ENERGY EFFICIENT LIGHTING TECHNOLOGIES AND THEIR APPLICATION IN COMMERCIAL AND RESIDENTIAL SECTORS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

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in

WATER RESOURCES DEVELOPMENT

By

MANOJ KUMAR SAROVA

DEPARTMENT OF WATER RESOURCES DEVELOPMENT AND MANAGEMENT
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE -247 667 (INDIA)

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation titled "*ENERGY EFFICIENT LIGHTING TECHNOLOGIES AND THEIR APPLICATION IN COMMERCIAL AND RESIDENTIAL SECTORS*" in partial fulfillment of the requirement of award of Degree of Masters of Technology in **WATER RESOURCES DEVELOPMENT** (Electrical) submitted to the Department of Water Resource Development & Management, Indian Institute of Technology, Roorkee, India is an authentic record of my own work carried out during a period from July 2010 to June 2011 under the supervision of **Prof. Devadutta Das,** Professor in Department of Water Resource Development & Management, Indian Institute of Technology, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree of this institute or any other institute.

Date:
Place: Roorkee

(Manoj Kumar Sarova)
Candidate

CERTIFICATE

This is to certify that the above mentioned statement made by the candidate is correct to the best of my knowledge.

Prof. Devadutta Das
Professor,
Department of Water Resources
Development and Management
I.I.T. Roorkee
Roorkee-247667
INDIA

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Manoj Kumar Sarova
Enrollment No. 09548020
WRD & M 54th Batch

Abstract

This study involves the design of lighting system by using energy efficient lighting technologies as a step towards reducing emission of greenhouse gases associated with energy production.

Since the invention of incandescent lamps in the nineteenth century, evolution in lighting technology has take place. Incandescent lamps have given a way to fluorescent lamps and thereafter to CFL (compact fluorescent lamps) for lighting of the interior spaces in homes, commercial and industrial establishments. In constant pursuit for conservation of energy, use of light emitting diodes (LEDs) for space lighting application has engaged the attention of researches from mid 1970's. Constant development in its technology has rendered LED lighting as strong contender for replacing even CFL system. Presently the cost of LED system is almost ten times of that of CFL system. But the advantage with the LED system is its energy efficiency coupled with long life and durability. The barrier for its wide scale use is its high cost. However, with technological improvement and large scale manufacture, the cost of LED lighting equipment is likely to substantially reduce in future, as has been the case with photovoltaic cells.

Sunlux is lighting design software developed by Surya Roshni Company as per the norms of Energy Conservation Building Code (ECBC)-2006 has been developed by the International Institute for Energy Conservation (IIEC) under contract with the United State Agency for International Development(USAID). It is used for both interior and outdoor design of lighting system. The database of this software is fully loaded with all the luminaries with their electrical and mechanical specifications. The software has been used in the study reported in the dissertation for lighting designing for a control room of a power plant and the building of Water Resource Development and Management, IIT Roorkee. This study also involves "Energy saving exercise", which is determined for the above two buildings.

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Chapter 1: Introduction

1.1 Green building concept

Green building[1.1] is the practice of increasing the efficiency with which buildings use resources like energy, water, and materials while reducing building impacts on human health and the environment during the building's lifecycle through better design, construction, operation, maintenance, and removal.

Green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation

Effective green building can lead to:

- reduced operating costs by increasing productivity and using less energy and water
- improved public and occupant health due to improved indoor air quality

Green building practices aim to reduce the environmental impact of buildings. Buildings account for a large amount of land use, energy and water consumption, and air and atmosphere alteration. In the United States, more than 2,000,000 acres (8,100 km^2) of open space, wildlife habitat, and wetlands are developed each year.

1.2 Energy Conservation Building Code 2006

The Energy Conservation Building Code (ECBC) 2006[1.2] has been developed by the International Institute for Energy Conservation (IIEC) under contract with the United States Agency for International Development (USAID) as a part of the Energy Conservation and Commercialization (ECO) Project providing support to the Bureau of Energy Efficiency (BEE) Action Plan.

The ECBC provides design norms for:

- Building Envelope, including thermal performance requirements for walls, roofs, and windows;
- Lighting System, including day lighting, and lamps and luminaries performance requirements;

- HVAC System, including energy performance of chillers and air distribution systems;
- Electrical System; and
- Water heating and Pumping Systems, including requirements for solar hot-water systems.

The Code provides three options for compliance:

1. Compliance with the performance requirements for each subsystem and system;
2. Compliance with the performance requirements of each system, but with tradeoffs between subsystems; and
3. Building-level performance compliance.

Simulation exercises indicate that ECBC-compliant buildings use 40 to 60% less energy than similar baseline buildings.

1.3 Energy efficient lighting technologies

An energy efficient lighting technology [1.3] was used from many years but they are different for domestic, commercial and industrial use. Latest revolutionary change in the present age is invention of LEDs. But you can't think to use LED lighting for domestic purpose, even they are very efficient, having long life and durability because these are very costly. The installation cost of LED's is almost 10 times the CFL's. But in the future the price of LED will goes down because technology improves day by day.

Mostly Indian people use T12 tube light. These are better than incandescent lamps but as life changes technologies change. After T12 tube light many company had made T8 tube light which are better than this. New improvement has been done in T8 tube light. But the latest technology in the market is T5 tube light. The lamp wattage of T5 tube light is 28W, lumen output of 2900 lumen, brightness level 20% more than convention T12 tube light, lamp life is 20000 burning hours, depreciation of lamp output is 5% up to end of life. This means that technologies are improving day by day so we have to adapt new technology for our better future.

Luminaries manufacturers create innovatively designed compact luminaries using up-to-date optical materials. Recently, lighting designers have begun to specify such T5 luminaries for high-end new construction. The marketing and innovative design of T5 systems have left many end users wondering whether they should consider T5 luminaries instead of T8 luminaries, especially in new construction and retrofitting of T12 magnetic systems. End users are confused by the 10°C (18°F) difference in optimal temperature and the small difference in system efficacy between T5 and T8 systems.

The change in technology can be easily understand by fig 1.1

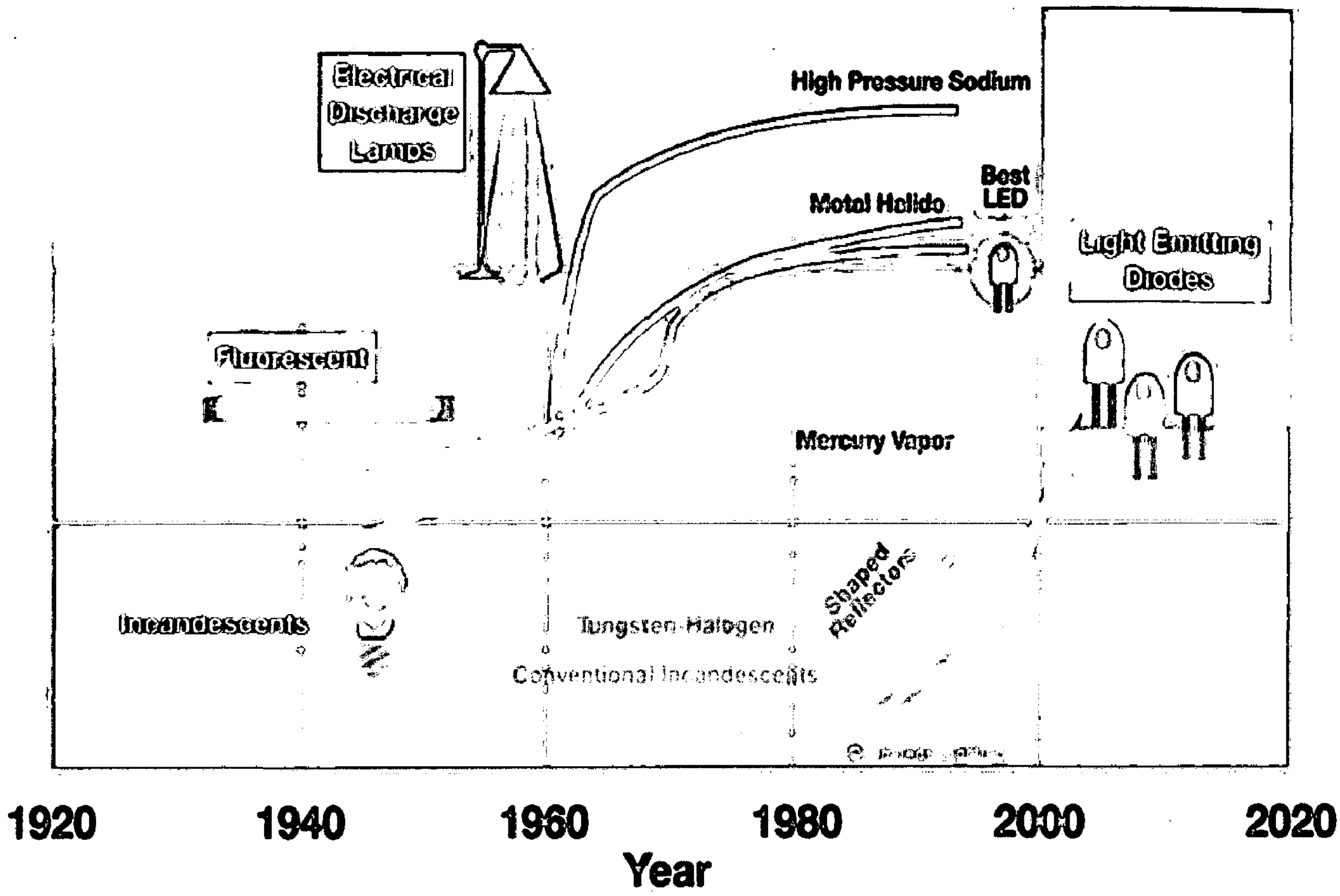


Fig 1.1 change in technology

1.4 Lighting design software

Sunlux v1.0 [1.4] is lighting designing software, which is designed by the engineers of Surya Roshni Company. This software is developed as per the norms of Energy Conservation Building Code (ECBC) 2006. It can be used for both interior designing and outdoor designing. This software gives a better idea to learn the lighting design. This software works on two methodologies, one is direct method and other is point by point method. For basic idea learner may use direct method in which learner has to specifies just the coordinates and the total no. of luminaries required. On the basis of input it gives an output. The output contains 3D LUX web, ISOLUX diagram, project layout, grey scale and luminance tabulation. The output of point by point comes in same manner but the difference is point by point method is more accurate than direct method. The database of this software is fully loaded with all the luminaries developed by Surya Roshni Company with their electrical and mechanical specifications.

1.5 The Next Step

Based on current lumen packages and the great potential for this light source to be adopted for more general lighting applications, the next step is for the fixture community to begin building more products designed to utilize LEDs as the primary or supplementary light source. There are many lighting applications that require only a few lumens, or tens of thousands of lumens, for which LEDs are ideal, future work, should focus on packaging LEDs into useful products.

The Future - OLED Lighting [1.5]

- OLEDs: Organic light-emitting diodes
- OLEDs are similar to electroluminescent lighting, in which a sheet of material is excited so that it emits light.
- An OLED light source is a thin, flexible sheet of material consisting of three layers, a polymer or sublimed molecular film sandwiched between two layers of electrodes, one of them transparent. Current passes through the material until it emits light through its transparent layer.
- Low-voltage OLED light sources can reach efficacies of 3-4 LPW. Unfortunately, such efforts produce too much heat and reduce the life of the light source. Manufacturers are currently working on developing commercial OLED products

1.6 Summary

- Green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment.
- Effective green building can lead to reduced operating costs by increasing productivity and using less energy and water.
- Simulation exercises indicate that ECBC-compliant buildings use 40 to 60% less energy than similar baseline buildings.
- Technologies are improving day by day so we have to adapt new technology for our better future.
- Point by point method is more accurate than direct method.
- The next step is for the fixture community to begin building more products designed to utilize LEDs as the primary or supplementary light source.

Chapter 2: Light and Electromagnetic Radiation

2.1 What is Light?

Light is simply a very small part of the electromagnetic spectrum, sandwiched between ultraviolet and infrared radiation. The visible portion of the electromagnetic spectrum extends from about 380 to about 780 nanometers (nm), as shown in Figure 2.1 [2.1]. What distinguishes this part of the electromagnetic spectrum from the rest is that radiation in this region is absorbed by the photoreceptors of the human visual system and thereby initiates the process of seeing. The Illuminating Engineering Society of North America (IESNA) defines light as "radiant energy that is capable of exciting the retina and producing a visual sensation." Light, therefore, cannot be separately described in terms of radiant energy or of visual sensation but is a combination of the two.

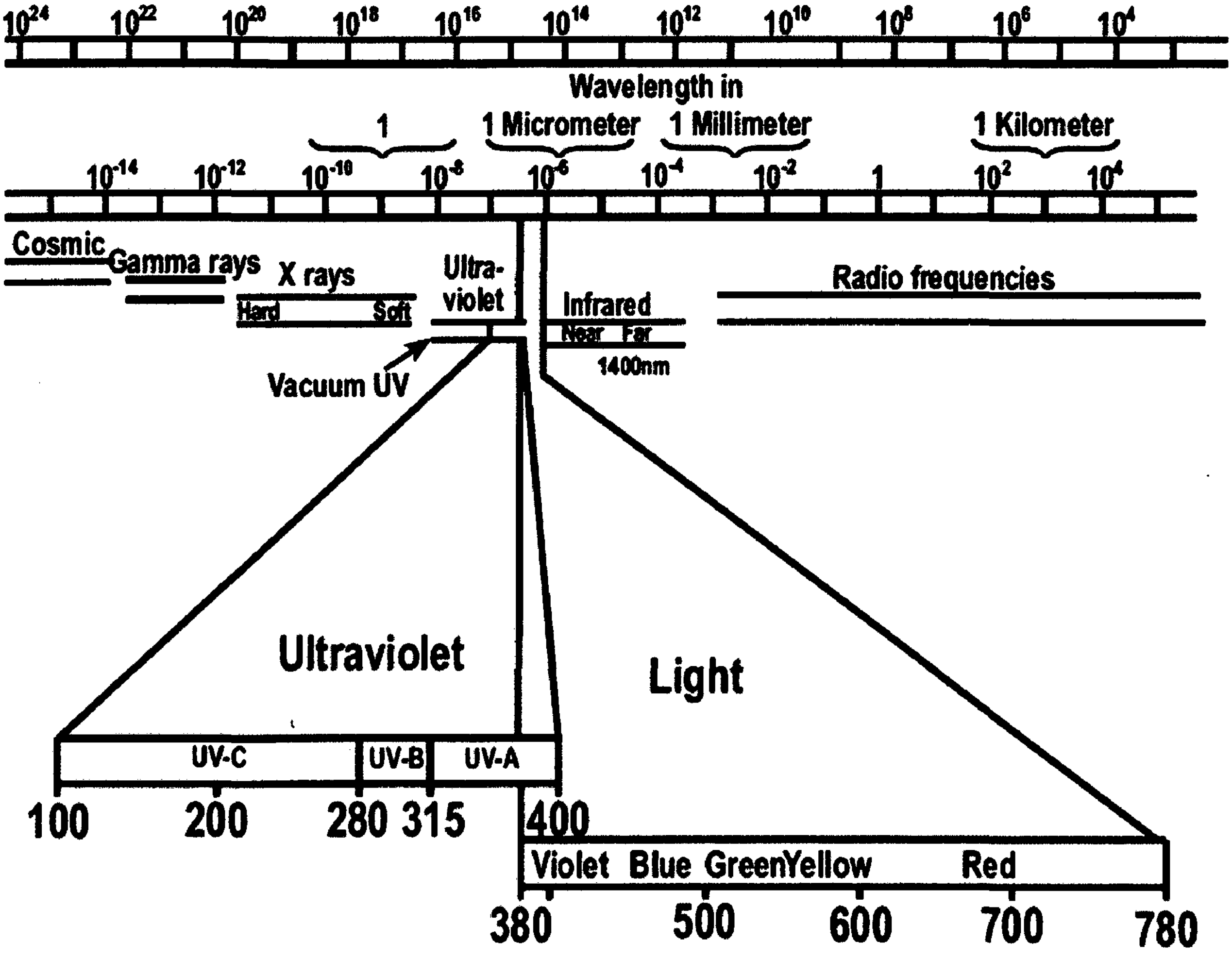


Fig 2.1 electromagnetic spectrum

2.2 Necessity of Illumination

Good illumination looks for producing clear and quick images. Humans depend on Light for all activities. Vision is the most important sense accounting for 80% information acquisition for humans. Light by definition connotes Electromagnetic radiation that has a wavelength in the range from about 4,000 (violet) to about 7,700 (red) angstroms and may be perceived by the normal unaided human eye.

However, Visible Light [2.2] – spans from 180nm to 700nm wavelength. It must be mentioned that human Eye responds from 380 (violet) to 700nm (red). This becomes necessary for us to understand the suitability of various types of sources of light. Fig. 2.2 shows the relative energy content of the solar radiation and table 2.1 shows the wavelengths of different color impressions.

