THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

Mahindra LIFESPACES

Guidelines for
Optimum Visual Comfort
derived from key performance parameters

Mahindra-TERI
Centre of Excellence

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optimum visual comfort derived from key performance parameters

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Foreword

The Mahindra-TERI Centre of Excellence (CoE) was established to carry out integrated research on resource efficiency, enhanced occupant comfort, and sustainable construction materials for the building industry. The objective is to provide validated information on materials, technologies and occupant comfort pertaining to the built environment with the underlying principles of "Greener yet Cheaper" built spaces.

Issues related to visual comfort have been persistent for the last many years and have posed a challenge to building professionals and architects, as these concepts have limited know-how in the Indian geo-climatic context. Lighting can enhance form and function, improve safety and security that create good workspaces. Good lighting at the workplace with well-lit task areas is essential for optimizing visual performance, visual comfort and overall ambience. The impact of good lighting extend beyond visual effects – they enhance productivity, make the environment more amiable and increase occupant comfort.

We, at the Mahindra-TERI CoE, are pleased to introduce "**Guidelines for optimum visual comfort derived from key performance parameters**" as a step towards achieving visual comfort and glare-free spaces in the built environment. These guidelines have been prepared to help building professionals, owners and end-users, to generate awareness on the impacts of glare. It talks about different lighting schemes, hardware typologies, steps for lighting designing and conclude with best practices for attaining optimum visual comfort in indoor spaces.

The "**Guidelines for optimum visual comfort derived from key performance parameters**" has been developed through a consultative process involving academia, lighting experts and building professionals. These will keep evolving in keeping with the advancements in technologies and practices in the urban built environment. I gratefully acknowledge the support of all those associated with the development of these guidelines and look forward to their continued guidance for their enhancement.

Mr Sanjay Seth
Senior Director, Sustainable
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Terms and Definitions

- **Ambient light**: The general lighting of the visual environment is provided by the ambient light. It is the light which is already present in the screen without any additional lighting.
- **Angle of view**: Angle at which an object under view is perceived, measure for the size of the image of the object on the retina of the eye.
- **Beam angle**: A light source's measure of spread is known as the beam angle. It is measured in degrees. A light's beam angle is determined when its lux level drops to half of the intensity of the centre beam.
- **Cut-off angle**: The angle taken from the horizontal to the line from the inner edge of the luminaire to the edge of the light source. This angle is used to identify the glare limitation of a luminaire.
- **Colour rendering index**: Measurement of the ability of a light source to reproduce the colour's vibrancy accurately compared to the reference illuminant (natural light). Light sources with a poor CRI (a lower number on the scale which goes from 0 to 100) will change how some colours appear.
- **Colour temperature**: This term defines whether a light source appears 'cool', 'neutral' or 'warm'; this is indicated by the Correlated Colour Temperature (CCT). Colour temperature is measured on the Kelvin (K) scale; lamps with a warm appearance have a CCT of 2700-3000K, and are considered appropriate for domestic settings; neutral lamps of 4000K and cool lamps of around 6000K are used more often in offices and retail. Very cool temperatures of 6000K plus can start to look almost blue-white and are used in car LED headlights.
- **Driver**: Auxiliary device(s) needed to operate and vary the intensity of light output from LED lamp source(s) by regulating the voltage and current powering the source.
- **Illuminance**: Represented by the symbol E (lx), illuminance is defined as the ratio of the amount of luminous flux falling on a surface to the area of the surface.
- **Luminance**: Luminance (cd/m^2) describes the brightness of a luminous surface which emits light through either auto luminance (as a light source), transmission, or reflection. Luminance is accordingly defined as the ratio of luminous intensity to the area on a plane at right angles to the direction of beam.
- **Luminous flux**: Represented by the symbol Ï (lm), luminous flux describes the total amount of light emitted by a light source. It is calculated from the spectral radiant power by the evaluation with the spectral sensitivity of the eye V (¬).
- **Luminous efficacy**: Luminous efficacy describes the luminous flux of a lamp in relation to its power consumption (lm/W).
- **Luminous intensity**: Represented by the symbol I (cd), luminous intensity is the amount of luminous flux radiating in a given direction (lm/sr). It describes the spatial distribution of the luminous flux.

Introduction

Lighting is vital to the modern world since it enables a 24-hour society to exist. When electric lighting was first introduced, it was expensive and available only to a few. However today, it is widely available at a very affordable cost.

Lighting is used for many different purposes, primarily to ensure the accuracy of visual work, enhance safety, security, human health and well-being, improve aesthetics, etc.

But lighting comes at a cost, both financial and environmental. The financial cost involves capital costs, operating costs, and disposal costs. The environmental cost can be categorized under three groups: generation of electricity to power lighting, chemical pollution upon disposal, and light pollution at night. This means that lighting recommendations are a balance between the benefits and the costs [1].

Energy reduction in the built environment is a continuing challenge and the lighting within a major contributor to the energy demands of a building [2]. By carefully selecting luminaires and light sources with appropriate controls, one can drastically reduce the energy demand. Designers and installers can make a significant impact at an early stage by understanding the user needs and providing a custom-made approach.

Access to daylight is also known to be beneficial to the health and wellbeing of occupants.

Visual comfort still remains a domain where-in most of the cases a quantitative approach is taken. However, recent studies have shown the importance of light and visual comfort in sleep. Studies have shown the effect of light on our daily circadian cycles. In the last two decades, scientists have discovered a new type of photoreceptor in the eyes [3], [4]. This photoreceptor via light is responsible for resetting our body clock (circadian rhythm), disruption of which can have huge impact on our functioning and health. Studies have shown that disruption of circadian rhythm has been linked with **metabolic disorders**, **obesity**, **diabetes,** and, at times, **depression** [5] [6]. All of this makes understanding the basics of visual comfort and parameters affecting it even more critical. This document tries to establish the definition of visual comfort, list down various parameters affecting it, provide information regarding different types of lighting system, light styles, and hardware associated with it. This document also presents the basic steps of designing a lighting layout and concludes with the practices to be followed for achieving optimum visual comfort using electric lighting.

What is Visual Comfort?

Visual comfort is generally represented as a subjective reaction to the quantity and quality of light within any given space at a given time. A widely accepted definition of human comfort does not exist, but several metrics have been developed to quantify how much users appreciate environments, objects, or interfaces. Both too little and too much light can cause visual discomfort. Visual comfort encompasses a variety of aspects [6]:

- Views of outside space and connected to nature
- Light quality
- Luminosity
- Absence of glare

To define visual comfort, two different approaches are usually considered:

- The most widely accepted approach is the '*Non-annoyance approach*' [7] based on the assumption that 'comfort is not discomfort'. It is easier to provide a quantitative and qualitative evaluation of visual discomfort parameters rather than comfort parameters that do not have a unique definition.
- The second approach is the '*well-being approach*' based on the evaluation of the positive effects induced by well-being and satisfaction. It needs methodologies to define and measure the well-being.

Multiple metrics exist for assessing visual comfort. The most common comfort metrics for lighted environments are based on the '*Non-annoyance approach*'. *Non-annoyance approach is* based on the following two factors:

- **Quantity of natural light around the year**: This metric is about the potential of a space or building in providing adequate daylight to occupants. Typically, it is represented by *Daylight Autonomy* (DA) or *Useful Daylight Illuminance* (UDI). Daylight autonomy is defined as the percentage of the operating period (or a number of hours) that a particular daylight level exceeds throughout the year. Useful daylight illuminance (UDI) [8] is a modification of daylight autonomy conceived by Mardaljevic and Nabil (2005). This metric, bins hourly time values based upon three illumination ranges: 0–100 lux, 100–2000 lux, and over 2000 lux. It provides full credit only to values between 100 lux and 2000 lux suggesting that horizontal illumination values outside of this range are not useful. These metrics can be used to analyse and evaluate different design alternatives to determine which design provides more usable daylight in the interior.
- **Distribution of light as perceived by the eye:** When the light intensity of a room changes, the human eye takes some time to adjust to it. When the lighting levels in a room are dimmed, there is a difference between the actual intensity of dimmed light and the perceived intensity of the dimmed light.

