are generally designed to be operated within approximately 45° of horizontal, particularly in the higher wattages in the range of 1 to 2 kW.

Operating Fresnel luminaires in this wattage range for long periods of time in a vertical position can cause damage to the luminaire and reduce lamp life (which is fairly short anyway), because the fixture cannot dissipate heat well in that position.

**Ellipsoidal Spotlight**. The ellipsoidal spotlight, or pattern light, consists of a lamp and ellipsoidal reflector mounted in a fixed relationship. The light is focused through the gate of the unit, where the beam can be shaped with the use of shutters, a gobo, or an iris. The shaped beam is then focused by the lens system. The output of the ellipsoidal spotlight is a hard-edged light with precise beam control. By defocusing the lens system, the hard edge can be softened somewhat. Units are also available with variable beam angles. The lens diameter and focal length determine the throw and coverage of the unit. Ellipsoidal spotlights are available in sizes from 90 mm (3.5 in.) and 400 W to 300 mm (12 in.) and 2000 W. Units employing metal halide lamps as the light source are also available. The effective throw of the larger units is about 30 m (100 ft).

**PAR Luminaires**. PAR luminaires embody a PAR lamp, lampholder, and housing. The performance of the luminaire depends on the type of lamp selected. The beam pattern of most PAR lamps is oval, so the luminaire is designed to rotate to cover the desired area. Glare can be reduced by barn doors, and the intensity can be modestly increased by applying a top hat. PAR luminaires using 650-, 1000- or 1200-W lamps are designed to accommodate either single lamps or groups of lamps in clusters of 3, 6, 9, 12, or more. For special effects, low-voltage, narrow-beam aircraft landing lights are commonly used. The PAR-64 luminaire is used in many theatres because it can do many jobs and is fairly inexpensive. It is popular with traveling road shows because it can withstand physical abuse.

**Striplights or Borderlights**. Striplights are compartmentalized luminaires. Every compartment contains a reflector lamp, or a lamp and reflector, and a color frame. The compartments are arranged in line and wired on two, three, or four alternate circuits, with each circuit producing a different color. Striplights provide an overall wash of illumination on a stage. They can also be located at the front of a stage as footlights to provide an overall low illuminance. Although striplights have been replaced in many applications by more versatile individual units such as Fresnel and ellipsoidal spotlights, they are still used in applications where cost is a major consideration. Striplights and borderlights are less expensive than Fresnel and ellipsoidal lights.

They are also used in applications where labor costs are high and the use of more flexible units would increase the labor required to set up a show. Luminaires using PAR-38, PAR-46, and PAR-56 lamps can be arranged in linear strips functioning as borderlights or striplights. There are striplights available that use 12-V multifaceted reflector (MR)-16 lamps wired in series. These units are useful in applications where space is at a premium, but they are generally not considered a suitable substitute for full-size striplights. In addition, cost and required maintenance are relatively high for these units.

**Follow Spot.** A follow spot is a special type of spotlight, stand mounted, with a shutter (commonly a douser), an iris, and a color frame or "boomerang" to hold color media. Most follow spots utilize a tungsten-halogen lamp, a metal halide lamp, or an arc source and a lens system. For high-intensity follow spots, the carbon arc has been almost totally replaced by compact metal halide or xenon lamps. All of these arc units produce more output, watt for watt, than the tungsten-halogen units. Follow spots are selected to provide the throws required for the application.

**Arc Light Luminaire**. There are still some arc units in use today, although they are not popular in new installations. An arc light luminaire uses a carbon electrode arc as the source of illumination. These produce carbon monoxide as a by-product. In some concentrations this is a deadly gas. In addition, the operators required for these luminaires can be expensive, particularly for the small theatre or school auditorium.

### 4.3 Control Systems for Theatre and Television Lighting

The design of a lighting control system is based on the artistic and technical needs of projected productions. It is related to the building architecture, luminaire rigging system, and density of electrical outlet distribution. Design parameters are expressed in terms of power capability, number of lighting outlets, dimmer bank capacity, interconnection system, and lighting control facilities. A lighting control system must provide the designers with total flexibility of control over all of the luminaires lighting the set. There must, therefore, be adequate dimmers, circuits, and control equipment to establish the number of lighting channels required, to assemble those channels into cues, and to switch and fade from one cue to another, thus achieving the desired lighting changes.

Lighting control systems for the theatre and for television differ slightly. Theatre lighting control systems make extensive use of memory, require accurately timed faders, and must be capable of complex simultaneous operations, whereas television lighting control systems generally require less memory and fewer operational features and benefit from automated dimmer channels.

**Dimmers.** Almost all of the lighting control devices used in theatre and television lighting use silicon-controlledrectifier (SCR) dimmers, which are manufactured in a range of 1 to 12 kW. Triac dimmers, manufactured in a nominal capacity of 2 kW, are used occasionally in inexpensive portable dimming equipment. Dimmers are rated by Underwriters Laboratory (UL) for continuous operation at 100% of their rating. Dimmers are assembled into portable packs of 6 to 24 or into racks that can contain several hundred dimmers custom built to suit the installation.
European countries have much more stringent harmonic requirements than North America, and companies wishing to do business on both continents have to comply with European requirements.

This likely requires a change from the current SCR-based dimmer circuits, which produce significant harmonics during dimming operation, to sinusoidal dimming circuits, which create no harmonics and also have the advantage of not producing high neutral currents. It is highly desirable for electronic dimmers to have stable output, cause no interference to audio and video circuits or to other dimmers, be insensitive to load, and have high efficiency. The relation of the dimmer line voltage output on the control input voltage is usually fixed,[15,16] but some systems allow other dimming curves to be selected from software options in the dimmer rack or at the control console. All electronic dimmers require ventilation to maintain components within specified operating temperature ranges. The amount of ventilation required depends on the dimmer's efficiency and the individual manufacturer's recommendations. A 97% efficient dimmer produces approximately 100 to 120 Btu/h for each kilowatt of connected load. Distributed dimming systems, those in which individual dimming modules are located at the lighting instrument rather than in a centralized dimmer enclosure, are becoming more common.

They are particularly cost effective in older theatres where existing wiring is to be reused and capacity is limited. The controls can follow a common protocol that can be easily "daisy-chained" to reduce the cost of installation and maintenance. Properly sized dimmers can be connected directly to the various lighting outlets. This is termed the dimmer-percircuit control method and is contrasted with power programming systems that employ a cord-and-jack or sliderand- bus system to switch individual outlets to larger-capacity dimmers. While the dimmer-per-circuit method leads to a large number of small dimmers, the improvement in wiring efficiency and the elimination of enclosures and power interconnect panels, when considered in conjunction with the added flexibility of these systems, usually amount to a cost savings and significant operating advantages.

The control console, whether computerized or manual, generally contains an electronic soft patch that connects the control channels to the dimmers, performing much the same function as the power interconnect panels formerly did.

**Manual Preset Lighting Control System.** The basic form of lighting control is the manual preset system, which employs groups of manual controllers for each dimmer or control channel. These controllers are arranged in horizontal rows termed presets. Presets are connected to submaster faders that are, in turn, switched to paired master faders for proportional, dipless (smooth dimming curve) cross fades between presets. Illuminances are set as required on individual controllers in each preset, and lighting cues are achieved through submaster and master controllers.

***Memory Lighting Control Systems***. Memory lighting control systems are generally programmed software-based systems. In such a system, the operational program is permanently stored in a read-only-memory (ROM) section, which may be updated by the manufacturer to provide additional operational facilities as they are developed. These systems may incorporate video monitors for displaying cue information and have a floppy disk or cassette for storage of program information. Peripheral equipment used with memory lighting control consoles may include hand-held remote controllers used with remote receptacles at lighting positions to assist in focusing lights, designer's remote consoles (used in conjunction with the console in the operator's booth), printers, and remote monitors.

Communications between control positions and the dimmers can be accomplished by discrete analog signals, by multiplexed control signals, by digital and analog multiplexed protocols, and by discrete analog methods. These standard protocols provide for interchangeable hardware, and may reduce the complexity and cost of wiring. There has been an industry shift toward standardizing on the Digital Multiplexing (DMX512) protocol. This control signal can now drive a whole range of peripheral equipment such as fog machines, moving lights, color scrollers, and more. The signal can be distributed to a number of control and equipment locations throughout the facility including back stage, orchestra pit, and equipment and lighting positions for total flexibility. This is relatively economical and allows the lighting console to drive all of these devices.

**Electrical Installation**. A major expenditure in any lighting system, whether theatrical or architectural, is the cost of the electrical distribution. To minimize this cost, care should be taken to locate the dimmer racks so as to achieve the most economical balance between the cost of the electrical feeders to the dimmer racks and the cost of the distribution wiring from there to the individual lighting positions or outlet boxes. For SCR-type solid-state dimming systems it is required to install a "hot" wire and a neutral from each dimmer module to its outlet. Therefore, the distribution wiring required for an electronically dimmed lighting system requires more wires than for a typical room lighting system. The cost of installing these additional wires must be included when determining the best location for major system components. The designer should consult the applicable codes when determining the size of power distribution feeders for electronic dimming systems (i.e., the wiring from the building electrical system to the dimming rack). Recent code changes have given more flexibility to the designer in determining the actual dimmer lighting load and required feeder size. Caution should be exercised in sizing the neutral conductor because SCR dimmer circuits can cause harmonic distortion that may result in neutral currents that are substantially higher than the line currents.

Neutral wire sizing for current capacities in the range of 1.5 to 2.0 times the line conductors is common. In portable installations, many municipalities have mandated two parallel neutral conductors, each sized the same as the individual feeder conductors, to provide adequate capacity for the neutral current.

In addition to the cost and number of wires required, there are noise consideration in locating and installing the dimming equipment and the wiring. It is important that noise generated by the dimming equipment is considered when locating the equipment. Although there may be no perceptible noise from modern dimming units, there may be a cumulative effect if a large number of dimming units are installed in the equipment racks. In addition, there is a significant amount of heat generated by the dimming equipment that must be removed from the equipment cabinets to keep operation within the temperature limits of the solid state in the dimmers. Fans are traditionally installed in the dimmer racks to force air through the rack. As the number of dimmers in a rack is increased by more effective miniaturization of the dimmers, the heat as well as the noise generated by the cooling fans increases. It is important that the dimmer racks be located far enough away from the audience, or in a sound conditioned location, to control the level of noise that can be heard in the theatre. Another potential source of noise is the alternating magnetic field generated between the "hot" and "neutral" wires of the individual dimmer circuits when the wiring is installed in the raceway system.

If several individual circuits are installed in a common raceway, the additive effects of the wiring noise could be audible. Therefore, it is wise to consider banding the individual hot and neutral wires of each circuit together to minimize some of this noise. It may also be appropriate to consider "tie-wrapping" all of the circuit wires in an individual raceway to reduce the generated noise. Caution must be exercised in doing this to ensure that there is not a significant heat buildup as a result of reducing the air flow around the individual conductors. The services of a qualified electrical engineer should be sought to help with these questions.

**Emergency Power**. A system of emergency lighting is required for spaces suitable for occupancy by 100 or more people. The lighting required to be supplied by the emergency system includes, as a minimum, house lights necessary to meet the minimum egress lighting illuminance requirements, exit signs, aisle lights if provided, step lights, and back stage lighting to allow safe egress. It is very difficult to provide the required emergency lighting throughout large spaces with self-contained units with adjustable heads.

Lighting other than that legally required may be added within the capacity of the emergency power system if it is judged to enhance the safety of the facility. Regulations now require dimmer-controlled lighting circuits used as part of the emergency lighting to be transferred by an automatic transfer switch that meets the requirements of UL 1008. Optional lighting deemed desirable for emergency lighting must be installed in accordance with the requirements of NFPA 70, Article 702. Requirements for the emergency lighting system can be found in the applicable regulatory documents.

### 4.4 LIGHTING FOR THEATRES

There are two basic types of theatres, for live productions and for film (motion picture). The former can be further classified as legitimate, community, and school theatre. The term "live production" refers to the presence of live actors on stage. In the case of motion picture theatres, there is only one classification to consider, and that is the indoor auditorium. Drive-in theatres, which were popular several years ago, have all but disappeared. Lighting requirements for the marquee, lobby, and foyer are similar for live and for film auditorium theatres. An important goal common to both types of theatre is to provide transitional illuminances to accommodate readaption as patrons proceed from the brightly lighted marquee and street area to the lobby, the foyer, and eventually the auditorium. The lighting requirements for the various types of spaces within the two types of theatres are quite different, however.

**Marquee.** Attracting attention is one of the motives in the design of theatre exteriors. Much of the selling for current and coming attractions can be done here. Flashing signs, running borders, color-changing effects, floodlighting, and architectural elements are but a few of the many techniques employed. As styles and tastes change, it is necessary to design the exterior elements of a theatre to convey the feeling of the neighborhood. Many marquee "current attraction" panels are lighted with incandescent filament lamps, fluorescent sign tubing, or fluorescent lamps behind diffusing glass or plastic. Opaque or colored letters on a lighted field are generally more effective than luminous letters on a dark field. The principal requirement is uniformity of luminance, because variations in luminance across the face of the sign that exceed a ratio of 3:1 from the brightest to the darkest area are noticeable and detract from the message being presented. Luminaires designed to emit infrared radiation for heating and snow melting can be used in cold climates.

| Type of Area in Which Theatre Is Located | Range of Ambient Horizontal Illuminances, lx (fc) | | Recommended Sign Luminance, cd / $m^2$ |
|---|---|---|---|
| City center | 50–100 | (5–10) | 500–1200 |
| Shopping mall | 20–70 | (2–7) | 400–700 |
| Residential | 10–50 | (2–5) | 300–500 |
| Under marquee | 200–500 | (20–50) | 2000–5000 |

**Table 1.** Recommended Illuminances and Theatre Advertising Sign Luminances in Various Locations [5]

**Lobby**. An illuminance of 200 lx (20 fc) is desirable in theatre lobbies. The ceiling luminaires are often integrated with the marquee soffit. Many lighting treatments are applicable here; some considerations are easy maintenance, designs that retain architectural elements, and brightness patterns that attract attention as well as influence the flow of traffic. (People tend to move toward brighter areas over darker areas; this is known as phototropism.) Poster panels often contain their own lighting system, including fluorescent lamps, spotlighting, or transillumination. Poster luminances should range from 70 to 350 cd/m2, depending on surroundings brightness. An important consideration is to allow sufficient depth behind the illuminated panel so fairly uniform brightness may be obtained.

**Foyer.** Usually a restful, subdued atmosphere is desirable in the foyer. Illumination from large, low-brightness elements, such as coves, is often employed. Wall lighting and accents on statuary, paintings, posters, and plants are important in developing atmosphere. Obviously, light must not spill into the auditorium. Before and after performances, general illuminance levels of 50 lx (5 fc) for motion picture theatres and 150 lx (15 fc) for live production theatres are recommended. Lobbies and foyers can also be used as public gathering places and as places of assembly for civic and business events. The likelihood of these events occurring should be considered in planning the lighting system as well.

**Live Production Theatres:** Although there are many varieties of indoor and outdoor live production theatres, such as amphitheater, music tent, arena, and open stage, the most common are the traditional proscenium and the open stage or thrust type

**Fig. 4.2:** Two views of the Ford Centre for the Performing Arts in Vancouver, British Columbia. The theatre has a traditional proscenium stage, shown here set for a chamber music performance with a large spotlight on the piano. An orchestra pit is located in front of the stage and would be used for musicals, opera, and ballet performances. The interior lighting design features evenly spaced downlights, mounted on the building's structural supports. The lighting provides adequate general illumination and contributes to the pleasantness of the space.

The proscenium-type theatre is composed, typically, of a seating area and a stage area. It may serve not only as a theatre, but as an assembly and lecture hall, a study room, and a concert area. Fig-4.2 shows the lighting of Ford Centre in Vancouver, British Columbia. Considerable attention is being given to the development of speech and theatre arts programs not only in schools but also as a community activity among adult groups. The many uses of the theatre require well-planned lighting.

It is important to provide a large number of power outlets at various locations, as well as the proper luminaires and control equipment, so that the stage lighting designer can create lighting for all stage performances. The necessary structural provisions must be made to allow placement of the lighting equipment and access for their installation, operation, and maintenance.

**Seating Area**. The seating area should have diffuse, comfortable illumination. Because the seating area often accommodates a variety of activities, different illuminances are necessary. A minimum illuminance of 100 to 200 lx (10 to 20 fc) should be provided in the seating area when performances are not taking place. This general lighting should be under dimmer control, preferably from several stations, such as the stage lighting control board, the projection booth, and a staff entrance.

There should be transfer capabilities, however, so that the lighting is not accidentally turned on during performances. Lighting equipment for the seating area may include general downlight luminaires, coves, sidewall urns, and curtain and mural lights. Higher illuminances of at least 300 lx (30 fc) are required to perform visual tasks, such as reading or the taking of examinations. Selected lighting system circuits can be used for cleaning and rehearsals. "Panic" switches independent of dimmers and switches should be provided to allow an operator to bring on selected lights in the house in case of emergency. In accordance with local and national codes, an alternate electrical supply for emergency lighting must be provided. This system may include emergency house lights, exit lights, shielded aisle and step lights, and other required lighting.

## 4.5 Stage Lighting

**Basic Lighting Functions.** An appreciation of the dramatic potential of lighting begins with an understanding of its four basic functions:

_ Visibility. This is the most basic function of lighting in the theatre. For the audience to hear and understand in the theatre, they must be able to see.

_ Motivation. Motivation or naturalism is the term given to the expression of time and place.

_ Composition. Composition is revealed artistically through light and shadow. Warm and cool light give plasticity and composition to the visual effect. The concept of the production as indicated by the playwright and implemented by the director determines the approach of the designer.

_ Mood. Mood, or atmosphere, as created by the total visual effect, brings the stage into focus with the meaning of the play. The final visual effect is provided by equipment that has been chosen by the designer because it supplies the desired output of light in terms of intensity, form, color, and movement.

**Properties of Light** The controllable properties of light as they apply to the theatre include intensity, form, color, and movement. The control exercised by the designer over these properties has a direct bearing on the success of the performers in achieving the intended response from the audience.

***Intensity.*** Intensity control is achieved with various types of luminaires, lamps, mounting positions, and color media and, of course, with dimmers. Precise, consistent dimmer control is essential for establishing and maintaining various intensity levels. Vertical illuminances of 2000 lx or higher are required to highlight selected performances.

***Form.*** Form, meaning the distribution of the light, calls for a wide variety of luminaire types and mounting positions. The angle of the light relative to the object and the viewer creates dimensionality, which in turn is a function of the fixture type, location, focus, and dimmer balance. Luminance ratios on the stage should not exceed 100:1.

***Color*** in lighting design is used to accent, enhance, distort, and motivate the scene. Color is controlled by means of lamp selection, dimmers, and filters that can be placed in front of each source. Incandescent lamps, in particular, become much yellower as they are dimmed. A tonal quality can be obtained by the additive mixture of two or more sources. The color rendering index (CRI) of light sources used in theatre should not be less than 80.

***Movement.*** Movement consists of a change in one or all light properties. Movement is usually accomplished by dimming individual luminaires rather than by luminaire movement. However, manually operated follow spots are commonly used.

**Lighting Locations**. There are two basic locations for lighting equipment:

(1) in front of the proscenium opening, including the auditorium ceiling, side walls of auditorium and proscenium, balcony front, follow-spot booth, and edge of the stage apron; and

(2) behind the proscenium opening, including pipes for attaching tormentor (side) lights, overhead cyclorama or top lights, and stage electrics (see below) above the stage. Also employed are cyclorama pit or base lights as well as special locations in free spaces at the side or rear of the stage, including ones that are floor mounted, hanging, or set beneath the stage area. Though the positions may be fixed, virtually every luminaire is portable and gets shifted around for each production. The focus, direction, intensity, and color generally are different for each production. To determine the required lighting positions, the stage is divided into lighting areas. Although every project has its own unique requirements, the following example is typical. A typical multipurpose stage can be divided into smaller lighting areas 3 to 4 m (10 to 12 ft) in diameter. Therefore, a stage 12 m (40 ft) wide by 9 m (30 ft) deep would each have three rows of four lighting areas, for a total of 12 lighting areas.

Each lighting area should have four sets of luminaires:

1. Two luminaires, 35 to 45° above horizontal and 45° to both sides of the lighting area should be located on a "front-of-house" ceiling bridge, box boom, stage electric, or tormentor position. Ellipsoidal and possibly Fresnel spotlights can be used at these locations.

2. One luminaire, 35 to 45° above horizontal, should be mounted directly in front of the lighting area on the same supports as those in number 1 above. These luminaires are also of the same type as in number 1 above, with the possible addition of PAR-type luminaires for the upstage positions.

3. One luminaire should be mounted from the stage electrics directly above the lighting area. An ellipsoidal spotlight, a PAR, a striplight or borderlight, or, possibly, a scoop can be used.

4. One luminaire 45 to 75° above the horizontal should be mounted from the stage electrics directly behind the lighting area as a back light(shown in fig 4.3). An ellipsoidal spotlight or a PAR can be used for this purpose. If low cost is a consideration, striplights (borderlights) can be used in this position.

In addition to the positions listed above, a row of cyc lights located at the top and ideally about 2.5 m (8 ft) in front of the cyclorama can be used to illuminate the background. Many times this space is not available for luminaires and compromises have to be made. In the case of high cycloramas, the cyc lights can be placed at the bottom of the cyclorama.

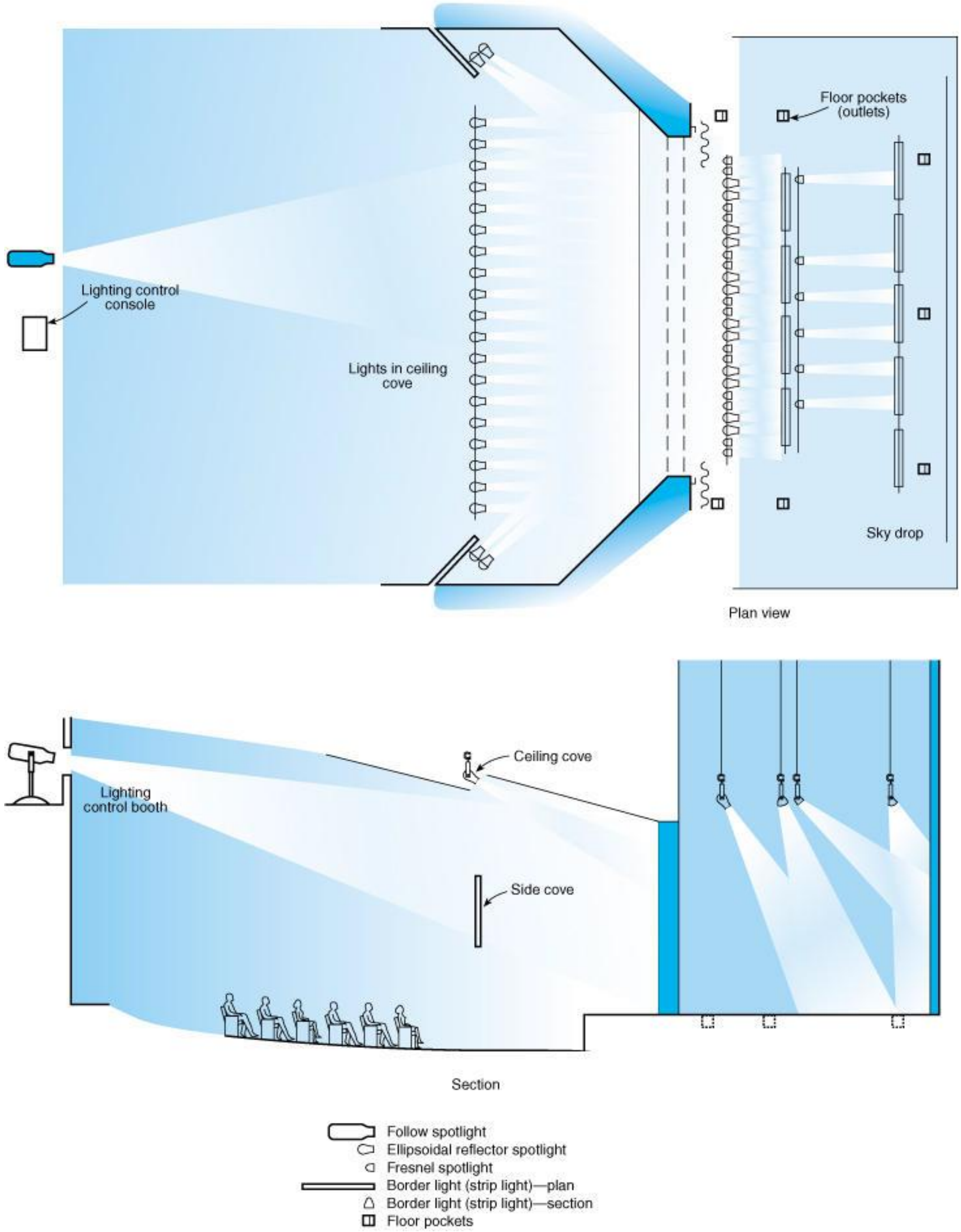



**Fig. 4.3:** Typical plan and section of an average size theatre.

There are many other possible luminaire positions. For example, a luminaire mounted 25 to 35° above the horizontal at the front of a balcony can be effective in reducing shadows. Further, the side-wall slots and tormentor positions are effective for modeling and for dance productions. In general, the lighting systems should permit the stage lighting designer enough flexibility to be as creative as necessary to provide the lighting required for the full range of activities envisioned for the stage.