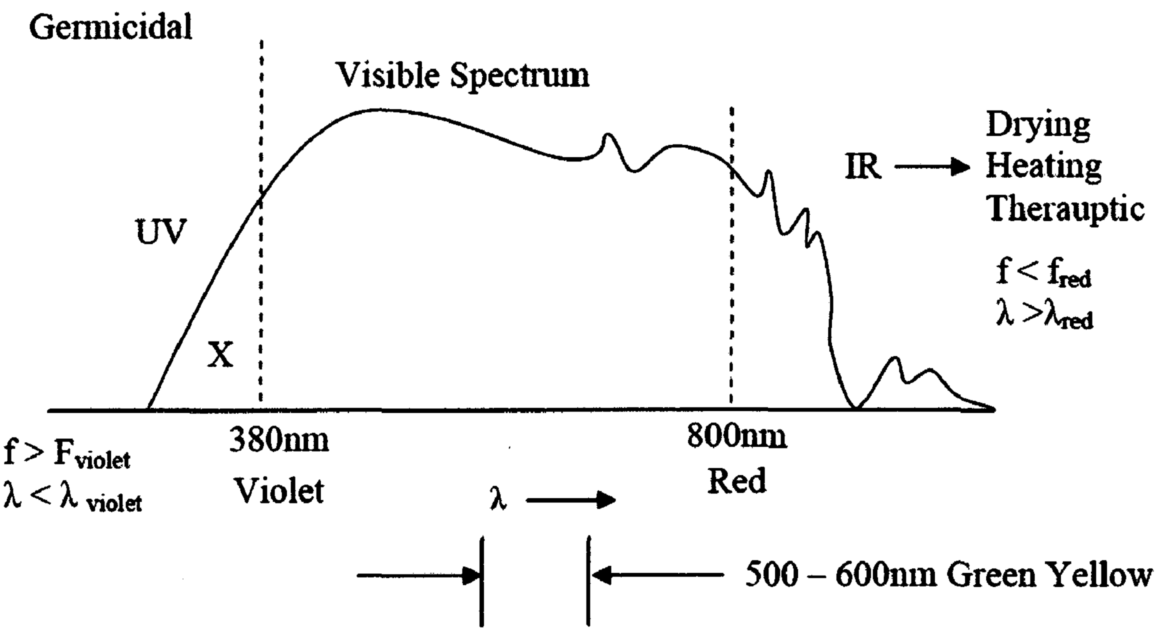


Fig 2.2 relative energy content of solar radiation

Illumination systems tend to produce radiation close to natural radiation. They employ artificial sources. These sources obey Laws of Illumination. The quantification is done through Photometry. Thus an Illumination system consists of Lamp which may be Incandescent lamp, Discharge lamp or Fluorescent lamp along with control gear placed in a suitable luminaire.

Table 2.1 wavelengths of different color impressions

Color impression	Violet	Blue	Green	Orange	Red
Wavelength (nm)	380-420	420-495	495-566	589-627	627-780

2.3 Basic Radiometric and Photometric Principles

Radiometry [2.3] is the study of optical radiation — light, ultraviolet radiation, and infrared radiation. Photometry, on the other hand, is concerned with humans' visual response to light. Radiometry is concerned with the total energy content of the radiation, while photometry examines only the radiation that humans can see. Thus, the most common unit in radiometry is the watt (W), which measures radiant flux (power), while the most common unit in photometry is the lumen (lm), which measures luminous flux. For monochromatic light of 555 nm, 1 watt = 683lumens. For light at other wavelengths, the conversion between watts and lumens is slightly different, because the human eye responds differently to different wavelengths. Table 2.2 summarizes the most common radiometric and photometric quantities, along with their symbols and units.

Table 2.2 *most common radiometric and photometric quantities*

	Radiometric		Photometric	
Quantity	**Symbol**	**Units**	**Symbol**	**Units**
Wavelength	λ	nanometer (nm)	λ	nanometer (nm)
Radiant & luminous energy	Q	watt-seconds (W-s)	Q_v	lumen-seconds (lm-s)
Radiant & luminous energy density	U	watt-seconds/m³ (W-s/m³)	U_v	lumen-seconds/m³ (lm-s/m³)
Radiant & luminous flux (power)	Φ	watts (W)	Φ_v	lumens (lm)
Irradiance & illuminance	E	watts/cm² (W/cm²) or watts/m² (W/m²)	E_v	lux (lx; lm/m²) or footcandle (fc; lm/ft²)
Radiance & luminance	L	watts/m²/steradian (W/m²/sr)	L_1	lumens/m²/steradians (lm/m²/sr)
Radiant & luminous intensity	I	watts/steradian (W/sr)	I_v	candela (cd; lm/sr)

2.4 Spectral Response [2.4]

Within the narrow spectrum of visible light, the human eye is more sensitive to some wavelengths than to others. This sensitivity depends on whether the eye is adapted for bright light or darkness because the human eye contains two types of photoreceptors — cones and rods. When the eye is adapted for bright light, called photopic vision (luminance level generally greater than 3.0 (cd/m2)), the cones dominate. At luminance levels below approximately 0.001 (cd/m2), the rods dominate in what is called scotopic vision. Between these two luminance levels, mesopic vision uses both rods and cones.

Figure 2.3 shows the relative sensitivity to various wavelengths for cones (photopic) and rods (scotopic). Standard luminous efficiency functions have not yet been defined for the mesopic region. However, there is a gradual shift from a peak spectral sensitivity at 555 nm for cone vision to a peak spectral sensitivity at 507 nm for rod vision as light levels are reduced. The CIE selected the wavelength 555 nm, the peak of the photopic luminous efficiency function, as the reference wavelength for the lumen, the standard photometric unit of light measurement. By definition, there are 683 lm/W at 555 nm and the lumens at all other wavelengths are scaled according to either the photopic or the scotopic luminous efficiency functions for example, at 507 nm there are 1700 lm/W when the scotopic luminous efficiency function is used, but only 304 lm/W when the photopic luminous efficiency function is used. Nearly every light measurement uses the photopic luminous efficiency function.

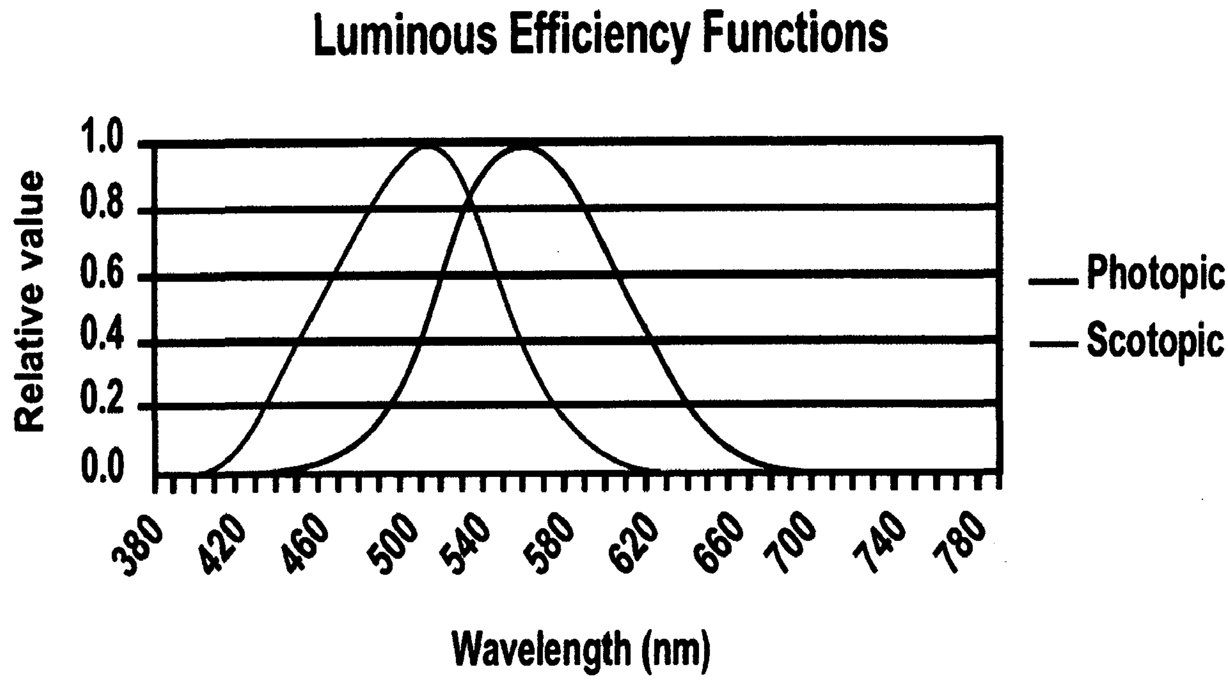


Fig 2.3 relative sensitivity to various wavelengths for cones and rods

Eye defects arise due to Age Use or Abuse. No doubt Eyes ability to adjust to severe or unnatural conditions – gets injured in the long run. Defective vision may be due to difference in size and location of images by way of Refractory errors. Easy limited tasks lead to no defects. Lower Retinal Sensibility calls for larger pupil diameter and higher illumination levels. Seeing is not instantaneous process. Countless impressions are formed on the retina. Good illumination looks for producing clear and quick images.

2.5 Basic Radiometric and Photometric Measurement

The Inverse Square Law [2.5] as a surface that is illuminated by a light source moves away from the light source, the surface appears dimmer. In fact, it becomes dimmer much faster than it moves away from the source. The inverse square law, which quantifies this effect, relates illuminance (E_v) and intensity (I_v) as follows:

$$E_v = I_v/d^2$$

Where d = the distance from the light source. For example, if the illuminance on a surface is 40 lux (lm/m^2) at a distance of 0.5 meters from the light source, the illuminance decreases to 10 lux at a distance of 1 meter, as shown in the following figure 2.4.[2.6]

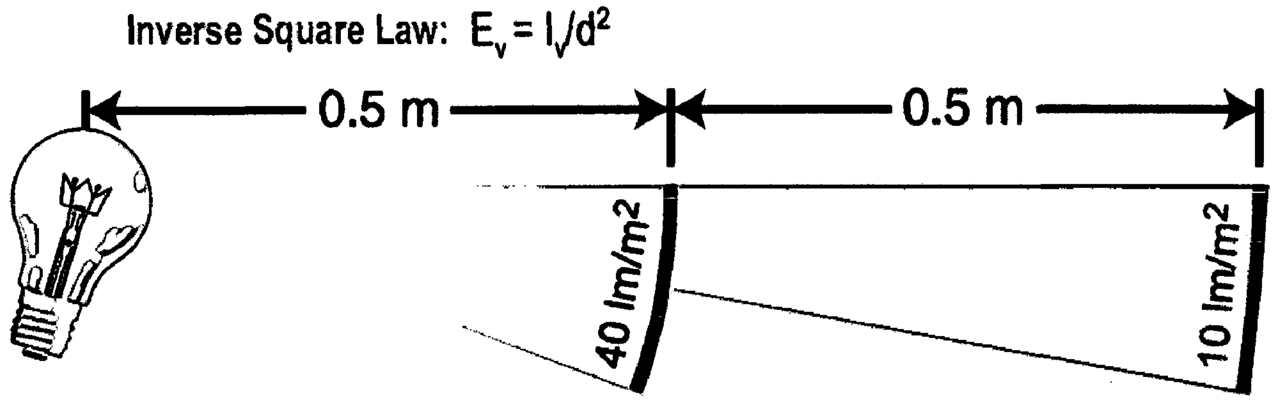


Fig 2.4 Inverse Square Law

Note: the inverse square law can only be used in cases where the light source approximates a point source.

Lambert's cosine law states that the illuminance falling on any surface depends on the cosine of the light's angle of incidence "θ", as shown in figure 2.5

$$E_\theta = E\cos\theta$$

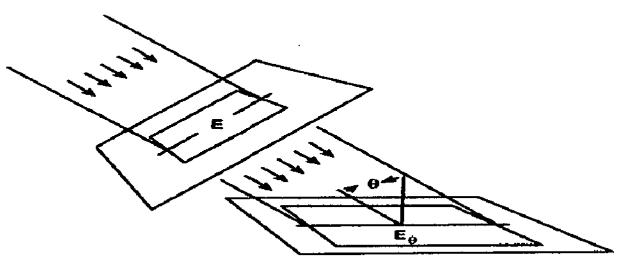


Fig 2.5 Lambert's cosine law

Lambertian Emission and Reflection A lambertian surface reflects or emits equal (isotropic) luminance in every direction. For example, an evenly illuminated diffuse flat surface such as a piece of paper is approximately lambertian, because the reflected light is the same in every direction from which you can see the surface of the paper.

However, it does not have isotropic intensity, because the intensity varies according to the cosine law. Figure 2.6 shows a lambertian reflection from a surface. Notice that the reflection follows the cosine law — the amount of reflected energy in a particular direction (the intensity) is proportional to the cosine of the reflected angle. Remember that luminance is intensity per unit area. Because both intensity and apparent area follow the cosine law, they remain in proportion to each other as the viewing angle changes. Therefore, luminance remains constant while luminous intensity does not.

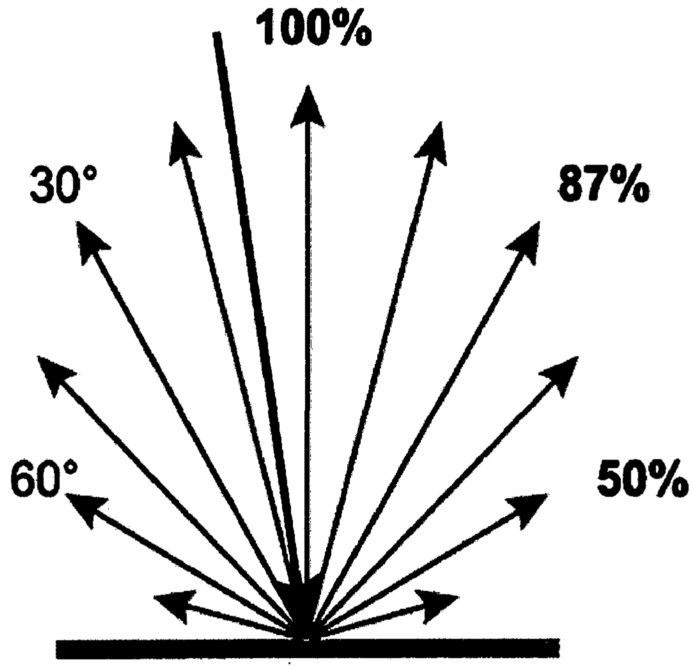


Fig 2.6 Lambertian reflection from a surface

To compare illuminance and luminance on a lambertian surface, consider the following example: a surface with a luminance of 1 $lm/m^2/sr$ radiates a total of πA lumens, where A is the area of the surface, into a hemisphere (which is 2π steradians). The illuminance of the surface is equal to the total luminous flux divided by the total area — π lux/m^2. In other words, if you were to illuminate a perfectly diffuse reflecting surface with3.1416 lm/m^2, its luminance would be 1 $lm/m^2/sr$.

Chapter 3: Lighting Design Basics

3.1 Some Important Terms in Lighting Design

Luminous flux [3.1] or **luminous power** is the measure of the perceived power of light. It differs from radiant flux, the measure of the total power of light emitted, in that luminous flux is adjusted to reflect the varying sensitivity of the human eye to different wavelengths of light.

The SI unit of luminous flux is the lumen (lm). One lumen is defined as the luminous flux of light produced by a light source that emits one candela of luminous intensity over a solid angle of one steradian. In other systems of units, luminous flux may have units of power.

Illuminance [3.2] is the total luminous flux incident on a surface, per unit area. It is a measure of the intensity of the incident light, wavelength-weighted by the luminosity function to correlate with human brightness perception.

In SI derived units these are measured in lux (lx) or lumens per square meter ($cd \cdot sr \cdot m^{-2}$). One lux is equal to one lumen per square meter:

$$1 \text{ lx} = 1 \text{ lm/m}^2 = 1 \text{ cd} \cdot \text{sr} \cdot \text{m}^{-2}.$$

In the following figure 3.1, the lamp is producing a candela. A 1-cd light source emits 1 lm/ sr in all directions (isotropically). "Solid Angle," one steradian has a projected area of 1 square foot at a distance of 1 foot, and an area of 1 square meter at a distance of 1 meter. Therefore, a 1-candela (1 lm/sr) light source produces 1 lumen per square foot at a distance of 1 foot, and 1 lumen per square meter at 1 meter.

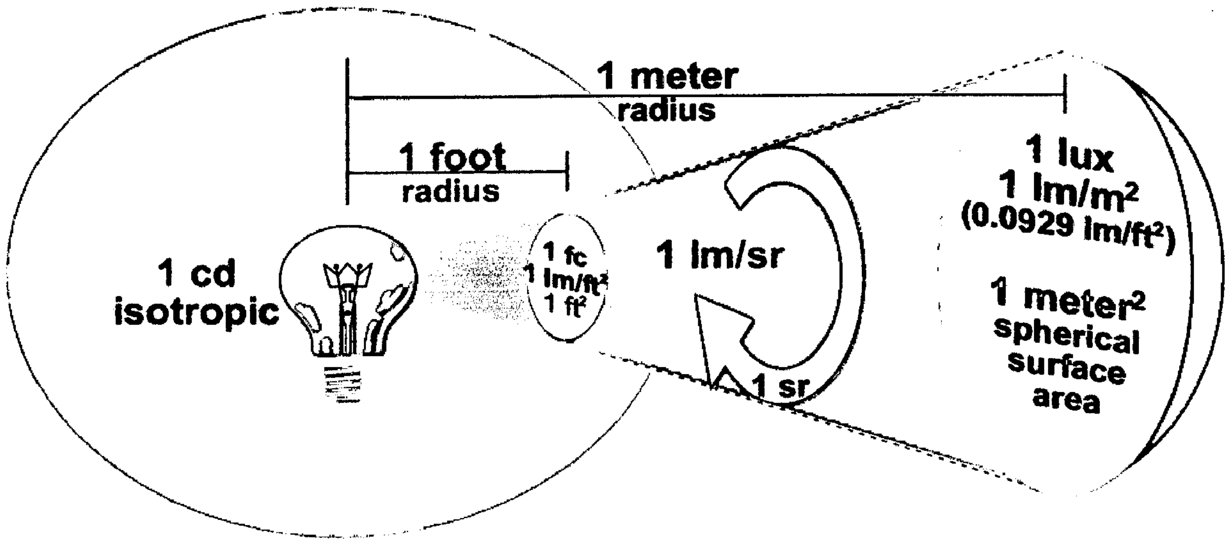


Fig 3.1 lamp is producing a candela

Luminous intensity [3.3] is a measure of the wavelength-weighted power emitted by a light source in a particular direction per unit solid angle, shown in figure 3.2.