PARAMETERS AFFECTING VISUAL COMFORT

It is relatively easy to identify a comfortable environment; however, it becomes a challenge to describe a visually comfortable environment because the effect produced by 'well-being' and 'satisfaction' levels is not a single effect but a generic condition of well-being. If the space is well-lighted, then the subjects usually do not experience any significant visual discomfort.

International Commission on Illumination (CIE) documents [7] standards on lighting environments, relevant codes and available research, results specifying/recognizing the following parameters as relevant for visual comfort in indoor lighting:

1. Illuminance
2. Surface reflectance
3. Uniformity ratio
4. Glare

ILLUMINANCE

Illuminance is a measure of how much the incident light illuminates the surface and is measured in lux. It is the total luminous flux incident on a surface per unit area (lumen per m²). The basic representation of illuminance is given in Figure 1.

Illuminance and its distribution on the task area and on the surrounding area have a greater impact on how quickly, safely, and comfortably a person perceives and carries out the visual task (European standard EN-12464-1, Light and lighting - Lighting of workplaces - Part 1: Indoor workplaces, June 2011).

Various codes and standards specify the minimum level of illuminance over the task area on the reference surface. The average illuminance should not fall below the recommended values (in lux). A typical example of illuminance at a horizontal work surface (office) is given in Table 1.

The 2009 IECC requires that a minimum of 50% of the lamps in permanently installed lighting fixtures be high-efficacy lamps (2009 IECC, Section 404.1). The 2012 IECC has increased the minimum percentage from 50% to 75%, along with an exception for low-voltage lighting (2012 IECC, Section R404.1).

TABLE 1: Illuminance range as per codes and rating system

Parameter	Codes/Rating system	Range
Illuminance (at work surface, horizontal)	EN 12464-1	500 lux Immediate surrounding illuminance: 300 lux Background area illuminance: 100 lux
	NBC 2016	300–500–750 lux
	GRIHA V - 2015	300–500–750 lux
	The WELL Building Standards v 1 with May 2016 addenda	300–500 lux if ambient lighting ≤ 300 lux
	CIBSE Code for lighting	300 lux: mainly screen-based tasks 500 lux: paper-based tasks

There are numerous ways and methods of devising the minimum illumination levels at any given surface. These levels vary based on the type of task to be conducted in that particular

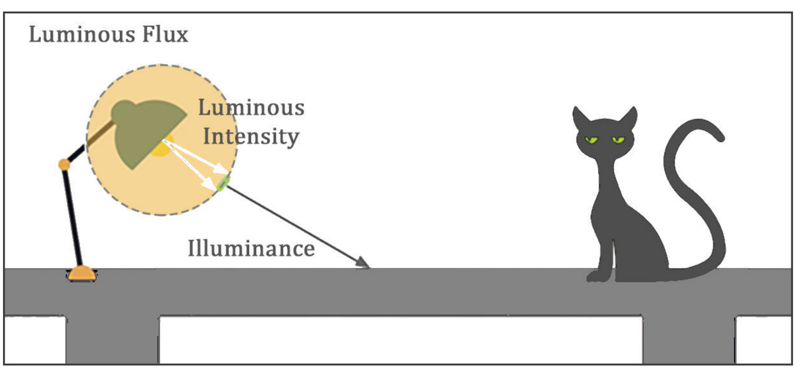


FIGURE 1: Luminous intensity and illuminance

space. The recommendations for minimum illumination levels are detailed for specific task areas based on the factors discussed in Figure 2.

The standard is based on illuminating the task area and not the total space with references to the areas referred to as 'immediate surroundings' with a minimum bandwidth of 0.5 m, and 'background area' with illumination ratios to the task and each other. The standard also details the uniformities of the respective areas in place of the whole workspace.

Typically, if the task area is illuminated to 500 lux the immediate surroundings should be at least 300 lux, whilst the background area should be illuminated to a one-third the value of the immediate surroundings. Figure 3 depicts illuminance for task, immediate, and background areas [9].

For residential sector there is no prevalent codes/standards specifying the Illuminance levels. However IESNA (Illuminating

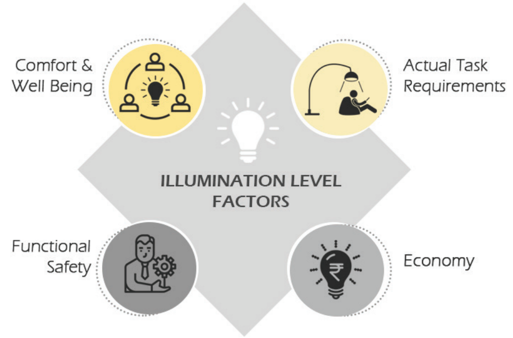


FIGURE 2: Factors affecting illumination levels

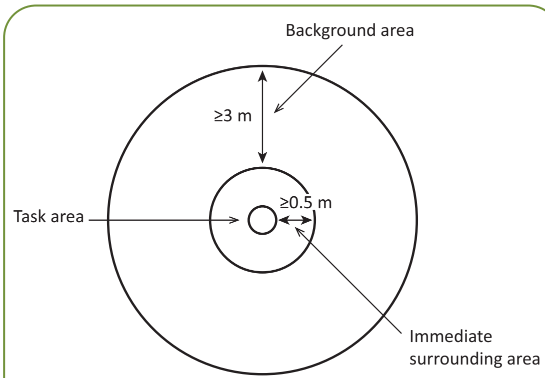


FIGURE 3:Task, immediate surroundings, and background areas

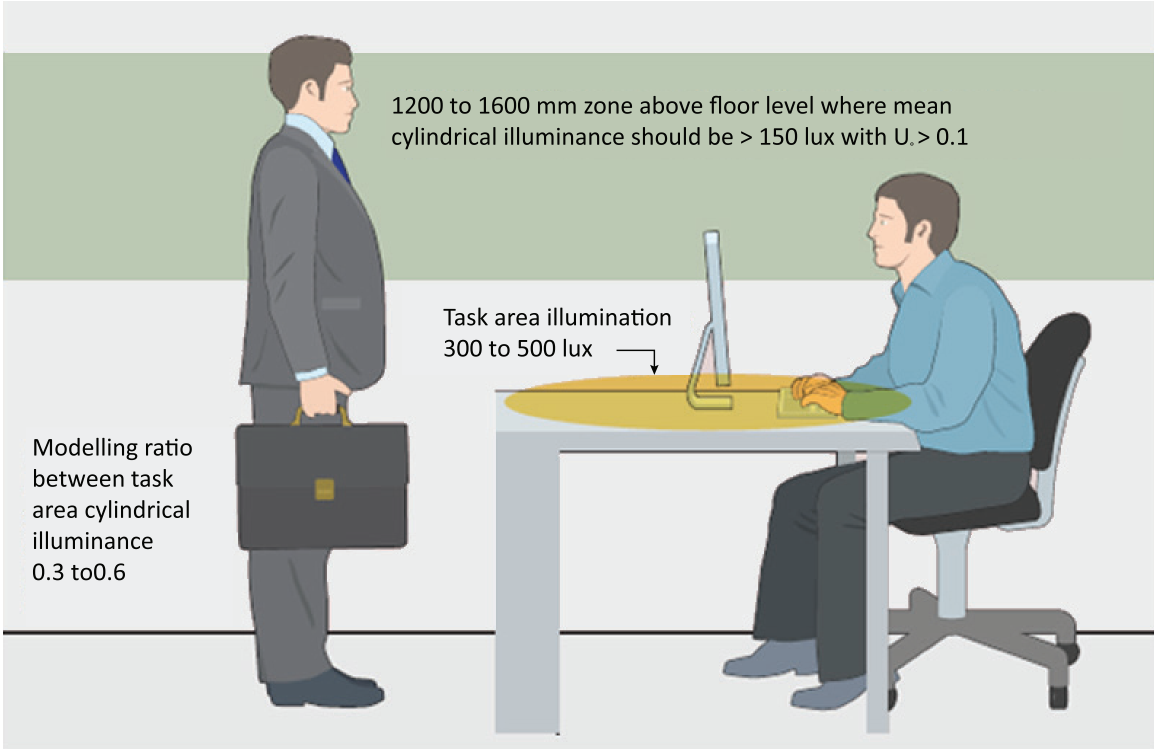


FIGURE 4: Application of cylindrical illuminance [2]

Engineering Society of North America) in its Lighting Handbook has specified illuminance levels. Below are the illumination levels specified in the IESNA documents below [11]:

SURFACE REFLECTANCE

Surface reflectance is the ratio of luminous flux reflected by a body (with or without diffusion) to the flux it receives (National Building Code of India, Volume 2, 2016).