**Luminaires in Front of the Proscenium Opening**

***Luminaires in the Auditorium Ceiling***. Stage-lighting luminaires in the auditorium ceiling are generally used for lighting downstage and apron acting areas. Each luminaire should produce a well-defined light beam that can provide an average illuminance of 500 to 1000 lx (50 to 100 fc) of white light on a vertical plane, with adjustable means for a controlled cutoff, so that the beam can be varied in shape to cover a desired area with little or no spill onto adjacent areas. These spotlights are best located behind slots, or coves, in the ceiling and are ideally mounted in a continuous slot stretching across the ceiling from side wall to side wall.

***Luminaires in Auditorium and Proscenium Side Walls***. Luminaires located on or in the side walls are recommended, although not absolutely required. They are used mainly as a supplement to the ceiling spotlights and are of a similar type. Preferably, these luminaires should be recessed into wall slots. They provide lower illumination angles than the ceiling luminaires as well as a variety of side lighting angles as shown in plan in Fig-11.

***Luminaires on the Balcony Front.*** There are occasions when the balcony position affords desirable low lighting angles or a soft wash of directional front lighting. Attention must be paid to shadows, however. There is a danger that shadows from low-angle front spots may fall on the scenery and move as the actor moves. This causes an unacceptable distraction. Easy access must be provided to these spaces so that the luminaires can be readily put in place, focused, and lamped.

***Follow Spot Booth***. Follow spots are used to highlight selected performers. A follow spot should be capable of providing a level of at least 2000 lx (200 fc) in an area of 2.5 m (8 ft) in diameter and should have available beam size and shape so that it can be reduced to only cover the head of a person or widened to flood a considerable portion of the stage. In addition to the usual accessories, such as an iris, spread lens, or horizontal paired shutters, follow spot equipment often includes a color wheel or boomerang (a device for inserting individual filters of several different colors into the follow spot) that can be operated from either the side or the rear of the spotlight. Follow spot positions should be near the center of the house at the rear. It should be possible for the beam of light to reach all areas of the stage and the orchestra pit in front of the stage, particularly because a portable stage can be used to fit over the orchestra pit. *Footlights.* Footlights are a set of striplights, sometimes multicolored, at the front edge of the stage platform, used to soften face shadows cast by overhead luminaires and to add general tone-lighting from below. Footlights may be used to light large flat scenery, for special effects, for mood, or to duplicate period scenes.

**Luminaires Behind the Proscenium Opening**

***Overhead Locations***. The greatest number of luminaires in any one location upstage of the proscenium is mounted on the first pipe, or bridge, immediately upstage. The luminaires for this position may include spotlights, borderlights, and scenic projectors. The majority of the spotlights have variable focus to produce a soft-edged beam. A number of ellipsoidal reflector spotlights or PARs are usually mounted in this row. There should be provisions for mounting additional rows of lights on pipes parallel with the proscenium opening every 2 to 2.5 m (6 to 8 ft) of stage depth.

***Stage Electric***. The stage electric is a pipe, or bridge, with an electrical connector strip mounted to it and running the width of the stage proscenium opening. The basic purpose of the connector strip is to provide a simple and quick method of electrically connecting a number of luminaires above the stage. Outlets on the connector strip should not be spaced closer than 300 mm (12 in) apart, and every outlet should be on an individual circuit with a separate neutral.
A more flexible alternative to connector strips incorporates a number of multiconductor cables and electrical boxes. Every cable should be long enough to locate the outlet box at any position on the stage electric and at any height above the stage.

***Border Lights and Scoops for Stage Light Pipes***. Although Fresnel and ellipsoidal luminaires are most commonly used on stage light pipes, other luminaires can also be used. A border light or series of scoops provides general stage lighting and illumination on hanging curtains and scenery. They contribute tonal quality to the overall lighting effect. Separate control of the border light or scoops enables parts of the stage to be variously accented in brightness and color. These luminaires should illuminate the whole width of the curtain or flat scenic drop but should be wired on three or four separate circuits to enable changes in the color of illumination. They should be mounted at least 1.2 m (4 ft) upstage of the conventional borderlight equipment. The illuminance provided by border lights or scoops in the center of the vertical surface should not be less than 250 lx (25 fc) of white light when measured at a point 1.8 m (6 ft) from the stage floor.

***Cyclorama Top Lighting***. Cyclorama borderlights must illuminate the visible width of the background, independent of illumination from cyclorama bottom lighting. Cyclorama lighting requires at least twice the illuminance provided by other borderlights. When the cyclorama is an important feature and deep color filters are used, then the wattage of the associated borderlight equipment can be from two to four times that of a regular borderlight, depending on the density of the filter. The required illuminance may necessitate two parallel rows of borderlights, using, for example, 250-W PAR-38 lamps on 150 mm (6 in.) centers or 500-W PAR-56 lamps on 200 mm (8 in.) centers in each strip. An alternative is striplights using series-wired MR-16 lamps.

***Backlighting From an Upstage Pipe***. It is desirable to provide a row of high-intensity, narrow-beam luminaires, such as Fresnel spotlights, parabolic spotlights, or PAR luminaires, suspended on an upstage pipe and directed downstage to provide backlighting of artists in the main acting area. There may be one 500- to 750-W luminaire for every 1.2 to 1.8 m (4 to 6 ft) of effective stage width.

***Mounting for Stage Side Lights***. There are two methods of providing side stage lighting; suspended three- or four-rung ladders or floor-mounted boomerangs or tormentor pipes. Side and modeling light are essential to a stage production.

***Special Theatrical Effects***. Fluorescent paints, fabrics, or other materials responding to ultraviolet (UV) radiation are often used for special theatrical effects. Sources for exciting the fluorescent materials include mercury lamps with filters for absorbing visible radiation; fluorescent "black light" lamps, which also require a filter; and integral filtered fluorescent "black light" lamps. Carbon arc follow spots are sometimes filtered for "black light" effects. Strobe lights and lasers are used in today's theatre. Great care must be exercised where using UV and lasers to comply with all government and municipal regulations and to avoid operations that could cause permanent eye damage to the audience, performers, or operators.

***Automated Luminaires and Accessories***. Many theatrical and television productions use luminaires that can be remotely moved or steered, or whose color, pattern and beam edge, and focus can be changed to achieve the effect of moving light. These luminaires generally are mounted in the same way as fixed luminaires but require additional power and control wiring.
Lens accessories are available for remote color selection. These require additional power and control wiring.

***Scenic Projectors***. An increased understanding of the techniques of slide projection by theatre personnel has led to an improvement of the basic optical design for projection in the live theatre. Some of the principal improvements include: increased projector lamp wattages up to 10 kW; the introduction of new compact metal halide lamps to provide additional scene illumination and coverage; improved methods for slidemaking; remote, programmed slide changing; wide-angle projection to screen widths of 1.5 times the projection distance; standardization of units to permit easy interchangeability; and the availability of relatively simple and inexpensive remote-control 35-mm projectors.

**Motion Picture Theatre Auditoriums**

The objectives of auditorium lighting in the motion picture theatre may be outlined as follows:
_ To create a pleasing, distinctive environment
_ To retain brightness and color contrasts inherent in the motion picture
_ To create adequate visibility for safe circulation at all times
_ To provide comfortable viewing conditions

For general lighting during intermission, 50 lx (5 fc) is considered the minimum. During the picture, illumination is necessary for safe and convenient circulation of patrons. Illuminances between 1 and 2 lx (0.1 and 0.2 fc) represent good practice. The screen luminance with the picture running is between 3 and 20 cd/m2. The need to eliminate stray light on the screen dictates controlled lighting for at least the front section of the auditorium. Downlighting is one of the most effective methods for this purpose. In general, diffusing elements, such as coves,
allow too much light to fall on the screen if they provide adequate illumination in the seating area. Diffusing wall brackets, semidirect luminaires, and luminous elements are generally too bright to be used for supplying illumination during the picture presentation. The luminous contrast between the screen and its black border is sometimes more than 1000:1, creating uncomfortable viewing conditions.

The luminance of areas around the screen can be raised; however, they should not have decorations that are distracting. Light for this purpose may be reflected from the screen under special conditions, or it may be supplied by supplementary projectors or by elements behind the screen. Curtains may be lighted in color with a projector border during intermissions. Adequate spotlighting on the stage is desirable for announcements and special occasions. Aisle luminaires should have low brightness and be spaced to give a uniform illuminance of 10:1 in the aisle. House lights should be dimmer controlled.

**Meetings, Conventions, and Industrial Show Facilities**

Meetings and conventions require comfortable ambient illumination as well as accent lighting. Where open discussion takes place between speakers and audience, the lighting should be free of glare to support dialog. Lighting for industrial shows and new-product presentations may require some form of theatre lighting. Stage locations may vary considerably from meeting to meeting. A show that uses rear projection may move the stage area 4.5 to 6 m (15 to 20 ft) forward. Another meeting may require a simple platform with maximum space for an audience seated in classroom or conference style. Many meetings use a center area or theatre-in-the-round arrangement.

Other producers find a projected stage along a wall more satisfactory for their presentation. Many meetings are conducted in multipurpose spaces that are used for food service, fashion shows, motion pictures, social events, and meetings. The ease and speed with which these areas can be changed from one arrangement to another are important economic factors.
Lighting must be coordinated with many other elements. These include wall surface brightness, projection screen location, and communications and sound systems.

Projection from audiovisual equipment and follow spots requires unobstructed views of the screens, stages, and acting areas. Chandeliers must not be placed in locations that interfere with the projection or "stage" lighting. A sufficient number of dimmers, as well as a flexible distribution of wiring and luminaire mounting locations, should be provided. For the required flexibility, no fewer than twenty-four dimmers should be available for spaces intended for complex presentations.

**Theatre-Restaurants, Lounges, and Discos**

Stage lighting design criteria for theatres and auditoriums are generally applicable to theatre restaurants, night clubs, and lounges. However, theatrical lighting in a small area, such as a lounge, utilizes more compact luminaires. For low ceilings, a basic luminaire is an "inky" with a 76-mm (3-in.) Fresnel lens or an adapter accessory having individually adjustable framing shutters and lamps up to 375 W. In larger spaces with longer throws, a Fresnel spotlight or a floodlight for 250- to 400-W lamps and a beamshaper accessory can be used. An alternative is a small ellipsoidal framing spot of 650 W or less, available with wide-, medium- and narrow-beam
lens systems. Discos employ many stage lighting techniques and a variety of theatrical equipment. Typically, flicker, flash, and movement in light patterns are introduced through the use of mirror shower balls, spinners, rotators, and police emergency lights. Control systems include presets, chasers, and programmers.

**Luminaire Locations**. Luminaires can be positioned closer to vertical than would be acceptable for legitimate theatre, the limit being closer to 30° than to the 45° prevailing in theatrical work. Downlights are used to produce pools of light on dancers and set pieces. Uplights, recessed in the stage floor, can also be used. Side-mounted luminaires, located from 45° in front of to 45° behind the performer, are essential for three-dimensional effects, particularly in dance and production numbers. Floor-mounted linear strips can be used for horizon effects on cycloramas.

These may be of the disappearing type or recessed with expanded metal covers to permit performers to walk over them.

**Follow Spots**. Locations for several follow spots should be provided to light the performers from all viewing directions. One or more follow spots should be able to cover audience areas. Some performers enter from the audience, and runways are frequently used to bring the chorus closer to the viewers. Side stages on each side of the main stage are frequently used for bands and stage action, and provision should be made for adequate lighting of these areas.

**Transparencies**. Scrims are frequently used to hide the band when playing for a show. On the other hand, the band and performers are frequently revealed by bringing up lighting behind the scrim and keeping light off the front of the scrim. These changes may occur on the side or on the principal (center) stage.

**Special Effects.** Mounting devices and switching circuits and receptacles are required for "black lights," projectors, electronic flash, motor-driven color wheels, and for dissolves, fog and smoke machines, mirror balls, and similar equipment. Color organs are used to pulsate lights with music. Plastic-covered floors for dancing and entertainment should provide selectable color and pattern effects. In small spaces, fluorescent lamps and dimming ballasts are used. If ventilation can be provided, incandescent lamps can be used for special effects.

**Controls.** Single lights are frequently used. Receptacles should be on individual dimmer circuits. Permanent grouping should be avoided. Non-dimmed controls should be integrated with the dimmer controls, that is, they should be switched with voltage-sensitive relays controlled by potentiometers of the same type as those used for the dimmer controls.

### 4.6 Lighting Equipment Installation

The method of supporting the luminaires depends to a great extent on the ceiling height and the intended use of the studio. Where the height is low, in the range of 3.5 to 5 m (12 to 16 ft), a permanent pipe or track grid is usually installed from which the luminaires are hung directly or through pantographs, which permit individual vertical positions. The luminaires are capable of complete rotation and tilting. In high-ceiling studios and in television theatres, the luminaires are supported either from fixed pipe or track grids or on counterweighted pipe or track battens. A overhead grid system for mounting lighting equipments in a studio where ceiling height is low, is shown in Fig-4.4

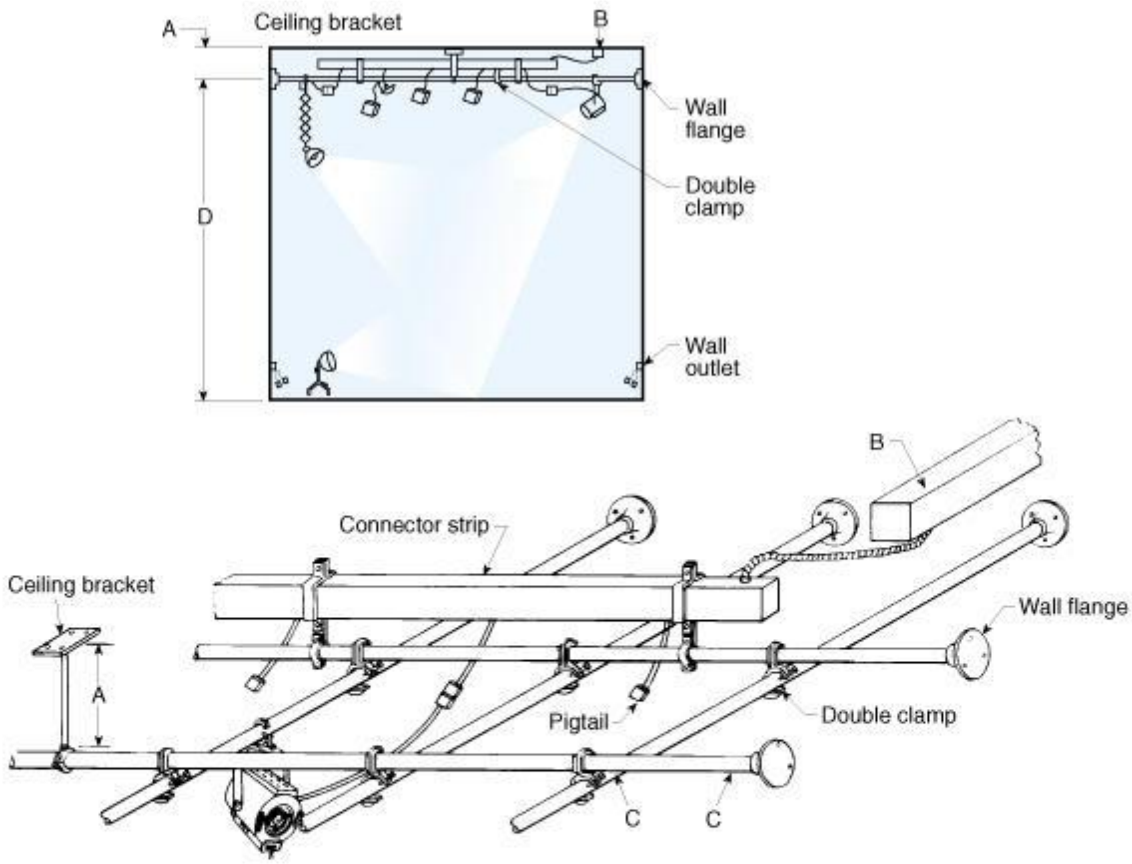



**Fig. 4.4.** Diagram showing a typical overhead grid system for mounting lighting equipment in a small low-ceiling studio. Typical systems for larger studios with higher ceilings can be raised and lowered. In the drawings *A* = 300 mm (12 in.), *B* = 100 × 100 mm (4 × 4 in.) duct, *C* = 32 mm (1.5 in.) ID pipe, and *D* = 3 to 3.7 m (10 to 12 ft).

## Projected Backgrounds

A scene may be projected onto a translucent screen from behind. This technique is used to simulate background scenery, which may take the form of stationary objects as produced by a slide, moving effects such as clouds and water, or continuous motion simulating moving trains or motion from an automobile as produced by a motion picture film. For realism, projected highlight levels should be within a 2:1 ratio of live highlight levels. As a rule, it is desirable to have a projected highlight luminance of 250 cd/m2 when the acting area is illuminated to 1000 lx (100 fc).

## Chroma Key

The production technique known as chroma key is a special effect that enables any background material to be matted into a scene. In the studio, a color camera views the subject against a backdrop of a primary color that has sufficient saturation to produce a full output level in the corresponding channel of the camera. This signal output is used to key a special effect

generator so that all information except the wanted subject is matted out of the original studio scene. Information from any other source, such as a film chain or video tape recorder, can then be inserted in the matted portions of the signal. The primary color used in the backdrop is chosen on the basis that it is not present in the color of the wanted subject. When human subjects are used, blue is usually the best background color because it is absent in flesh tones. Additional precaution must be taken to avoid the use of the background color in costumes or stage props.
The illuminance on the backdrop must be high enough to produce a full output signal from the camera without excessive noise. Light should not be reflected from the background onto the subject, because it will create spurious keying signals.

### 4.7 Types of Illumination

***Base Light or Fill Light***. Base light or fill light is usually supplied by floodlights that supply broad, soft illumination. It is desirable to aim base lights at a 12 to 15° angle below horizontal.

***Key or Modeling Light***. Key or modeling light is usually supplied by Fresnel lens spotlights ranging in lamp size from 500 to 10,000 W. Fresnel luminaires are equipped to hold supplementary masking devices, such as barn doors, snoots, and color frames. The barn door fits in front of the lens and is used to limit the bottom, top, or sides of the light beam. These units can either be hung or used on floor stands and are generally aimed at a 20 to 40° angle below horizontal. Back light is used for separation (Refer to Fig-13). Back lights are hung behind a subject and are aimed at approximately a 45° angle to light the back of the head and shoulders, and to separate the subject from the background. Back light illuminances should be from one-half to the same as that of the front light, depending on the reflectance of the hair and the costume.

***Set Light***. Set light is used to decorate or help give dimension to scenery. The amount of light necessary is totally dependent on the reflectance of the scenery. Light skin reflects 40 to 45% of the illuminance. Therefore, the major part of the background must be kept below the luminance of the face. A gray-scale reflectance of 30% is a good average value for the background. There are many other luminaires that can be used to help dramatize a show, such as sun spots, ellipsoidal spots, follow spots, pattern projectors, and striplights.

***Balancing for Correct Contrast***. It is important to have the proper balance among the different types of lighting discussed above. For instance, if the set is painted in a color value that reflects more light than the flesh of the actor, skin tones may appear darker than desired in the picture. This means that the set light should be reduced. A quick way to do this is to cover the set-lighting luminaires with diffusing material.

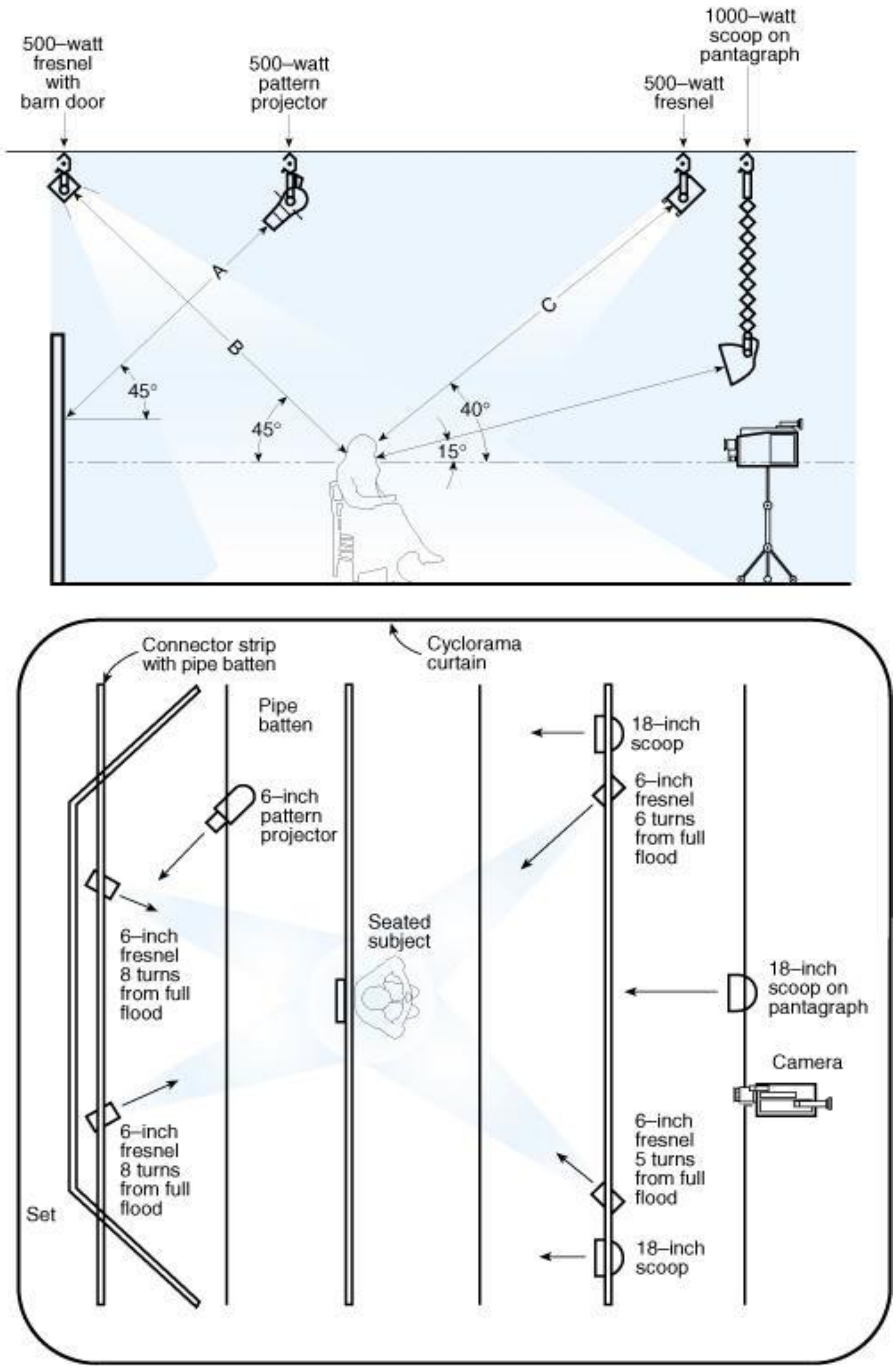



**Fig.4.5**: Diagrams showing good practice in luminaire location and aiming angles. In the top diagram *A* = 3 m (10 ft), *B* = 3.7 m (12 ft), and *C* = 4 m (13 ft). The 1000-W scoop on the pantograph provides base light; the 6-inch Fresnel in front of the subject provide key light; the 6-inch Fresnel behind the subject provide back light; and the pattern projector provides set light.

Spun-glass diffuser material is available in 1 by 4 m (3 by 12 ft) rolls and can be cut to fit the luminaire. One 0.38 mm (0.015 in.) thickness cuts about 20% of the light. Additional thicknesses can be used until the correct contrast is obtained. The problem in using spun glass is that the character of the light has been altered from somewhat firm image-forming to soft, diffuse, flood, and less directional ambient light. Another medium that is sometimes used to balance the lighting is one or more layers of ordinary house window screening. Black window screening material has the virtue of minimizing changes to the optical characteristics of the light. If the installation includes dimmers and a cross-connecting system, (shown in fig-4.5) the different luminaires can be grouped and then dimmed until the desired contrast is obtained. There is no apparent color effect due to dimming in black-and white television. In the case of color television, the correlated color temperature decreases 10 K per volt for lamps operated at 120 V. As stated before, differences of 300 K contained in one scene are perceptible. A very low correlated color temperature contains little short-wave energy and may make blue hues dark and as a result introduce unwanted noise into the picture.