The SI unit of luminous intensity is the candela (cd).

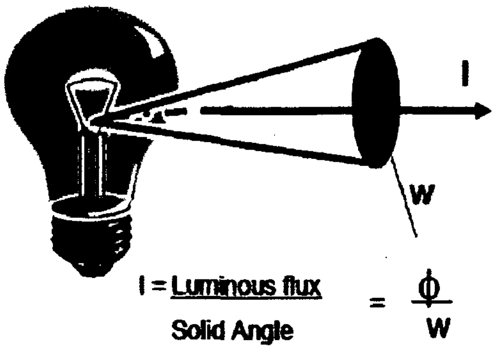


Fig 3.2 Luminous intensity

Candela (symbol: cd) is the SI base unit of luminous intensity; that is, power emitted by a light source in a particular direction, weighted by the luminosity function. The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of $^{1}/_{683}$ watt per steradian.

Luminance [3.4] is per unit area of light travelling in a given direction. It describes the amount of light that passes through or is emitted from a particular area, and falls within a given solid angle. The SI unit for luminance is candela per square meter (cd/m^2).

Luminance is defined by

$$L_v = \frac{d^2F}{dA\, d\Omega \cos\theta}$$

Where

L_v Is the luminance (cd/m^2),

F is the luminous flux or luminous power (lm),

θ Is the angle between the surface normal and the specified direction,

A Is the area of the surface (m^2), and

Ω Is the solid angle (sr).

Luminous efficacy is a figure of merit for light sources. It is the ratio of luminous flux to power. Its unit is lumen per watt.

Circuit efficacy is the ratio of luminous flux emitted by the lamp to the power consumed it and control gear. Its unit is lumen per watt.

Working plane is the plane on which specified illuminance level is to be ensured or measurements are made. Unless otherwise stated the plane s assumed to be horizontal and .85m above the floor

Spacing/ Height ratio is the ratio of distance between two adjacent luminaries to its mounting height above the working plane.

Uniformity ratio is defined as the ratio of the minimum illuminance to the average illuminance.

$$U_0 = L_{min} / L_{avg}$$

U_0 should not be below 0.4. From visual comfort view point uniformity ratio is defined as:

$$U_1 = L_{min} / L_{max}$$

measured along the line passing through the observer positioned in the middle of the traffic facing the traffic flow. Termed longitudinal uniformity ratio.

Rated illuminance flux is the total luminous flux of the entire object source in the concerned space.

Effective luminous flux ($Ø_n$) is the flux received by the working plane.

Average illumination in working plane is the effective luminous flux divided by the area

$$E_{avg} = Q_m/s$$

The method used for determining Lumens required is the "Lumen Formula" as shown below.

Lamp Lumens Req.** = (E* x *A)/UF* x ***LLF

Where: E = standard service illuminance (lx) A = area of working plane (m^2)
UF = Utilisation factor LLF = Lamp loss factor

Light loss factors are induced by the output from a lamp reducing as its operational hour's increases; a buildup of dust on the luminaire reducing the transmissivity of the light into the room; and a buildup of dust on room surfaces reducing the reflectance over a period of time.

The Light Loss Factor (LLF) is a product of all three maintenance factors (MF) mentioned above.

$$LLF = Lamp\ lumen_{MF} \times Luminaire_{MF} \times Room\ surface_{MF}$$

The lumen output from a high efficiency discharge lamp (fluorescent tube) after 2000 hrs of operation is typically about 0.9 of the initial lumen output when new.

Utilisation Factor (UF). This measures the efficiency of the lighting scheme to deliver the light to the working plane relative to the room/environment it is operating within. This incorporates the proportion of flux reaching the working plane from both the direct and reflected off other surfaces encasing the room/environment. Or in an easy words it is the ratio of luminous flux received by the working plane to the total luminous flux of the light source employed.

$$U = (\varnothing_n / \varnothing_0)$$

Room index (Kr). The room index is used to establish an appropriate Utilisation Factor from manufacturer's data sheet supporting a chosen lamp/luminaire operating within an environment where approximate values of reflectance for ceilings, walls and floors can be established.

$$Kr = (Length \times Width) / (Length + Width) \times Height\ of\ lamp\ above\ working\ plane$$

Luminaire efficiencies are quoted in terms of the light output ratios (LOR), downward light output ratio (DLOR) and upward light output ratio (ULOR), where:

$$LOR = \frac{\text{Total lumen output}}{\text{Lamp lumen output}}$$

$$DLOR = \frac{\text{Down lumen output}}{\text{Lamp lumen output}}$$

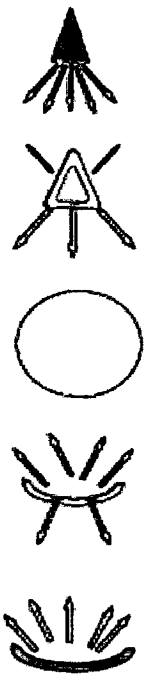
$$ULOR = \frac{\text{Up lumen output}}{\text{Lamp lumen output}}$$

$$LOR = DLOR + ULOR$$

Maintenance factor is the ratio of illumination supplied by an installation which has lost his effectiveness owing to dust, to the deterioration of lamps to the other cause to average illumination in the working plane provided by new installation.

3.2 Classification of luminaries by light distribution

Classifications [3.5] of luminaries are depends on the flux distribution which are shown in figure 3.3 as follows:



	DOWN %	UP %
DIRECT	100-90	0 - 10
SEMI-DIRECT	90- 60	10 - 40
GENERAL DIFFUSING	60 - 40	40 - 60
SEMI-INDIRECT	40 - 10	60 - 90
INDIRECT	10 - 0	90 - 100

Fig 3.3 flux distribution

3.3 Color rendering index

Color Rendering Index (CRI) is a measure of the effect of light on the perceived color of objects. To determine the CRI of a lamp, the color appearances of a set of standard color chips are measured with special equipment under a reference light source with the same correlated color temperature as the lamp being evaluated. If the lamp renders the color of the chips identical to the reference light source, its CRI is 100. If the color rendering differs from the reference light source, the CRI is less than 100. A low CRI indicates that some colors may appear unnatural when illuminated by the lamp. Values for common lighting source vary from about 20 to 99. The higher is the number, better will the color rendering.

Color temperature of a light source is the absolute temperature in the Kelvins at which a black body radiator must be operated to have a chromacity (color spectrum) equals to the light source. This is described by the color appearance of a light source.

3.4 Glare [3.6]

Glare by definition brightness within the field of vision that causes discomfort, annoyance interference and eye fatigue. It reduces the visibility of an object. This is the common fault of lighting installations. It injures the eye, disturbs the nervous system, causes discomfort and fatigue, reduces efficiency, interferes with clear vision and increases risk of accident.

Glare is experienced, when Lamps, Windows, Luminaries, other areas are brighter than general brightness in the environment. Glare may be Direct and Reflected. Direct glare results from bright luminaire in the field of vision. Reflected glare arises due to reflection of such a source from a glossy surface it is more annoying than direct glare can be avoided by appropriate choice of interiors.

Direct glare, minimization or avoidance is possible by mounting luminaries well above the line of vision or field of vision. Limit both brightness and light flux (in the normal field of view). Disability glare is that level of glare that impairs the vision. Whereas Discomfort glare only causes feeling of discomfort that increases or depends on time of exposure. There is no reduction of visual acuity but leads to fatigue.

Disability Glare is the glare which impairs the ability to see detail without necessarily causing visual discomfort. It can be measure in terms of visual performance and its effect can be expressed as a shift in the adoption level of eye. If the adoption level is raised by a light source such as a un shaded lamp or window, then the eye become less sensitive to small differences in brightness. The change in the adoption level can be expressed as:

$$\textbf{Adoption luminance} = L_0 + (kE/\Theta)$$

Where

L_0 original average luminance

E illuminance from glare source of the eye

Θ angle between line of sight and direction of glare

K constant related to the age of the observer

Disability Glare is defined as the glare which causes visual discomfort without necessarily impairing the vision of the subject. It is depends on the type of location and angle of view. This is very much a subjective assessment. Discomfort glare of a light source is:

$$g = 0.478(L_s^{1.6} \times w^{0.8}) / L_B \times P^{1.6}$$

Where

L_S is the luminance of source in candela per meter square

L_B average luminance of the background in candela per meter square

w angular size of source

P position index which indicates the effect of position of source or glare

Glare index is defined by the following equation:

$$G = 10\log (g)$$

Calculation of Glare

Some assumptions are made that are useful in calculating glare, which are as follows:

1. Room is rectangular and has a regular array of luminances.
2. The direction of view is horizontal at a height of 1.2m above flour level and straight across the room.
3. Glare is additive and hence for a complete installation the glare from all the luminaries would be same as for a single luminaire of the same luminance L_s , but the angular size 'w' being the total of all the individual fittings.

The steps to be followed for calculation of glare are:

1. The initial glare index for all the particular type of luminaire (BZ classification)[3.7]in the specific room is calculated from the equation:

$$G = 10 \log \Sigma g$$

2. The room dimensions x and y are determined in terms of fitting height 'H' have 1.2m (eye level).
3. The values of initial glare index for the particular room dimensions, flux fraction and room refraction factors reed from the selected table interpolating where necessary.
4. When linear fitting are used having different eye end-wise and cross-wire distribution, (Bz-4,6,7, and 8)[3.7], the appropriate conversion term given on right hand side of the table is added or subtracted from the initial glare index as indicated.

Chapter 4: Light Sources

4.1 Introduction

The lighting industry makes millions of electric light sources, called lamps. Those used for providing illumination can be divided into three general classes: incandescent, discharge, and solid-state lamps. Incandescent lamps produce light by heating a filament until it glows. Discharge lamps produce light by ionizing a gas through electric discharge inside the lamp. Solid-state lamps use a phenomenon called electroluminescence to convert electrical energy directly to light. In addition to manufactured light sources, daylight — sunlight received on the Earth, either directly from the sun, scattered and reflected by the atmosphere, or reflected by the moon — provides illumination. The prime characteristic of daylight is its variability. Daylight varies in magnitude, spectral content, and distribution with different meteorological conditions, at different times of the day and year, and at different latitudes.

4.2 Incandescent Lamps

Incandescent [4.1] lamp technology uses electric current to heat a coiled tungsten filament to incandescence. The glass envelope contains a mixture of nitrogen and a small amount of other inert gases such as argon. Some incandescent lamps, such as some flashlight lamps, also contain xenon. Some of these incandescent lamps are called xenon lamps, but are not the same as the high-pressure xenon lamps discussed in Section 4.3. Incandescent lamps have come a long way since Thomas Edison's first carbon filament lamp, which, when introduced in 1879, had a life of about 40 hours. Today, commonly available incandescent lamps have average lives of between 750 and 2000 hours. Figure 4.1 shows the construction of a typical incandescent lamp, while some commonly used bulb shapes are shown in Figure 4.2.

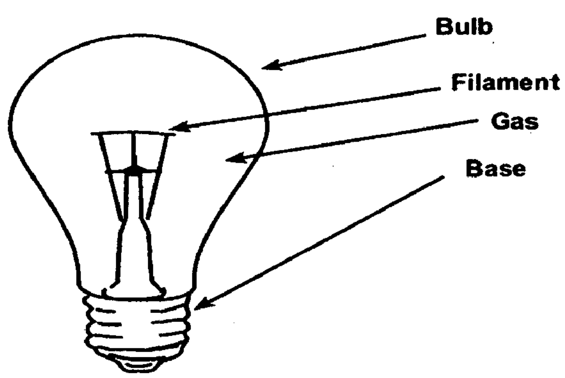


Fig 4.1 Construction of a typical incandescent lamp

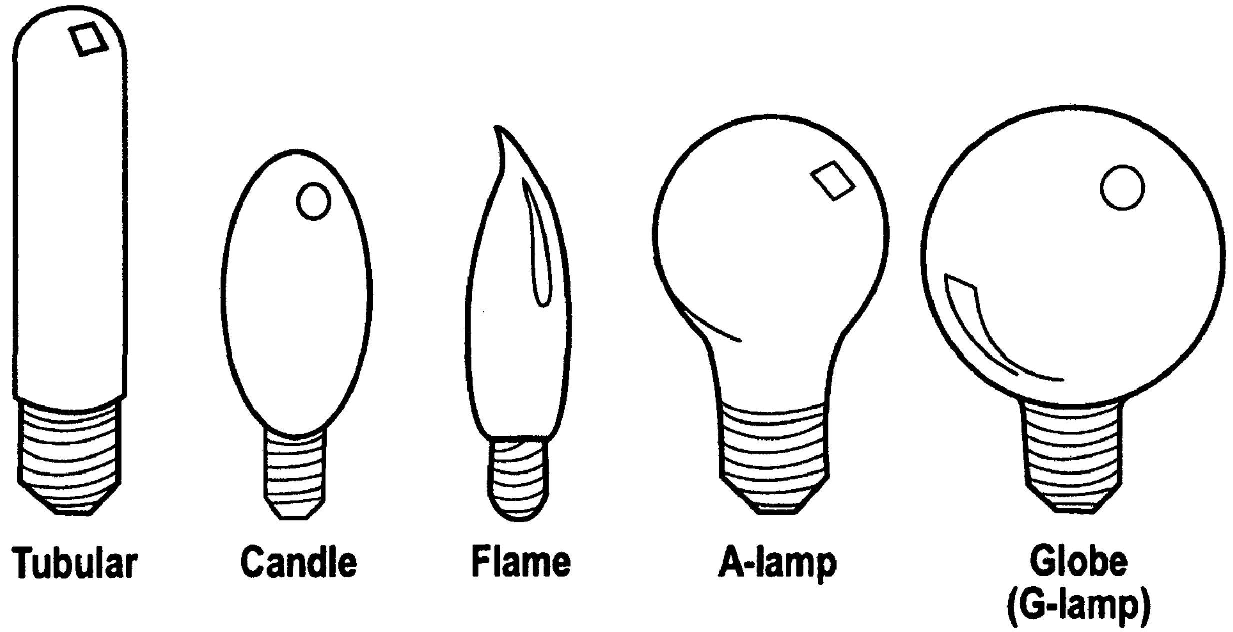


Fig 4.2 Common shapes of incandescent lamps

Incandescent lamps are strongly affected by input voltage. For example, reducing input voltage from the normal 110 volts (V) to 104.5 V (95%) can double the life of a standard incandescent lamp, while increasing voltage to just 115.5 V (105% of normal) can halve its life. Voltage variations also affect light output (lumens), power (watts), and efficacy (lumens per watt), as shown in Figure 4.3.

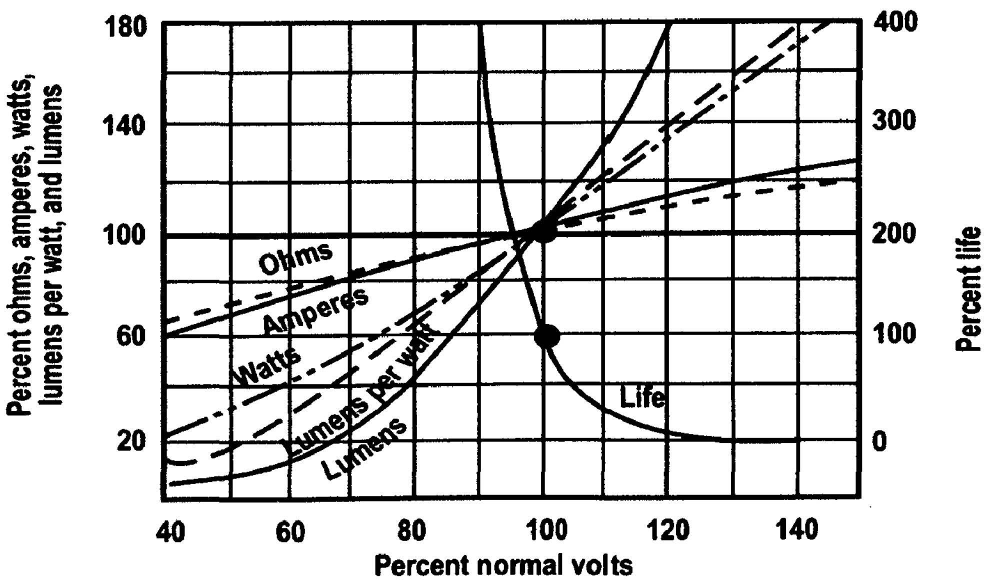


Fig 4.3 Effect of voltage on lamp life, light output, power, and efficacy

Halogen Lamps Unlike incandescent lamps, halogen lamps use a halogen gas fill (typically iodine or bromine), to produce what is called a "halogen cycle" inside the lamp. In the halogen cycle, halogen gas combines with the tungsten that evaporates from the lamp filament, eventually re-depositing the tungsten on the filament instead of allowing it to accumulate on the bulb wall as it does in standard incandescent lamps. The tungsten- halogen lamp has several differences from incandescent lamps:

- The lamps have a longer life (2000-3500 hours).
- The bulb wall remains cleaner, because the evaporated tungsten is constantly redeposited on the filament by the halogen cycle. This allows the lamp to maintain lumen output throughout its life.
- The higher operating temperature of the filament improves luminous efficacy.
- The lamp produces a "whiter" or "cooler" light, which has a higher correlated color temperature (CCT) than standard incandescent lamps.
- The bulbs are more compact, offering opportunities for better optical control.

Halogen lamps are sometimes called "quartz" lamps because their higher temperature requires quartz envelopes instead of the softer glass used for other incandescent lamps.