Areas/Tasks	Illuminance
For Specific Visual Tasks	Lux
Dining	100-150-200
Reading (Casual, Normal, Books, Magazine, Papers)	200-300-500
Kitchen Counter (Range, Sink, Non-Critical)	200-300-500
Laundry (Preparation at tubs, washer, and dryer)	200-300-500
Ironing	200-300-500
Grooming	200-300-500
Multi-Purpose Tables	200-300-500
Full Length Mirror	200-300-500
Hand and Machine Sewing (Occasional, High Contrast)	200-300-500
Music Study (Simple Scores)	200-300-500
Workbench Hobbies	200-300-500
Reading (Handwriting, Reproductions, Poor Copies)	500-750-1000
Study (Prolonged, Serious or Critical)	500-750-1000
Kitchen Counter (Range, Sink, Difficult Seeing)	500-750-1000
Hand and Machine Sewing (Light to Medium Fabrics)	500-750-1000
Workbench Hobbies (Difficult Tasks)	500-750-1000
Easel Hobbies	500-750-1000
For General Lighting	
General Lighting	50-75-100
Conversation, Relaxation, and Entertainment	50-75-100
Passageways	50-75-100

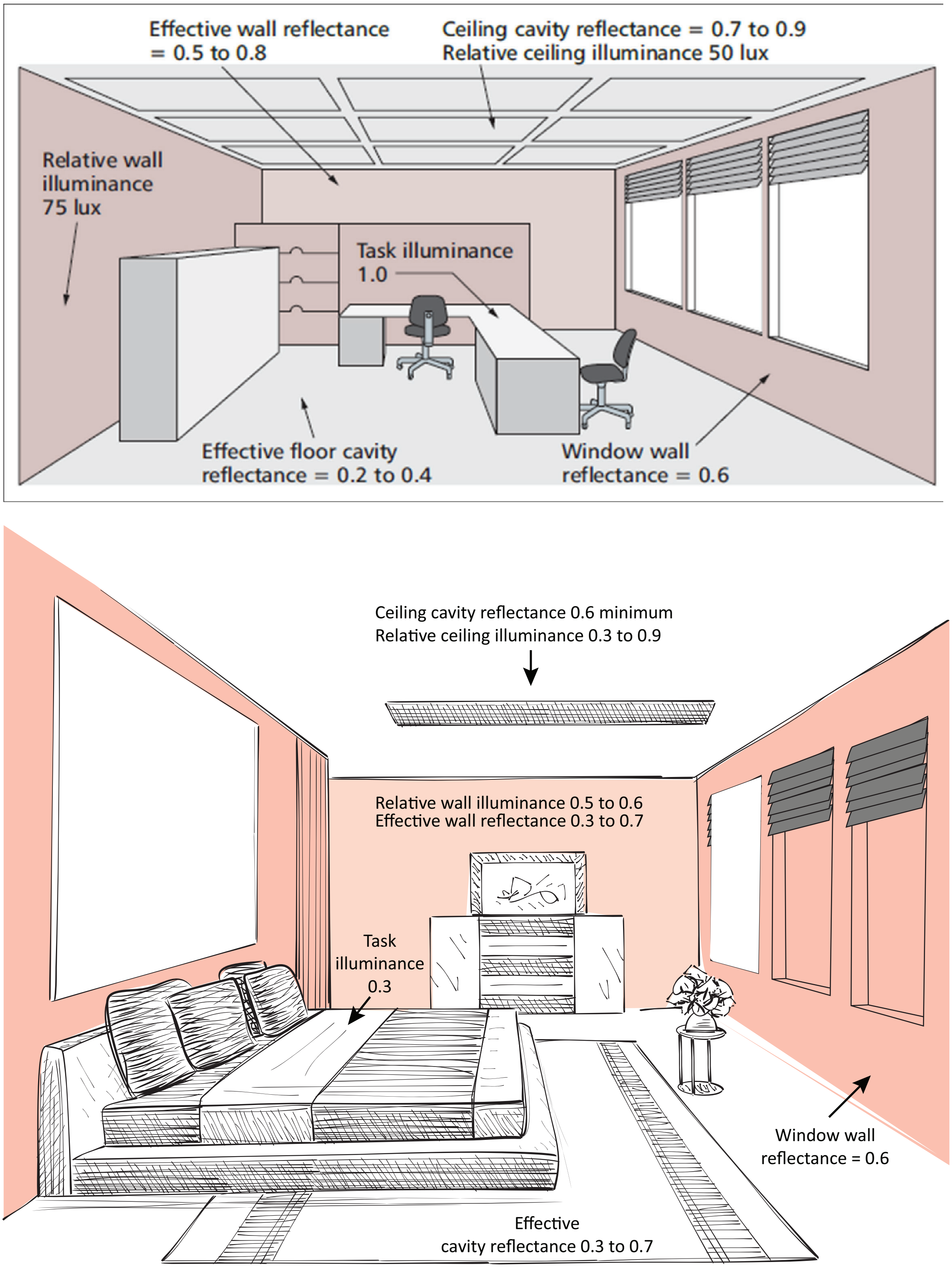


FIGURE 5: Surface reflectance at various surfaces

Reflectance creates a well-balanced luminance distribution. If reflectance is more than the desired range, it will contribute to high luminance, which will cause glare. If reflectance is lower than the desired range, it will contribute to low luminance, which results in a dull and non-stimulating working environment (European standard EN-12464-1, Light and lighting - Lighting of workplaces - Part 1: Indoor workplaces, June 2011). Reflectance values described in various codes and standards are given in Table 2.

Reflectance is dependent on various factors. The finishes and paints of the wall play a crucial role in determining the overall reflectance. An example of effect of reflectance via blinds is shown in Figure 6.

Figure 6 clearly shows the increased level of illuminance when the blinds are up. However,

TABLE 2: Surface reflectance range as per standard codes and rating systems for office space

Parameter	Codes/ Rating system	Range			
		Ceiling	Walls	Floors	Furniture
Reflectance	EN 12464-1	0.7–0.9	0.5–0.8	0.2–0.4	0.2–0.7
	CIBSE Code for Lighting	0.7–0.9	0.5–0.8	0.2–0.4	0.2–0.7
	LEED v4.1 Interior Design	85%	60%	25%	Work Surfaces: 45% Movable Partitions: 50%
	The WELL Building Standards v 1 with May 2016 addenda	≥ 0.8	≥ 0.7		≥ 0.5
	NBC 2016	For ceilings and walls			
		Dark colours : 0.1	Middle tints : 0.3	Light colours: 0.5	White and very light colours : 0.7

TABLE 3: Surface reflectance range as per standard codes and rating systems for residential spaces

Parameter	Codes/ Rating system	Range		
		Ceiling	Walls	Floors
Reflectance	IESNA Lighting Handbook	60% - 90%	35% - 60%*	15% - 35%*

* in areas where lighting for specific visual tasks takes precedence over lighting for the environment, the minimum reflectance should be 40% for the walls and 25% for the floors

FIGURE 6: Comparison of the room with blinds raised and lowered showing the effect of changing the window wall reflectance

when the blinds are down, the overall illuminance at the workplace reduces because of their lower reflectance. Room surface finishes can play a significant role in maximizing the efficiency of a lighting system because lighter finishes can produce relatively higher light levels and perceptions of brightness. In fact, in an existing space with a large area of dark surfaces, the light levels and visual comfort can be improved almost immediately by simply repainting the walls a lighter colour as it will improve reflectance.

UNIFORMITY RATIO

Uniformity ratio plays a vital role in improving user perception, visual acuity, and overall visibility. When referring to light uniformity of an area, the task area in which the objects and immediate surroundings are considered. Uniformity ratio as defined in EN- 12464-1 is the ratio of minimum to average illuminance in the visual task area (European standard EN-12464-1, Light and lighting - Lighting of workplaces - Part 1: Indoor workplaces, June 2011). A working environment should ideally be the one in which the occupants do not notice different lighting levels with the naked eye and feel themselves in an environment in which the light is well-distributed. The higher the uniformity ratio, the better is the uniformity, which will make people more comfortable.