## 4.8 AUDITORIUM LIGHTING AS DESCRIBED IN IS 3646 PART II:

The illuminance requirements in auditoriums is given in IS 3646 Part I&II. [6]

| | |
|---|---|
| Foyers | 150-300-300 |
| Auditoria | 50-100-150 |
| Booking office | 200-300-500 |
| Dressing rooms | 200-300-500 |
| Projection room | 100-I50-200 |
| Corridors | 70 |
| Stairs | 106 |

Table 2: Illuminance Values

## 4.9 AUDITORIUM LIGHTING AS DESCRIBED IN National Lighting Code (2010):

### General

This clause deals with assembly halls, concert halls, theatres, cinemas, dance halls and exhibition halls and parts of such buildings to which the general public have access, for example, foyers, idors, stairways, auditoria and service areas. Safety lighting is required to assist members of the public to leave the premises if the normal lighting is switched off. Emergency lighting is also required to be immediately available in the event of failure of the mains supply.

### Foyers

In foyers, the lighting should be such that visual adaptation can be satisfactorily achieved when entering or leaving the building during both day and night. The necessity for visual adaptation coupled with the advertising value of bright surroundings, has often led to the adoption of higher illuminances than the minimum recommended. Tungsten filament, compact fluorescent and tubular fluorescent lamps can be used for these areas, the choice generally depending on aesthetic considerations. The problem of visual adaptation between the brightly lit foyer and the darker auditorium should be solved by progressively reducing the illuminance in the connecting corridors. In cinema and theatre foyers the luminaires should be decorative, but at the same time provide adequate illuminance.

### Auditorium

In multipurpose halls the lighting system should be as versatile as possible. If a substantial reduction in illuminance is required, the lighting should be capable of being dimmed smoothly or switched in stages. Cinemas and auditoria may be provided with direct or indirect lighting, or a mixture of both, but all visible luminaires should be decorative and compatible with the interior design.

### Stage Areas

In assembly and concert halls a means should be provided to highlight the performers either by increasing their illuminance or by subtly dimming the auditorium lighting in order to focus the attention in the required direction. To enhance modelling, some light may be directed onto the stage from the sides of the auditorium and from as high up as possible.

**Dance Halls**

Dance halls require good general lighting, usually capable of being dimmed, over the dance floor and adjacent areas. Although this may be provided by tubular fluorescent lamps, it is usual to add a degree of sparkle and modelling by the use of luminaires with incandescent lamps. In addition, the provision of special effects produced by coloured lighting or ultraviolet radiation is often a permanent feature of dance hall installations.

**Exhibition Halls**

Exhibition halls should be uniformly illuminated by general lighting having reasonable colour rendering properties. Provision should be made for additional electrical outlets for the directional lighting of exhibits.

**Special Lighting Requirements**

Recommended systems of lighting in cinema premises and other similar public premises are as follows:

a) In auditoria during the entertainment: both safety lighting and subdued general lighting;
b) In auditoria during intervals: both safety lighting and normal general lighting; and
c) Passages, stairs, etc and exterior exit ways: in the absence of adequate daylight, both safety lighting and general lighting.

# Chapter-5:
# Light Sources

Electric light sources can be subdivided by their main principle of operation(as shown in fig-5.10):

a) Incandescent lamps: In these the light comes from a heated metal wire. The halogen lamp contains a special gas to improve the efficacy. These types are widely used, but wi ll be phased out in the coming years due to their low efficacy;

b) Gas Discharge lamps: The light from these lamps, comes from a discharge between two electrodes in a gas tilled glass or ceramic tube. There are two ranges depending on the most important gas , mercury or sodium. Both these ranges can be subdivided by the pressure in the glass tube high or low pre source; and

c) Solid State Lighting or LED lamps: An LED is a semiconductor device. When a current is passed through an LED, electrons move through the semiconductor material and some of them fall into a lower energy state . In the process, the 'spare 'energy is emitted as light. The wavelength (and hence colour) of the light can be tuned as required by using different semiconductor materials and manufacturing processes. Furthermore, the wavelength spread ofthe emitted light is relatively narrow, giving pure (or saturated) colours.

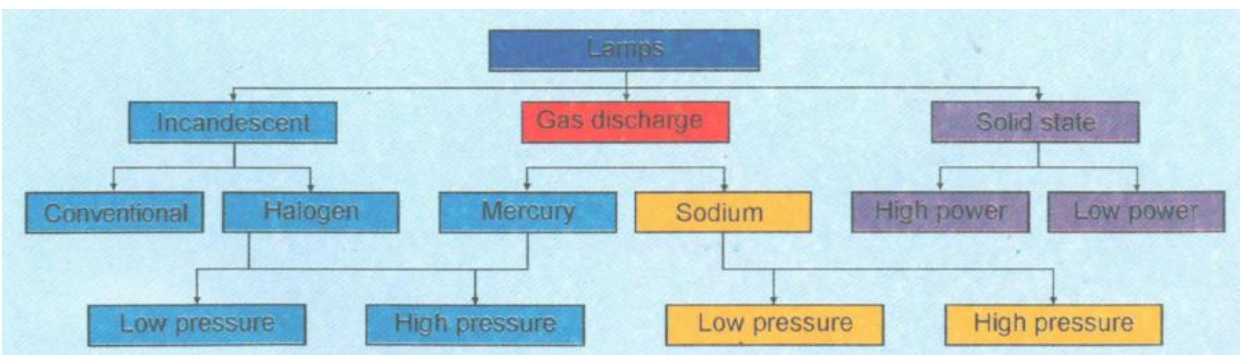



**Fig. 5.1**: Types of light sources

## 5.1 INCANDESCENT LAMPS

The first incandescent lamp was invented by Thoma Alva Edison in 1879 and comprise d carbon filaments instead of tungsten filaments. These lamps had an efficacy of 2.54 Im/W. The incandescent lamp family can be subdivided into 2 group (shown ini Fig-14):
a) GLS; and
b) Tungsten Halogen lamps.

### 5.1.1 GLS LAMPS

GLS (general lighting service) lamps consist of a tungsten wire filament on a suitable mount structure enclosed in a glass bulb containing an inert gas or vacuum. The base of the GLS incandescent lamp is either bayonet cap or screw cap type ; the outer envelope can be clear, inside frosted , white diffused coated, and specially shaped for decorative purpose. Although, GLS lamps are the simplest in terms of technology and usability, they are already on their way out, and many countries have banned (or are in the process of banning) them as they are extremely energy inefficient. Tungsten has many desirable properties for use as an incandescent light source. Its low vapour pre sure and high melting point (3655 K) permit high operating temperatures. evaporation of the filament is reduced by filling the bulb with an inert gas. The operating temperature of the filament can then be correspondingly higher . nitrogen and argon are the gases most commonly used. The "bulb may be of clear, coloured or white translucent glass and, a wide variety of shapes.

The cap provides the means of connecting the lamp to the socket. These cap ' are identified by the letters E (Edison) and B (Bayonet) in the type reference followed by a figure indicating the diameter of the cap in millimeters. The most common types of caps used in India for general lighting service lamps are bayonet (B22d), medium crew (E27) and large screw (E 40) type caps. For some of the decorative lamps smaller bayonet (for example, B15) or screw (E 14, E17) caps are also used. A wide variety of tungsten filament lamps are being produced by different manufacturers for various application.

### 5.1.2 HALOGEN LAMP

A halogen lamp, also known as a tungsten halogen, quartz-halogen or quartz iodine lamp, is an incandescent lamp consisting of a tungsten filament sealed into a compact transparent envelope that is filled with a mixture of an inert gas and a small amount of a halogen such as iodine or bromine. The combination of the halogen gas and the tungsten filament produces a halogen cycle chemical reaction which redeposits evaporated tungsten to the filament, increasing its life and maintaining the clarity of the envelope. For this to happen, a halogen lamp must be operated at a higher envelope temperature (250° C; 482° F than a standard vacuum incandescent lamp of similar power and operating life; this also produces light with higher luminous efficacy and color temperature.

The small size of halogen lamps permits their use in compact optical systems for projectors and illumination. The small glass envelope may be enclosed in a much larger outer glass bulb for a bigger package; the outer jacket will be at a much lower and safer temperature, and it also protects the hot bulb from harmful contamination and makes the bulb mechanically more similar to a conventional lamp that it might replace. Standard and halogen incandescent bulbs are much less efficient than LED and compact fluorescent lamps, and have been banned in many jurisdictions because of this.

In ordinary incandescent lamps, evaporated tungsten mostly deposits onto the inner surface of the bulb, causing the bulb to blacken and the filament to grow increasingly weak until it eventually breaks. The presence of the halogen, however, sets up a reversible chemical reaction cycle with this evaporated tungsten. The halogen cycle keeps the bulb clean and causes the light output to remain almost constant throughout the bulb's life. At moderate temperatures the halogen reacts with the evaporating tungsten, the halide formed being moved around in the inert gas filling. At some point, however, it will reach higher temperature regions within the bulb where it then dissociates, releasing tungsten back onto the filament and freeing the halogen to repeat the process. However, the overall bulb envelope temperature must be significantly higher than in conventional incandescent lamps for this reaction to succeed: it is only at temperatures of above 250 °C (482 °F)[1] on the inside of the glass envelope that the halogen vapor can combine with the tungsten and return it to the filament rather than the tungsten becoming deposited on the glass.[9] A

300 watt tubular halogen bulb operated at full power quickly reaches a temperature of about 540 °C (1,004 °F), while a 500 watt regular incandescent bulb operates at only 180 °C (356 °F) and a 75 watt regular incandescent at only 130 °C (266 °F).
The bulb must be made of fused silica (quartz) or a high-melting-point glass (such as aluminosilicate glass). Since quartz is very strong, the gas pressure can be higher,[11] which reduces the rate of evaporation of the filament, permitting it to run a higher temperature (and so luminous efficacy) for the same average life. The tungsten released in hotter regions does not generally redeposit where it came from, so the hotter parts of the filament eventually thin out and fail.

Quartz iodine lamps, using elemental iodine, were the first commercial halogen lamps launched by GE in 1959. Quite soon, bromine was found to have advantages, but was not used in elemental form. Certain hydrocarbon bromine compounds gave good results. Regeneration of the filament is also possible with fluorine, but its chemical reactivity is so great that other parts of the lamp are attacked. The halogen is normally mixed with a noble gas, often krypton or xenon. The first lamps used only tungsten for filament supports, but some designs use molybdenum – an example being the molybdenum shield in the H4 twin filament headlight for the European Asymmetric Passing Beam.
For a fixed power and life, the luminous efficacy of all incandescent lamps is greatest at a particular design voltage. Halogen lamps made for 12 to 24 volt operation have good light outputs, and the very compact filaments are particularly beneficial for optical control (see picture). The ranges of multifaceted reflector "MR" lamps of 20–50 watts were originally conceived for the projection of 8 mm film, but are now widely used for display lighting and in the home. More recently, wider beam versions have become available designed for direct use on supply voltages of 120 or 230 V.

## 5.2 GAS DISCHARGE LAMP

Gas-discharge lamps are a family of artificial light sources that generate light by sending an electric discharge through an ionized gas, a plasma. Typically, such lamps use a noble gas (argon, neon, krypton, and xenon) or a mixture of these gases. Some include additional substances, like mercury, sodium, and metal halides, which are vaporized during startup to become part of the gas mixture. In operation, some of the electrons are forced to leave the atoms of the gas near the anode by the electric field applied between the two electrodes, leaving these atoms positively ionized. The free electrons thus released flow onto the anode, while the cations thus formed are accelerated by the electric field and flow towards the cathode. Typically, after traveling a very short distance, the ions collide with neutral gas atoms, which transfer their electrons to the ions.

The atoms, having lost an electron during the collisions, ionize and speed toward the cathode while the ions, having gained an electron during the collisions, return to a lower energy state while releasing energy in the form of photons. Light of a characteristic frequency is thus emitted. In this way, electrons are relayed through the gas from the cathode to the anode. The color of the light produced depends on the emission spectra of the atoms making up the gas, as well as the pressure of the gas, current density, and other variables. Gas discharge lamps can produce a wide range of colors. Some lamps produce ultraviolet radiation which is converted to visible light by a fluorescent coating on the inside of the lamp's glass surface. The fluorescent lamp is perhaps the best known gas-discharge lamp.

Compared to incandescent lamps, gas-discharge lamps offer higher efficiency, but are more complicated to manufacture and most exhibit negative resistance, causing the resistance in the plasma to decrease as the current flow increases. Therefore, they usually require auxiliary electronic equipment such as ballasts to control current flow through the gas, preventing current runaway (arc flash). Some gas-discharge lamps also have a perceivable start-up time to achieve their full light output. Still, due to their greater efficiency, gas-discharge lamps were preferred over incandescent lights in many lighting applications, until recent improvements in LED lamp technology.

The history of gas-discharge lamps began in 1675 when French astronomer Jean-Felix Picard observed that the empty space in his mercury barometer glowed as the mercury jiggled while he was carrying the barometer. Investigators, including Francis Hauksbee, tried to determine the cause of the phenomenon. Hauksbee first demonstrated a gas-discharge lamp in 1705. He showed that an evacuated or partially evacuated glass globe, in which he placed a small amount of mercury, while charged by static electricity could produce a light bright enough to read by. The phenomenon of electric arc was first described by Vasily V. Petrov in 1802; Sir Humphry Davy demonstrated in the same year the electric arc at the Royal Institution of Great Britain. Since then, discharge light sources have been researched because they create light from electricity considerably more efficiently than incandescent light bulbs.
The father of the low-pressure gas discharge tube was German glassblower Heinrich Geissler, who beginning in 1857 constructed colorful artistic cold cathode tubes with different gases in them which glowed with many different colors, called Geissler tubes. It was found that inert gases like the noble gases neon, argon, krypton or xenon, as well as carbon dioxide worked well in tubes. This technology was commercialized by French engineer Georges Claude in 1910 and became neon lighting, used in neon signs.

The introduction of the metal vapor lamp, including various metals within the discharge tube, was a later advance. The heat of the gas discharge vaporized some of the metal and the discharge is then produced almost exclusively by the metal vapor. The usual metals are sodium and mercury owing to their visible spectrum emission.

One hundred years of research later led to lamps without electrodes which are instead energized by microwave or radio frequency sources. In addition, light sources of much lower output have been created, extending the applications of discharge lighting to home or indoor use.

### 5.2.1 MERCURY VAPOUR LAMP

A mercury-vapor lamp is a gas discharge lamp that uses an electric arc through vaporized mercury to produce light. The arc discharge is generally confined to a small fused quartz arc tube mounted within a larger borosilicate glass bulb. The outer bulb may be clear or coated with a phosphor; in either case, the outer bulb provides thermal insulation, protection from the ultraviolet radiation the light produces, and a convenient mounting for the fused quartz arc tube.

Mercury vapor lamps are more energy efficient than incandescent and most fluorescent lights, with luminous efficacies of 35 to 65 lumens/watt. Their other advantages are a long bulb lifetime in the range of 24,000 hours and a high intensity, clear white light output. For these reasons, they are used for large area overhead lighting, such as in factories, warehouses, and sports arenas as well as for streetlights. Clear mercury lamps produce white light with a bluish-green tint due to mercury's combination of spectral lines. This is not flattering to human skin color, so such lamps are typically not used in retail stores. "Color corrected" mercury bulbs overcome this problem with a phosphor on the inside of the outer bulb that emits white light, offering better color rendition.

They operate at an internal pressure of around one atmosphere and require special fixtures, as well as an electrical ballast. They also require a warm-up period of 4 – 7 minutes to reach full light output. Mercury vapor lamps are becoming obsolete due to the higher efficiency and better color balance of metal halide lamps

Charles Wheatstone observed the spectrum of an electric discharge in mercury vapor in 1835, and noted the ultraviolet lines in that spectrum. In 1860, John Thomas Way used arc lamps operated in a mixture of air and mercury vapor at atmospheric pressure for lighting. The German physicist Leo Arons (1860–1919) studied mercury discharges in 1892 and developed a lamp based on a mercury arc.[4] In February 1896 Herbert John Dowsing and H. S. Keating of England patented a mercury vapour lamp, considered by some to be the first true mercury vapour lamp.

The first mercury vapor lamp to achieve widespread success was invented in 1901 by American engineer Peter Cooper Hewitt. Hewitt was issued U.S. Patent 682,692 on September 17, 1901. In 1903, Hewitt created an improved version that possessed higher color qualities which eventually found widespread industrial use. The ultraviolet light from mercury vapor lamps was applied to water treatment by 1910. The Hewitt lamps used a large amount of mercury. In the 1930s, improved lamps of the modern form, developed by the Osram-GEC company, General Electric company and others led to widespread use of mercury vapor lamps for general lighting

The mercury in the tube is a liquid at normal temperatures. It needs to be vaporized and ionized before the lamp can produce its full light output. To facilitate starting of the lamp, a third electrode is mounted near one of the main electrodes and connected through a resistor to the other main electrode. In addition to the mercury, the tube is filled with argon gas at low pressure. When power is applied, if there is sufficient voltage to ionize the argon, the ionized argon gas will strike a small arc between the starting electrode and the adjacent main electrode. As the ionized argon conducts, the heat from its arc vaporizes the liquid mercury, next the voltage between the two main electrodes will ionize the mercury gas. An arc initiates between the two main electrodes and the lamp will then radiate mainly in the ultraviolet, violet and blue emission lines. Continued vaporization of the liquid mercury increases the arc tube pressure to between 2 and 18 bar, depending on lamp size. The increase in pressure results in further brightening of the lamp. The entire warm-up process takes roughly 4 to 7 minutes. Some bulbs include a thermal switch which shorts the starting electrode to the adjacent main electrode, extinguishing the starting arc once the main arc strikes.

The mercury vapor lamp is a negative resistance device. This means its resistance decreases as the current through the tube increases. So if the lamp is connected directly to a constant-voltage source like the power lines, the current through it will increase until it destroys itself. Therefore, it requires a ballast to limit the current through it. Mercury vapor lamp ballasts are similar to the ballasts used with fluorescent lamps. In fact, the first British fluorescent lamps were designed to operate from 80-watt mercury vapor ballasts. There are also self-ballasted mercury vapor lamps available. These lamps use a tungsten filament in series with the arc tube both to act as a resistive ballast and add full spectrum light to that of the arc tube. Self-ballasted mercury vapor lamps can be screwed into a standard incandescent light socket supplied with the proper voltage.

### 5.2.2 Metal halide

A very closely related lamp design called the metal halide lamp uses various compounds in an amalgam with the mercury. Sodium iodide and scandium iodide are commonly in use. These lamps can produce much better quality light without resorting to phosphors. If they use a starting electrode, there is always a thermal shorting switch to eliminate any electrical potential between the main electrode and the starting electrode once the lamp is lit. (This electrical potential in the presence of the halides can cause the failure of the glass/metal seal). More modern metal halide systems do not use a separate starting electrode; instead, the lamp is started using high voltage pulses as with high-pressure sodium vapor lamps.

### Self-ballasted lamps

Self-ballasted (SB) lamps are mercury vapor lamps with a filament inside connected in series with the arc tube that functions as an electrical ballast. This is the only kind of mercury vapor lamp that can be connected directly to the mains without an external ballast. These lamps have only the same or slightly higher efficiency than incandescent lamps of similar size, but have a longer life. They give light immediately on startup, but usually need a few minutes to restrike if power has been interrupted. Because of the light emitted by the filament, they have slightly better color rendering properties than mercury vapor lamps.

### Operation

When a mercury vapor lamp is first turned on, it will produce a dark blue glow because only a small amount of the mercury is ionized and the gas pressure in the arc tube is very low, so much of the light is produced in the ultraviolet mercury bands.

As the main arc strikes and the gas heats up and increases in pressure, the light shifts into the visible range and the high gas pressure causes the mercury emission bands to broaden somewhat, producing a light that appears more nearly white to the human eye, although it is still not a continuous spectrum. Even at full intensity, the light from a mercury vapor lamp with no phosphors is distinctly bluish in color. The pressure in the quartz arc-tube rises to approximately one atmosphere once the bulb has reached its working temperature.

If the discharge should be interrupted (e.g. by interruption of the electric supply), it is not possible for the lamp to restrike until the bulb cools enough for the pressure to fall considerably. The reason for a prolonged period of time before the lamp restrikes is because the elevated pressure, which leads to higher breakdown voltage of the gas inside (voltage needed to start an arc – Paschen's law), which is outside the capabilities of the ballast.

**Color considerations**

To correct the bluish tinge, many mercury vapor lamps are coated on the inside of the outer bulb with a phosphor that converts some portion of the ultraviolet emissions into red light. This helps to fill in the otherwise very-deficient red end of the electromagnetic spectrum. These lamps are generally called "color corrected" lamps.

Most modern mercury vapor lamps have this coating. One of the original complaints against mercury lights was they tended to make people look like "bloodless corpses" because of the lack of light from the red end of the spectrum. A common method of correcting this problem before phosphors were used was to operate the mercury lamp in conjunction with an incandescent lamp.

There is also an increase in red color (e.g., due to the continuous radiation) in ultra-high-pressure mercury vapor lamps (usually greater than 200 atm.), which has found application in modern compact projection devices. When outside, coated or color corrected lamps can usually be identified by a blue "halo" around the light being given off.

### 5.2.3 SODIUM-VAPOR LAMP

A sodium-vapor lamp is a gas-discharge lamp that uses sodium in an excited state to produce light at a characteristic wavelength near 589 nm.

Two varieties of such lamps exist: *low pressure* and *high pressure*. Low-pressure sodium lamps are highly efficient electrical light sources, but their yellow light restricts applications to outdoor lighting, such as street lamps. High-pressure sodium lamps emit a broader spectrum of light than the low-pressure lamps, but they still have poorer color rendering than other types of lamps. Low-pressure sodium lamps only give monochromatic yellow light and so inhibit color vision at night.

Low-pressure sodium (LPS) lamps have a borosilicate glass gas discharge tube (arc tube) containing solid sodium, a small amount of neon, and argon gas in a Penning mixture to start the gas discharge. The discharge tube may be linear (SLI lamp) or U-shaped. When the lamp is first started, it emits a dim red/pink light to warm the sodium metal; within a few minutes as the sodium metal vaporizes, the emission becomes the common bright yellow. These lamps produce a virtually monochromatic light averaging a 589.3 nm wavelength (actually two dominant spectral lines very close together at 589.0 and 589.6 nm). The colors of objects illuminated by only this narrow bandwidth are difficult to distinguish.

LPS lamps have an outer glass vacuum envelope around the inner discharge tube for thermal insulation, which improves their efficiency. Earlier LPS lamps had a detachable dewar jacket (SO lamps). Lamps with a permanent vacuum envelope (SOI lamps) were developed to improve thermal insulation. Further improvement was attained by coating the glass envelope with an infrared reflecting layer of indium tin oxide, resulting in SOX lamps.

LPS lamps are among the most efficient electrical light sources when measured in photopic lighting conditions, producing above 100 and up to 206 lm/W.[7] This high efficiency is partly due to the light emitted being at a wavelength near the peak sensitivity of the human eye. They are used mainly for outdoor lighting (such as street lights and security lighting) where faithful color rendition is not important. Recent studies show that under typical nighttime mesopic driving conditions, whiter light can provide better results at a lower level of illumination.

LPS lamps are similar to fluorescent lamps in that they are a low-intensity light source with a linear lamp shape. They do not exhibit a bright arc as do High-intensity discharge (HID) lamps; they emit a softer luminous glow, resulting in less glare. Unlike HID lamps, during a voltage dip low-pressure sodium lamps return to full brightness rapidly. LPS lamps are available with power ratings from 10 W up to 180 W; longer lamp lengths can, however, suffer design and engineering problems.

Modern LPS lamps have a service life of about 18,000 hours and do not decline in lumen output with age, though they do increase in energy consumption by about 10% towards end of life. This property contrasts with mercury vapor HID lamps, which become dimmer towards the end of life to the point of being ineffective, while consuming undiminished electrical power.

### Light pollution considerations

For locations where light pollution is a consideration, such as near astronomical observatories or sea turtle nesting beaches, low-pressure sodium is preferred (as formerly in San Jose and Flagstaff, Arizona).[9][10] Such lamps emit light on just two dominant spectral lines (with other much weaker lines), and therefore have the least spectral interference with astronomical observation.[11] The yellow color of low-pressure sodium lamps also leads to the least visual sky glow, due primarily to the Purkinje shift of dark-adapted human vision, causing the eye to be relatively insensitive to the yellow light scattered at low luminance levels in the clear atmosphere.[12][13] One consequence of widespread public lighting is that on cloudy nights, cities with enough lighting are illuminated by light reflected off the clouds. Where sodium vapor lights are the source of urban illumination, the night sky is tinged with orange.

Sodium vapor process (occasionally referred to as yellowscreen) is a film technique that relies on narrowband characteristics of LPS lamp. Color negative film is typically not sensitive to the yellow light from an LPS lamp, but special black-and-white film is able to record it. Using a special camera, scenes are recorded on two spools simultaneously, one with actors (or other foreground objects) and another that becomes a mask for later combination with different background.

This technique originally yielded results superior to blue-screen technology, and was used in years 1956 to 1990, mostly by Disney Studios. Notable examples of films using this technique include Alfred Hitchcock's *The Birds* and the Disney films *Mary Poppins* and *Bedknobs and Broomsticks*. Later advancements in blue- and green-screen techniques and computer imagery closed that gap, leaving SVP economically impractical

High-pressure sodium lamps (sometimes called HPS lights) have been widely used in industrial lighting, especially in large manufacturing facilities, and are commonly used as plant grow lights. They contain mercury. They have also been widely used for outdoor area lighting, such as on roadways, parking lots, and security areas. Understanding the change in human color vision sensitivity from photopic to mesopic and scotopic is essential for proper planning when designing lighting for roadways.