4.3 Discharge Lamps

Discharge lamps produce light by passing an electric current through a gas that emits light when ionized by the current. An auxiliary device known as a ballast supplies voltage to the lamp's electrodes, which have been coated with a mixture of alkaline earth oxides to enhance electron emission. Two general categories of discharge lamps are used to provide illumination: high-intensity discharge and fluorescent lamps. **HID Lamps** Four types of high-intensity discharge (HID) lamps are most widely available on today's market: high-pressure mercury vapor lamps, metal-halide lamps, high-pressure sodium lamps, and xenon lamps.

High-Pressure Mercury Vapor Lamps In a high-pressure mercury vapor lamp, light is produced by an electric discharge through gaseous mercury. The mercury, typically along with argon gas, is contained within a quartz arc tube, which is surrounded by an outer bulb of borosilicate glass. Figure 5.4 shows the construction of a typical high-pressure mercury vapor lamp. Xenon may also be used in high-pressure mercury vapor lamps to aid starting time, and does not significantly change the visible spectrum of the lamp.

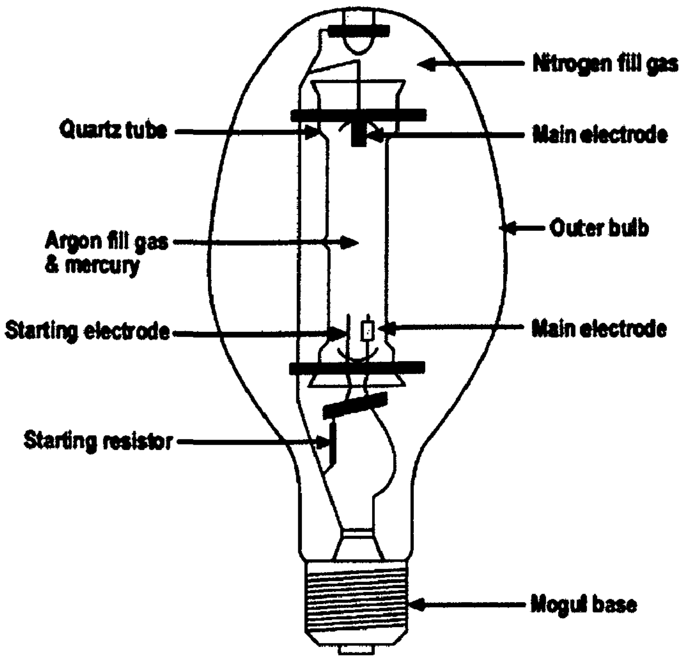


Fig 4.4 Construction of a high-pressure mercury vapor lamp

Metal-Halide Lamps A metal-halide lamp is a mercury vapor lamp with other metal compounds (known as halides) added to the arc tube to improve both color and luminous efficacy. Figure 4.5 shows the construction of a typical single-ended, screw base metal-halide lamp.

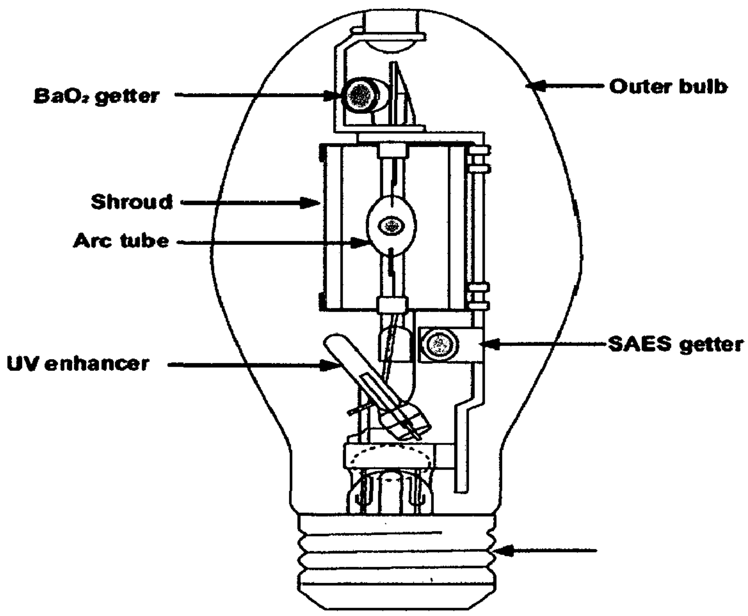


Fig 4.5 Construction of a metal-halide lamp

High-Pressure Sodium Lamps Light is produced in a high-pressure sodium (HPS) lamp by an electric discharge through combined vapors of mercury and sodium, with the sodium radiation dominating the spectral emission. The hard glass outer bulb may be clear, or its inner surface may be coated with a diffuse powder to reduce the brightness of the arc tube. Figure 4.6 shows the construction of a typical single-ended, screw base high- pressure sodium lamp.

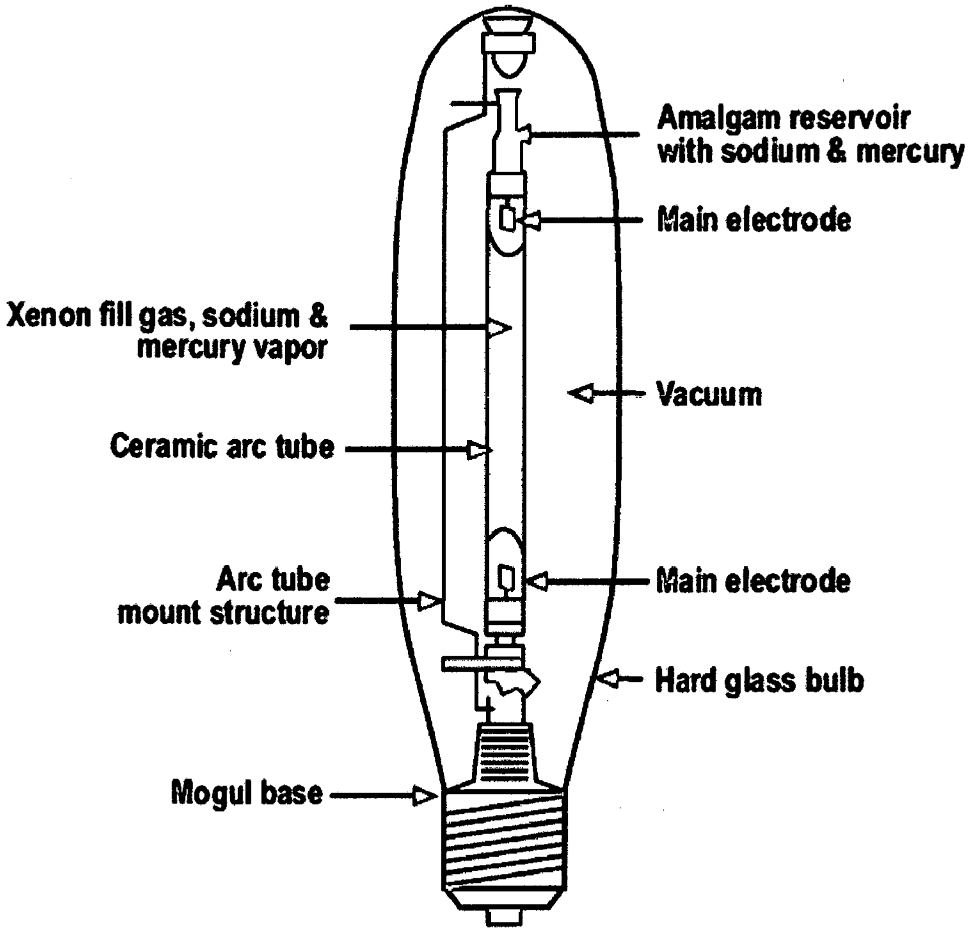


Fig 4.6 Construction of a high-pressure sodium lamp

Xenon Lamps Unlike the other three HID lamps described here, xenon lamps do not contain mercury vapor. They contain xenon gas, kept at a pressure of several atmospheres. Xenon lamps are available in wattages from 5 to 32,000 watts. Figure 4.7 shows some examples of xenon lamps. Some incandescent lamps, such as some flashlight lamps, also contain xenon. These incandescent lamps are sometimes called xenon lamps, but are not the same as high-pressure xenon lamps.

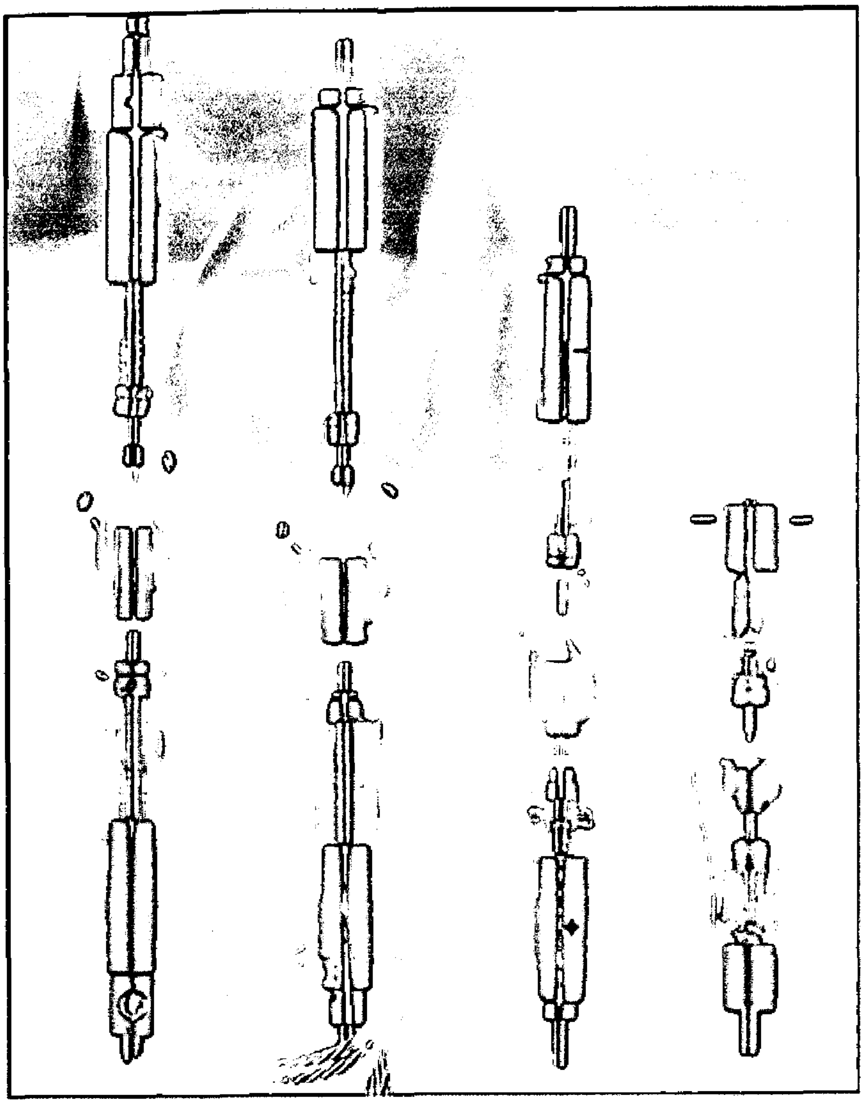


Figure 4.7 Typical xenon lamps

Fluorescent Lamps Fluorescent lighting accounts for two-thirds of all electric light in the United States. The fluorescent lamp is a gas discharge source that contains mercury vapor at low pressure, with a small amount of inert gas for starting. Once an arc is established, the mercury vapor emits ultraviolet radiation. Fluorescent powders (phosphors) coating the inner walls of the glass bulb respond to this ultraviolet radiation by emitting wavelengths in the visible region of the spectrum.

Ballasts, which are required by both fluorescent and HID lamps, provide the necessary circuit conditions (voltage, current, and wave form) to start and operate the lamps. Two general types of ballasts are available for fluorescent lamps: magnetic and electronic. Electronic ballasts are often more expensive, but are usually lighter, quieter, and eliminate the lamp flicker associated with magnetic ballasts. Fluorescent lamps are often described in terms of the diameter of the lamp tube. For this designation, the diameter is given in eighths of an inch. For example, a T8 lamp has a diameter of one inch (eight eighths), while a T5 lamp has a diameter of 5/8 inch.

Linear Fluorescent Lamps Linear fluorescent lamps range in length from six inches to eight feet, and in diameter from 2/8 inch (T2) to 2-1/8 inches (T17). Their power ranges from 14 to 215 watts. Figure 4.8 shows the construction of a linear fluorescent lamp.

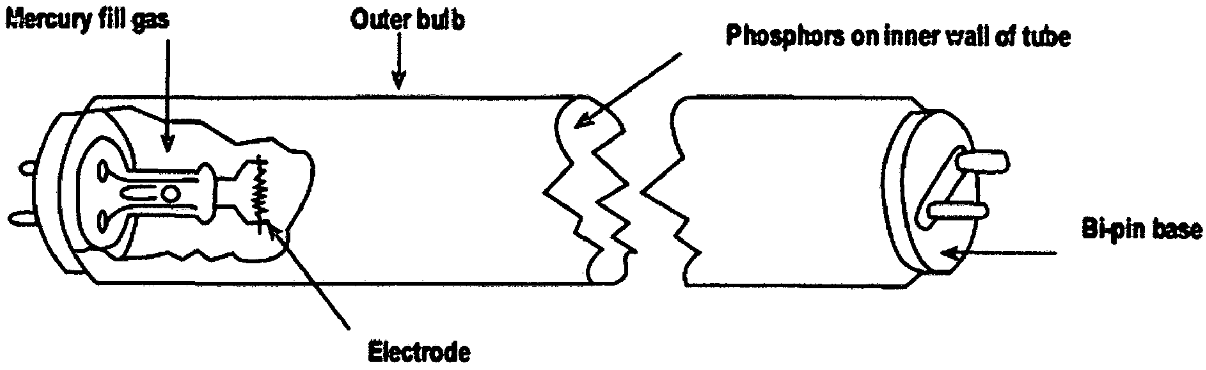


Figure 4.8 — Construction of a linear fluorescent lamp. Lighting

What are T5 lamps?

T5 lamps are fluorescent lamps that are 5/8 of an inch in diameter. This report discusses only linear T5 lamps. Differences in length and socket pin design versus conventional fluorescent lamps prevent any problems with electric circuits or human factors. This section focuses on the physical characteristics of T5 systems compared with T12 systems.

What does T5 mean?

The "T" in lamp nomenclature represents the shape of the lamp-tubular. The number following the "T" usually represents the diameter of the lamp in eighths of an inch (1 inch equals 2.5 centimeters). T5 lamps have a diameter equal to 5 times an eighth of an inch, or 5/8". These lamps are approximately 40% smaller than T8 lamps, which are one inch in diameter, and almost 60% smaller than T12 lamps, which are 1½" in diameter. Figure 4.9 shows diagrams of lamp ends of T5, T8, and T12 lamps. Figure 4.9 also shows that pin base type of T5 lamps is different from that of T8 and T12 lamps. T5 lamps have a miniature bi-pin base while T8 and T12 lamps use a medium bi-pin base.

Luminaire manufacturers create innovatively designed compact luminaries using up-to-date optical materials. Recently, lighting designers have begun to specify such T5 luminaires for high-end new construction. The marketing and innovative design of T5 systems have left many end users wondering whether they should consider T5 luminaires instead of T8 luminaires, especially in new construction and retrofitting of T12 magnetic systems. End users are confused by the 10°C (18°F) difference in optimal temperature and the small difference in system efficacy between T5 and T8 systems.

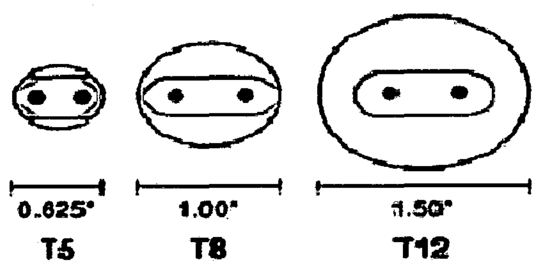


Fig 4.9 lamp ends

TECHNICAL SPECIFICATIONS OF T5 LAMP & BALLAST OVER CONVENTIONAL FIXTURE

Table 4.1

SPECIFICATIONS OF LAMP	**CONVENTIONAL**	**ENERGY SAVING T5 LAMP**
LAMP WATTAGE	40W	28W
LUMEN OUTPUT	2450 LUMEN	2900 LUMEN
BRIGHTNESS LEVEL		20% MORE
LAMP LIFE	5000Hrs	20000 BURNING Hrs
DEPRICIATION OF LAMP PUTPUT	25%	5% UPTO END OF LIFE
SPECIFICATIONS OF BALLAST	**COPPER WOUND BALLAST**	**ELECTRONIC BALLAST**
WATTAGE LOSS	13W	2W
OPERATION	FLICKERED	FLICKER FREE
RELATION WITH LAMP LIFE	EFFECTED	NOT EFFECTED

Compact Fluorescent Lamps (CFLs) CFLs produce light in the same manner as linear fluorescent lamps. Their tube diameter is usually 5/8 inch (T5) or smaller. CFL power ranges from 5 to 55 watts. Figure 4.10 shows several styles of CFLs

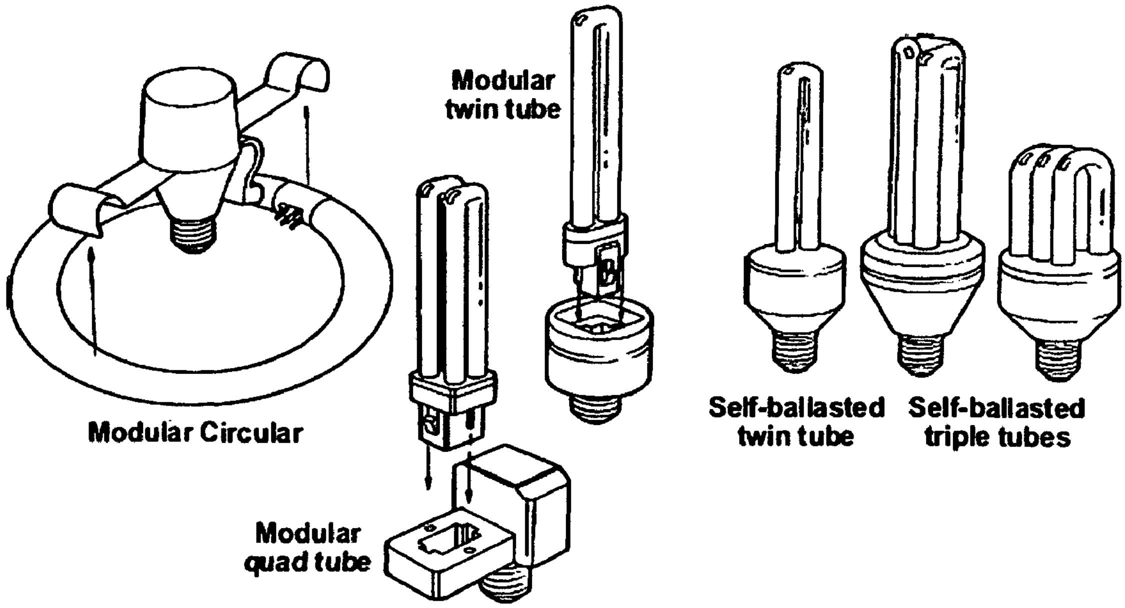
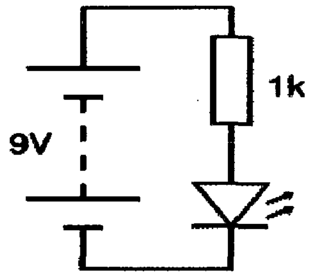
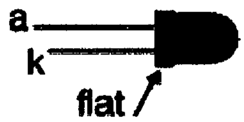


Figure 4.10 — Examples of compact fluorescent lamps.