TABLE 4: Uniformity ratio as per different codes and rating system

Parameter	Codes/Rating system	Range
Uniformity Ratio	EN 12464-1	Task area ≥ 0.6 Immediate surrounding illuminance: ≥ 0.4 Background area illuminance: ≥ 0.1
	GRIHA V - 2015	Min. 0.4
	NBC 2016	Min. 0.7

GLARE

Glare is the sensation produced by bright areas within the field of view. It may be experienced either as discomfort glare or as disability glare. The glare caused by reflections in specular surfaces is usually known as veiling reflections or reflected glare.

In interior workplaces, discomfort glare may arise directly from bright luminaires or windows. Glare from windows can be minimized either by using shading devices such as louvers, external hoods, curtains, or by cross-lighting the surroundings to a comparable level. For glare produced by electric lighting, shielding is used. While technically both shading and shielding are almost the same and used to either diffuse the light to reduce the luminance or shield the source from view, the slight difference in language helps in differentiating between lighting and daylighting.

For electric lamps, the minimum shielding angles for lamp luminance shall not be less than the values given in Table 5.

Shielding angle is the angle between the horizontal plane and the first line of sight at which the luminous parts of the lamps in the luminaire are directly visible.

If discomfort glare limits are met, disability glare is not usually a major problem. For determining the rating of discomfort glare directly from the luminaires of an indoor lighting installation, CIE **Unified Glare Rating** (UGR) tabular method shall be used.

The UGR rating helps to determine how likely a luminaire is to cause discomfort to those around it.

There are generally two methods of reducing the glare that is present in relation to interior lighting [10]:

- To use luminaires that are UGR<19 rated

- To ensure that the lighting design is appropriate for the environment it is being used in, i.e. the correct number and position of luminaires

The series of UGR is: 10, 13, 16, 19, 22, 25, and 28. In most situations, the less the glare the better, so a low UGR is better than a high UGR. Some of the typical spaces with maximum UGR value is provided in Table 6 [11].

TABLE 5: Shielding angle as per different codes and rating system

Parameter	Codes/ Rating system	Range				
Shielding angle w.r.t lamp luminance	NBC 2016	Lamp Luminance (kcd/m²)	1 to 20	20 to 50	50 to 500	≥ 500
		Min. Shielding angle	10°	15°	20°	30°
	The WELL Building Standards v 1 with May 2016 addenda	Lamp Luminance (kcd/m²)	1 to 20	20 to 50	50 to 500	≥ 500
		Min. Shielding angle	No shielding required	15°	20°	30°
	EN 12464-1	Lamp Luminance (kcd/m²)	1 to 20	20 to 50	50 to 500	≥ 500
		Min. Shielding angle	-	15°	20°	30°

Note: The above-mentioned shielding angle should not be applied to luminaires that do not appear in the field of view of a worker during usual work and/or do not give the worker any noticeable disability glare

TABLE 6: UGR values of various task areas

BS EN 12464 table	Type of area, task or activity (no. of sub-divisions)	Maximum UGR
5.1.1	Circulation areas and corridors	28
5.1.3	Elevators, lifts	25
5.2.1	Canteens, pantries	22
5.2.2	Rest rooms	22
5.26.2	Offices: Writing, typing, reading, data processing	19
5.26.5	Offices: Conference and meeting rooms	19
5.26.6	Offices: Reception desk	22
5.29.2	Places of public assembly – Restaurants and hotels - Kitchen	22

Electric Lighting Systems

FUNDAMENTAL LIGHTING SYSTEMS

Extensive interest has developed in light and electric lighting systems owing to the growing awareness of better architectural quality and visual comfort, which has increased the demand for good electric lighting. A variety of light sources and luminaires are now available and researched upon that focus on the technical progress to expand the scope of lighting technology, and this has, in turn, led to the growth of more specialized lighting equipment and tools. It is this fact that makes it more difficult for the electric lighting designer to be adequately informed regarding the comprehensive range of lamps and luminaires available and to decide on the correct surrounding parameters and technical solutions to meet the lighting requirements of a specific project. The balance of lighting system to be thus really good, the lighting has to be matched in some way to the particular environment and should be task appropriate.

In order to achieve these lighting solutions, a combination of architectural design and the specificity of placement of lighting suggests that the requirements necessary for good lighting quality are more likely to change over time and space and, hence, will not be achievable through the use of lighting recommendations alone. Therefore, each lighting solution must be designed specifically and not generically. To enable users to perform visual tasks efficiently and accurately, adequate and appropriate lighting should be selected and provided. The illumination levels can be achieved by multiple light sources including daylighting, artificial lighting, or a combination of both, where the degree of visibility and visual comfort required in a wide range of spaces is governed by the type and the duration of the activity performed.

Hence, in order to understand the implications and fundamentals of the lighting systems better, we need to understand the different types and combinations of lighting sources, hardware and lighting styles, which we majorly incorporate to design an electric lighting system.

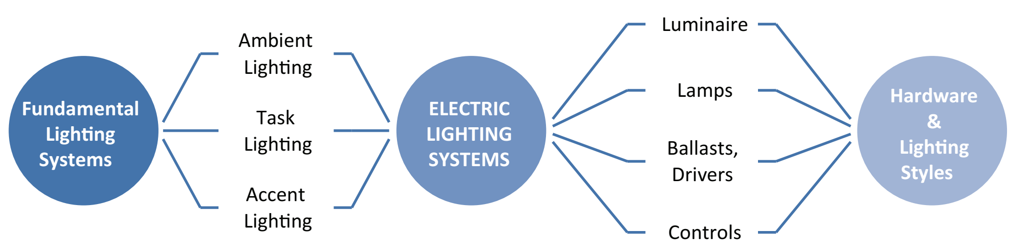


FIGURE 7: Electric lighting systems

Ambient Lighting

Ambient lighting, also known as general lighting, is used as a primary lighting source in a working space. It ensures comfortable illumination, glare-free environment, and appropriate brightness level, which act as foundation or the first layer of the lighting placement of all other lights in the room. It is also considered as an important and dominant source of establishing the feel and mood of the space.

Ambient lighting selection depends on the following factors:

- Size of the room
- Natural source of light, which may enter the room and contribute to lighting the indoor environment

Ceiling decorative mounted lights, wall mounted ambient lights (e.g. for staircase and landing area), floor recessed ambient lights, etc. with a combination of fixtures from track lights, down lights, fan lights, cove, wall scone, or any other type of fixture with the ability to produce a wide beam span can be used as ambient lighting.

Task Lighting

Task lighting is the additional lighting of a room that goes beyond general lighting in conjugation with ambient lighting to meet the demands of any specific visual task or task area. It is to be noted that not all tasks require same level of illumination level. For example, in a typical office, task lighting might be accomplished with a system of luminaires on the desks or a system of ceiling-mounted luminaires correlated to the desk locations. These are designed and controlled to affect only specific task areas being lighted.

Task lighting control strategies vary depending on the following applications:

- The extent of ambient and accent lighting
- The extent of daylighting and its integration with electric lighting, and the ambient lighting

The control of task lighting can offer significant energy reductions provided the function does not interfere with the expected use of the facility. Task lighting along with other ambient or accent lighting are therefore designed to classify lighting in accordance with code-

FIGURE 8: Ambient lighting with multiple light sources in a workspace


FIGURE 9: Task lighting in a workspace

and/or standards-definitions for purposes of meeting their respective requirements.

Accent Lighting

The main purpose of accent lighting is to highlight a specific object or an area. They are generally three times as bright as ambient lights. Accent lighting draws attention to a feature, such as planters, sculptures, artwork, furnishings or any other architectural details, converting them into focal points. For this type of lighting, adjustable fittings are preferred as they allow precision focusing on small areas or objects. It also adds style and drama to a space, and is especially suited to living and garden areas, entrances, and anywhere the goal is to display special features.

Accent lighting is a necessity in many situations as it also minimizes the fatiguing effects of long-term close-up viewing of tasks and provides visual relief. Fixtures such as wall lights, recessed spot lighting, track lighting, wall-mounted picture lights are commonly used for accent lighting.