High-pressure sodium lamps are quite efficient — about 100 lumens per watt, when measured for photopic lighting conditions. Some higher-power lamps (e.g. 600 watt) have efficacies of about 150 lumens per watt.

Since the high-pressure sodium arc is extremely chemically reactive, the arc tube is typically made of translucent aluminum oxide. This construction led the General Electric Company to use the tradename "Lucalox" for its line of high-pressure sodium lamps.

Xenon at a low pressure is used as a "starter gas" in the HPS lamp. It has the lowest thermal conductivity and lowest ionization potential of all the stable noble gases. As a noble gas, it does not interfere with the chemical reactions occurring in the operating lamp. The low thermal conductivity minimizes thermal losses in the lamp while in the operating state, and the low ionization potential causes the breakdown voltage of the gas to be relatively low in the cold state, which allows the lamp to be easily started.

### 5.2.4 "White" SON

A variation of the high-pressure sodium introduced in 1986, the White SON has a higher pressure than the typical HPS/SON lamp, producing a color temperature of around 2700 kelvins with a color rendering index (CRI) of about 85, greatly resembling the color of an incandescent light.[15] These lamps are often used indoors in cafes and restaurants for aesthetic effect. However, white SON lamps have higher cost, shorter service lives, and lower light efficiency, and so they cannot compete with HPS at this time.

**Theory of operation**

An amalgam of metallic sodium and mercury lies at the coolest part of the lamp and provides the sodium and mercury vapor that is needed to draw an arc. The temperature of the amalgam is determined to a great extent by lamp power. The higher the lamp power, the higher will be the amalgam temperature. The higher the temperature of the amalgam, the higher will be the mercury and sodium vapor pressures in the lamp and the higher will be the terminal voltage. As the temperature rises, the constant current and increasing voltage consumes increasing energy until the operating level of power is reached. For a given voltage, there are generally three modes of operation:

1. The lamp is extinguished and no current flows.
2. The lamp is operating with liquid amalgam in the tube.
3. The lamp is operating with all amalgam evaporated.

The first and last states are stable, because the lamp resistance is weakly related to the voltage, but the second state is unstable. Any anomalous increase in current will cause an increase in power, causing an increase in amalgam temperature, which will cause a decrease in resistance, which will cause a further increase in current.

This will create a runaway effect, and the lamp will jump to the high-current state . Because actual lamps are not designed to handle this much power, this would result in catastrophic failure. Similarly, an anomalous drop in current will drive the lamp to extinction. It is the second state that is the desired operating state of the lamp, because a slow loss of the amalgam over time from a reservoir will have less effect on the characteristics of the lamp than a fully evaporated amalgam. The result is an average lamp life in excess of 20,000 hours.

In practical use, the lamp is powered by an AC voltage source in series with an inductive "ballast" in order to supply a nearly constant current to the lamp, rather than a constant voltage, thus assuring stable operation. The ballast is usually inductive rather than simply being resistive to minimize energy waste from resistance losses. Because the lamp effectively extinguishes at each zero-current point in the AC cycle, the inductive ballast assists in the reignition by providing a voltage spike at the zero-current point. The light from the lamp consists of atomic emission lines of mercury and sodium, but is dominated by the sodium D-line emission. This line is extremely pressure (resonance) broadened and is also self-reversed because of absorption in the cooler outer layers of the arc, giving the lamp its improved color rendering characteristics. In addition, the red wing of the D-line emission is further pressure broadened by the Van der Waals forces from the mercury atoms in the arc.

### 5.3 Light Emitting Diode

In this chapter, I have described how a basic LED operates, obtain an overview of the basic technology associated with LEDs, examine how LEDs can be used in series and parallel circuits, note the use of resistors with LEDs, and understand how to develop circuitry that operates LEDs.

The basic technology behind the development of the LED dates back to the 1960s when scientists were working with a chip of semiconductor material. That material was doped, or impregnated with impurities, to create a positive-negative or p-n junction.

**Similarity to a Diode**

An LED can be considered to resemble a diode because it represents a chip of semiconducting material that is doped or impregnated with impurities to form a p-n junction. Similar to a diode, current easily flows from the p-side to the n-side of the semiconductor via a forward-bias potential, but not in the reverse direction.

**LED Evolution**

In the following sections we will briefly discuss the evolution of the LED. This discussion will include how experiments in the use of different doping materials resulted in the development of different colors and color intensities for LEDs.

#### 5.3.1 The First LED

The actual invention of the first practical LED is attributed to Nick Holonyak in l962. Holonyak, who attained the position as the John Bardeen Professor of Electrical and Computer Engineering and Physics at the University of Illinois, was the first student of Professor John Bardeen, who was one of the inventors of the basic transistor during the 1950s. After completing graduate school in l954, Nick Holonyak took a job with Bell Laboratories and contributed to the development of the integrated circuit. Later, while working at General Electric, Holonyak was responsible for the development of the p-n-p-n switch, which is now widely used in homes and apartments as a dimmer switch to control lighting to a chandelier on another light source. On April 23, 2004, Mr. Holonyak was officially recognized as the inventor of the LED at a ceremony that was held in Washington, D.C. At that ceremony, Holonyak received the half-million dollar Lemelson-MIT Prize for Invention, which is the world's largest cash prize awarded to an inventor.

**Doping Materials**

Although Nick Holonyak is recognized as the inventor of the LED, during the 20th century, several companies either inadvertently or by design were able to generate electroluminescence from different materials by the application of electric fields. For example, in a report (1923), the generation of blue electroluminescence was based on the use of silicon carbide

(SiC) that had been manufactured as sandpaper grit. Although the sandpaper grit inadvertently contained what are now referred to as p-n junctions, at the time the generation of light was both poorly controlled and not exactly scientifically understood. However, fast-forwarding to the 1960s, SiC films were prepared by a much more careful process than manufacturing sandpaper grit, whereas the evolution of p-n junction semiconductors was driven by curiosity and practical experimentation. In fact, by the mid-1960s this author remembers taking several graduate physics courses that involved the doping of various materials to create p-n semiconductor junction diodes. By the later portion of the 1960s, p-n junction devices were fabricated that resulted in the development of blue LEDs. Although this first generation of blue
LEDs were extremely inefficient, subsequent efforts to improve the efficiency of blue SiC LEDs only marginally improved due to an indirect band gap in the p-n junction. By the early 1990s, the maximum efficiency of blue SiC LEDs that emitted blue light at a 470 nm wavelength was only approximately 0.03 percent. Thus, the low efficiency of SiC LEDs resulted in scientists turning their attention to other semiconductor materials both as a mechanism to enhance efficiency as well as a method to generate light from other areas of the frequency spectrum. One such approach was the development of infrared LEDs based on the use of GaAs.

### 5.3.2 Gallium Arsenide LEDs

During the 1960s, infrared (IR) LEDs were developed based on the use of GaAs that was grown as a crystal, then sliced and polished to form the substrate of a p-n junction diode. As previously mentioned, the use of GaAs resulted in the development of IR LEDs whose application capability was limited owing to the absence of visible light. The development of IR LEDs resulted in several key differences between the electrical characteristics of IR and visible LEDs. Those differences are primarily in the forward voltage used to drive the LED, its rated current, and the manner in which its output is rated. IR LEDs typically have a lower forward voltage and higher rated current than a visible LED due to the material properties of the p-n junction. Concerning their output rating, because IR LEDs do not output light in the visible spectrum, they are commonly rated in milliwatts. In comparison, the output of visible LEDs is rated in millicandelas (mcd), where 1000 mcd equals a candela, which represents lumens divided by the beam coverage.

### 5.3.3 Gallium Arsenide Phosphide LEDs

To obtain a visible light emission, GaAs was alloyed with phosphide (P), resulting in a gallium arsenide phosphide (GaAsP)-based LED that emitted red light.

### Use of Other Doping Materials

During the 1960s, scientists and physicists experimented with the use of various doping materials to generate various portions of the visible wavelength. The doping of GaP with nitrogen resulted in the generation of a bright yellow green 0.550 nm wavelength, whereas at RCA's then central research laboratory in Princeton, New Jersey, the use of gallium nitride (GaN) was used to generate blue light peaking at a wavelength of 475 nm during the summer of 1971. Approximately a year later, Herbert Maruska at RCA decided to use magnesium as a p-type dopant instead of zinc. Maruska then began growing magnesium-doped GaN films, resulting in the development of a bright violet-colored LED emitting light at 430 nm. Due to RCA's financial problems during the mid-1970s, work on a blue LED using GaN was cancelled. However, in 1989, Isamu Akasaki was able to use magnesium-doped GaN to achieve conducting material by using an electron beam annealed magnesium-doped GaN. A little more than a decade later, in 1995, a blue and green GaN LED with an efficiency exceeding 10 percent was developed at Nichia Chemical Industries in Japan.

**Rainbow of Colors**

Over a period of approximately 50 years, LEDs have been manufactured using different inorganic semiconductor materials to generate a wide variety of colors. Table 3 lists in alphabetical order common semiconductor materials used to create LEDs as well as the type of generated light. Note that the use of certain types of semiconductor materials is currently under development. This development effort is primarily focused on research into generating bright white light. Due to the development of several methods to generate bright white light, the number of applications available for LEDs has considerably expanded, including one application familiar to many consumers. That application is the use of bright white LEDs in high-end flashlights.

| SEMICONDUCTOR MATERIALS | LED EMISSION |
|---|---|
| Aluminum gallium arsenide (AlGaAs) | Red and infrared |
| Aluminum gallium phosphide (AlGaP) | Green |
| Aluminum gallium indium phosphide (AlGaInP) | Bright orange red, orange, yellow |
| Aluminum gallium nitrate (AlGaN) | Near to far ultraviolet |
| Aluminum nitrate (AlN) | Near to far ultraviolet |
| Diamond (C) | Ultraviolet |
| Gallium arsenide phosphide (GaAsP) | Red, orange and red, orange, yellow |
| Gallium phosphide (GaP) | Red, yellow, green |
| Gallium nitrate (GaN) | Green, emerald green |
| Gallium nitrate (GaN) with AlGan quantum barrier | Blue, white |
| Indium gallium nitrate (InGaN) | Bluish green, blue, near ultraviolet |
| Sapphire ($Al_2O_3$) as substrate | Blue |
| Silicon (Si) as substrate | Blue (under development) |
| Silicon carbide (SiC) | Blue |
| Zinc selenide (ZnSe) | Blue |

**Table 5.1:** Use of Semiconductor Materials to Generate LED Light

Unlike incandescent and fluorescent lights, LEDs emit near-monochromatic light. That is, an LED emits light at a specific wavelength; this explains why this type of diode is efficient for colored light applications.

### 5.3.4 Comparing LEDs

The information in this table is not all inclusive, and it is highly likely that there are other LEDs that vary from the properties shown. However, by examining the entries in the table, you can obtain at a minimum the ability to associate LED color and wavelength, as well as an appreciation for the variance in forward voltage (*Vf* ), and knowledge about the doping materials used to manufacture LEDs.

#### White Light Creation Using LEDs

It should be noted that there are currently several methods employing LEDs that are commonly used to generate white light. One method of making white light with LEDs is by mixing monochromatic LEDs. A second method is coating certain types of LEDs with a phosphor. In this section we will initially review the primary methods used to create white light using LEDs. In Section 2.3.8 we will go into considerable more detail concerning the generation of white light by LEDs.

#### White Light Creation by Mixing Colors

Red, green, and blue, and occasionally amber, light from monochromatic LEDs is mixed to generate white light. The result is referred to as an *RGB-generated white light*.

#### White Light Creation Using Phosphor

A phosphor-coated LED or a blue or near-ultraviolet LED is also used to produce white light. Because they are based on a blue or near-ultraviolet LED, they usually have very high color temperatures, which results in a cool or blue appearance. By adding phosphors that emit in the red area of the visible spectrum, it becomes possible to obtain a warmer white color, although the luminous efficacy of the LED is reduced by approximately 50 percent.

#### Intensity of an LED

The intensity of an LED can be defined in terms of millicandela (mcd), which represents 1/1000 of a candela. To obtain an appreciation for what the candela represents, a brief overview of an older term known as *candlepower* is in order.

#### On-Axis Measurement

Because the intensity of an LED depends on the on-axis measurement, its possible for a 100 mcd LED to produce less light than an 80 mcd device. This results from the fact that the millicandela rating is determined by an on-axis measurement of peak intensity at a specific current and not by the measurement of total light output. Thus, a diffused LED that spreads light over a wide viewing angle could have an on-axis intensity of 80 mcd yet emit more light than a nondiffused LED whose on-axis intensity is 100 mcd or more. When two LEDs have the same luminous intensity value, the device with the larger viewing angle will always have the higher total light output, which explains the prior example (in which an 80 mcd LED can have a greater light output than a 100 mcd LED).

**Theta One-Half Point**

Its important to note that because of its shape, the LED encapsulation functions as a lens that will magnify light emitted from the LED. The off-axis point where the intensity of the LED is half its on-axis intensity is referred to as *theta one-half* (q .).-(shown in Fig-5.2) Thus, twice the q . value represents the LED's full viewing angle. Figure 16 illustrates the on-axis luminous intensity value (*lv*) with respect to its theta one-half point. Note that the intensity is normally obtained through the use of a photometer and that light is visible beyond the q . point.

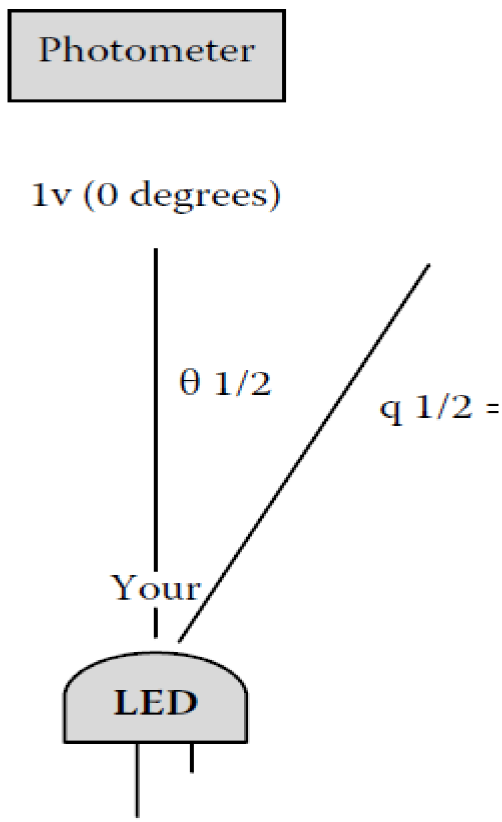



**Fig. 5.2:** Measuring luminous intensity and the theta one-half point of an LED.

**Voltage and Current Requirements**

An LED has the electrical characteristics of a diode. This means that it will pass current in one direction but block it in the reverse direction. Depending on the semiconductor material and its doping, the LED will emit light at a particular wavelength. In general, LEDs require a forward operating voltage of approximately 1.5‑3 V and a forward current ranging from 10 to 30 mA, with

20 mA being the most common current they are designed to support. Both the forward operating voltage and forward current vary depending on the semiconductor material used. For example, the use of gallium arsenide (GaAs) with a forward voltage drop of approximately 1.4 V generates infrared to red light. In comparison, the use of gallium arsenide phosphide (GaAsP) with a voltage drop near 2 V is used to generate wavelengths that correspond to frequencies between red and yellow light, whereas gallium phosphide LEDs have a blue-green to blue color and a voltage drop of approximately 3 V.

**Current and Voltage Considerations**

The luminous intensity of an LED is approximately proportional to the amount of current supplied to the device. Thus, the greater the current, the higher is the intensity. However, design limits will result in an upper boundary on both current and light intensity. Most LEDs are designed to operate at a current of 20 mA. When considering an LED for a specific application, you need to consider the operating current of the LED in comparison to the amount of heat that can be tolerated by the application also. For example, LEDs that are designed to operate at 12 V would have a greater heat dissipation than LEDs designed to operate at 6 V. Because heat dissipation is a significant factor in the life of an LED, it's important to consider the current rating of the LED and its applied and forward voltage if your application requires a long-life LED.

In addition, its also important to consider the location of the LED as this will govern its ability to dissipate heat. For example, although most LEDs used as indicators in monitors, televisions, and various types of toys do not reside under a plastic panel, in certain instances products are designed to include this type of panel as a protective measure against glare, dirt, dust, or other elements. In this situation, the plastic panel will adversely affect the ability of the LED to dissipate the generated heat.

**Color Temperature**

Color temperature provides a measure of the color of a light source that is relative to a black body at a particular temperature. This temperature is expressed in degrees Kelvin (K), where Kelvin represents a thermodynamic temperature scale in which the coldest temperature possible is zero Kelvin (0 K). The Kelvin scale and the unit Kelvin are named after the physicist and engineer William Thomson (first Baron Kelvin), who identified the need for an absolute thermometric scale. Absolute zero (0 K) is equivalent to −459.63° F and −273.15° C. Another term related to Kelvin that you will occasionally encounter is *mired*. Mired represents the color temperature in Kelvin divided by one million.

**Luminous efficacy of LED**

| | OVERALL LUMINOUS EFFICIENCY (LM/W) | OVERALL LUMINOUS EFFICIENCY (PERCENTAGE) |
|---|---|---|
| Incandescent | | |
| 5 W tungsten | 5 | 0.7 |
| 40 W tungsten | 12.6 | 1.9 |
| 100 W tungsten | 17.5 | 2.6 |
| Fluorescent | | |
| 5–24 W compact fluorescent | 45–60 | 6.6–8.8 |
| 34 W tube | 50 | 7.0 |
| Halogen | | |
| Glass | 16 | 2.3 |
| Quartz | 24 | 3.5 |
| LED | | |
| White | 20–70 | 3.8–10.2 |

**Table 5.2** Luminous Efficacy of LED compared to other light sources

**Representative Lighting Color Temperature**

Incandescent lights have a low color temperature of approximately 2800 K. In comparison, daylight has a high color temperature at or above 5000 K. In between the two are popular fluorescent lighting referred to as "cool white" at approximately 4000 K and "white" or "bright white" at approximately 2900-3100 K.. In general, lighting having a low color temperature at approximately 2200 K has a red-orange tone. At 2800 K, lighting has a red-yellowish tone and the color is typically referred to as "warm white" or "soft white." Daylight has a relatively high color temperature at or above 5000 K and appears bluish.

In between, a halogen lamp at 3000 K generates a yellowish light, whereas the color of the most popular fluorescent light, which is rated at approximately 4000 K, is referred to as "cool white." At the high end of the color temperature, an LED "cool white" occurs at a color temperature of 8000 K.

## LED White Light Creation

Initially, the first series of LEDs emitted red light, followed by yellow and orange. To emit white light, the LED manufacturer commonly uses one of three approaches: wavelength conversion, color mixing, or a technology referred to as *homoepitaxial ZnSe*.

## Wavelength Conversion

Wavelength conversion involves converting all or a part of an LED’s emission into visible wavelengths that are perceived as white light. Currently, there are several methods that have been developed over the years to generate white light using LEDs. Some of these methods include the use of blue LED and yellow phosphor; blue LED and several phosphors; ultraviolet LED and blue, green, and red phosphors; and an LED with quantum dots.

## Blue LED and Yellow Phosphor

In this method of wavelength conversion, blue light from an LED is used to excite a yellow phosphor, resulting in the emission of yellow light. The resulting mixture of blue and yellow light results in the appearance of white light. This method of wavelength conversion is considered to be the least expensive method for producing white light *Blue LED and Several Phosphors* In this method of wavelength conversion, the use of multiple phosphors results in each phosphor emitting a different color. These emissions are combined with
the original blue light to produce white light. Compared to the use of a blue LED and a yellow phosphor, the use of multiple phosphors results in white light having a broader wavelength spectrum and a higher color quality. However, the use of multiple phosphors makes this method more expensive than the former.

## Ultraviolet LED with RGB Phosphors

A third wavelength conversion method involves the use of an ultraviolet LED with red, green, and blue (RGB) phosphors. Ultraviolet light is used to excite the red, green, and blue phosphors, whose emissions are mixed to provide a white light having a broad wavelength and rich spectrum.

## Blue LED and Quantum Dots

This method involves the use of a blue LED and quantum dots. Quantum dots are extremely small semiconductor crystals that can be between 2 and 10 nm, which corresponds to 10–50 atoms in diameter. When used with a blue LED, the quantum dots represent a thin layer of nanocrystal particles that contain 33 or 34 pairs of cadmium or selenium that are coated on top of the LED. The blue light emitted by the LED excites the quantum dots. This action results in the generation of a white light that has a wavelength spectrum similar to the ultraviolet LED that uses RGB phosphors.

## Color Mixing

This method for generating white light involves using multiple LEDs in a lamp and varying the intensity of each LED. Referred to as *color mixing*, a minimum of two LEDs are used, generating blue and yellow emissions that are varied in intensity to generate white light. Color mixing can also occur using three LEDs, where red, blue, and green are mixed, or four LEDs where red, blue, green, and yellow are mixed. Because phosphors are not used in color mixing, there is no loss of energy during the conversion process; as a result, color mixing is more efficient than wavelength conversion.

## Homoepitaxial ZnSe

A third method for generating white light is based on a technology referred to as homoepitaxial ZnSe. This technology was developed by Sumitomo Electric Industries, Ltd., Osaka, Japan, which teamed with Procomp Informatics, Ltd., Taipei, Taiwan, to commercialize the technology under a joint venture that was named Supra Opto, Inc. A homoepitaxial-ZnSe-based white LED is produced by growing a blue LED on a zinc selenide (ZnSe) substrate, which results in the simultaneous emission of blue light from the active region and yellow from the substrate. Because no phosphors are used, this approach makes packaging less complicated and increases the overall efficiency of the device. In addition, the elimination of phosphors eliminates any potential patent problems. In a research study, it was found that the epitaxial layer of the LED emitted a greenish blue light at a wavelength of 483 nm, whereas the ZnSe substrate simultaneously emitted an orange-colored light at a wavelength of 595 nm. Together, this results in a white LED whose operating characteristics include an operating voltage of 2.7 V, a 20 mA current, an optical output of 20 mW, a luminous efficiency of 8 lm/W, minimum lifetime of 8000 hr until the optical output decreases to half the initial value, and a color temperature of white light in the range of 3000 K and above. Currently, this LED is being used in a range of applications such as lighting, indicators, and backlights for liquid crystal displays. As its life is expected to improve due to further development efforts, this LED will become suitable for additional applications.

## Manufacture of LEDs

In a manufacturing environment, different amounts of arsenide and phosphide are commonly used to produce LEDs that emit different colors. Currently, blue and bright white LEDs are more difficult to manufacture and are usually less efficient than other LEDs. Their lower efficiency and greater manufacturing difficulty results in an increase in their unit cost. LEDs are manufactured in several sizes and shapes. Some are manufactured as multicolor devices that contain both a red and a green chip, enabling the production of light between the two colors.

Tricolor, red, blue, and green (RGB), LEDs are also manufactured as well as various types of white LEDs that vary in intensity and are used for different applications. Applications of LEDs range from use as indicators to lighting and data transmission. Visible light LEDs are primarily used for indicator lights, such as an emergency path on an aircraft floor. In comparison, high-intensity white LEDs are used for short-range lighting in flashlights, whereas IR LEDs are commonly used for data transmission.

**Types, Functions, and Applications**

To conclude this chapter, we will turn our attention to several LED topics that will expand our knowledge about this ubiquitous electronic device. First, we will focus our attention on the different types of LEDs based on their physical characteristics and color generation capability. Once this is accomplished, we will examine the functions and applications associated with the use of LEDs. However, because LEDs are ubiquitous, our examination of applications will be limited to describing the major areas that use this device. In actuality, the use of an LED is only limited by one’s imagination.

**Physical Characteristics**

When work commenced on developing semiconductor materials and doping the materials to generate light, the resulting LED was far from being miniaturized. Gradually, efficiencies in the development of manufacturing small disk drives, modems, personal digital assistants (PDAs), and other electronic devices with relatively small footprints facilitated a revolution in the development of LEDs. Today, LEDs can be obtained in a wide variety of shapes and sizes. LEDs can be obtained in round, square, rectangular, and triangular cross-sectional shapes. The most common shape is a round cross-section LED, as it's easy to install by simply drilling a hole matching the size of the LED diameter into the surface of the device it is to be mounted on.

Then, a spot of glue can be used to fasten the LED to the surface of the device. In addition to glue, some LEDs are designed to be pressed into a clip to facilitate their attachment to a device. Initially, LEDs were individually encased in a plastic housing that had leads for the anode and cathode protruding from the bottom. This design, although still in use, represents only a small portion of currently manufactured LEDs due to the development of surface mount LEDs. However, before discussing surface mount LEDs, a few words are in order concerning the life expectancy of an LED.