4.4 LEDs (Light-Emitting Diodes)

Light-emitting diodes (LEDs) are a relatively old technology (1970s) that has advanced from use in numeric displays and indicator lights to a range of new and potential new applications, including exit signs, accent lights, task lights, traffic lights, signage, cove lighting, wall sconces, outdoor lighting and down lighting.





a => anode

k => cathode

Circuit symbol:

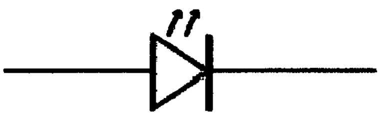


Figure 4.11 symbol of LED

LEDs offer benefits such as small size, long lamp life, low heat output, energy savings and durability. They also allow extraordinary design flexibility in color changing, dimming and distribution by combining these small units into desired shapes, colors, sizes and lumen packages.

Currently, relatively low overall light output, poor color rendering and questions about advertised service life may indicate that LEDs, while very useful in many applications, are not yet ready for "prime time" in some architectural applications. Notably promising current applications include retail display, colored lighting, tight spaces, areas that require low light levels, exterior lighting and applications where the integration of light sources and architectural elements is critical.

LEDs currently dominate the exit sign market and many cities have adopted them as a replacement for incandescent lamps in traffic signals. In the architectural market, the development of a visible/white light LED has awakened lighting designers to new possibilities with this light source. White light LEDs, however, currently do not produce enough lumen output to make them competitive with many general light sources. This restricts their use in architectural projects to applications where small lumen packages are needed and where the characteristics of a lower CRI rating and high color temperature are acceptable.

Method of Operation [4.2]:

- When an LED unit is activated
- power supply converts AC voltage into sufficient DC voltage
- which is applied across the diode semiconductor crystal
- This results in electrons (negative charge carriers [N]) in the diode's electron transport layer and holes (positive charge carriers [P]) in the diode's hole transport layer combining at the P-N junction and converting their excess energy into light
- The LED is sealed in a clear or diffuse plastic lens that can provide a range of angular distributions of the light.

4.4 Advantages and Disadvantages of LED Lighting

4.4.1 Advantages of LED Lighting [4.3]

- **Energy Efficiency:**

The key strength of LED lighting is reduced power consumption. When designed properly, an LED circuit will approach 80% efficiency, which means 80% of the electrical energy is converted to light energy. The remaining 20% is lost as heat energy. Compare that with incandescent bulbs which operate at about 20% efficiency (80% of the electrical energy is lost as heat)

- **Cost:**

There is no comparison between the costs of LED lights vs. traditional incandescent options. With incandescent bulbs, the true cost of the bulb is the cost of replacement bulbs and the labor expense and time needed to replace them.

These are significant factors, especially where there are a large number of installed bulbs. For office buildings and skyscrapers, maintenance costs to replace bulbs can be enormous. These issues can all be virtually eliminated with the LED option

- **Long Life:**

The operational life of current white LED lamps is 100,000 hours. This is 11 years of continuous operation, or 22 years of 50% operation. The long operational life of an led lamp is a stark contrast to the average life of an incandescent bulb, which is approximately 5000 hours. If the lighting device needs to be embedded into a very inaccessible place, using LEDs would virtually eliminate the need for routine bulb replacement.

- **Range of Colors**:

LEDs are available in a range of colors. In addition, through the innovative combination of various-colored LEDs, dramatic color-changing effects can be produced from a single fixture through dynamic activation of various sets of LEDs.

- **No UV Emissions/Little Infrared:**

LEDs produce no UV radiation and little heat, making them ideal for illuminating objects, such as works of art, that are sensitive to UV light.

- **Durable**

LEDs are highly rugged. They feature no filament that can be damaged due to shock and vibrations. They are subject to heat, however, and being overdriven by the power supply.

- **Small Size/Design Flexibility:**

A single LED is very small and produces little light overall. However, this weakness is actually its strength. LEDs can be combined in any shape to produce desired lumen packages as the design goals and economics permit. In addition, LEDs can be considered miniature light fixtures; distribution of light can be controlled by the LEDs' epoxy lens, simplifying the construction of architectural fixtures designed to utilize LEDs.

A controller can be connected to an LED fixture to selectively dim individual LEDs, resulting in the dynamic control of distribution, light output and color. Finally, DC power enables the unit to be easily adaptable to different power supplies.

4.4.2 Disadvantages of LED Lighting

There are several major disadvantages to LEDs that restrict their application and slow their wider adoption in general lighting applications.

- **Lack of Choice**

There is currently a relative lack of availability of product choices for white LEDs. LEDs are undergoing continuous development, particularly in terms of lumen package per unit and lumens per watt.

- **Color Quality**

White LEDs currently offer poor color rendering and a high color temperature. As improvements are made to the technology in the lab, however, we can expect these problems to be corrected.

- **Product Standardization**

There is currently no standardization for this technology, raising questions about maintainability. Will the manufacturer offer matching spare parts when systems begin to fail or will entire systems need to be replaced?

4.4.3 Other Benefits:

- Lights instantly
- Can be easily dimmed
- Silent operation
- Low-voltage power supply (increased safety)

4.4.4 Applications

- automotive headlights
- traffic light
- indoor & outdoor lighting
- architectural lighting in modern offices
- walk ways
- parks and garden lighting

4.5 Comparison between LEDs, Incandescent Bulbs and CFLs[4.4]

Comparison shown in table 4.2 to table 4.5

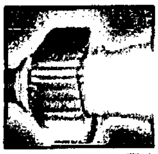
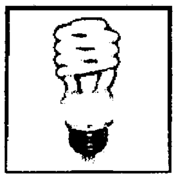
Energy Efficiency & Energy Costs	 Light Emitting Diodes (LEDs)	 Incandescent Light Bulbs	 Compact Fluorescents (CFLs)
Life Span (average)	50,000 hours	1,200 hours	8,000 hours
Watts of electricity used (equivalent to 60 watt bulb). LEDs use less power (watts) per unit of light generated (lumens). LEDs help reduce greenhouse gas emissions from power plants and lower electric bills	6 - 8 watts	60 watts	13-15 watts
Kilo-watts of Electricity used (30 Incandescent Bulbs per year equivalent)	329 KWh/yr.	3285 KWh/yr.	767 KWh/yr.
Annual Operating Cost (30 Incandescent Bulbs per year equivalent)	$32.85/year	$328.59/year	$76.65/year

Table 4.2 Comparison in terms of energy efficiency and costs

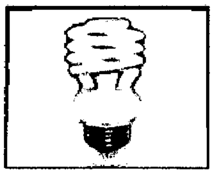
Environmental Impact	 Light Emitting Diodes (LEDs)	 Incandescent Light Bulbs	 Compact Fluorescents (CFLs)
Contains the TOXIC Mercury	No	No	Yes - Mercury is very toxic to your health and the environment
RoHS Compliant	Yes	Yes	No - contains 1mg-5mg of Mercury and is a major risk to the environment
Carbon Dioxide Emissions (30 bulbs per year) Lower energy consumption decreases: CO2 emissions, sulfur oxide, and high-level nuclear waste.	451 pounds/year	4500 pounds/year	1051 pounds/year

Table 4.3 Comparison in terms of environmental impacts

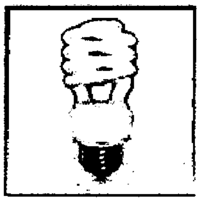
Important Facts	 **Light Emitting Diodes (LEDs)**	 **Incandescent Light Bulbs**	 **Compact Fluorescents (CFLs)**
Sensitivity to low temperatures	None	Some	Yes - may not work under negative 10 degrees Fahrenheit or over 120 degrees Fahrenheit
Sensitive to humidity	No	Some	Yes
On/off Cycling Switching a CFL on/off quickly, in a closet for instance, may decrease the lifespan of the bulb.	No Effect	Some	Yes - can reduce lifespan drastically
Turns on instantly	Yes	Yes	No - takes time to warm up
Durability	Very Durable - LEDs can handle jarring and bumping	Not Very Durable - glass or filament can break easily	Not Very Durable - glass can break easily
Heat Emitted	3.4 btu's/hour	85 btu's/hour	30 btu's/hour
Failure Modes	Not typical	Some	Yes - may catch on fire, smoke, or omit an odor

Table 4.4 Comparison in terms of important facts

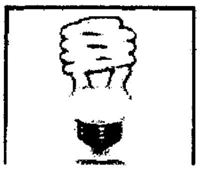
Light Output	 **Light Emitting Diodes (LEDs)**	 **Incandescent Light Bulbs**	 **Compact Fluorescents (CFLs)**
Lumens	**Watts**	**Watts**	**Watts**
450	4-5	40	9-13
800	6-8	60	13-15
1,100	9-13	75	18-25
1,600	16-20	100	23-30
2,600	25-28	150	30-55

Table 4.5 Comparison in terms of light output

Chapter 5: Lighting Design

5.1 Objectives of Lighting Design

The general lighting design approach is a common strategy used to provide a fairly uniform amount of light throughout a room [5.1]. This approach usually results in regular pattern of light fixtures that produces very even light levels, slightly higher than the average value in the center of the room and slightly lower in the outer corners of the room. New studies show the quality of light affects people in many different ways. For example [5.2], office worker satisfaction and productivity can be positively affected by well-designed illumination. Building owners and managers have the potential to add value, reduce costs and enhance performance through the application of good lighting. It's no secret that people are attracted to well-lighted public facilities, commercial shopping districts and parks.

5.2 Advantages Of Lighting Design Services

The involvement of a professional lighting designer in a project can assure long-term cost-savings in terms of [5.3] equipment, operations, people, and aesthetics.

1. **Equipment Cost Control**

   A lighting designer may either provide a design to meet an established budget, or may help to establish the budget early in the design phase. The lighting designer will select equipment from numerous manufacturers to help keep bids competitive and/or recommend lighting equipment or techniques to reduce installation costs. Because a lighting designer does not manufacture, sell or install equipment, his or her involvement in the project may serve to encourage competition, for example:

   1.1. Negotiating One-of-a-Kind Pricing If the luminaire is "one of a kind," the lighting designer may be helpful in obtaining an agreed upon price from the manufacturer.

   1.2. Identifying Lowest-Cost Unit Pricing In other instances, unit pricing may be obtained independently and compared with that of the bidding contractors. The designer also may recommend distributors who will furnish additional competitive pricing. Finally, the professional lighting designer will work with the owner's representative and contractors to achieve cost objectives without sacrificing design objectives.

2. **Operations Cost Control**

   Methods to reduce long-term operations costs may be an important consideration for the owner. A professional lighting designer's life cycle cost analysis will demonstrate the return on initial investment benefits of certain techniques or technologies. There are numerous ways in which a professional designer can introduce cost reduction methods to benefit the project, for example:

2.1. Avoiding Over-Lighting In some areas, costs can be reduced simply by not over-lighting a space. Over-lighting is common when visual issues are not understood, or when "going by the book" in determining "foot-candle" requirements. Over-lighting also may occur if the recommendations of individuals who sell equipment are relied upon too heavily.

2.2. Improving Reflectance and Integrating Daylight Additionally, improving the reflectance value of a surface can help reduce lighting costs, as well as integrating daylight with electric light.

3. People Costs

The quality of light affects people costs. New studies are demonstrating the effects of lighting on retail sales, office productivity, and the ability to attract people to commercial downtown districts after dark. Lighting designers are keenly aware of these issues, as well as the techniques recommended for achieving positive results.

4. Aesthetic Costs

Technical skill can be learned, but talent cannot. The "value-added" for good, creative design is difficult to assess, and will depend upon the appreciation of the decision-makers. However, the difference between great and average lighting design is very apparent.

5.3 Lighting design

Good lighting design means the right amount of light in the right places, not over lighting and not having lighting on when not required. Done right it cans [5.4]:

1. Optimize lighting levels for accuracy and safety
2. Enhance architecture
3. Add to the 'look and feel' of a space
4. Highlight products in a retail environment.

There are psychological benefits too; good lighting design is an essential part of people's feelings of comfort and satisfaction, providing productivity benefits in the short run and potential employee retention in the long run. Most people spend on average 8 hours a day in the workplace. So it is important to ensure they feel comfortable in that space. Here's what you can do:

1. Maximize natural daylight levels, while avoiding glare.
2. Light walls and ceilings with bright room surface finishes, so people can safely move around the space.
3. Provide the correct color rendering and color temperature to improve the feeling of comfort

4. Allow for zoning so people can dim lights or switch them off when they are not required, thus saving on electricity.

5.4 Parameters required for Lighting Design

For interior lighting design different types of parameters are required. These parameters are as follows:

1. Room Specifications: While doing lighting design, the designer should have to specify the length, width, height and working plane height in terms of meter. Another factor that we have to specify is maintenance factor. How we have to specify these things are shown in the figure 5.1

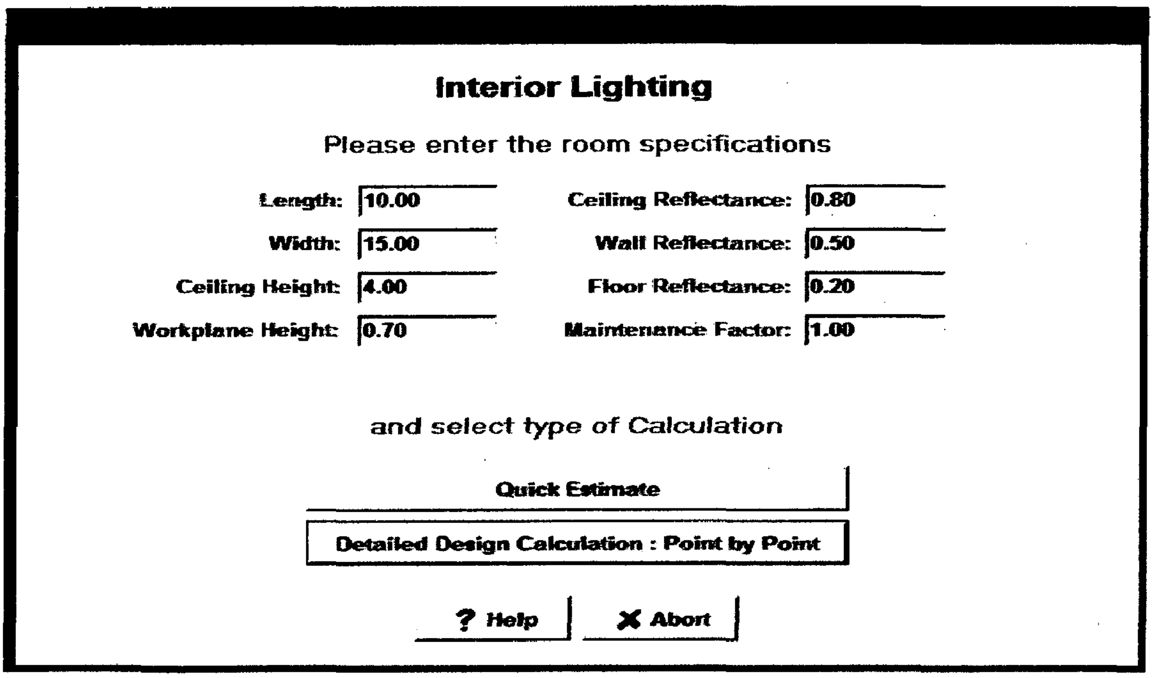


Fig 5.1 Room Specifications

2. Reflectance Factors: It contains ceiling, wall and floor reflectance.

3. Electrical parameters: While doing lighting design, the designer should know the total wattage he is implementing in the room. The other factor which is very important in terms of lighting design is Light per Density (LPD) value. If the final LPD value comes out is less than the specified value this means that the design is suitable for implement. Otherwise he has to check with the combination of fixtures and design. LPD value that is recommended by energy conservation of building code is shown in the figure 5.2. In this figure LPD values are given in terms of watt/square meter for different types of space function.