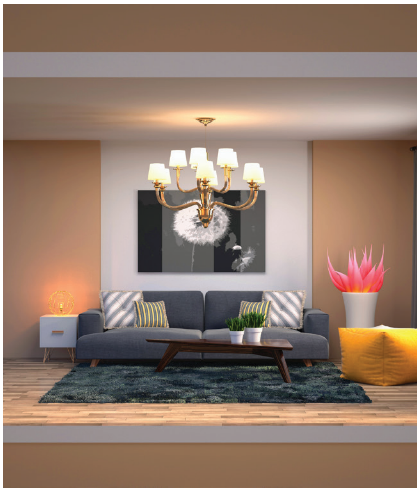
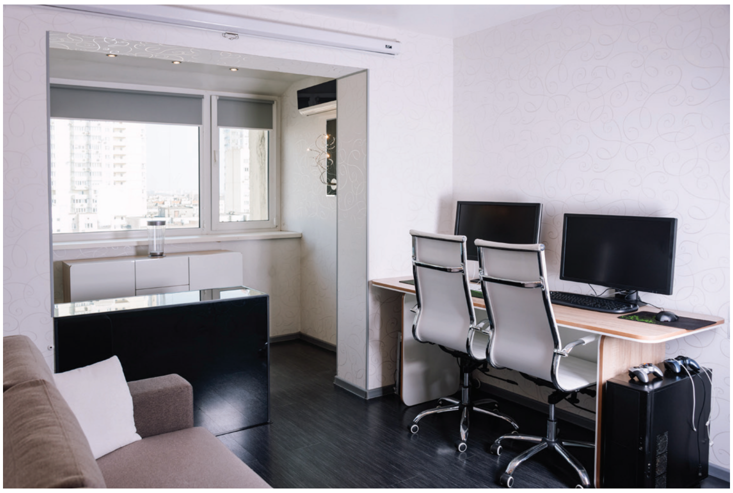



FIGURE 10: Accent lighting in a workspace

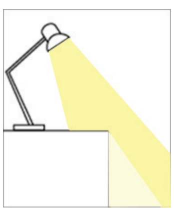
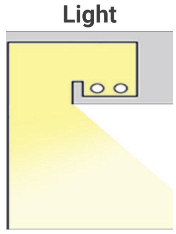
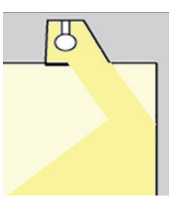
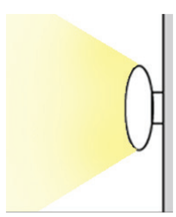
FIGURE 11: Accent lighting in a home environment

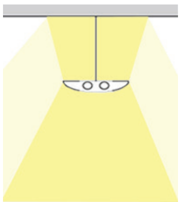
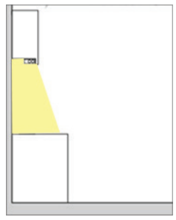
HARDWARE

Luminaires

A luminaire is a complete lighting unit, comprising a light source (lamp or lamps), together with parts that distribute the light, position and protect the lamps, and connect the lamps to the power supply [12]. The luminaire's function is to direct light to appropriate locations, without causing glare or discomfort. With thousands of different luminaires made by hundreds of manufacturers, more luminaires are available in the market than any other type of lighting equipment.

TABLE 7: Various types of lighting configuration

Task Light 	Task lighting is the additional lighting of a room, which goes beyond the general lighting. In conjugation with ambient lighting, it meets the demands of any specific visual task or work that is being done. Task lights can be table lamps, focus lights, lights mounted to desks, under the cabinet lights, or any lighting that helps people see their work better.	**Recessed Cove Light** 	A recessed cove fixture is fixed in a light cove, which is built above the ceiling at the intersection point of the ceiling and the wall. These fixtures generally function to direct the light towards the wall. It is important to note that the height of the trim at the edge of the cove fixture should be tall enough to hide the lighting fixture.
Wall Wash 	Wall wash fixtures are recessed lights with reflectors that direct the light towards the wall. It 'washes' the wall or distributes the wall with uniform illumination than creating a focused beam of light at a particular area. They are most often used to highlight art, signage, or other items on a wall. In many cases, wall washers are recessed fixtures, sometimes with a socket or 'eyeball' style, featuring a housing that moves by hand, allowing you to turn and angle the light as needed to achieve the desired effect.	**Wall Scone** 	A wall scone is typically a wall lighting fixture that is installed using the support of the wall. Such lights are usually directed upwards or downwards to provide general lighting in the room. A sconce owes its existence to the pre-modern age, when such fixtures were used to hold candles and torches. The modern wall sconces come in a wide variety of shapes and sizes for decorative purposes and, generally, require some sort of electric light source that connects within the fixture.

Direct / Indirect pendant 	A direct/indirect pendant is a ceiling-mounted lighting fixture that directs the light upwards and downwards simultaneously. These types of fixtures thus provide a combination of general lighting and task lighting, and are widely used in offices and commercial spaces. These fixtures are designed in variations to enable designers with control over the light distribution up and down as per the requirements.	**Under Cabinet Light** 	Under cabinets lights are task-specific lighting. These lights are often mounted below cabinets/ shelves so that the objects on the counter below can be seen easily. These can be found in kitchen, accessory showcase, etc. in homes and in offices. They are generally controlled from a nearby switch or a switch on the light fixture.

Lamps

A lamp is an artificial source of light. Over the last 100 years, lamps have become an integral part of our daily lives. Various types of lamps are available in the market. These lamps differ in their operating principle, materials used, and importantly – their energy efficiency.

The grouping of these various types of lamps has been illustrated in Figure 12.

The types of lamps differentiate on various factors such as wattage, efficacy, average life. Detailed information is provided in Table 6:

Ballast

Ballast is a device connected between the supply and one or more discharge lamps. It serves mainly to limit the current of the lamp(s) to the required value [1]. Some of the functions of ballast are mentioned here:

1. It transforms the supply voltage, correcting the power factor, either alone or in combination with a secondary starting device, providing the necessary conditions.
2. Without a ballast to limit the current flow, an electric-discharge lamp connected directly to a high voltage power source would rapidly

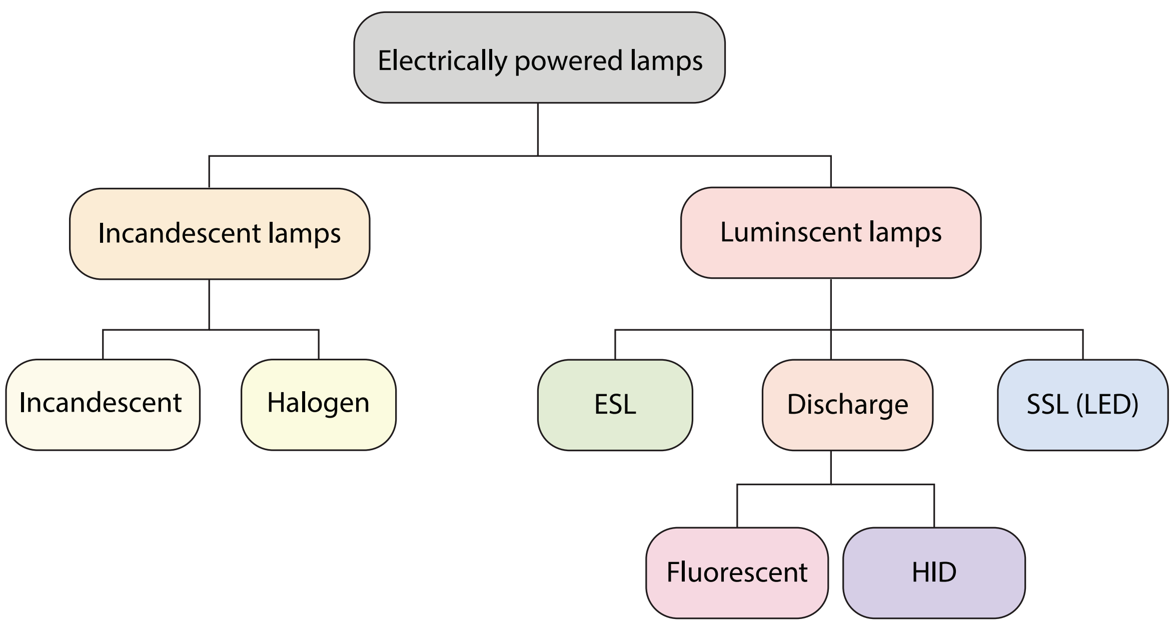


FIGURE 12: Lamps grouping and hierarchy [13]