**Life Expectancy**

One of the major advantages of an LED is its life expectancy. Most modern LEDs have a half-life of approximately upto 100,000 hr prior to its brightness level being halved. Because a year consists of 8760 hr, this means that the half-life of an LED is approximately 11.4 years, which explains why they have become the preferred lighting source for traffic lights and other applications where it is difficult to predict bulb burnouts and even more troublesome if a bulb used in an application fails. Though commercial LED’s available nowadays comes with 50,000 hr of life.

**Surface Mount LEDs**

Today, perhaps the most popular type of LED is the surface mount device (SMD). An SMD LED represents an integrated LED as an epoxy package, which facilitates its use as an indicator in denoting the operational status of a device. The epoxy packaging provides a focus for the LED light beam, otherwise the resulting beam would have a wider viewing angle but would not be as visible.

**Sizes**

SMD LEDs are available in four popular sizes. These sizes are designated by the use of four numeric codes. Table 5.2 lists the SMD LED designators and their package sizes in terms of length, width, and height in millimeters. As indicated in the table, the 0402 SMD LED represents the smallest package whereas the 1206 represents the largest.

| DESIGNATOR | LENGTH × WIDTH × HEIGHT |
|---|---|
| 0402 | 1.0 mm × 0.5 mm × 0.45 mm |
| 0603 | 1.6mm × 0.8 mm × 0.60 mm |
| 0805 | 2.0 mm × 1.25 mm × 0.80 mm |
| 1206 | 3.2 mm × 1.5 mm × 1.10 mm |

**Table 5.2** Surface Mount Device (SMD) LEDs

Because there are 2.54 cm in an inch, a centimeter is approximately 0.39 in. in length. As a millimeter is a tenth of a centimeter, then the length of a millimeter is equal to approximately 0.039 in. Thus, if you use a ruler and measure the letters in the inscription "United States of America One Dime" on a 10¢ U.S. coin, you would note that the 0603 SMD LED is approximately the size of the letter "D" in "Dime," whereas a 0805 SMD LED would cover the letter "I." SMD LEDs are similar to standard LEDs, having a typical forward current of 35 mA with an average forward voltage of 3.6 V and a maximum forward voltage of 4.0 V. Because SMD LEDs are relatively tiny, they are normally packaged within a tape reel to facilitate their use. Once removed from tape, the SMD LED can be easily soldered to a circuit board or into the housing prefabricated on a disk drive, monitor, modem, or another device, where its illumination indicates a predefined action or activity. For example, a green LED might be used to indicate that a monitor was in a powered-on state.

**Colors**

The actual color generated by an LED is determined by the semiconductor material and its doping, and not by the color of the plastic body that forms an LED package. Today, LEDs are available in a variety of colors, ranging from red, orange, and yellow (the "ROY" in the famous name ROY G. BIV used as a mnemonic to remember primary colors), to amber, green, blue, and white. LEDs can be obtained in uncolored packages that can be diffused (milky) or clear. Colored packages are also offered as diffused or transparent.

**Color Variations**

Through the use of multiple LEDs, it becomes possible to obtain a bicolor or tricolor LED. A bicolor LED is formed by packaging two LEDs that are wired in an inverse parallel combination; that is, one is wired backward, enabling one of the LEDs to be illuminated at one time, depending on the lead on which voltage is applied. When two LEDs are combined in one package with three leads, the result is a tricolor LED(shown in Fig. 5.3) The name "tricolor" results from the fact that the light generated by each LED can be mixed to form a third color when both LEDs are turned on.

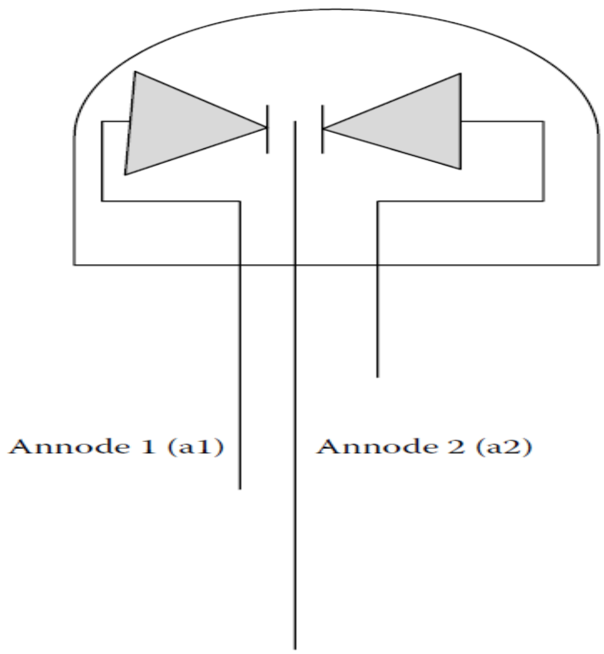



**Figure 5.3:** A tricolor LED.

Figure 17 illustrates a tricolor LED. Note that the center lead represents a common cathode (c) for both LEDs, whereas the outer leads represent the anodes (a1, a2) for each LED. Thus, each LED can be illuminated separately, or both can be lit to form a third color, for example, mixing red and green to obtain yellow.

**LED Binning**

Slight variations in the LED manufacturing process, particularly in regards to lumens, colour temperature and LED voltage, means individual LEDs are extremely difficult to make exactly alike. LEDs tend to be similar but rarely exact. In order for a light to be, say, red, manufacturers need a technique to ensure all of their LEDs are indeed red. The technique manufacturer's use is called LED binning.

The technique manufacturers have developed to classify their LEDs is called LED binning. That is, LEDs are placed into similar categories, or bins, with the category/bin defined by the similarity in lumens, colour and voltage. Lumens and colour are the most important parameters in LED variability. Fortunately, binning according to lumens is relatively strait forward to define and measure. Binning LEDs according to colour is more complex and to understand the process it is necessary to introduce chromaticity diagrams.

LEDs can be characterized in multiple ways. For color mixing, the two most important dimensions are color expressed as chromaticity (CCx, CCy), and luminous flux, measured in lumens (lm). These parameters are collected as part of the LED component manufacturing process and are the basis for the component binning discussed in this document.

**Flashing LEDs**

You may have noticed that when certain types of electronic devices are turned on, the LED flashes on and off repeatedly until you turn power off. A flashing LED consists of an integrated circuit (IC) and an LED. The purpose of the IC is to flash the LED by turning power to the diode on and off at a fixed rate, typically 3 or 4 flashes per second (3 Hz to 4 Hz). A flashing LED package, including the IC, is designed to be directly connected to a power supply and does not require the use of a resistor.

Typically, they are connected to a 9–12 V power source. By combining a bicolor or tricolor LED with an IC, some manufacturers offer combined devices. For example, you can obtain an RGB flashing LED that toggles from red to blue to red to green to red, repeating this pattern over and over when power is applied to the device. Through the use of one or more IC, several LED effects can occur when bicolor or tricolor LEDs are integrated with the ICs. For example, by removing power from one anode while applying power to the other anode of a tricolor LED, the color generated can appear to fade to a second color. Due to the visual attraction resulting from flashing LEDs, they have found a viable market, being incorporated into a range of products.

**Lighting**

With the development of white-light-generating LEDs, they have found a relatively new series of lighting applications. For example, if you examine modern high-end flashlights, you will note that the vast majority now use LEDs. Not only do they require considerably less power but, in addition, the life of an LED is typically several orders of magnitude beyond that of the bulb used in conventional flashlights. Other lighting applications in which LEDs are used include traffic lights and architectural lighting; they are even beginning to replace conventional incandescent light bulbs. Concerning the latter, currently LEDs are relatively expensive, LED’s extremely low power requirements, long life, and the fact that they produce nearly no heat will make them attractive replacements for incandescent and any other light sources.

**Other Applications**

To illustrate the versatility of LEDs in a variety of applications (described in table-5.3) Although this list is far from being fully comprehensive, it does illustrate the wide range of application areas where LEDs are currently used.

That is, few years ago, compact fluorescent bulbs were relatively expensive when used as replacements for incandescent light bulbs. However, the increasing awareness of the inefficiency of incandescent lighting, in which approximately 90 percent of the electricity used by a bulb is wasted as heat, resulted in an increase in consumer demand for alternative lighting, especially, as the cost of electricity increased. This in turn allowed manufacturers of compact fluorescent lightbulbs to expand production and reduce their retail cost, resulting in an increasing demand for the product.

In late 2007, General Electric, one of the primary manufacturers of incandescent light bulbs, announced that it would close several manufacturing facilities, whereas it would expand its production of compact fluorescent light bulbs. Today, LED light bulbs cost almost similar to the cost of compact fluorescent light bulbs.

| | | |
|---|---|---|
| Automobiles | Household lighting | Mobile phones and PDA |
| Indicator lights | Bulb replacement | Backlight for screen display |
| Turn signal lights | Flood lights | Operational status indicator |
| Rear brake lighting bar | Landscape lighting | DVD player |
| Data Communications | Track lighting | Electronic air filter |
| Optical fiber transmission | LCD televisions | Television |
| Device indicators | Backlight | Traffic light |
| Displays | | |
| Digital counter | | |
| Digital clock | | |
| Scoreboard | | |

**Table 5.3** General LED Application Areas

# Chapter-6: Design Details

## 6.1 About The Workspace:

**National Instruments India**:

National Instruments India was set up in 1998 to propagate the revolutionary Virtual Instrumentation technology in the country.

National Instruments invests 16% of its annual revenue in Research & Development. National Instruments India has a Research and Development wing in Bangalore which helps customers across the globe. NI India R&D has received more than 7 patents for innovations in the fields of Motion Control algorithms, RF and software development.

In Kolkata, NIL has stopped their activities and that campus at Jadavpur area has been given to Jadavpur University Authority to make their third campus in that place. University Authority is now planning to construct an Auditorium in one portion there.

The proposed auditorium is planned to be done by Macintosh Burn Ltd. and the Architectural design has been done by Espace. The lighting design for this proposed auditorium is being done by Trilux Lighting India Pvt. Ltd., which is reported here.


**Fig 6.1:** Sectional view of the proposed Auditorium

It comprises of one multipurpose Auditorium and two no. of Black Boxes. Also, there is an Exhibition space at basement. As shown in Fig 6.1.

## 6.2 Floor Plans of the Auditorium in AutoCAD :

In the proposed design there are floor plans at four levels at +600 level , +7200Level, +11000 level & +20000 Level which are shown in Fig 6.2, Fig 6.3, Fig 6.4 and Fig 6.5 respectively. Also Side profile Plan is shown in the Fig 6.6.

The Lighting Design has been done on the basis of these floor plans.


**Fig. 6.2:** Floor Plan at +600 Level

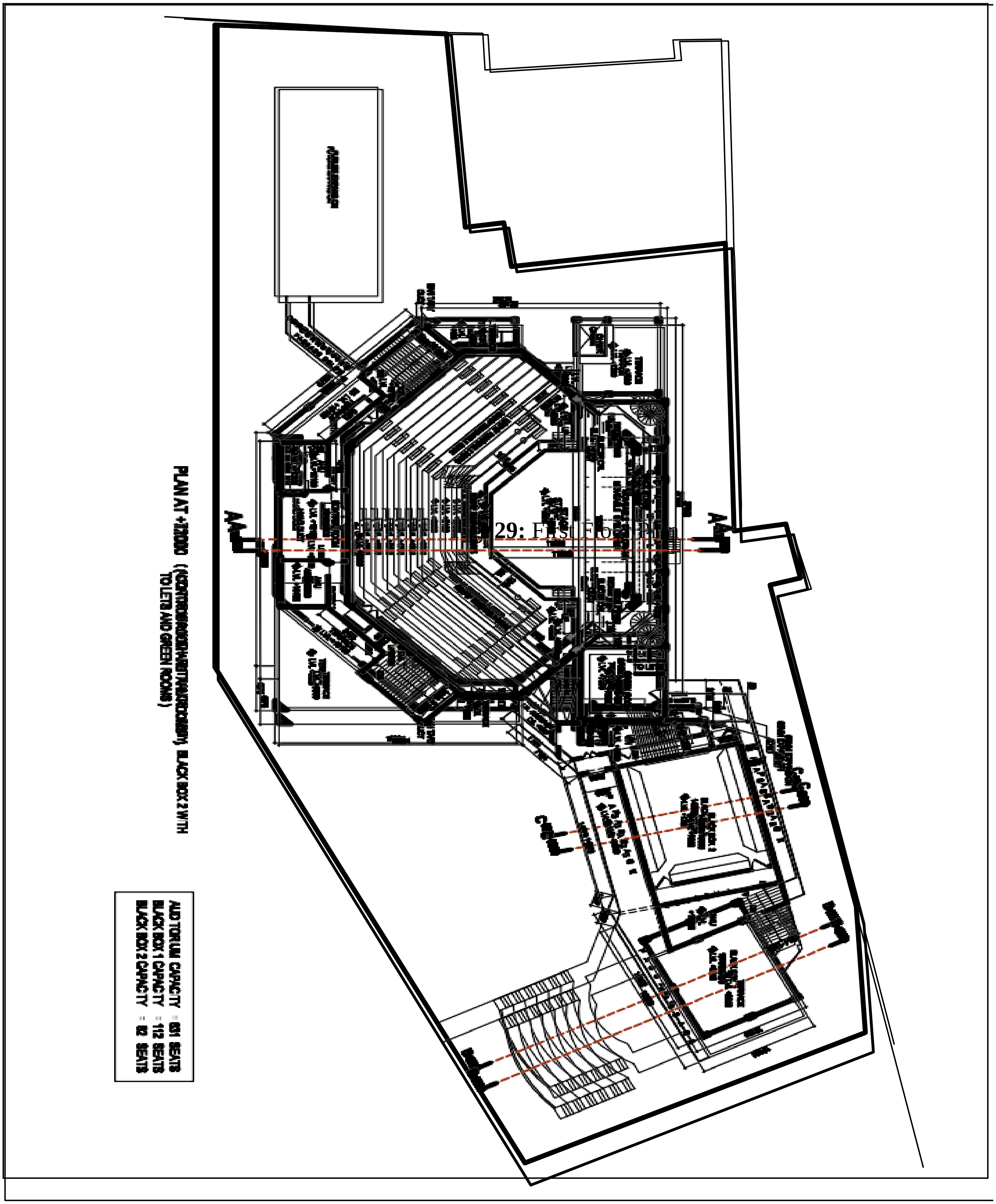


**Fig. 6.3:** Plan at +7200 Level

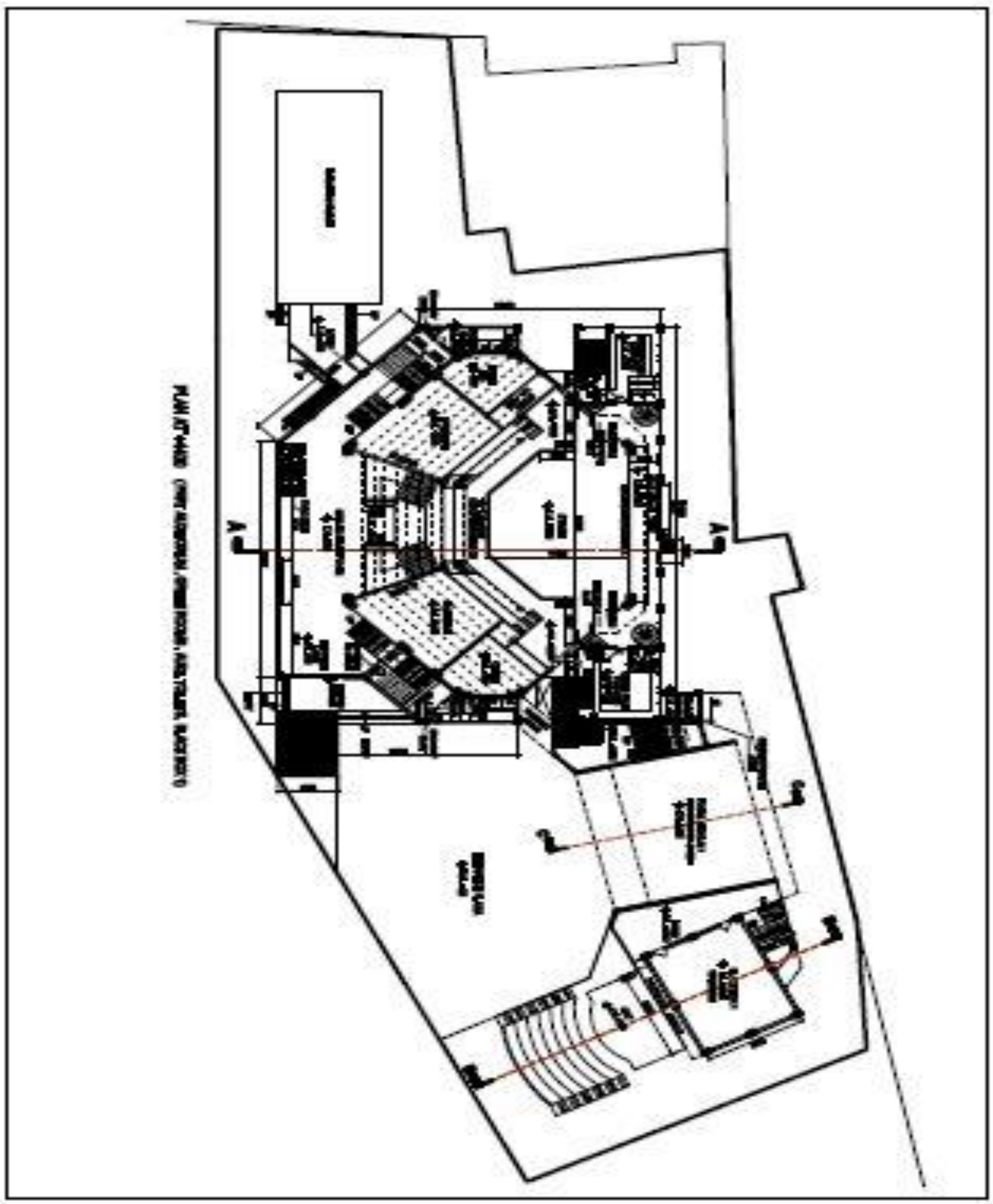


**Fig 6.4:** Plan at +11000 level

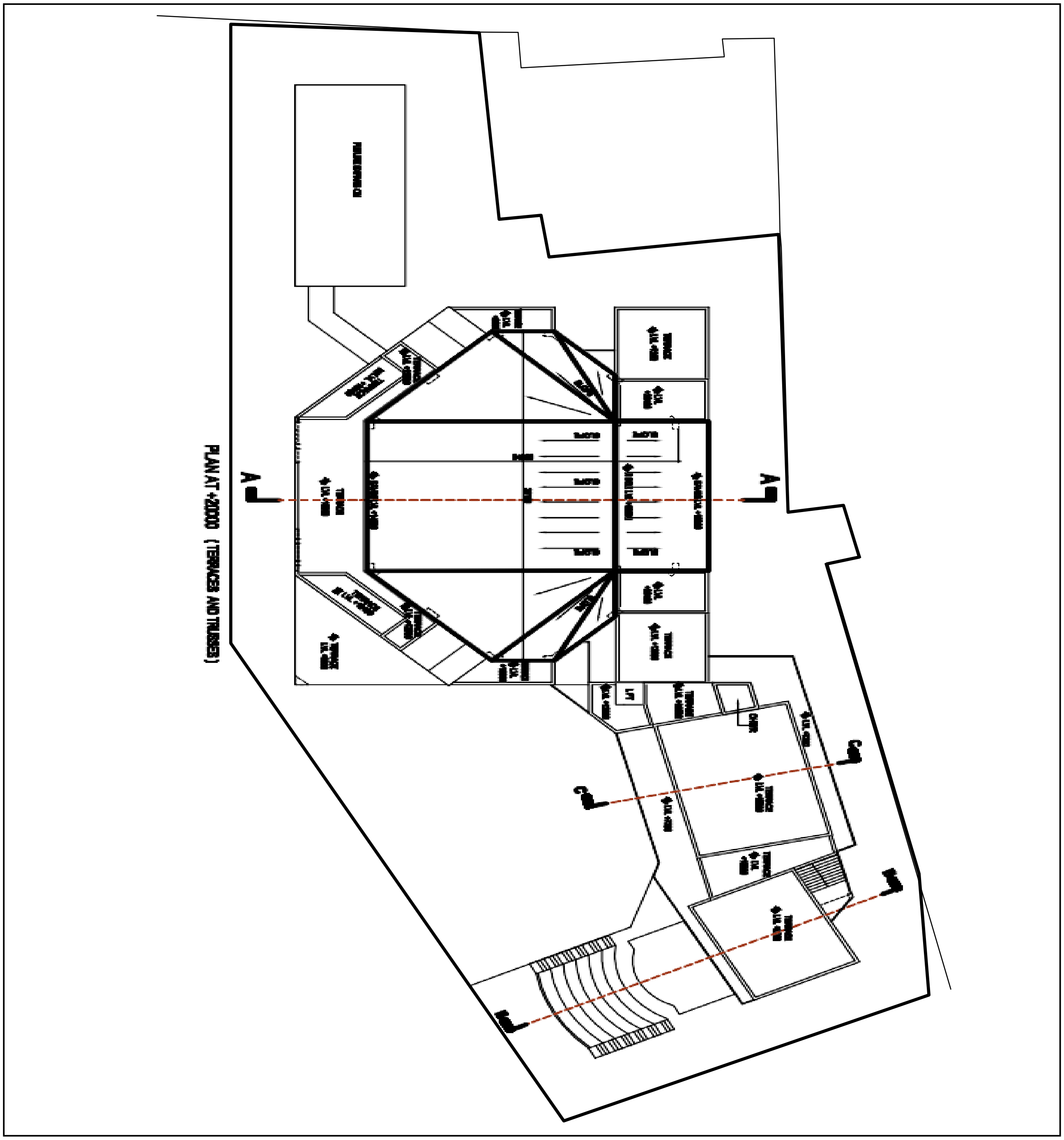



**Fig. 6.5:** Plan at +20000 Level

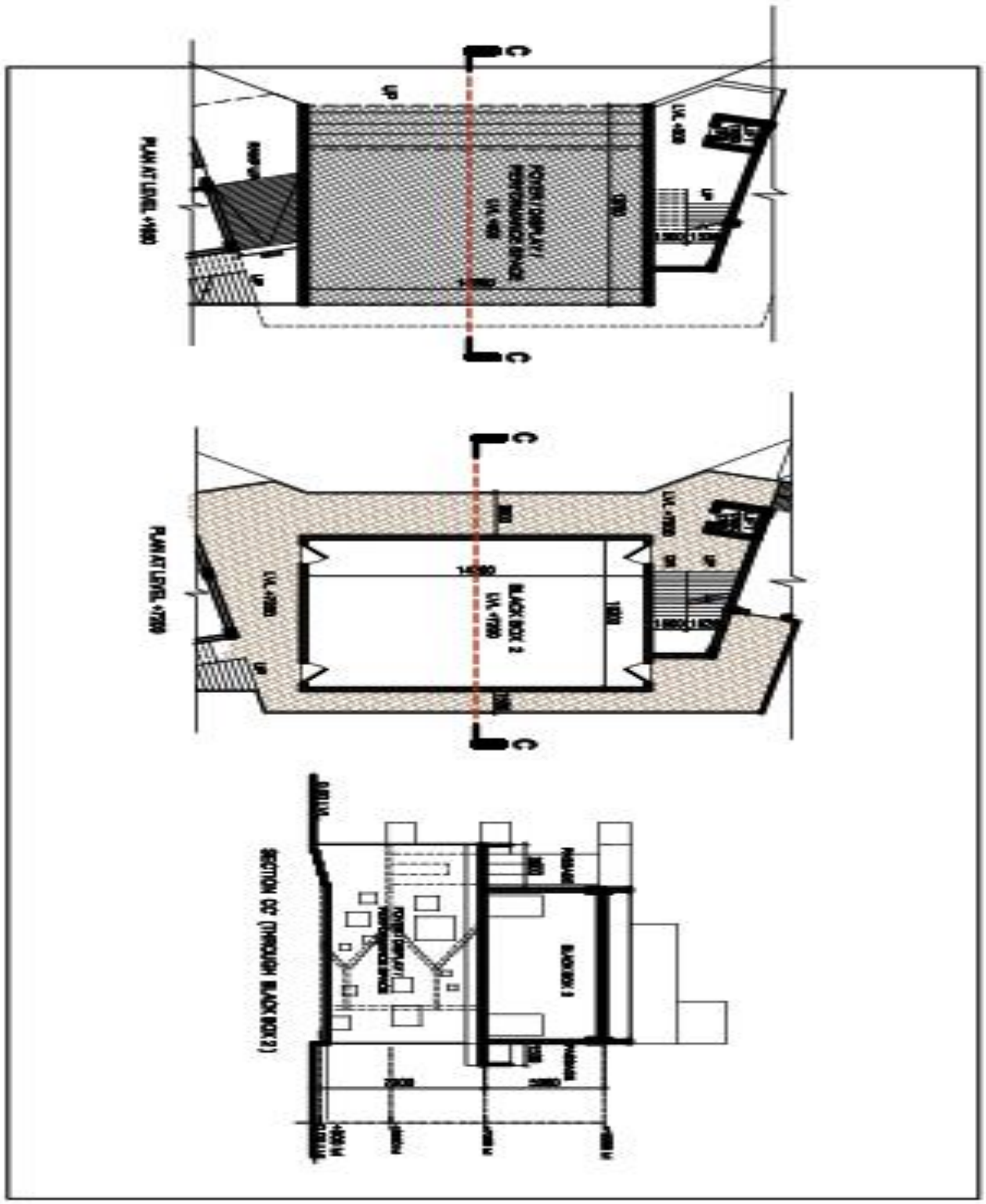


**Fig. 6.6:** Side Profile Plan

## 6.3 Types of Spaces that has been Designed:

- Auditorium
- Black Box theatre -large
- Black Box theatre -small
- Exhibition space
- Foyer areas
- Green Rooms
- Office
- Control room for Auditorium
- Toilets
- Utility rooms
- AHU rooms

## 6.4 Section-wise Design :

### 6.4.1 Auditorium :

Fig-6.7 shows a 3D rendered image of the Auditorium, done in DiaLux.