INTERIOR LIGHTING POWER LIMIT,-Space Function Method
Recommended by Energy Conservation Building Code 2006

SPACE FUNCTION	LPD(W/m²)	SPACE FUNCTION	LPD(W/m²)
Office - Enclosed	11.8	Library	
Office - Open Plan	11.8	Card File and Cataloging	11.8
Conference/Meeting/Multipurpose	14	Stacks	18.3
Classroom/Lecture/Training	15.1	Reading Areas	12.9
Lobby	14	Hospital	
For Hotel	11.8	Emergency	29.1
For Performing Arts Theater	35.5	Recovery	8.6
Audience/Seating Area	9.7	Exam Treatment	16.1
For Gymnasium	4.3	Pharmacy	12.9
For Exercise Centre	3.2	Patient Room	7.5
For Convention Centre	7.5	Operating Room	23.7
For Religious Building	18.3	Nursery	6.5
For Sports Arena	4.3	Medical Supply	15.1
For Performing Arts Theater	28	Physical Therapy	9.7
For Motion Picture Theater	12.9	Radiology	4.3
For Transportation	5.4	Laundry - Washing	6.5
Atrium - First Three Floors	6.5	Automotive - Service Repairs	7.5
Atrium - Each Additional Floor	2.2	Manufacturing	
Lounge/Recreation	12.9	Low Bay (<8m ceiling)	12.9
For Hospital	8.6	High Bay (>8m ceiling)	18.3
Dining Area	9.7	Detailed Manufacturing	22.6
For Hotel	14	Equipment Room	12.9
For Motel	12.9	Control Room	5.4
For Bar Lounge/Leisure Dining	15.1	Hotel/Motel Guest Rooms	11.8
For Family Dining	22.6	Dormitory - Living Quarters	11.8
Food Preparation	12.9	Museum	
Laboratory	15.1	General Exhibition	10.8
Restrooms	9.7	Restoration	18.3
Dressing/Locker/Fitting Room	6.5	Bank Office - Banking Activity Area	16.1
Corridor/Transition	5.4	Religious Buildings	
For Hospital	10.8	Worship - Pulpit, Choir	25.8
For Manufacturing Facility	5.4	Fellowship Hall	9.7
Stairs - Active	6.5	Retail	
Active Storage	8.6	Sales Area	18.3
For Hospital	9.7	Mall Concourse	18.3
Inactive Storage	3.2	Sports Arena	
For Museum	8.6	Ring Sports Area	29.1
Electrical/Mechanical	16.1	Court Sports Area	24.8
Workshop	20.5	Indoor Field Area	15.1
Sleeping Quarters	3.2	Warehouse	
Convention Centre - Exhibit space	14	Fine Material Storage	15.1
		Medium/Bulky Material Storage	9.7
		Parking Garage - Garage Area	2.2
		Transportation	
		Airport Concourse	6.5
		Air/Train/Bus - Baggage Area	10.8
		Terminal - Ticket Counter	16.1

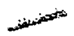
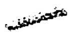
Fig 5.2 LPD value recommended by energy conservation of building code

4. Lighting Parameters: While doing lighting design, the designer should know the average, minimum, and maximum horizontal illuminance. He had also to calculate uniformity and diversity ratio shown in the figure 5.3

Calculation Area Details

Room Length:	11.0 m	Ceiling Reflectance:	0.80
Room Width:	8.00 m	Wall Reflectance:	0.50
Ceiling Height:	3.08 m	Floor Reflectance:	0.20
Workplane Height:	0.70 m	Maintenance Factor:	0.50

Type of Luminaire

Sr. No.	Photo	Luminaire Type	Luminaire Qty	Catalogue Number	Lamp Wattage	Lamp Type	Lamp Qty
1		Brite Star T5	9	SCS 228 T5 EB1 / P3	28.0W	FTL-T5	18
2		Brite Star T5	2	SCS 228 T5 EB1 / P3	28.0W	FTL-T5	4

Lighting Parameters

Avg. Horz. Illuminance (Eav= 261 Lux
Max. Horz. Illuminance (Ema= 414 Lux
Min. Horz. Illuminance (Emi= 100 Lux
Uniformity Ratio (Emin/Eavg= 0.384 (1 : 2.60)
Diversity Ratio (Emin/Emax) = 0.242 (1 : 4.13)

Electrical Parameters

Total Wattage = 658 W
Total Wattage/Luminai= 59.8 W
LPD (watt/squ.ft) = 0.69
LPD (watt/squ.m) = 7.47
Watt / squ.m / 100 lux = 2.86

Fig 5.3 Lighting Parameters

5.5 Lighting Design using Sunlux software

Lighting design is shown in figure 5.4 to figure 5.17

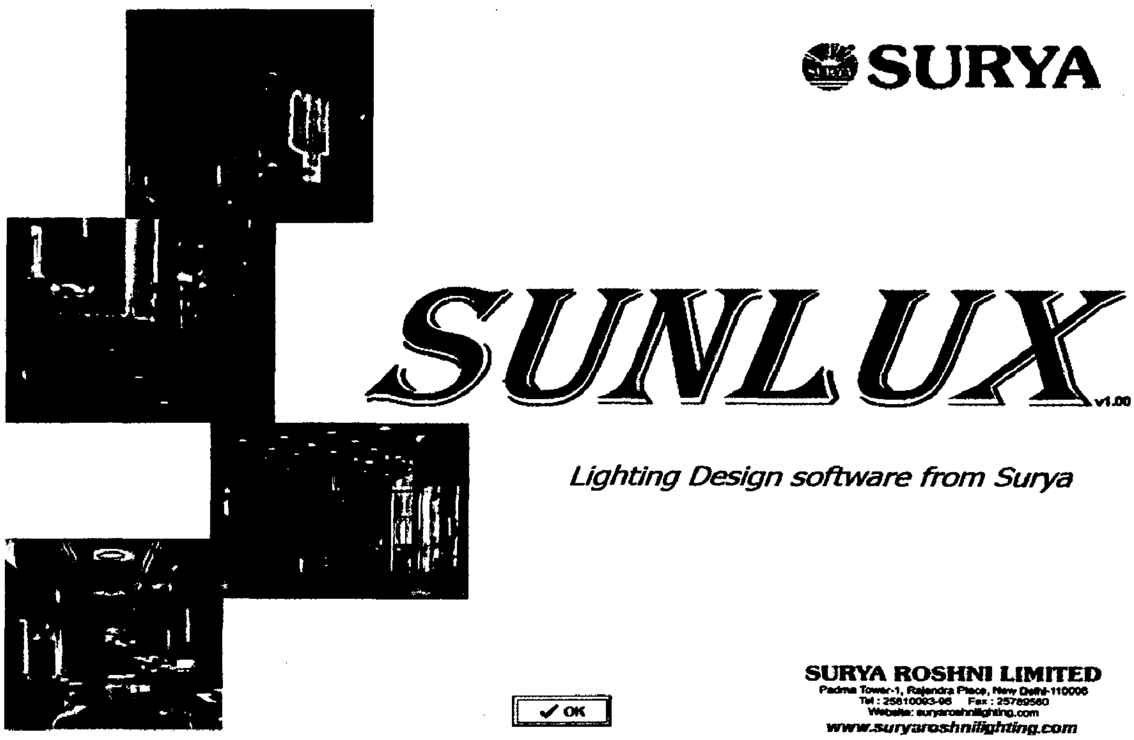


Fig 5.4 welcome screen

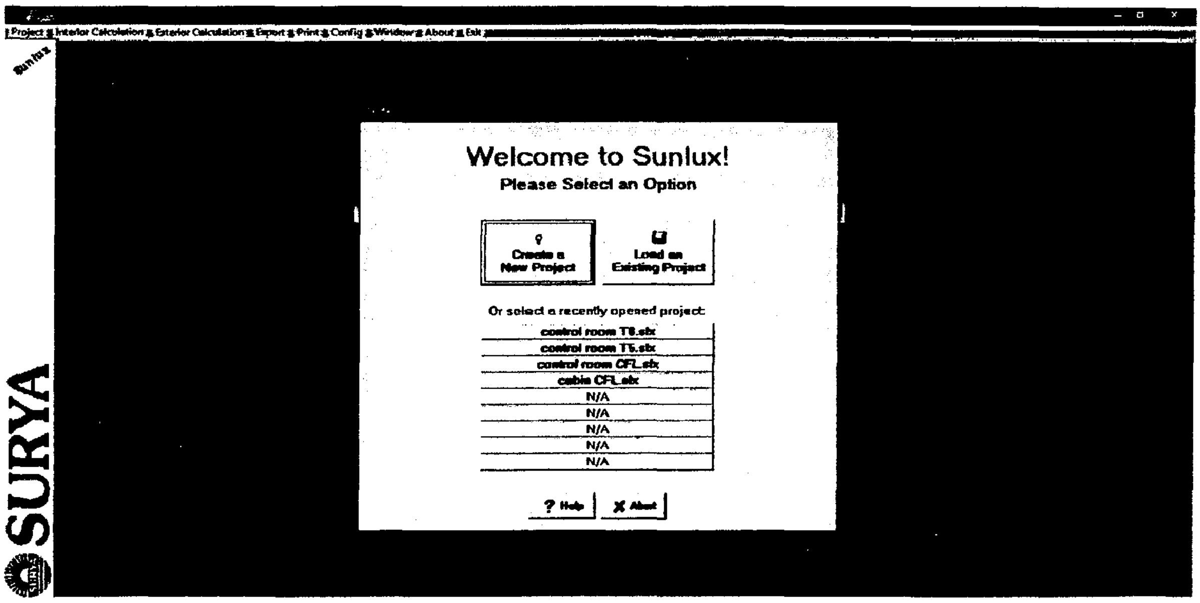


Fig 5.5

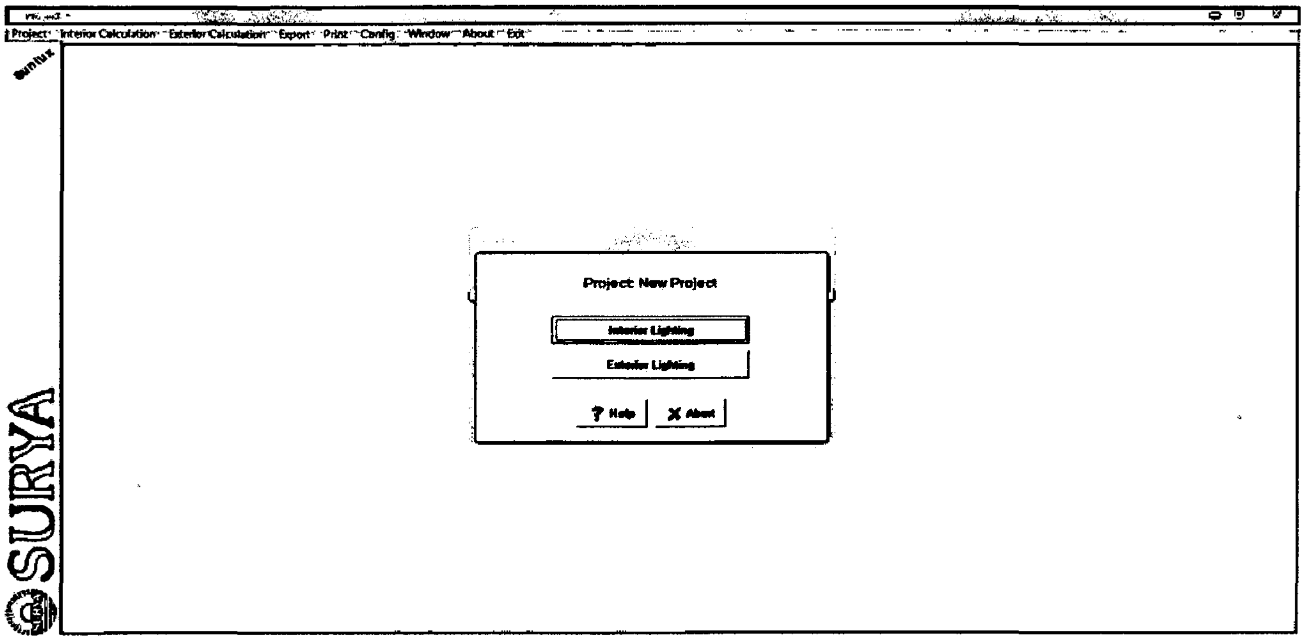

Project Interior Calculation Exterior Calculation Export Print Config Window About Exit
Project: New Project
Interior Lighting
Help
Abort
SURYA

Fig 5.6

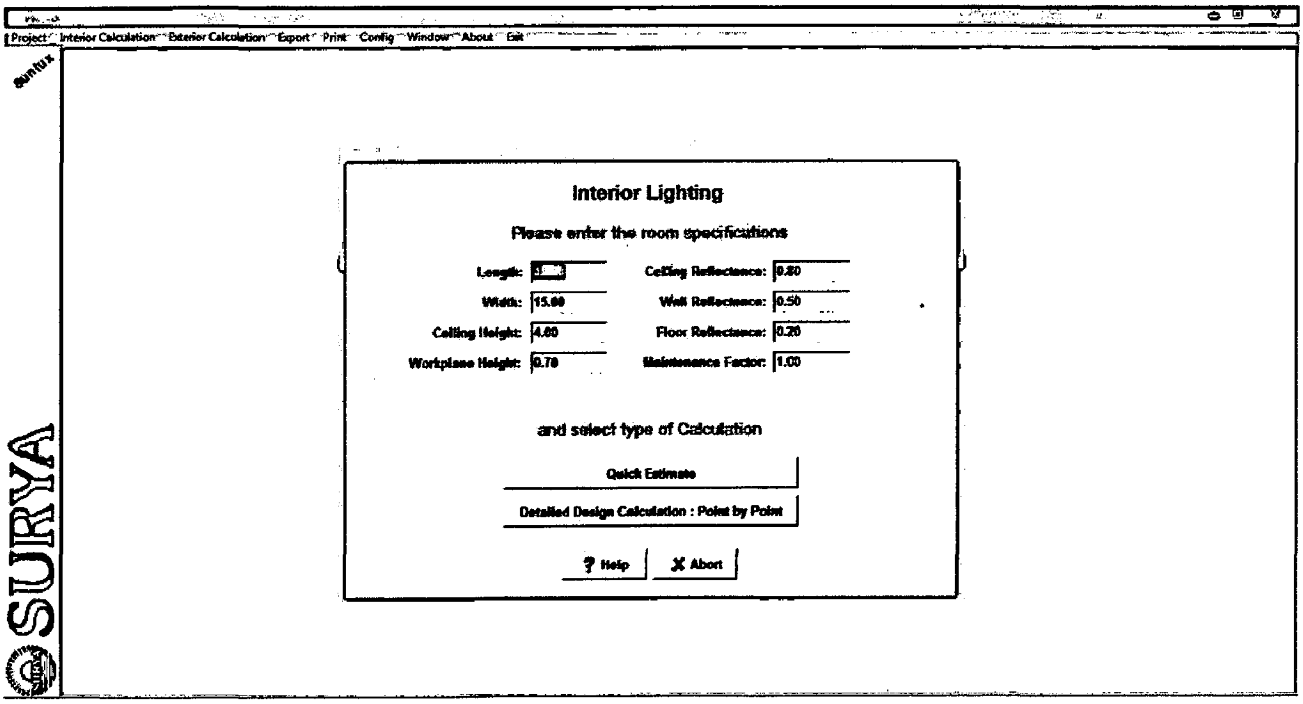
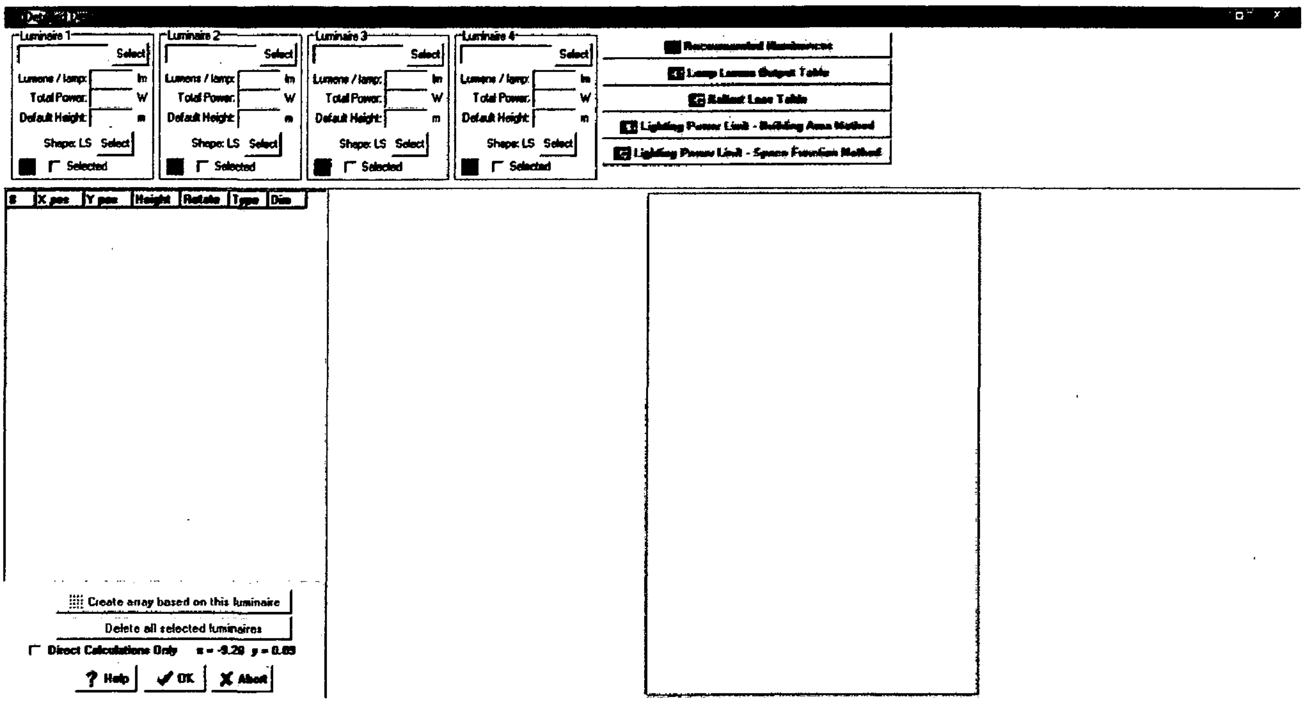
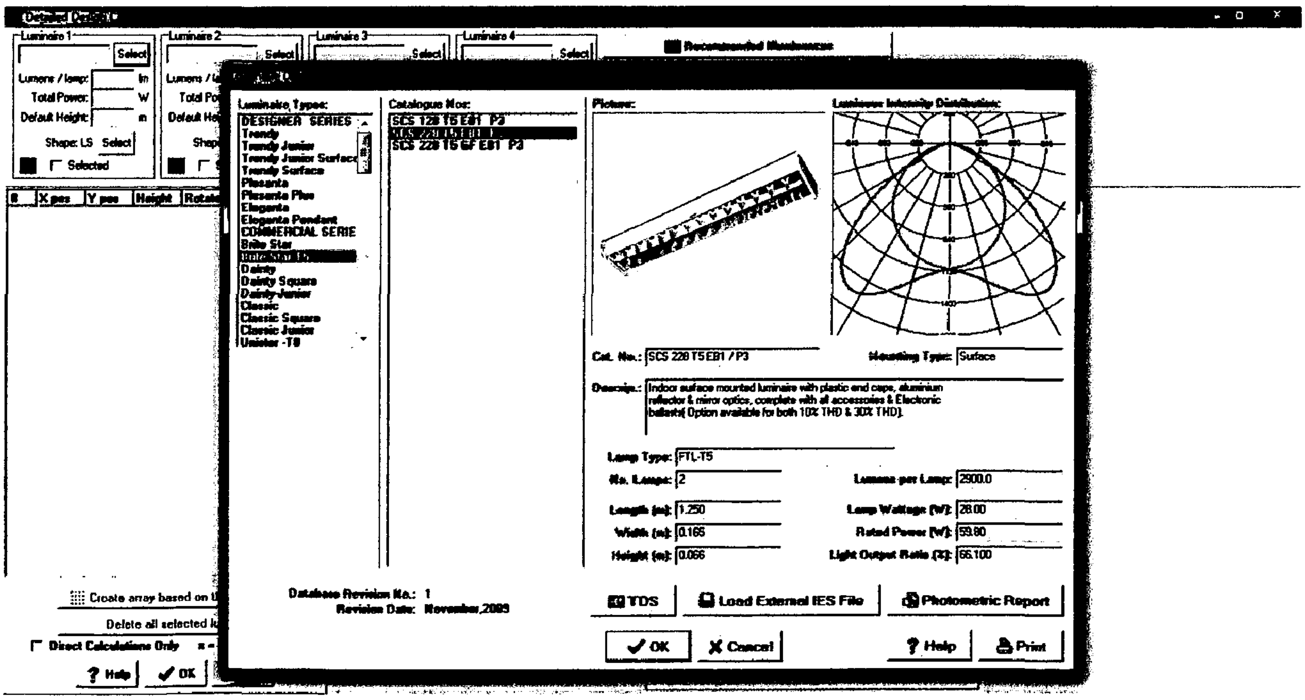