TABLE 8: Requirements luminous efficacy, life, lumen maintenance and colour rendition of light source

S. No.	Light source	Wattage range (W)	Efficacy (lm/W)	Average life	Lumen maintenance	Colour rendition
1.	Incandescent lamps	15 to 200	12 to 20	500 to 1000	Fair to good	Very good
2.	Tungsten halogen	300 to 1500	20 to 27	200 to 2000	Good to very good	Very good
3.	Standard fluorescent lamps (CFL)	5 to 40	60 to 70	7500	Good	Good to very good
4.	Slim line fluorescent	18 to 58	57 to 67	5000	Fair to good	Good
5.	High pressure mercury vapour lamps	50 to 1000	90 to 125	10000 to 15000	Fair to good	Federate
6.	Blended- light lamps	160 to 250	20 to 30	5000	Low to fair	Federate
7.	High pressure sodium vapour lamps	50 to 1000	90 to 125	10000 to 15000	Fair to good	Low to good
8.	Metal halide lamps	35 to 2000	80 to 95	4000 to 10000	Very low	Very good
9.	Low pressure sodium	10 to 180	100 to 200	18000 to 20000	Good to very good	Poor
10.	LED	2 to 200	80 to 110	10000	Very good	Good for white LED

NOTES:

The table includes lamps and wattages in use in buildings in India.
Luminous efficacy varies with the wattage of the lamp.
Average life values are based on available Indian Standards.

and uncontrollably increase its current draw leading to overheating of the lamp within a few seconds and burn out.

3. It briefly supplies high voltage to establish a circuit between the two electrodes of the lamp. Once the circuit is established, the ballast quickly reduces the voltage and regulates the electric current to produce a steady light output.
4. To achieve a full-rated lamp life and light output from an electric-discharge lamp lighting system, the ballast's output

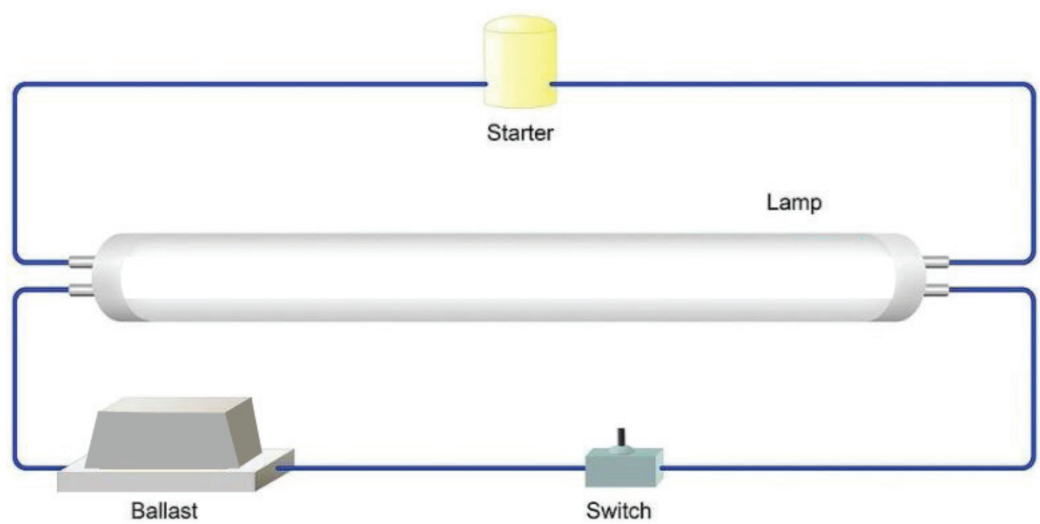


FIGURE 13: The working of a ballast in a florescent lamp

characteristics must precisely match the electrical requirements of the lamps it operates.

A special typology of ballasts, known as dimming ballasts, which when used together with a dimmer, will vary the light output of a lamp. Thus, to find a ballast compatible with a particular light fixture, the lamp type, lamp quantity, and line voltage must all be known.

LED Drivers

Today, most people are familiar with the benefits of using LEDs (light emitting diode) and its link to the energy-efficient lighting design with a longer life span. However, many of us are not aware that these innovative light sources require specialized devices called LED drivers to operate. LED drivers (also known as LED power supplies) are similar to ballasts for fluorescent lamps or transformers for low-voltage bulbs. They provide LEDs with the electricity they require to function and perform at their best. LEDs require drivers for three purposes:

1. An LED driver rectifies higher voltage, alternating current to low voltage, direct current.
2. LED drivers also protect LEDs from voltage or current fluctuations. A change in voltage could cause a change in the current being supplied to the LEDs.
3. LED light output is proportional to its current supply, and LEDs are rated to operate within a certain current range (measured in amps). Therefore, too much or too little current can cause light output to vary or degrade faster as a result of higher temperatures within the LED.

Internal vs. External LED Drivers

Internal LED Drivers: The internal LED drivers are the most widely used drivers and usually found in domestic LED bulbs. The internal drivers are usually housed in the same case as the LEDs and make it easy during the replacement of the bulbs.

External LED Drivers: The external LED drivers are housed separately from the LEDs and usually used for applications such as outdoor, commercial, roadways lighting. These types of lights require separate drivers, which are easier and cheaper to replace. In most of these applications, the manufacturer specifies the type of LED driver to use for a particular light assembly.

Most of the LED bulb failures are due to the failure in the driver, and it is easier to replace

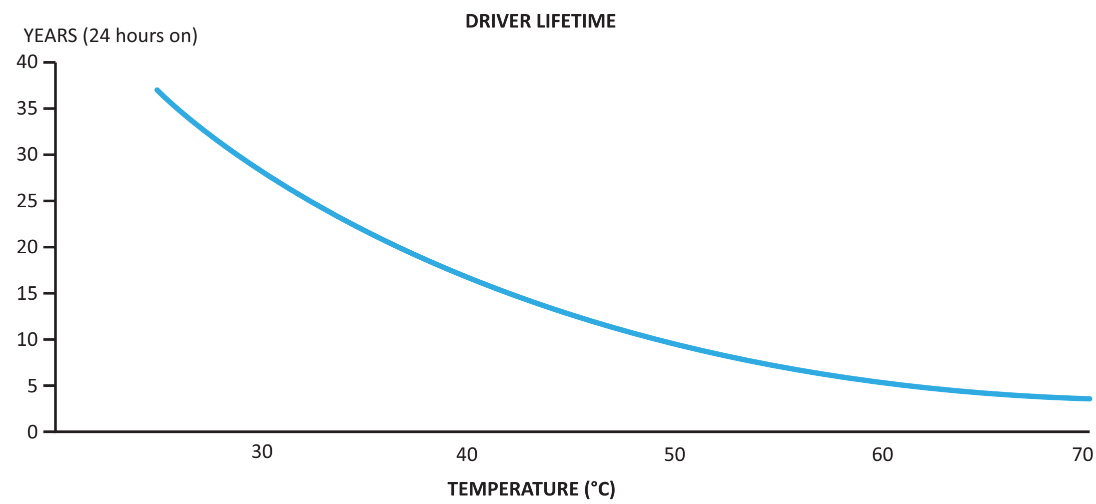


FIGURE 14: Typical performance curve LED driver [16]

FIGURE 15: Internal vs. External LED Drivers [16]

or repair the external driver compared to the internal driver.[1]

LIGHTING STYLES

There are numerous methods of lighting a particular place. The lighting style depends on several factors: user requirement, furniture layout, design scheme, etc. The lighting scheme can range from pure direct to a combination of direct and indirect to a fully indirect lighting scheme. Table 9 lists the advantages and disadvantages of each lighting scheme [15].