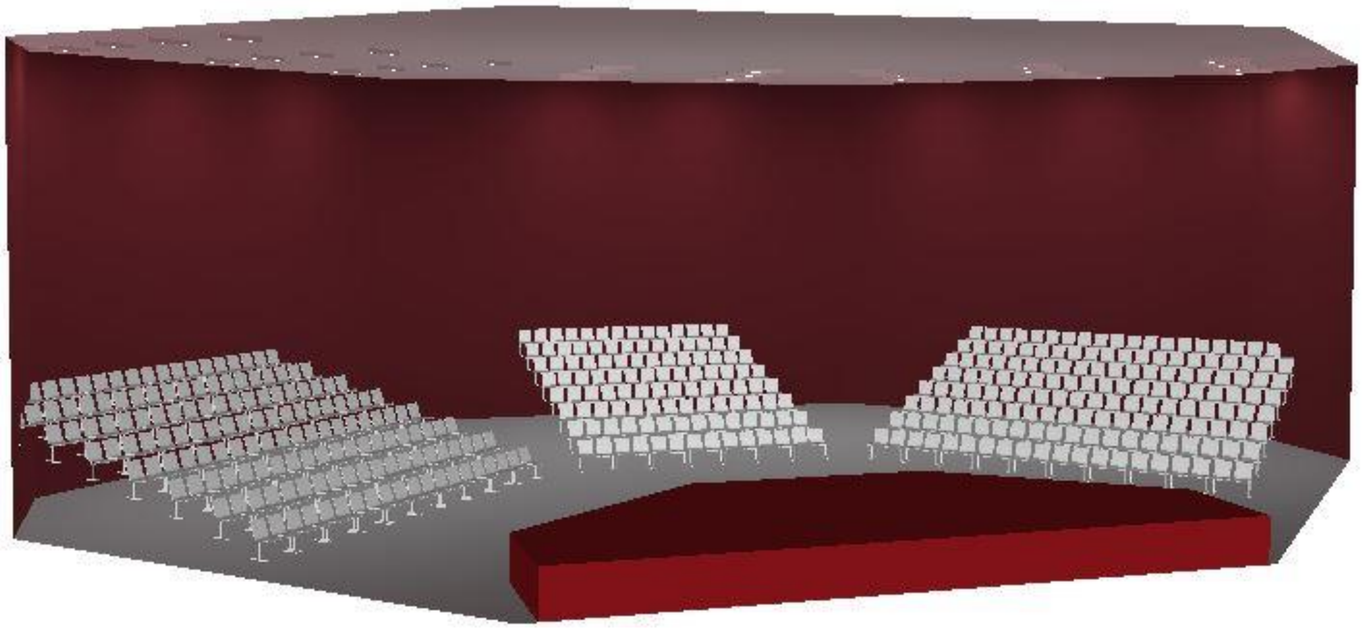


**Fig 6.7:**

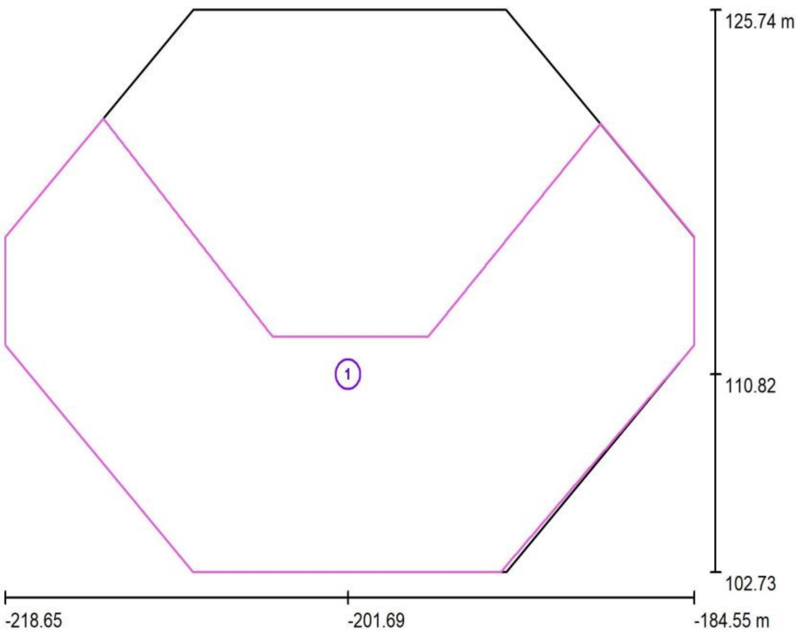
**Factors considered:**

- Lighting design is done for the sitting and free area. Stage lighting was not in the author's scope.
- Light loss factor: 0.80
- Ground area: 611.76 m²
- Desired Lux value at sitting area= 100 Lux (as per client) & uniformity= 0.5
- Reflectance for ceiling, wall & floor are 20%, 80% & 7% respectively
- Linear channel Lights are used to design the area [7]

**Luminaire Used:**

**LCL C 1200 OTA 52 LED** *****TDS of Luminaires are given in ANNEXURE

## Auditorium I Calculation surfaces (results overview)



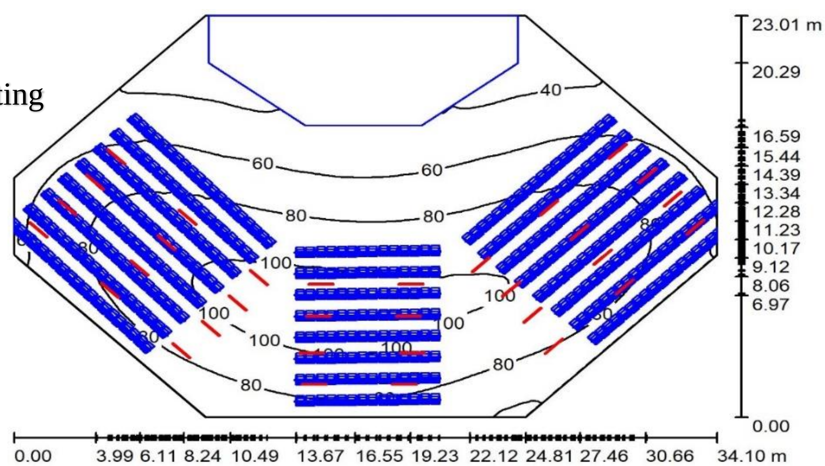

Scale 1 : 262

Calculation Surface List

| No. | Designation | Type | Grid | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 | $E_{min}$ / $E_{max}$ |
|---|---|---|---|---|---|---|---|---|
| 1 | Calculation Surface | perpendicular | 128 x 128 | 105 | 61 | 128 | 0.584 | 0.510 |

**Output**

- Avg Illuminance at sitting area= 105Lx
- Uniformity= 0.51



**6.4.2 Foyer area:**
This place is basically a common area where people would gather during their entry to the building.
Ground level- Fig 6.8 shows a 3D rendered view of ground level Foyer

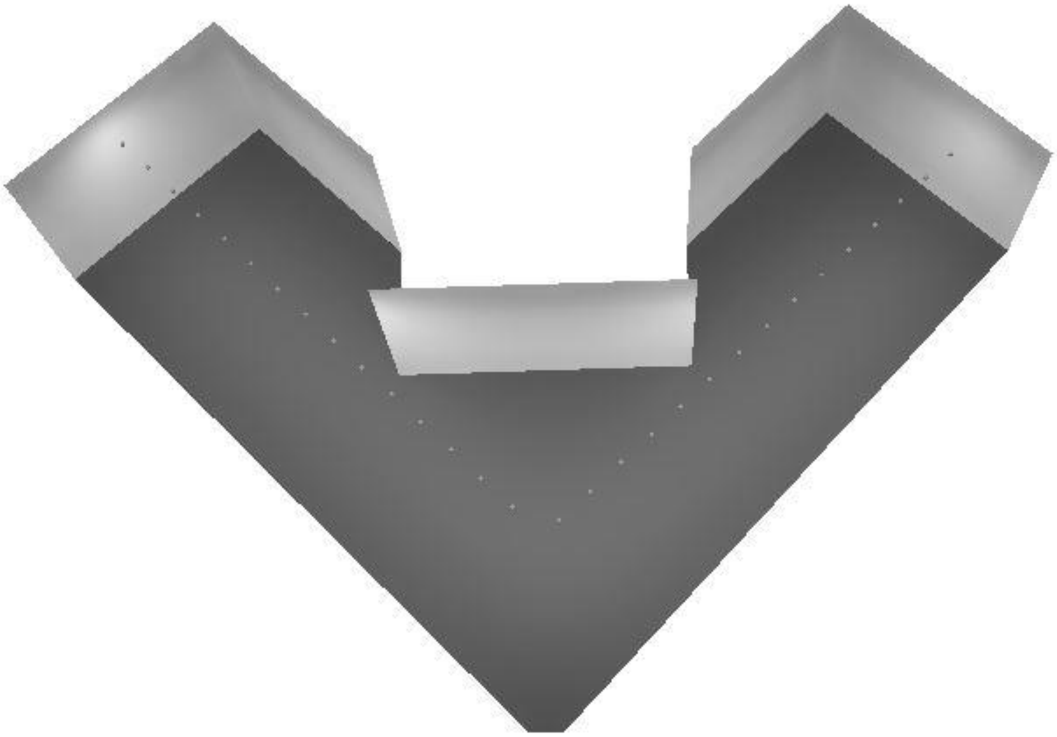


**Fig 6.8**

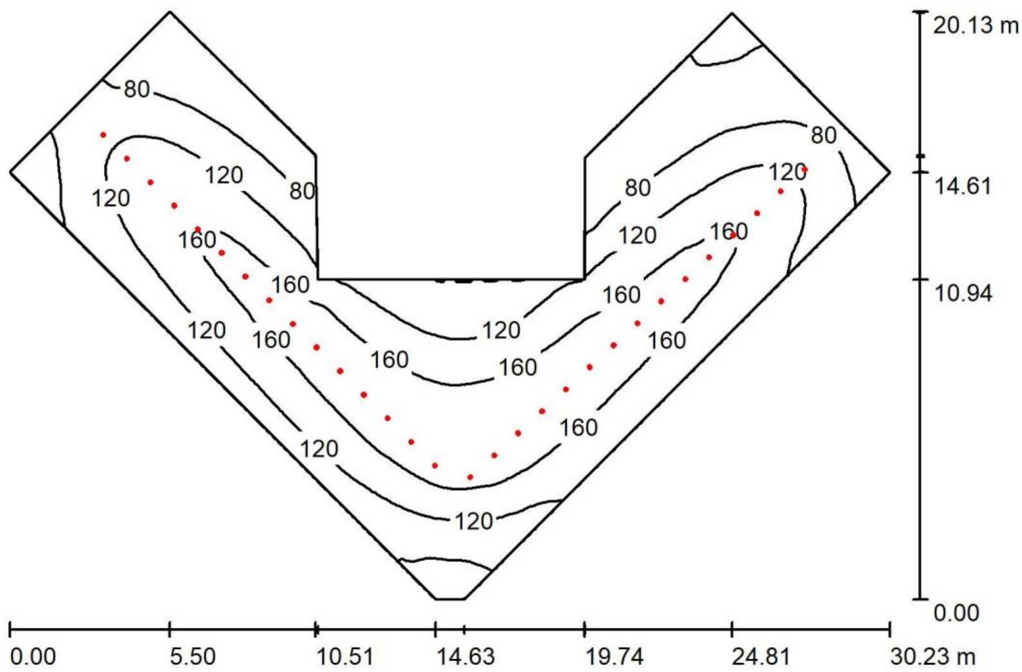
**Factors:**

- Ground level foyer is adjacent to the Entrance and Exhibition space
- M.F.= 0.8
- Reflectance for Floor, ceiling & wall is 20%, 80% and 50% respectively
- Desired Lux level= 100 lux

**Luminaire Used:**

**Adrastia LED**

## Ground Foyer area I Summary




Height of Room: 5.700 m, Mounting Height: 5.700 m, Light loss Factor: 0.80 Values in Lux, Scale 1:259

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 123 | 34 | 192 | 0.502 |
| Floor | 20 | 114 | 36 | 170 | 0.314 |
| Ceiling | 80 | 27 | 16 | 39 | 0.588 |
| Walls (10) | 50 | 59 | 22 | 114 | / |

Workplane:
Height: 0.760 m
Grid: 128 x 128 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.485, Ceiling / Working Plane: 0.219.

Luminaire Parts List

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 30 | ADRASTIA 15W 6500K (1.000) | 1658 | 1659 | 15.6 |
| | | | Total: 49753 | Total: 49770 | 468.0 |

Specific connected load: 1.84 W/m² = 1.50 W/m²/100 lx (Ground area: 254.76 m²)

**Output:** Avg illuminance= 123Lx; uniformity= 0.502

**First Floor Foyer Area:**

It is adjacent to the entrance of the Auditorium Hall. Below image is a 3D rendered image of the area which has been made in DiaLux.

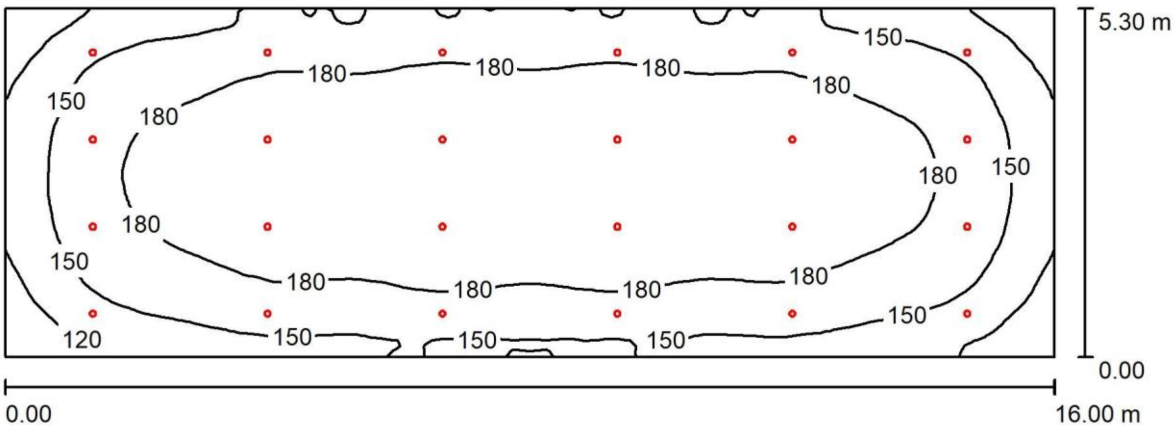
**Factors:**

- Ground level foyer is adjacent to the Entrance and Exhibition space
- M.F.= 0.8
- Reflectance for Floor, ceiling & wall is 20%, 80% and 50% respectively
- Desired Lux level= 100-150 lux, uniformity =0.5
- Surface mounted luminaires has been used for absence of false ceiling

**Luminaire Used:**

Ambiella D IND LED 1000-860

## 1st Floor Foyer I Summary




Height of Room: 3.800 m, Mounting Height: 3.800 m, Light loss factor: 0.80

Values in Lux, Scale 1:115

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 171 | 93 | 208 | 0.544 |
| Floor | 20 | 154 | 94 | 185 | 0.606 |
| Ceiling | 80 | 42 | 34 | 59 | 0.818 |
| Walls (4) | 50 | 98 | 40 | 244 | / |

Workplane:
Height: 0.760 m
Grid: 128 x 64 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.602, Ceiling / Working Plane: 0.243.

Luminaire Parts List

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 24 | TRILUX 10165554 Ambiella D IND LED 1000-860 ET 01 (Type 1)* (1.000) | 1000 | 1000 | 10.0 |
| | | *Modified Technical Specifications | Total: 24000 | Total: 24000 | 240.0 |

Specific connected load: 2.83 W/m² = 1.66 W/m²/100 lx (Ground area: 84.80 m²

**Output:**

- **Avg Illuminance= 171 lux**
- **Uniformity= 0.544**

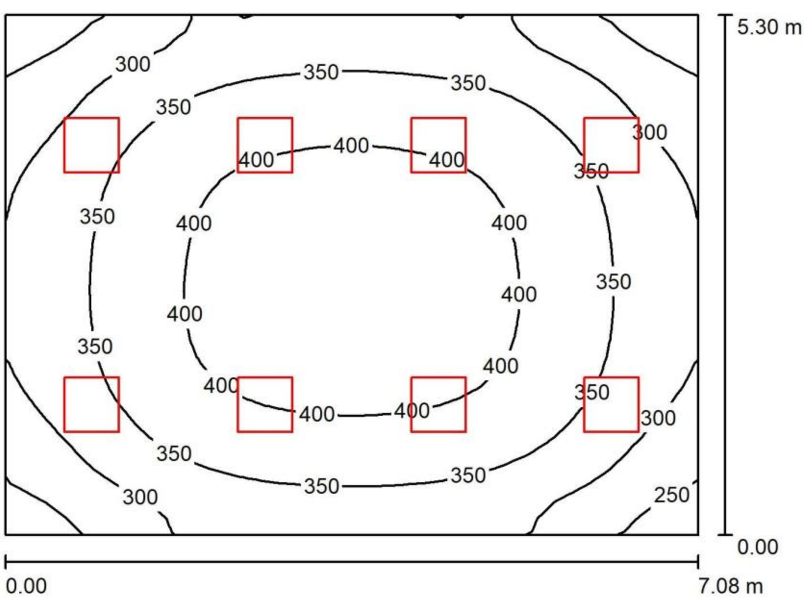
**6.4.3 Control Room:**
This room is for Light & electrical controls;
Adjacent to the Auditorium.

- M.F=0.8;
- Reflectance for Floor, ceiling & wall is 20%, 80% and 50% respectively
- Desired lux level= 300 Lux
- Ceiling recessed Panel LED luminaires are used

**Luminaires Used:**

Enterio IND M73 OA LED

Room:Control room I Summary



M.F

Height of Room: 3.800 m, Mounting Height: 3.800 m, Light loss factor: 0.80 Values in Lux, Scale 1:69

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 351 | 223 | 429 | 0.635 |
| Floor | 20 | 303 | 208 | 370 | 0.684 |
| Ceiling | 80 | 96 | 77 | 134 | 0.797 |
| Walls (4) | 50 | 223 | 101 | 430 | / |

Workplane:
Height: 0.760 m
Grid: 32 x 32 Points
Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.678, Ceiling / Working Plane: 0.275.

Luminaire Parts List

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 8 | TRILUX 10152591 Enterio IND M73 OA LED | 3188 | 3188 | 33.0 |
| | | | Total: 25504 | Total: 25504 | 264.0 |

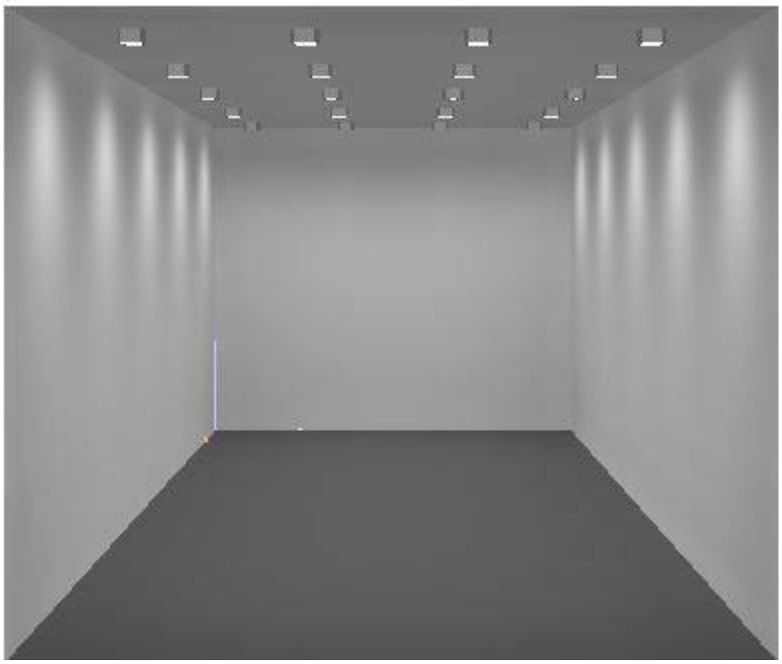
Specific connected load: 7.04 W/m² = 2.01 W/m²/100 lx (Ground area: 37.50 m²)

**Output :**

- Avg. Illuminance = 351 lux
- Uniformity = 0.635

**6.4.4 Green Room:**
This room is adjacent to the Black box made for the purpose of dressing and background preparation of the performance.

- LED's with neutral white colour are used.
- Desired Lux level= 300-400 Lux ; Uniformity= 0.5
- M.F. = 0.8;
- Reflectance for Floor, ceiling and wall are 20%, 80% and 50% respectively.



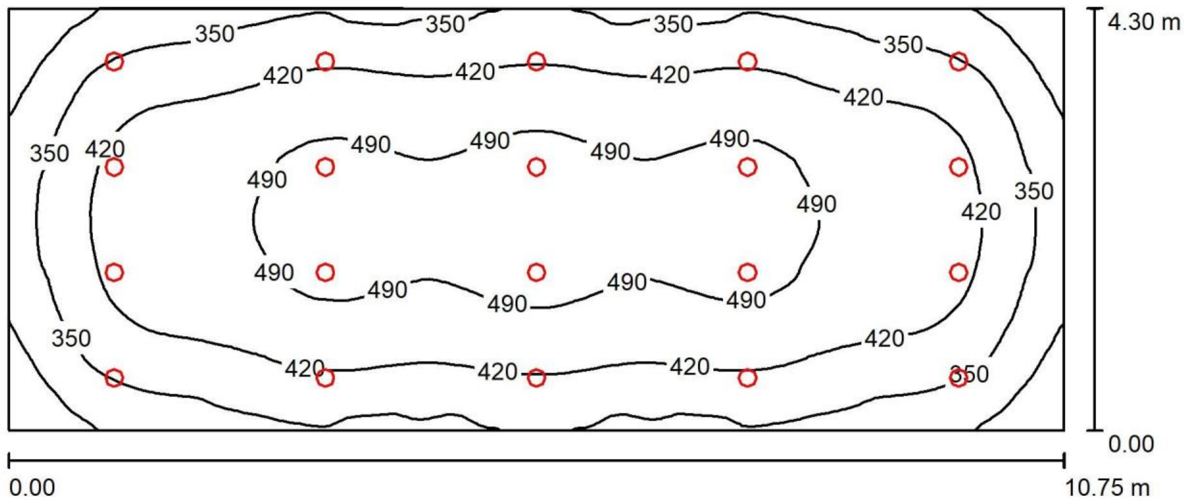
This is a 3D rendered image which has been prepared in DiaLux.

**Luminaire used:**

Trilux Ambiella Plus IND G3 LED

## Green room for small Black Box I Summary

la




Height of Room: 3.650 m, Mounting Height: 3.650 m, Light loss factor: 0.80

Values in Lux, Scale 1:77

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 418 | 212 | 520 | 0.509 |
| Floor | 20 | 376 | 218 | 464 | 0.579 |
| Ceiling | 80 | 83 | 67 | 95 | 0.799 |
| Walls (4) | 50 | 178 | 76 | 400 | / |

Workplane:
Height: 0.760 m
Grid: 128 x 64 Points
Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.432, Ceiling / Working Plane: 0.199.