Project Interior Calculation Exterior Calculation Export Print Config Window About Exit
Interior Lighting
Please enter the room specifications
Length:
Width: 15.00
Ceiling Height: 4.00
Workplane Height:
Ceiling Reflectance: 0.80
Wall Reflectance: 0.50
Floor Reflectance: 0.20
Maintenance Factor: 1.00
and select type of Calculation
Quick Estimate
Detailed Design Calculation : Point by Point
Help
Abort
SURYA

Fig 5.7



Luminaire 1
Luminaire 2
Luminaire 3
Luminaire 4
Select
Lumens / lamp:
Total Power:
Default Height:
Shape: LS
Selected
Create array based on this luminaire
Delete all selected luminaires
Direct Calculations Only
Help
OK
Abort

Fig 5.8



Luminaire Types:
Catalogue Nos:
Picture:
Cat. No.: SCS 228 T5 EB1 / P3
Mounting Type: Surface
Lamp Type: FTL-T5
No. Lamps: 2
Lumens per Lamp: 2900.0
Length (m): 1.250
Lamp Wattage (W): 28.00
Width (m): 0.166
Rated Power (W): 59.80
Height (m): 0.066
Light Output Ratio (%): 66.100
TDS
Load External IES File
Photometric Report
OK
Cancel
Help
Print

Fig 5.9

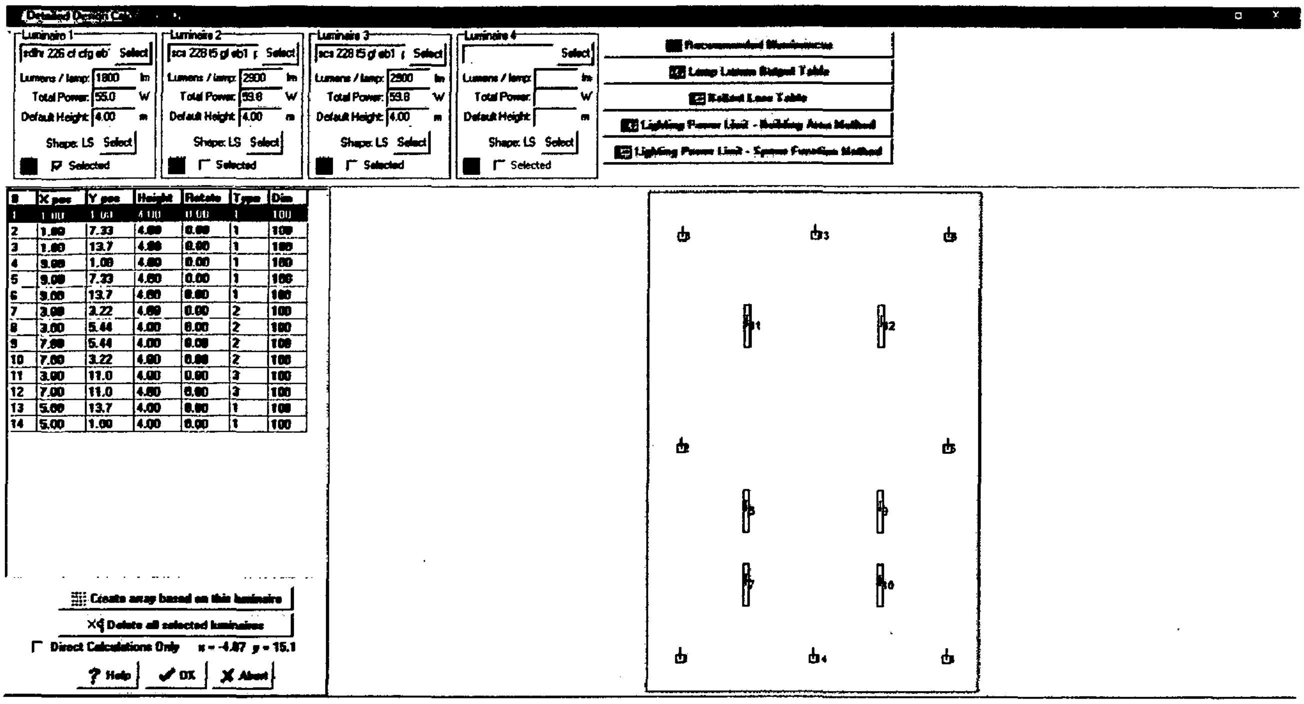


Fig 5.10

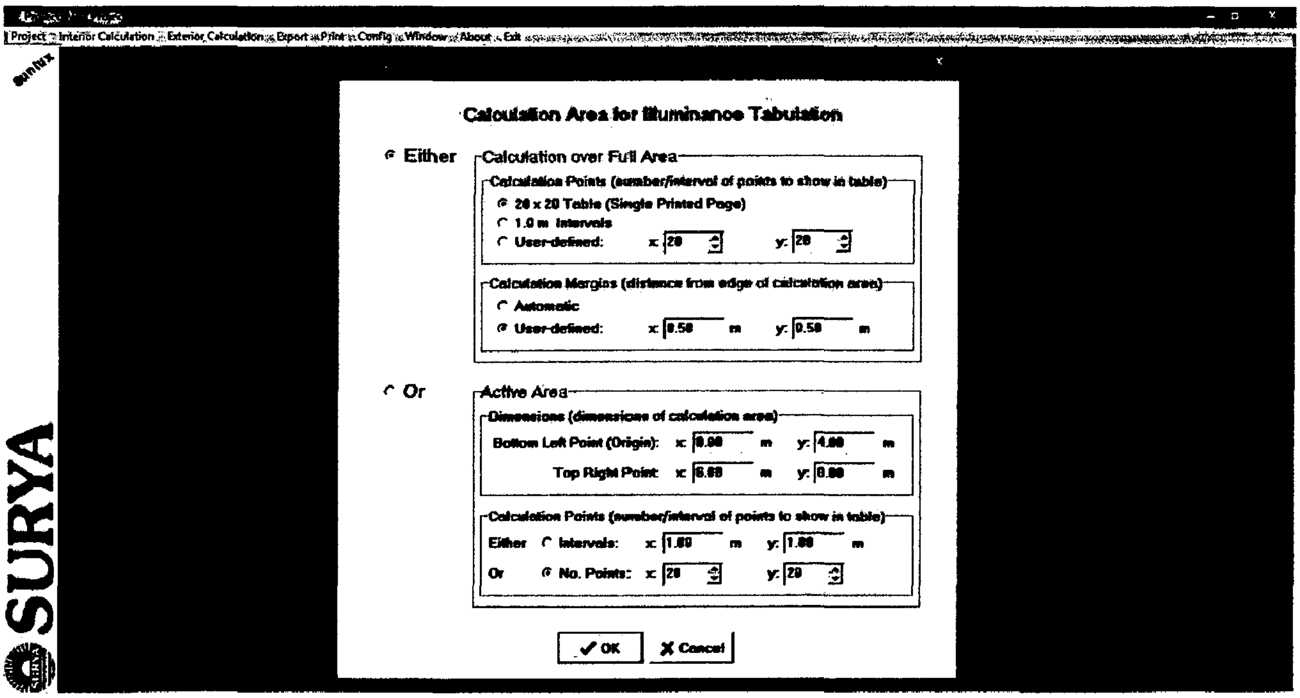


Fig 5.11

Project | Interior Calculation | Exterior Calculation | Export | Print | Config | Window | About | Exit

Sunlux

Luminaire Type no. 1: SDLHR 226 CF CFG EB1 / P3

Type:	*Jupiter*	Lamp Type:	*CFL*
Cat. No.:	*SDLHR 226 CF CFG EB1 / P3*	No. of Lamps:	*2*
Length:	*0.210 m*	Lumens per Lamp:	*1800.0 lm*
Width:	*0.210 m*	Light Output Ratio:	*67.0 %*
Height:	*0.105 m*	Rated Power:	*55.0 W*

Luminaire Type no. 2: SCS 228 T5 GF EB1 / P3

Type:	*Brite Star T5*	Lamp Type:	*FTL-T5*
Cat. No.:	*SCS 228 T5 GF EB1 / P3*	No. of Lamps:	*2*
Length:	*1.250 m*	Lumens per Lamp:	*2900.0 lm*
Width:	*0.165 m*	Light Output Ratio:	*71.6 %*
Height:	*0.065 m*	Rated Power:	*59.0 W*

Luminaire Type no. 3: SCS 228 T5 GF EB1 / P3

Type:	*Brite Star T5*	Lamp Type:	*FTL-T5*
Cat. No.:	*SCS 228 T5 GF EB1 / P3*	No. of Lamps:	*2*
Length:	*1.250 m*	Lumens per Lamp:	*2900.0 lm*
Width:	*0.165 m*	Light Output Ratio:	*71.6 %*
Height:	*0.065 m*	Rated Power:	*59.0 W*

#	Type	X (m)	Y (m)	H (m)	O (°)	T (°)
1	1	1.00	1.00	4.00	0.00	0.00
2	1	1.00	7.33	4.00	0.00	0.00
3	1	1.00	13.66	4.00	0.00	0.00
4	1	9.00	1.00	4.00	0.00	0.00
5	1	9.00	7.33	4.00	0.00	0.00
6	1	9.00	13.66	4.00	0.00	0.00
7	2	3.00	3.22	4.00	0.00	0.00
8	2	3.00	5.44	4.00	0.00	0.00
9	2	7.00	5.44	4.00	0.00	0.00
10	2	7.00	3.22	4.00	0.00	0.00
11	3	3.00	11.00	4.00	0.00	0.00
12	3	7.00	11.00	4.00	0.00	0.00
13	1	5.00	13.70	4.00	0.00	0.00
14	1	5.00	1.00	4.00	0.00	0.00

SURYA

Fig 5.12

Project | Interior Calculation | Exterior Calculation | Export | Print | Config | Window | About | Exit

Calculation Area Details

Room Length:	*10.0 m*	Ceiling Reflectance:	*0.80*
Room Width:	*15.0 m*	Wall Reflectance:	*0.50*
Ceiling Height:	*4.00 m*	Floor Reflectance:	*0.20*
Workplane Height:	*0.70 m*	Maintenance Factor:	*1.00*

Type of Luminaire

Sr. No.	Photo	Luminaire Type	Luminaire Qty	Catalogue Number	Lamp Wattage	Lamp Type	Lamp Qty
1		Jupiter	8	SDLHR 226 CF CFG EB1 / P3	26.0W	CFL	16
2		Brite Star T5	4	SCS 228 T5 GF EB1 / P3	28.0W	FTL-T5	8
3		Brite Star T5	2	SCS 228 T5 GF EB1 / P3	28.0W	FTL-T5	4

Lighting Parameters

Avg. Horz. Illuminance (Eav= *301 Lux*
Max. Horz. Illuminance (Em= *474 Lux*
Min. Horz. Illuminance (Emi= *167 Lux*
Uniformity Ratio (Emin/Eavg= *0.556 (1 : 1.80)*
Diversity Ratio (Emin/Emax) = *0.353 (1 : 2.83)*

Electrical Parameters

Total Wattage = *799 W*
Total Wattage/Luminai = *57.1 W*
LPD (watt/squ.ft) = *0.49*
LPD (watt/squ.m) = *5.33*
Watt / squ.m / 100 lux = *1.77*

Fig 5.13

Horizontal Illuminance

Average: 300.7 lx | Maximum: 473.9 lx | Minimum: 167.2 lx
Max / Min: 2.83 | Ave / Min: 1.80

	0.50	0.97	1.45	1.92	2.39	2.87	3.34	3.82	4.29	4.76	5.24	5.71	6.18	6.66	7.13	7.61	8.08	8.55	9.03	9.50
14.50	167.2	174.8	182.8	188.7	190.4	190.9	195.0	199.3	201.8	200.5	200.5	201.8	199.3	195.0	190.9	190.4	188.7	182.8	174.8	167.2
13.76	192.6	212.3	228.9	247.9	261.4	267.9	272.9	276.6	272.7	270.6	270.6	272.7	276.6	272.9	267.9	261.4	247.9	228.9	212.3	192.6
13.03	216.5	237.6	259.5	281.5	295.2	301.7	312.1	321.7	324.2	322.8	322.8	324.2	321.7	312.1	301.7	295.2	281.5	259.5	237.6	216.5
12.29	208.0	231.2	254.3	277.4	297.5	310.2	320.0	322.7	320.1	316.8	316.8	320.1	322.7	320.0	310.2	297.5	277.4	254.3	231.2	208.0
11.55	188.3	210.4	236.0	261.6	284.2	297.8	305.3	303.8	297.4	290.4	290.4	297.4	303.8	305.3	297.8	284.2	261.6	236.0	210.4	188.3
10.82	174.2	194.5	218.2	241.3	262.1	275.0	281.5	279.6	271.1	265.2	265.2	271.1	279.6	281.5	275.0	262.1	241.3	218.2	194.5	174.2
10.08	182.2	204.0	230.1	256.4	279.4	292.4	298.5	295.2	287.4	278.4	278.4	287.4	295.2	298.5	292.4	279.4	256.4	230.1	204.0	182.2
9.34	196.3	219.7	240.8	260.0	274.3	282.5	290.0	290.0	289.4	285.2	285.2	289.4	290.0	290.0	282.5	274.3	260.0	240.8	219.7	196.3
8.61	215.6	243.4	273.3	298.8	317.6	323.2	324.7	321.2	312.9	304.2	304.2	312.9	321.2	324.7	323.2	317.6	298.8	273.3	243.4	215.6
7.87	224.5	250.9	282.4	311.5	327.8	330.4	329.4	324.8	316.2	306.6	306.6	316.2	324.8	329.4	330.4	327.8	311.5	282.4	250.9	224.5
7.13	224.5	250.9	273.7	295.8	305.4	306.4	309.5	306.3	304.3	299.5	299.5	304.3	306.3	309.5	306.4	305.4	295.8	273.7	250.9	224.5
6.39	233.0	263.1	298.8	332.6	356.6	365.3	367.6	361.4	346.8	332.4	332.4	346.8	361.4	367.6	365.3	356.6	332.6	298.8	263.1	233.0
5.66	238.1	275.9	317.1	355.9	389.2	406.3	413.6	408.5	396.6	386.7	386.7	396.6	408.5	413.6	406.3	389.2	355.9	317.1	275.9	238.1
4.92	242.1	281.8	324.7	370.1	408.6	434.0	447.8	444.9	436.8	425.3	425.3	436.8	444.9	447.8	434.0	408.6	370.1	324.7	281.8	242.1
4.18	241.4	281.9	330.3	382.7	430.1	458.6	473.9	469.9	455.4	441.1	441.1	455.4	469.9	473.9	458.6	430.1	382.7	330.3	281.9	241.4
3.45	237.8	277.5	320.0	364.7	402.1	423.8	440.1	444.4	436.4	429.3	429.3	436.4	444.4	440.1	423.8	402.1	364.7	320.0	277.5	237.8
2.71	232.5	270.6	311.4	352.8	391.2	412.5	424.2	423.6	412.6	404.7	404.7	412.6	423.6	424.2	412.5	391.2	352.8	311.4	270.6	232.5
1.97	229.4	257.0	287.7	318.9	344.3	359.5	372.0	374.9	370.5	363.5	363.5	370.5	374.9	372.0	359.5	344.3	318.9	287.7	257.0	229.4
1.24	219.8	244.1	266.7	292.5	306.5	312.5	324.4	336.1	337.5	333.4	333.4	337.5	336.1	324.4	312.5	306.5	292.5	266.7	244.1	219.8
0.50	194.8	213.2	232.4	251.2	264.5	270.2	276.1	280.7	278.7	275.7	275.7	278.7	280.7	276.1	270.2	264.5	251.2	232.4	213.2	194.8