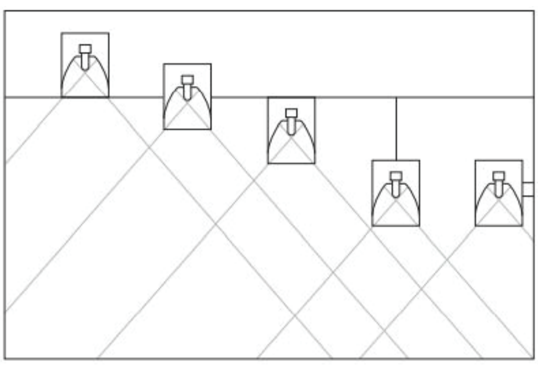


FIGURE 16: Mounting options for downlights: recessed, semi-recessed, surface, pendant and wall mounting

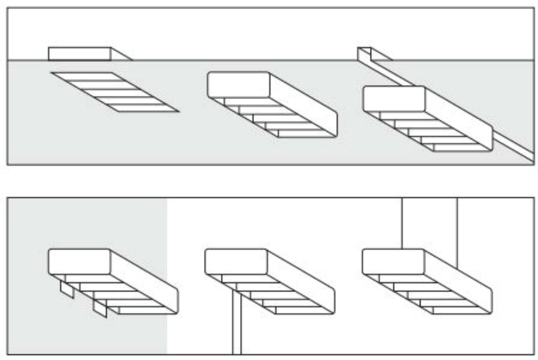


FIGURE 17: Mounting options for louvered luminaires: recessed ceiling, surface, mounting on tracks, walls, floor-standing or pendant mounting

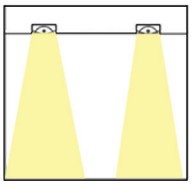
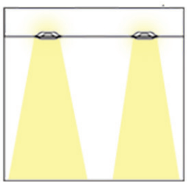
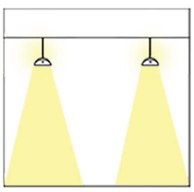
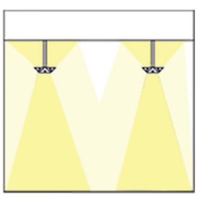
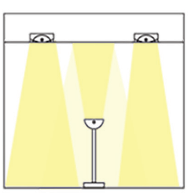
Sustainability in Lighting Systems and Design

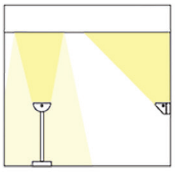
Lighting is an essential element in quality environments that support health and wellness. Similar to acoustic design, a lighting design too can have both positive and negative effects on people. This effect is heightened in areas where many people spend relatively more time, such as in schools, offices.

A wide variety of sustainability issues clash with architectural lighting such as light pollution, life cycle impacts of lighting products, chemicals of concern, energy efficiency, occupant health, and wellness. While designing new projects or doing retrofitting in an existing building, the

1 Details available at 100bulbs.com

TABLE 9: Advantages and Disadvantages of different lighting styles

Lighting style	Advantages	Disadvantages
Direct light only 	• Efficient delivery of light to task area • Less energy required than for uplighting styles • Usually the lowest capital cost for installation	• Poor illumination of walls and ceiling • Possible issues with glare and reflections in computer screens • Uniformity can be poor • Can feel oppressive, leading to poor productivity • Poor cylindrical illuminance • Lack of visual interest
Direct with ceiling glow 	• Efficient delivery of light to task area • Less energy required than for uplighting styles but more than for direct lighting only • Usually a lower capital cost for installation than for a style using uplighting • Some minimal ceiling illumination	• • Poor illumination of walls • Possible issues with glare and reflections in computer screens • Improved uniformity over direct-only style but can still be poor
Direct with uplight 	• Improved ceiling and wall illumination over direct-only styles • Feeling of a larger space can be achieved • Lighting can be used to add visual interest and achieve better interaction with the interior design • Improved uniformity over direct-only styles • Improved cylindrical illuminance over direct-only types	• • Will probably involve increased cost over direct-only styles • Increased energy use over direct-only styles • Lower ceiling height may impact usable space
Direct/indirect light 	• Much improved ceiling and wall illumination over direct-only styles • Feeling of a larger space can be achieved • Lighting can be used to add visual interest and achieve better interaction with the interior design • Improved uniformity over direct-only styles • Improved cylindrical illuminance over direct-only types	• • Will probably involve increased cost over direct-only styles • Increased energy use over direct-only styles • Lower ceiling height may impact on usable space
Direct and indirect light 	• Improved ceiling and wall illumination over direct-only styles • Flexibility to site direct and indirect components to best suit the room or individuals' needs • Feeling of a larger space can be achieved • Improved cylindrical illuminance over direct-only types	• • Will probably involve increased cost over direct-only styles • Increased energy use over direct-only styles • Loss of floor space • Obstructions on floor may lead to accidental damage • Issues with glare and reflections in computer screens

Indirect light only 	• Good uniformity when used with appropriate ceiling height • Positioning is not critical so gives more flexibility for unusual rooms or individuals' needs • Feeling of a larger space can be achieved • Lighting can be used to add visual interest and provide better interaction with the interior design • Good cylindrical illuminance	• Likely increased cost over direct-only styles • Increased energy use over direct-only styles • Shadow-free environment may feel bland • Obstructions on floor may lead to accidental damage

designer should keep the below-mentioned points in mind w.r.t sustainability in lighting system and design:

1. Maximize daylighting and its integration with electric lighting—use daylighting as the primary source.

2. Parameters related to lighting layouts that are specific to function, architectural and interior design aspects, and energy modelling should be finalised at the design stage.

3. The lighting system should be designed keeping in mind the future technology advancements. The adaptability for retrofits will help in extending the life of the building and further reduce environmental impacts [16].

4. Overall lighting efficiency—select efficient lamps and luminaires within the classes or families best suited for the application.

5. Component longevity—select longest-life lamps and luminaires within the classes or families best suited for the application.

6. Usage of intelligent controls can make significant, on-going energy savings.

7. Recyclability of lighting equipment and components—select equipment that consists of recycled materials and is prepped to be recycled at the end of its use.

8. The proximity of qualified vendors to the project site—select vendors of the classes or families best suited for the application that is closest to the project site.

9. Reduce lighting's impact on the greater night environment—employ strategies to limit night-lighting effects.

10. Make the project eminently liveable or workable—make the most of the energies expended in manufacturing, procuring, installing, and operating the lighting and provide a complete and well-executed design.

BASIC STEPS FOR DESIGNING

Lumen Method Calculations

This method uses the utilization factor tables created from the photometric measurement of each luminaire. First, the Room Index (K) of the space must be calculated, which is the relationship and measure of the proportions of the room:

$$K = \frac{L \times W}{(L+W) \times Hm}$$

where
L = length of room
W = width of room
Hm = height of luminaire above the working plane

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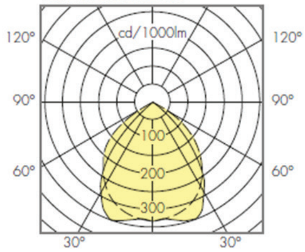


LOR: 0.86
ULOR: 0.09
DLOR: 0.85

SHR nom: 1.75
SHR max: 1.79

Utilisation factors / TM5

Reflectances			Room Index								
C	W	F	0.75	1.0	1.25	1.5	2.0	2.5	3.0	4.0	5.0
70	50	20	N/A	66	72	76	81	85	87	90	92
70	30	20	N/A	60	66	71	77	81	84	87	90
70	10	20	N/A	56	62	67	73	78	81	85	88
50	50	20	N/A	64	70	73	79	82	84	87	89
50	30	20	N/A	59	65	69	75	78	81	84	86
50	10	20	N/A	56	61	66	72	76	78	82	85
30	50	20	N/A	63	68	71	76	79	81	83	85
30	30	20	N/A	58	64	68	73	76	78	82	83
30	10	20	N/A	55	61	65	70	74	76	80	82
0	0	0	N/A	53	58	62	67	71	73	76	78
BZ-class			1	2	2	2	2	2	3	3	3

FIGURE 18: Sample polar intensity curve

Using Photometric Data

Polar Intensity Curves

Whilst most lighting design is based on computer simulation, photometric datasheets are still provided for luminaires as they can provide a quick and efficient way of picking a luminaire that is suitable for a given application. Polar intensity curves illustrate the distribution of luminous intensity (in cd/1000 lm) for the transverse (solid line) and axial (dashed line) planes of the luminaire. The curve provides a visual guide to the type of distribution expected from the luminaire, e.g. wide, narrow, direct, and indirect, in addition to intensity.