Luminaire Parts List

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 20 | TRILUX Ambiella Plus IND G3 LED1530-840 | 1530 | 1530 | 18.0 |
| | | | Total: 30600 | Total: 30600 | 360.0 |

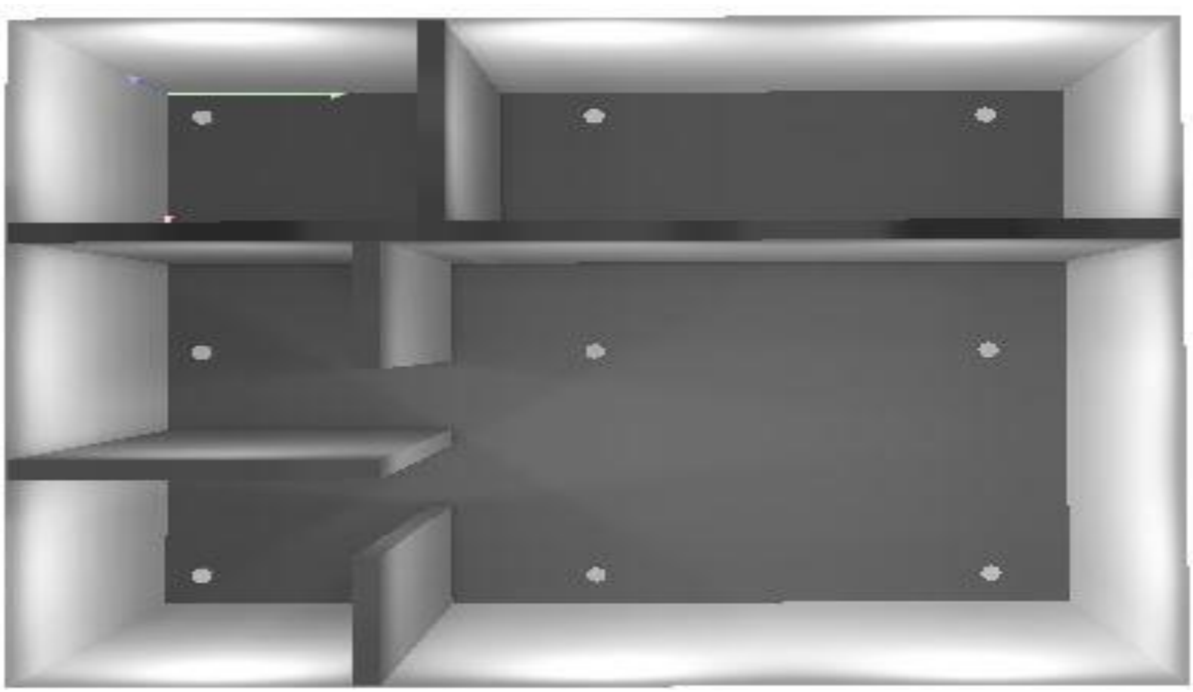
Specific connected load: 7.79 W/m² = 1.86 W/m²/100 lx (Ground area: 46.22 m

**Output:**

- Avg Illuminance = 418 Lux
- Uniformity = 0.509

**6.4.5 Toilets:**

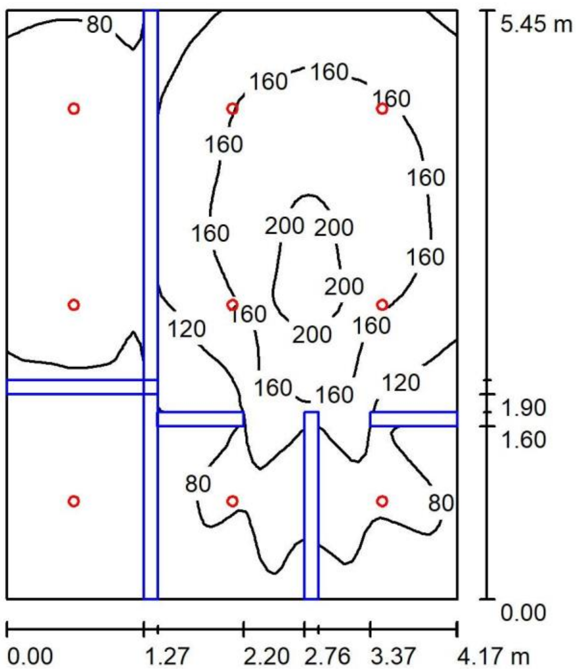
- Separate for Male and Female.
- Desired lux level= 100 Lux
- Maintenance Factor= 0.67
- Reflectance for Floor, ceiling & wall is 20%, 80% and 50% respectively
- Mirror Lights were not in our scope.



**Luminaire Used:**

Ambiella Plus IND G3

## Gents toilet + Utility room I Summary




| S | | [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| W | | 118 | 50 | 208 | 0.522 |
| Floor | 20 | 85 | 8.48 | 161 | 0.099 |
| Ceiling | 80 | 34 | 17 | 49 | 0.493 |
| Walls (4) | 50 | 74 | 7.00 | 268 | / |

Workplane:

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

Height of Room: 3.650 m, Mounting Height: 3.650 m, Light loss factor: 0.67

Values in Lux, Scale 1:70

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.705, Ceiling / Working Plane: 0.290.

Luminaire Parts List

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 9 | TRILUX 10155570 Ambiella Plus IND G3 | 1166 | 1166 | 16.8 |
| | | | Total: 10494 | Total: 10494 | 151.2 |

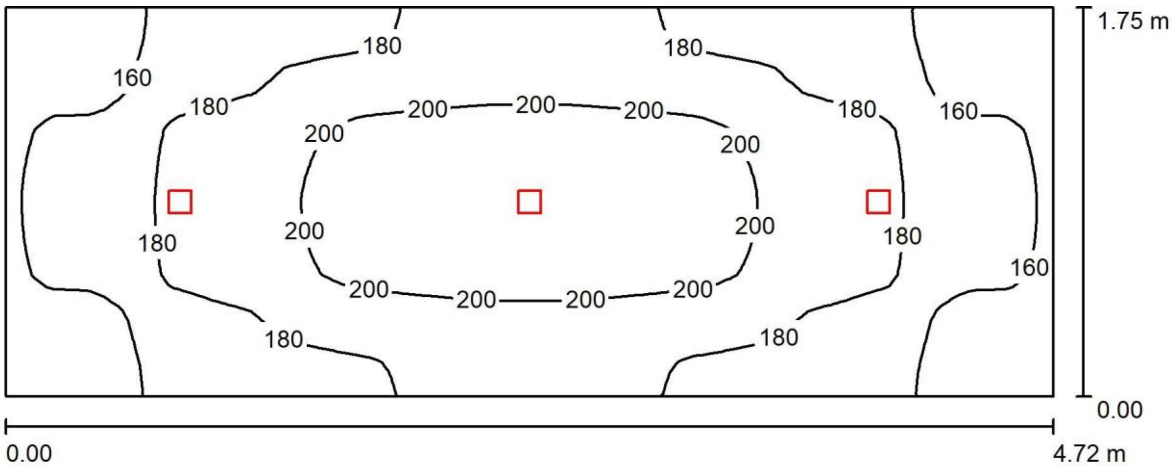
Specific connected load: 6.65 W/m² = 5.62 W/m²/100 lx (Ground area: 22.75 m

**Output:**

- Avg Illuminance = 118 Lux; Uniformity = 0.522

### 6.4.6 AHU Rooms:

Two no's of AHU rooms are present in the design. These area Air Handling Units.
Desired Lux level= 100-150 Lux; M.F.= 0.67




Height of Room: 3.800 m, Mounting Height: 3.800 m, Light loss factor: 0.67

Values in Lux, Scale 1:34

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 181 | 142 | 209 | 0.785 |
| Floor | 20 | 135 | 113 | 152 | 0.833 |
| Ceiling | 80 | 109 | 79 | 125 | 0.727 |
| Walls (4) | 50 | 185 | 56 | 520 | / |

Workplane:
Height: 0.760 m
Grid: 64 x 32 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 1.185, Ceiling / Working Plane: 0.603.

Luminaire Parts List

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 3 | TSmart Linea F 2200 20W (1.000) | 2360 | 2360 | 21.5 |
| | | | Total: 7079 | Total: 7080 | 64.5 |

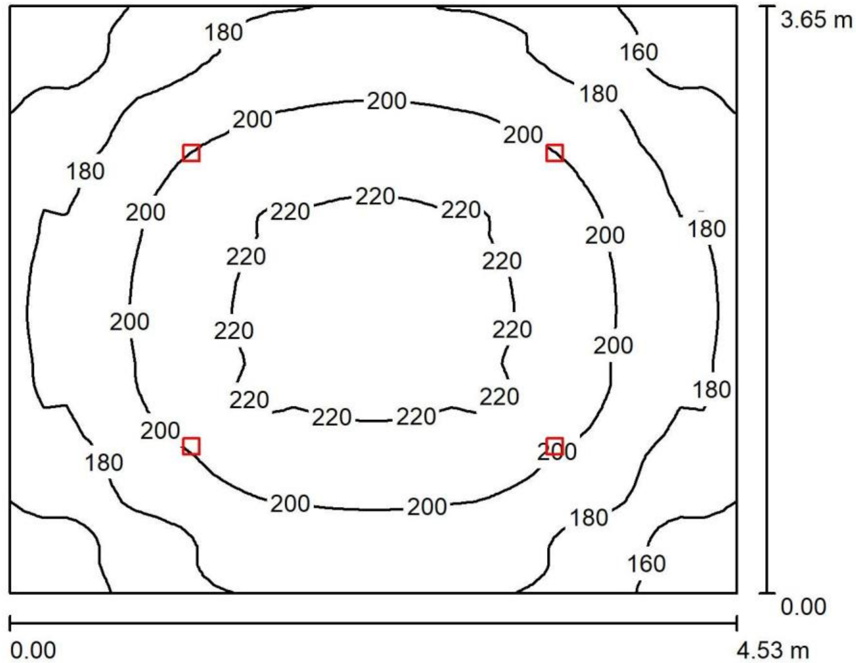
Specific connected load: 7.80 W/m² = 4.31 W/m²/100 lx (Ground area: 8.27 m²)

**Luminaires used:**

TSmart Linea

**Output :**

- Avg illuminance = 181 lux
- Uniformity = 0.78




**Output:**

- Avg. Illuminance= 181 Lux
- Uniformity = 0.785

Height of Room: 3.800 m, Mounting Height: 3.800 m, Light loss factor: 0.67

Values in Lux, Scale 1:4

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 193 | 144 | 224 | 0.747 |
| Floor | 20 | 154 | 118 | 177 | 0.768 |
| Ceiling | 80 | 81 | 56 | 98 | 0.693 |
| Walls (4) | 50 | 168 | 75 | 415 | / |

Workplane:

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

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.975, Ceiling / Working Plane: 0.418.

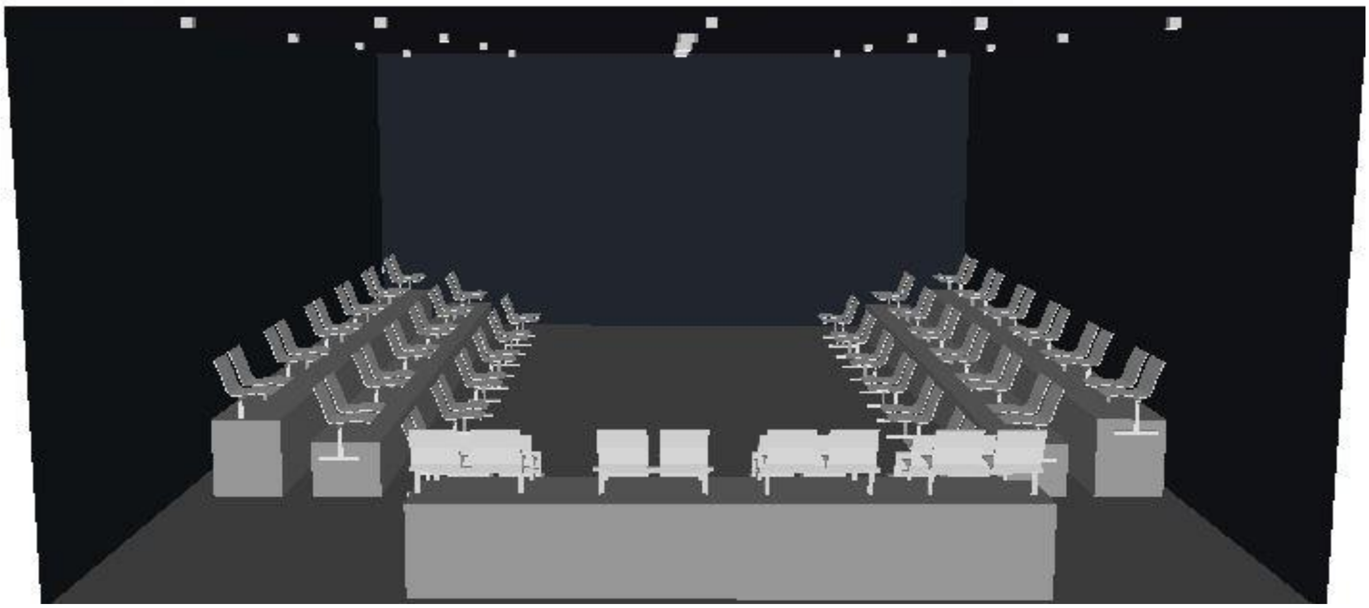
Luminaire Parts List

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 4 | TSmart Linea F 2200 20W (1.000) | 2360 | 2360 | 21.5 |
| | | | Total: 9438 | Total: 9440 | 86.0 |

Specific connected load: 5.21 W/m² = 2.70 W/m²/100 lx (Ground area: 16.52 m²)

## 6.4.7 Black Box Theatre:

A black box theater (or experimental theater) is a simple performance space, that varies in size, and is usually a square room with black walls and a flat floor. The simplicity of the space is used to create a flexible stage and audience interaction. The black box is a relatively recent innovation in theatre.
In this design, two numbers of black boxes are there. One small and another relatively larger.
The rendered image below showing the larger box.
.



**Factors Considered:**

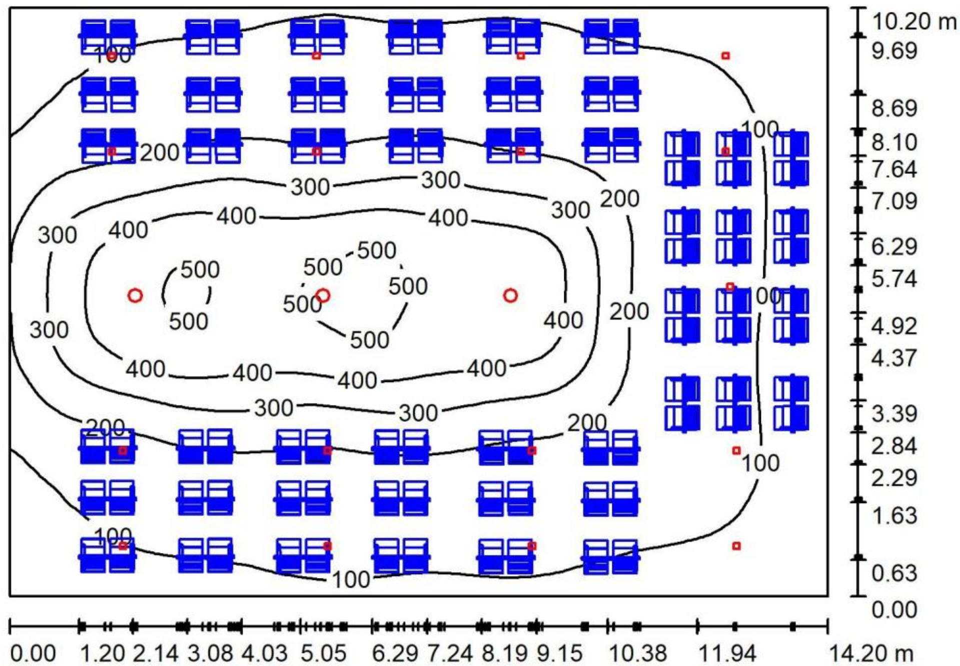
- Maintenance factor = 0.8
- All the walls and ceilings are painted in black colour, hence Reflectance factor for ceiling & wall= 5% ; Floor= 20%
- Bay-lights are used in the Centre area and rest are the downlights.
- Downlighters are used above the sitting area, whereas Bay lights are used in the centre areas for performance purpose.

**Luminaire Used:**

LBL Bay

Adrastia LED

## Black Box large I Summary




Height of Room: 5.000 m, Mounting Height: 5.000 m, Light loss factor: 0.80

Values in Lux, Scale 1:131

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 206 | 49 | 521 | 0.336 |
| Floor | 20 | 195 | 48 | 452 | 0.246 |
| Ceiling | 5 | 21 | 10 | 33 | 0.494 |
| Walls (4) | 5 | 67 | 13 | 202 | / |

Workplane:
Height: 0.760 m
Grid: 128 x 128 Points
Boundary Zone: 0.000 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.337, Ceiling / Working Plane: 0.103.

### Luminaire Parts List

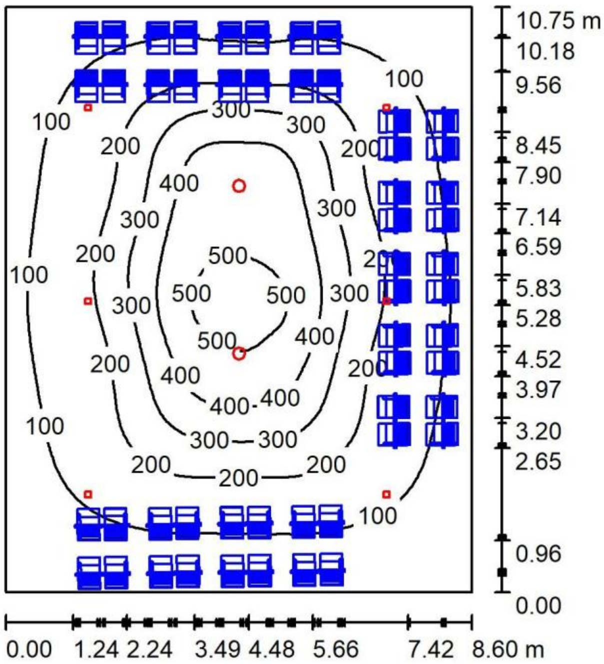
| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 17 | ADRASTIA 15W 6500K (1.000) | 1658 | 1659 | 15.6 |
| 2 | 3 | LBL - 60W (1.000) | 7782 | 7785 | 62.2 |
| | | | Total: 51539 | Total: 51558 | 451.8 |

Specific connected load: 3.12 W/m² = 1.51 W/m²/100 lx (Ground area: 144.84 m²)

**Output:**

- Avg Illuminance = 206 Lux
- Uniformity= 0.336
- Due to use of Bay Lights[8] uniformity is unlike other spaces. For this specific space uniformity is not the primary concern. Uniformity more than 3 is acceptable.
- Bay lights has been used for the performance zone and use of dimmers and smart controls have been proposed to get a charming lighting ambience according to the need of the performance.
- Special lights used for the play and theatres were not in the author’s scope.

## Black Box small I Summary




Specific connected load: 2.90 W/m² = 1.48 W/m²/100 lx
(Ground area: 92.45 m²)
Values in Lux, Scale

Height of Room: 5.000 m, Mounting Height: 5.000 m, Light loss factor: 0.80

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 202 | 43 | 530 | 0.320 |
| Floor | 20 | 184 | 41 | 453 | 0.223 |
| Ceiling | 5 | 17 | 10 | 25 | 0.602 |
| Walls (4) | 5 | 54 | 10 | 107 | / |

Workplane:
Height: 0.760 m
Grid: 128 x 128 Points
Boundary Zone: 0.0 m

### Luminaire Parts List

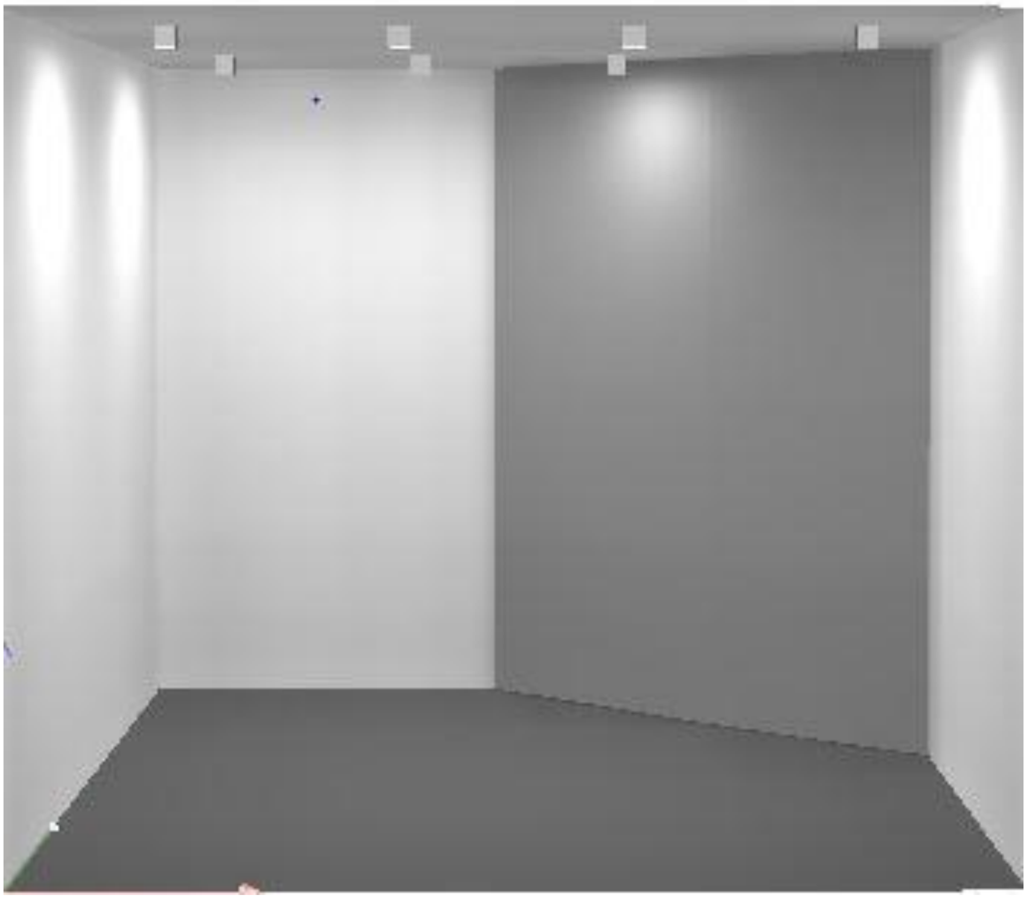
*Modified Technical Specifications

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 6 | ADRASTIA 15W 6500K (Type 1)* (1.000) | 2639 | 2640 | 24.0 |
| 2 | 2 | LBL - 60W (1.000) | 7782 | 7785 | 62.2 |

### 6.4.8 Office:

- This space is to be used for official purpose and booking.
- Reflectance for Floor, ceiling & wall is 20%, 80% and 50% respectively
- Desired Lux level= 300Lux;
- M.F.= 0.8;

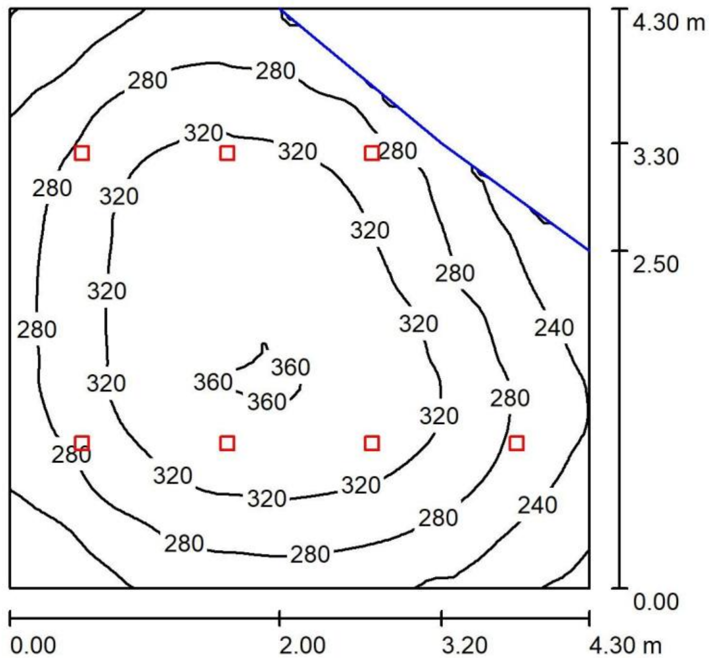
Below image shows a 3D rendered image of the office



**Luminaire Used:**

Adrastia LED

## OFFICE I Summary




| Height of Room: 3.700 m, Mounting Height: 3.700 m, Light loss factor: 0.80 | | | | Values in Lux, Scale 1:56 | |
|---|---|---|---|---|---|
| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
| Workplane | / | 302 | 193 | 363 | 0.655 |
| Floor | 20 | 214 | 4.29 | 291 | 0.020 |
| Ceiling | 80 | 70 | 3.47 | 100 | 0.050 |
| Walls (4) | 50 | 136 | 1.81 | 500 | / |

Workplane:
Height: 0.760 m
Grid: 64 x 64 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.502, Ceiling / Working Plane: 0.238.