Using lighting software

Professional lighting design requires detailed luminaire photometric and product design data. Lighting designers use software as a design tool to complement and contribute to the design process. Lighting calculation software depends on two important components to produce accurate calculations: the selected light sources and the surfaces within the model. All available lighting software options use one of the two methods of calculation: Radiosity or Raytracing.

- **Radiosity**: Radiosity is a calculation method that divides each surface into small pieces, called patches. Each patch is calculated individually for the amount of light that enters or leaves the surface. The programme then solves the system of equations in the model by determining the quantity of light on each patch as a result of the total sum of all the patches. This method works well for all matte model surfaces as Radiosity is based on Lambertian reflectance calculations. Lambertian reflectance refers to surfaces that have reflected light scattered in such a way that the apparent brightness of the surface is the same regardless of the observer's angle of view. Because of the surface dependency of the calculation, the Radiosity method can calculate a model once and produce any desired view.
- A disadvantage to the Radiosity method is that it applies to matte and diffuse surfaces only, so contributions from translucent, transparent, and specular (shiny) surfaces are not included in the calculation.
- **Raytracing** [16]**:** It is a point-specific lighting calculation process. Calculation rays are sent outwards from a particular viewpoint and the programme follows each ray as it hits and reflects off different surfaces and divides into more rays. This method works for all object types including transparent, translucent, and specular surfaces. Raytracing creates beautiful renderings and presentation-quality images by visually representing light on all surfaces, including the sparkle and highlights on specular materials. Unlike Radiosity, Raytracing is view dependent, meaning renderings must be recalculated from each new angle. Additionally, Raytracing can be a slow process, especially if the model contains a large quantity of surfaces.

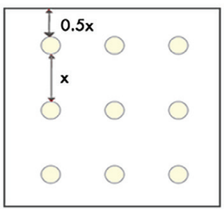
All lighting software use one or both of these two options to calculate the illuminance (the amount of luminous flux per unit area) and luminance (the intensity of light emitted from a surface per unit area in a given direction) of surfaces, and provisions to export lighting calculation data. Some of the commonly used lighting software's are as follows:

- DIALux
- Radiance
- AGI32
- Lumen Designer etc.

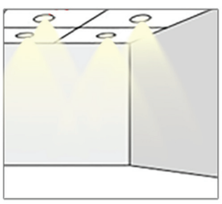
Practices for Optimum Visual Comfort

LOCATION OF LUMINAIRE

The location of luminaire plays a very vital role in determining the visual comfort from electric lighting. Factors like uniformity and glare can be maintained using location of luminaire and proper shielding.

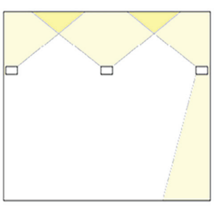


In general, luminaires are spaced *x* metre apart in either direction, while the distance of the end luminaire from the wall is 0.5*x* metre. The distance *x* is more or less equal to the mounting height H_m between the luminaire and the working plane

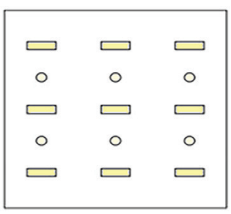


For small rooms where the room index[1] (K) is less than 1, the distance *x* should always be less than H_m, as otherwise luminaires cannot be properly located.

In most cases, four or two luminaires are placed in such rooms for good general lighting. If, however, such rooms have only one luminaire installed in the middle, then higher utilization factors are obtained, but the uniformity of distribution is poor

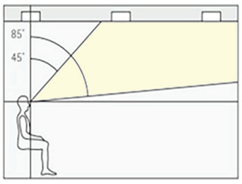


Indirect lighting, or up lighting, can create a low glare environment by uniformly lighting the ceiling (e.g. cove-type fixtures, lighted valences, wall washers, floor lamps). Use it wherever possible to produce high levels of ambient light



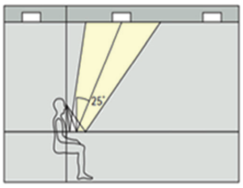
Provide high levels of light within each spacing fixture to ensure that light is uniform throughout

1 The room index is a number that describes the ratios of the rooms' length, width and height.

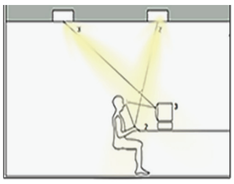


Local/task lighting should not be installed in the forbidden angle (field of vision) as it will become a source of direct glare (with respect to the height of lighting installation) or mount luminaries out of the field of view of the common workplace.

To evaluate direct glare, the luminance of the luminaires within the range 45° to 85° is considered.

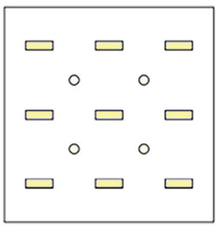


For the basic planning of a lighting installation, the CRF value is generally only calculated for the primary viewing angle of 25°.

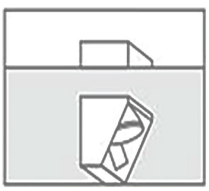


Luminaires placed on either side of the task (office desk) should not be directly above the observer.

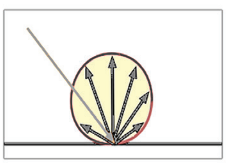
Avoid positioning work station with light fixture directly behind the worker.



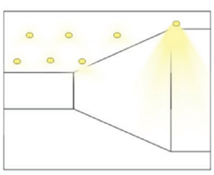
Use a large number of small-luminance sources rather than a small number of high-luminance sources for better uniformity of light.



Screening and shielding the sources from direct view or covering with diffusing plates or filters or cross polarizers greatly reduce glare



Use proper or correct lighting and avoid specular materials such as metallic paint on mechanics or wall rock, and choose flat paint when possible (surface reflectance)



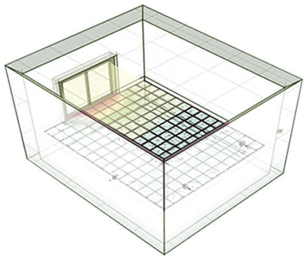
Provide a 'transition zone' with medium-bright lighting in areas where residents must pass from a brightly lit space to a more dimly lit space.

Provide multiple layers of light in spaces where appropriate with ambient light, task lights, and a bit of accent lighting, as long as accents do not produce direct glare.

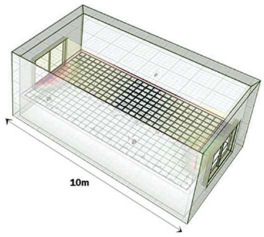
Luminaires more than 53° above the centre of view (degrees above horizontal) should have luminance less than 8,000 cd/m².

DAYLIGHT ON THE WORKING PLANE IN A ROOM

For good distribution of daylight on the working plane in a room, window height, window width, and height of sill should be chosen in accordance with the following recommendations:



In-office buildings windows of height, 1.2 m or more in the centre of a bay with sill level at 1.0 to 1.2 m above the floor and in residential buildings windows of height 1.0 m to 1.1 m with sill height as 0.7 m to 0.9 m above the floor are recommended for good distribution of daylight indoors. Window width can accordingly be adjusted depending upon the required fenestration percentage of the floor area.



If the room depth is more than 10 m, windows should be provided on opposite sides for bilateral lighting.

It is desirable to have a white finish for ceiling and off white (light color) to white for walls. There is about 7% improvement in lighting levels in changing the finish of walls from moderate to white.

Provide as much natural light as possible. If skylights are specified, they should be fitted with partially obscure glazing rather than clear glass or plastic to prevent glare effects.

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The overall scope of the project includes standardization and measurement of building material, thermal and visual comfort study, development of performance standard matrices, guidelines and numerical toolkits and water related activity for sustainable water use in habitats.

The activities related to the sustainable use of water in habitats, includes both macro and micro level analysis in terms of water efficiency, conservation and management within a premise by end users in Indian cities. The study identifies potential risks associated with water sources, governance, infrastructure and demand & supply and provide recommendations to combat those risks.

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