Luminaire Parts List

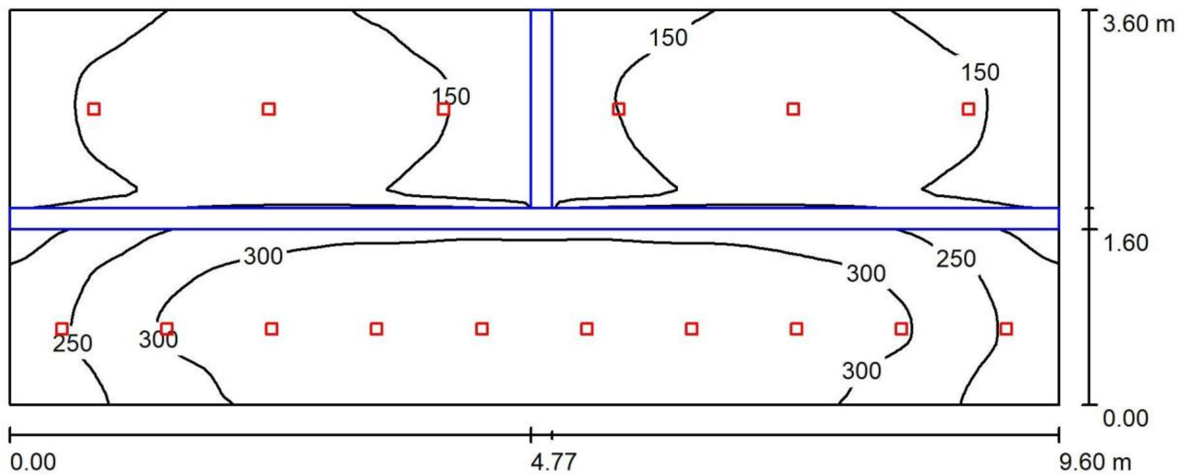
| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 7 | ADRASTIA 15W 6500K (1.000) | 1658 | 1659 | 15.6 |
| | | | Total: 11609 | Total: 11613 | 109.2 |

Specific connected load: 5.92 W/m² = 2.01 W/m²/100 lx (Ground area: 18.46 m²)

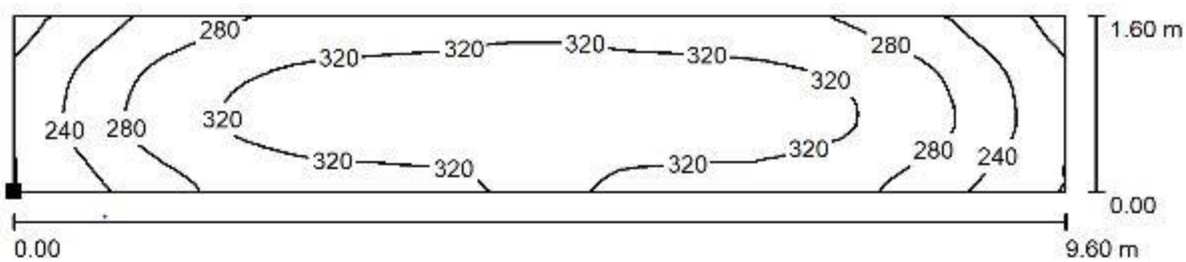
**Output :**

- Avg. Illuminance = 302 lux
- Uniformity = 0.65

## Green room with Toilet I Summary




Calculation surface1- room




Position of surface in room:
Marked point: (0.000 m, 0.000 m, 0.760 m)

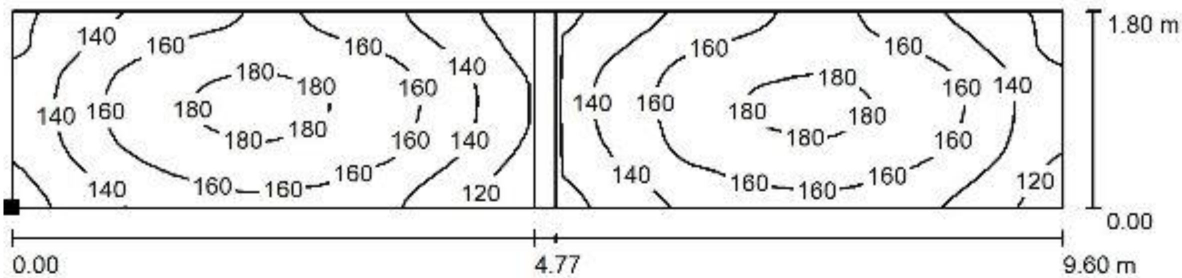
Grid: 64 x 16 Points

| $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|
| 298 | 187 | 349 | 0.627 |

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 16 | ADRASTIA 15W 6500K (1.000) | 1658 | 1659 | 15.6 |
| | | | Total: 26535 | Total: 26544 | 249.6 |

Specific connected load: 7.22 W/m² = 3.24 W/m²/100 lx (Ground area: 34.56 m²)

Calculation surface 2- Toilets




Position of surface in room:
Marked point: (0.000 m, 1.797 m, 0.760 m)

Grid: 128 x 32 Points

| $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|
| 153 | 102 | 185 | 0.667 |

Factors:

- Separate calculation surface is considered for room and toilet
- Reflectance for Floor, ceiling & wall is 20%, 80% and 50% respectively
- M.F.= 0.8
- Desired illuminance for room= 250-300lux
- Desired illuminance for room= 100lux
- Uniformity desired= 0.5 or above

**Luminaires used:**

Adrastia LED

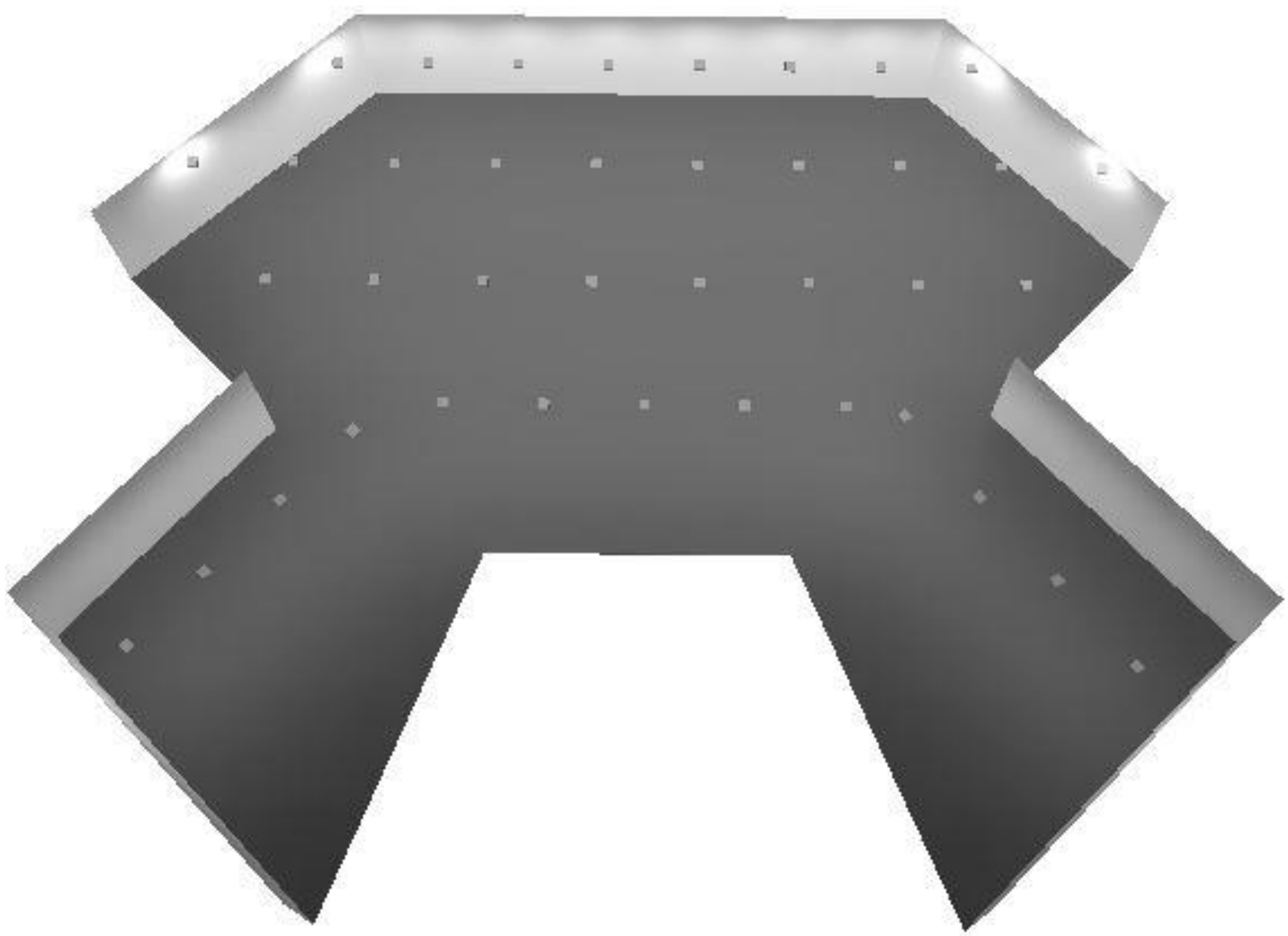
**Output:**

- Illuminance for room & Toi= 298 lx & 153 lx respectively
- Uniformity >6 for both the spaces

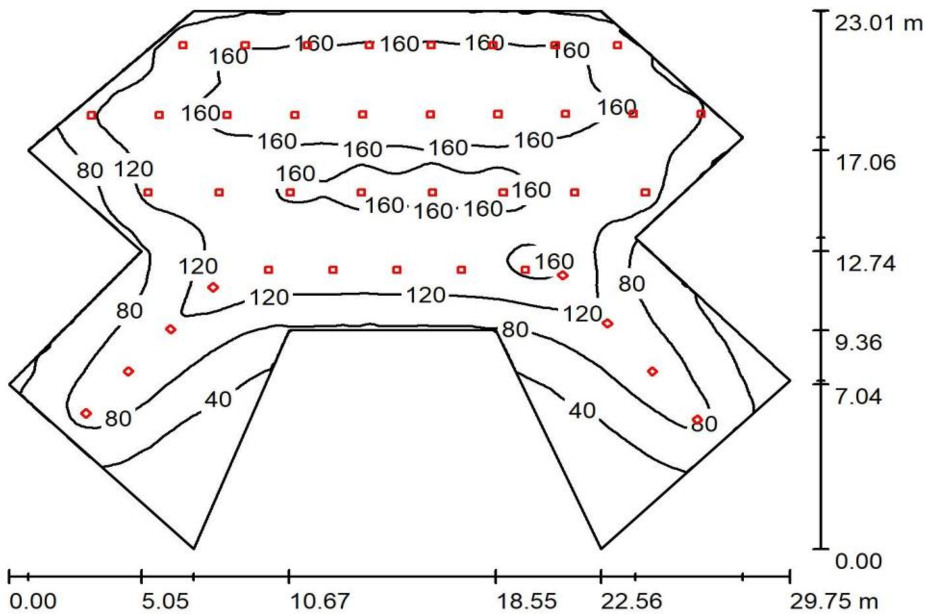
### 6.4.9 Exhibition Space:

Exhibition space is located at the basement of the Auditorium. Entry of Exhibition is from the Foyer area. General lighting for the space is designed here. Spotlights were not in scope.

M.F.= 0.8; Reflectance of Floor, ceiling and wall are 20%, 80% and 50% respectively.



## Exhibition I Summary




| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 115 | 12 | 176 | 0.104 |
| Floor | 20 | 110 | 14 | 166 | 0.129 |
| Ceiling | 80 | 25 | 7.99 | 98 | 0.324 |
| Walls (12) | 50 | 52 | 9.36 | 746 | / |

Workplane:
Height: 0.760 m
Grid: 128 x 128 Points
Boundary Zone: 0.0 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.455, Ceiling / Working Plane: 0.213.

Luminaire Parts List

| No. | Pieces | Designation (Correction Factor) | Φ (Luminaire) [lm] | Φ (Lamps) [lm] | P [W] |
|---|---|---|---|---|---|
| 1 | 39 | TRILUX 10161547 Enterio IND M41 OA LED 2000-840 ET (1.000) | 1581 | 1581 | 20.4 |
| | | | Total: 61660 | Total: 61660 | 795.6 |

Specific connected load: 1.92 W/m² = 1.66 W/m²/100 lx (Ground area: 415.35 m²)

# Chapter-8: Conclusion

With such an adaptive space, a conscious effort was made to make the room as versatile as possible so it was capable of accommodating any situation in which the room would be used. Comfort was a key factor in creating the design of the space, as the space could be used for a potentially long period of time, and it is very important that the user of the space would not feel uncomfortable in these situations. Utilizing the architecture of the auditorium also impacted the design of the space. Negating glare sources while implicating the most efficient method of lighting the space was very important not only to the effectiveness of the room. Using a lighting system to help accent some of the more dynamic and unique systems in the auditorium became an important factor in elevating the status of the space. Easy methods of controlling the space were also pivotal in the design of this space.

All design criteria are based upon the standards set forth in the IESNA Lighting Handbook, and NLC-2010 and the following criteria was taken from it. One of the larger considerations for the space was the elimination of direct glare. The primary use of the space will most likely be that of performance and lecture, and avoiding glare on the work plane must be minimized. Accounting for reflected glare from specular surfaces and avoiding it will help to create a more visually comfortable environment. Contrast ratios between task planes and visual surroundings will be very important in visual comfort. Maintaining proper ratios according to IESNA standards will be important in creating a comfortable environment for the user. An even distribution of light across the work plane is also important in proper design of the space. Providing not only proper fc values on the work plane, but also making sure there are not large disparities in the fc or Lux level is important to the use-ability of the space and also to the visual comfort of the space. Creating an environment that does not only provide proper lighting levels, but accents the unique architectural aspects of the room will enhance the atmosphere in the space. While lighting these different spaces, it is also important to avoid over lighting which could cause glare source or even begin to wash out the finish on the surface.

Selection of lamps containing good CRI and CCT lamps is important to the space as well. Improper selection can cause the light to clash with the finish colors and help to create a space that is not very visually inviting.

The design for the auditorium resulted in a more than acceptable design for this space. Proper illuminance levels were reached throughout the room.

# Chapter-9: References

**References:**


1. ‘APPLIED ILLUMINATION ENGINEERING’ by Jack L. Lindsey. published by the FAIRMONT PRESS INC, Second Edition; May,1997
2. ‘LAMPS AND LIGHTING’ by S.T. Henderson and A.M. Marsden, published by ROUTLEDGE, 4th Edition; August, 2012.
3. IESNA lighting handbook. - 10th Edition, 2011.
4. LIGHTING ENGINEERING APPLIED CALCULATIO by R H Simon & A R Beans, published by ARCHITECTURAL PRESS, 1st edition; June,2001.
5. National Lighting Code (NLC): April 2010.
6. IS 3646 (Part – I):1992; Code of Practice for Interior Illumination; Bureau of Indian Standards.
7. Trilux India Intrinsic catalogue, 2016
8. Trilux India Highlighted catalog- 2016

# ANNEXURE 1

## Internship Details:

Company Name: Trilux Lighting India Pvt Ltd
Branch: Kolkata
Duration: 9 Months 12 Days (June 19,2018 to Mar 31, 2019)
Reporting Head: Mr. Sreemanta Chakraborty, Area Manager, Trilux Lighting India Pvt Ltd.

**Work Summary:**

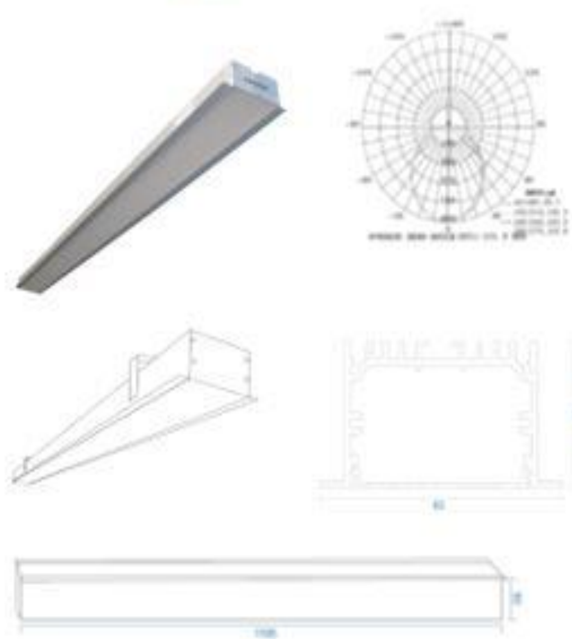
- Worked as Lighting Designer Trainee in *Trilux Lighting India Pvt Ltd*.
- The major responsibility was to meet clients, providing lighting solutions according to their need, Preparing BOQ, making Lux reports.
- In case of Revamp projects, conducted Lux audit and provided Payback calculation
- Have done lighting design simulation in software for different types of Indoor and Outdoor requirements using LED products as per IS standards and guidelines.

**Design Domain:**

- Office lighting
- Auditorium
- Educational institute
- Townhall
- Building façade
- Industry
- Road lighting

# ANNEXURE 2

## Product information
## LCL C 1200 OTA 52 LED 2600-840 ET 01
## TK: 10165192



**Luminaire type**
LED linear luminaire, Recessed with Direct Light Emission.

**Application areas**
Very slender recessed continuous line Luminaire with filigree cubic form for the visual and sensory illumination of conference and office areas, corridors, foyers, and exhibition
and retail spaces

**Mounting Types**
For system ceilings with exposed grids, false ceilings.

**Optical system**
With a finely structured, opal PMMA cover, integrated flush into the luminaire body.

**LED system**
Luminaire luminous flux 3100 lm, Nominal Input Power 28 Watt, luminous efficacy of luminaire 120 lm/W. Light colour neutral white, colour temperature 4000 K. Colour rendering index Ra › 80,
LED service life: L70 (t25 °C) = Service life 35,000 operating hours.

**Luminaire body**
Luminaire body of Aluminum Extrusion. Anodized Grey for 02 and RAL 9016 finish in powder coat for 01 Version.
Dimensions (L x W) 1195 mm x 65 mm.
Luminaire height 35mm. PMMA Diffuser.

**Electrical version**
Electronic switchable ,DALI & Analogue Dimmable versions

# ANNEXURE 3

## ADRASTIA LG7 LED Downlighter, 15W

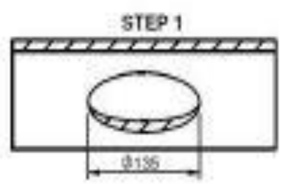
**Luminaire type**
Compact LED downlight with round construction.

**Applications**
Offices, Corridors, Foyers, Conference rooms, Retail areas, waiting zones.

**Mounting methods**
Recessed downlight for cut-out ceiling openings. Tool-free ceiling installation via rapid mounting springs.Housing dimensions: Ø160mm. Height 85mm.Ceiling Clearance 100mm.

**Optical system**
Harmonious light effect due to homogeneously illuminated light emission. Cover of translucent PMMA. Diffused optics with full glow for soft down lighting. Fixture compliance with LG7 guidelines

**LED system**
Luminaire luminous flux 1650 lm Connected load 15 Watt, Luminous efficiency of luminaire 110 lm/W. Colour rendering index Ra > 80, Service life 50000 operating hours. CCT 3000K, 4000K and 5700K available




Cut Ø135mm mounting hole.

**Luminaire body**
Ceiling rim and heat sink of Aluminum Extrusion. Luminaire body and heat sink form a compact unit.

**Electrical connection**
Mains connection is achieved via connection cable.

**Electrical version**
Electronic Switchable/DALI.

## ANNEXURE 4

### Ambiella D IND LED 14W

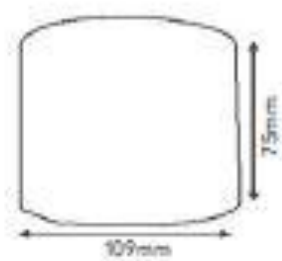
**Luminaire type**
Surface Mounted LED Downlight with cylindrical construction.

**Applications**
Offices, Corridors, Lobbies, Guest Rooms.

**Mounting Method**
Surface mounted downlight, cylindrical for exposed ceilings. Housing Dia 109 mm, height 75 mm.

**Optical System**
Cover of translucent PMMA with direct light distribution. Harmonious light effect due to homogenously illuminated light emission.

**LED System**
Luminous flux 1260 Lm, Nominal Input Power 14 W, Luminous efficiency of 90 Lm/W. Colour rendering index > 80. Service Life 50,000 Hrs.




**Luminaire Body**
Aluminum Housing, Powder Coated

**Electrical Connection**
Main connection is achieved via connection cable

**Electrical Version**
Electronic Switchable
POE Compatible version on request

# ANNEXURE 5

## Ambiella IND Plus G3 LED, 15W

**Luminaire type**
Compact LED downlight with round construction.

**Applications**
Offices, Corridors, Foyers, Conference rooms, Retail areas, waiting zones.

**Mounting methods**
Recessed downlight for cut-out ceiling openings. Tool-free ceiling installation via rapid mounting springs. Housing Dia 145mm. Cut-out opening 125 mm diameter, Ceiling Clearance 70 mm.

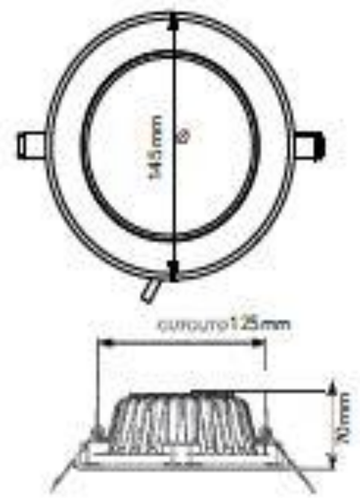
**Optical system**
Harmonious light effect due to homogeneously illuminated light emission. Cover of translucent PMMA.

**LED system**
Luminaire luminous flux 1500 lm Connected load 15 Watt, Luminous efficiency of luminaire 100 lm/W. Colour rendering index Ra > 80, Service life 50000 operating hours.

**Luminaire body**
Ceiling rim and heat sink of die-cast Aluminum.
Luminaire body and heat sink form a compact unit.

**Electrical connection**
Mains connection is achieved via connection cable.

**Electrical version**
Electronic Switchable/Analog/DALI.
POE compatible version on request.



# ANNEXURE 6

## Enterio IND M73

**Luminaire type**
Recessed LED luminaire with translucent PMMA cover.

**Applications**
Offices, Banks, Hospitality, Hospitals, Corridors, Foyers, Conference rooms, Retail areas, waiting zones.

**Mounting types**
For system ceilings with exposed grids, False Ceilings.

Dimensions (L x W X H) 595 mm x 595 mm x 90 mm;
Cut Out Dimensions (L x W) 570 mm x 570 mm

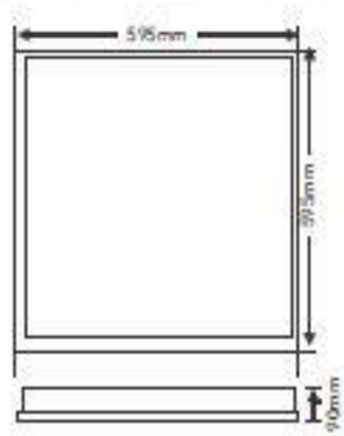
**Optical system**
Harmonious light effect due to homogeneously illuminated light emission. Cover of translucent PMMA.

**LED system**
Luminaire luminous flux 3600 lm, Connected load 36 Watt Luminous efficiency of luminaire 100 lm/W. Colour rendering index Ra > 80, Service life 50000 operating hours.

**Luminaire body**
Powder Coated CRCA, white; options available

**Electrical connection**
Mains connection is achieved via connection cable.

**Electrical version**
Electronic Switchable/Analog/DALI.
POE compatible version on request.



# ANNEXURE 7

## Tsmart Linea F 20W 36W


**Luminaire type**
Sleek surface LED Batten.

**Applications**
Home, Factories, Business Centres, Offices, School & College,
Café & Restaurants, Shopping Arcades, Hotel & Resorts,
Theatres, Retail Shops, Modern Retail, Hospitals

**Mounting methods**
Suspended / Surface Mounted with length of 1150mm available

**Optical system**
With diffused polycarbonate cover,
integrated flush into the luminaire body.

**LED system**
Best in class LEDs, with Luminaire luminous flux 2200lm/3960lm,
connected load 20/36W, luminous efficiency of luminaire 110 lm/W.
Light Colour temperature- 3000 K/ 4000 K/ 5700 K,
Colour rendering index Ra > 80
Operating Temperature range: -10degC to 45degC, IP 20

**Luminaire body**
Extruded Aluminium Housing with 28X43X1150mm(WxHxL) available

**Electrical connection**
Mains connection is achieved via connection.

**Electrical version**
With Electronic Switchable

# ANNEXURE 8

## LBL 60W

**Luminaire type**
Round wide-area LED high bay luminaire for suspended mounting.

**Applications**
High rooms, Halls, Warehouses, Manufacturing halls, damp Rooms and exhibition halls

**Mounting methods**
For suspended mounting as single luminaire. Single point suspension to centrally integrated fixing hooks. Mounting accessory must be ordered separately.

**Optical system**
Optical system with PC lens optic. Each LED module has own optical unit. Optimized luminance contrasts due to homogeneous, light-scattering Glass panel. With rotationally symmetric light distribution.

**LED system**
Luminaire luminous flux 7500 lm, connected load 60 W, luminous efficiency of luminaire 125 lm/W. Light colour neutral white, colour temperature 4000 / 5700 K, colour rendering index Ra > 80. Service life 50,000 h,

**Luminaire body**
Robust die-cast housing with integrated cooling ribs. Permissible ambient temperature (ta): 0 °C - +45 °C. IP-65 Protection

**Electrical connection**
Mains connection is achieved via a 3-pole connection cable.

**Electrical version**
Electronic Switchable.