Fig 5.14

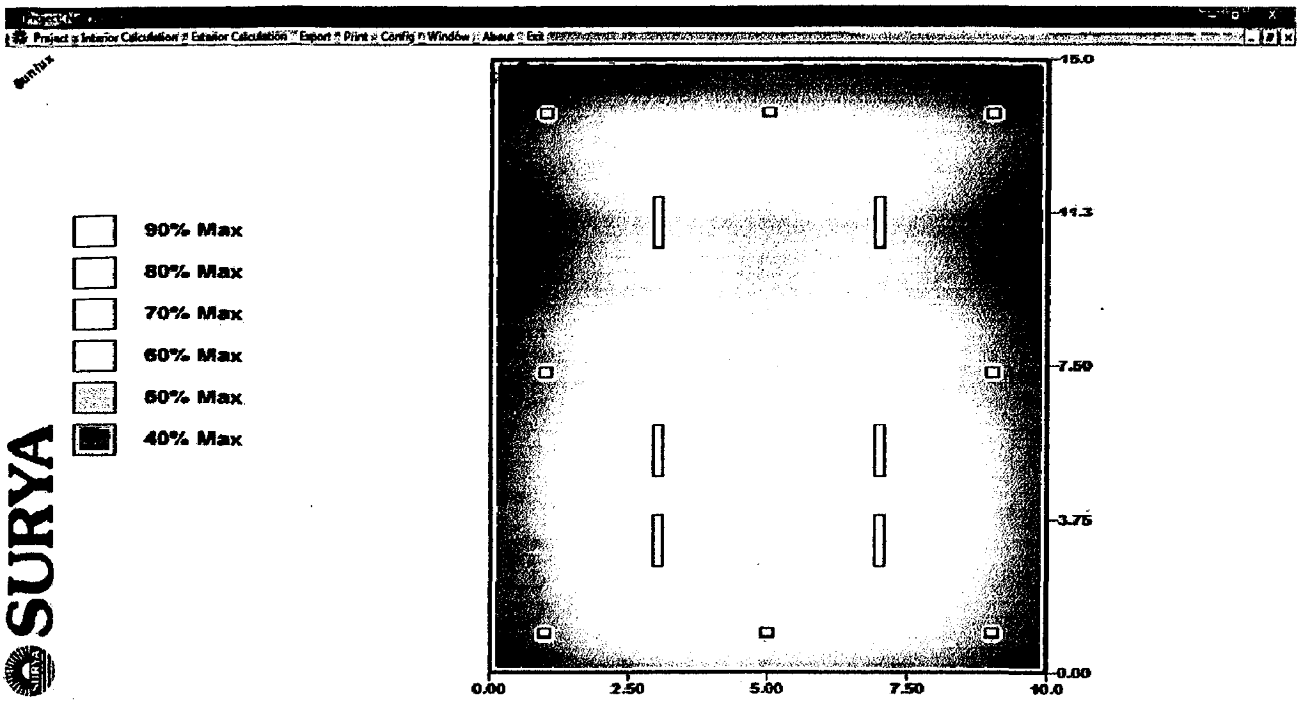


Fig 5.15

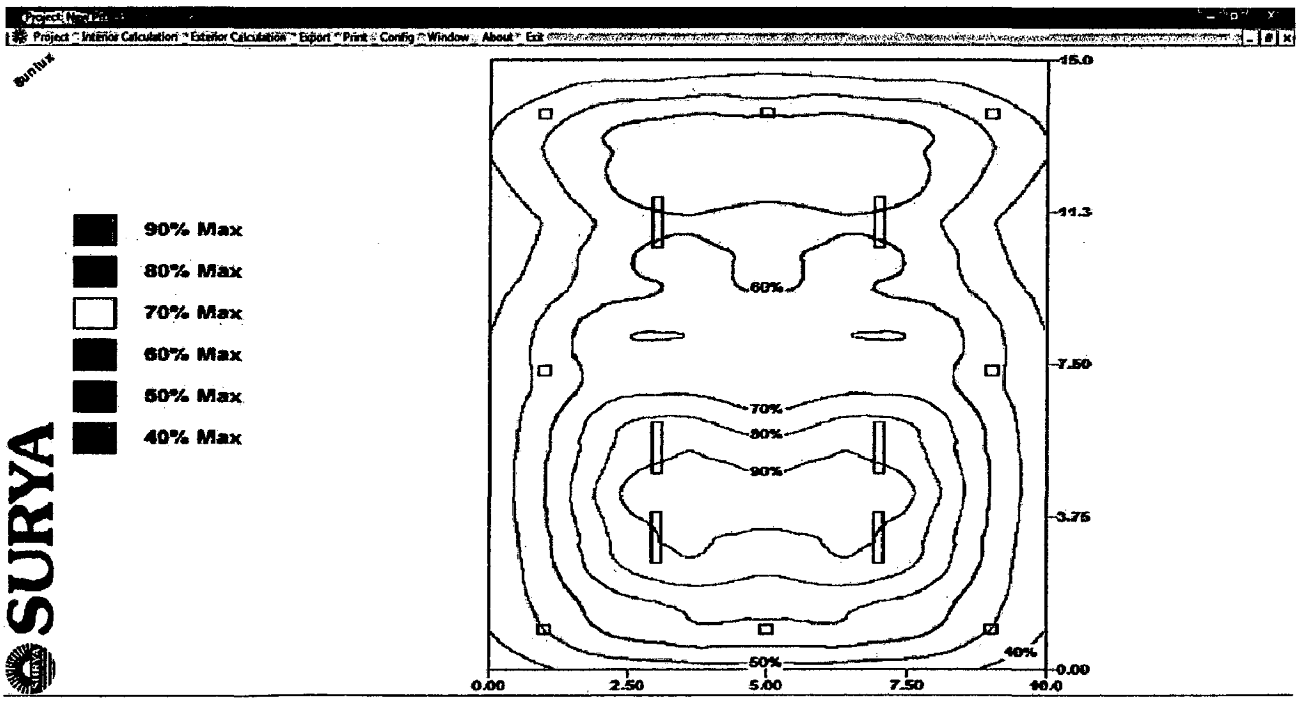


Fig 5.16

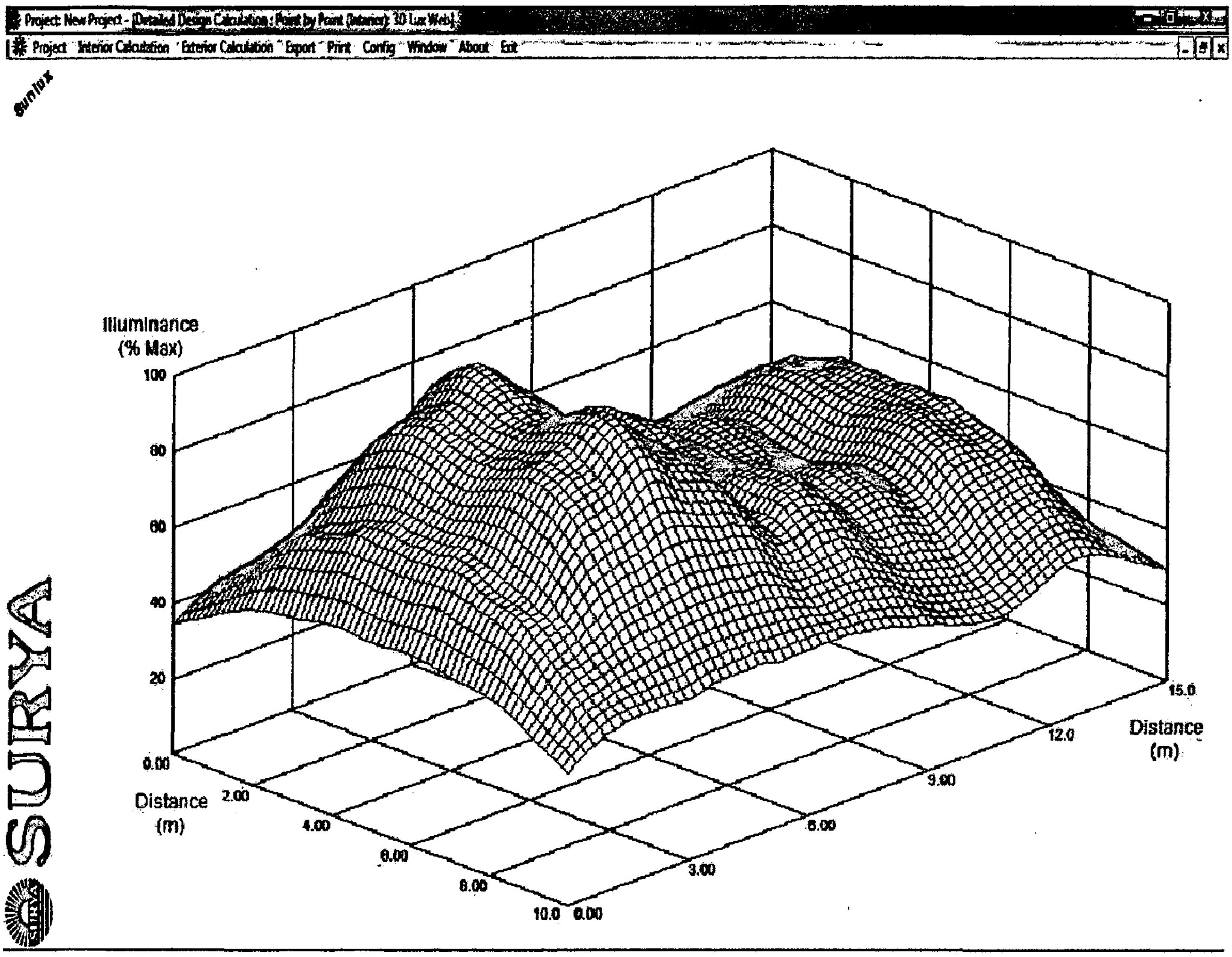


Fig 5.17

5.6 Application of Lighting Design using Sunlux software

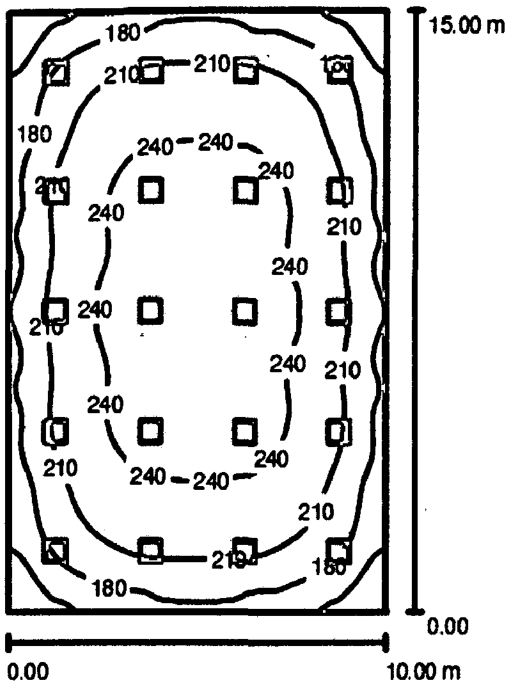
This software is developed as per the norms of Energy Conservation Building Code (ECBC) 2006. It can be used for both interior designing and outdoor designing. This software gives a better idea to learn the lighting design. Some examples of lighting design using this software are as follows:

1 lighting design for control room in a power plant

2 lighting design for faculty room of WRDM, IIT Roorkee

3 lighting design for corridor of WRDM, IIT Roorkee

4 lighting design lecture room of WRDM, IIT Roorkee



Height of Room: 4.000 m, Mounting Height: 4.000 m, Light loss factor: 0.95   Values in Lux, Scale 1:193

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	213	122	259	0.574
Floor	20	198	117	241	0.589
Ceiling	80	50	47	67	0.925
Walls (4)	50	126	55	195	/

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

UGR	Lengthways-	Across	to luminaire axis
Left Wall	19	19	
Lower Wall	19	19	
(CIE, SHR = 0.25.)			

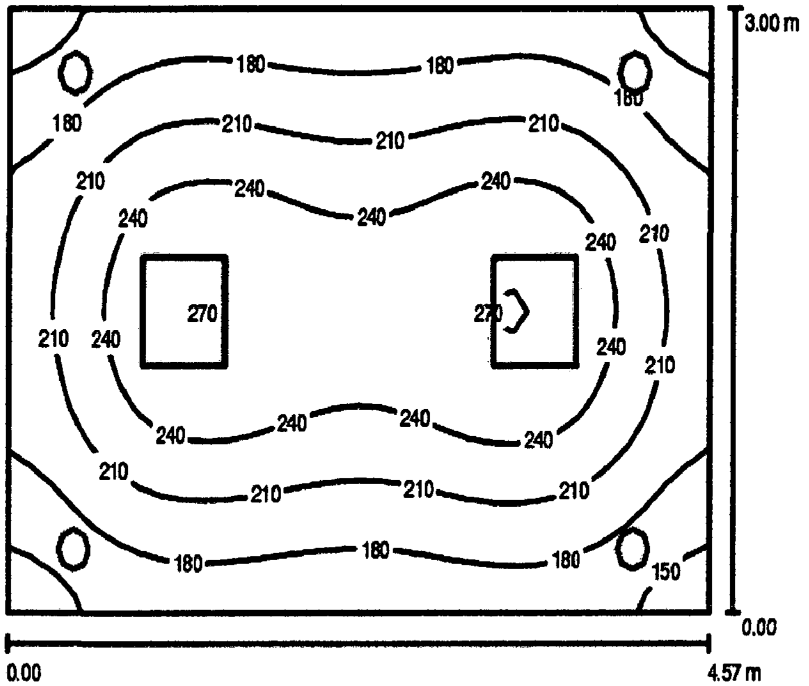
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.610, Ceiling / Working Plane: 0.236.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	20	SLE FP R 39W 2'x2 Flat Panel LED - 2' x 2 (Type 1)* (1.000)	2000	50.3
		Total:	40000	1006.0

*Modified Technical Specifications

Specific connected load: 6.71 W/m² = 3.14 W/m²/100 lx (Ground area: 150.00 m²)



Height of Room: 2.700 m, Mounting Height: 2.700 m, Light loss factor: 0.95 Values in Lux, Scale 1:39

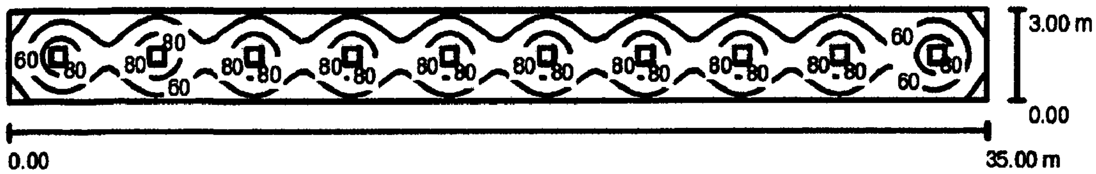
Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	210	139	272	0.660
Floor	20	164	119	195	0.728
Ceiling	80	53	42	63	0.798
Walls (4)	50	122	53	267	/

Workplane:
Height: 0.760 m
Grid: 32 x 32 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.630, Ceiling / Working Plane: 0.252.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	2	SLE FP R 39W 2'x2 Flat Panel LED - 2' x 2 (Type 1)* (1.000)	2000	50.3
2	4	Surya Roshni Limited[LUMCAT] SLE DLAR 6-9W 01[LUMINAIRE]6LED DOWNLIGHT (Type 1)* (1.000)	540	9.0
*Modified Technical Specifications		Total:	6160	136.6

Specific connected load: 9.96 W/m² = 4.74 W/m²/100 lx (Ground area: 13.71 m²)



Height of Room: 2.700 m, Mounting Height: 2.700 m, Light loss factor: 0.95 Values in Lux, Scale 1:251

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	65	32	100	0.484
Floor	20	55	34	68	0.617
Ceiling	80	14	12	17	0.810
Walls (4)	50	35	14	56	/

Workplane:
Height: 0.760 m
Grid: 128 x 32 Points
Boundary Zone: 0.000 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.541, Ceiling / Working Plane: 0.221.

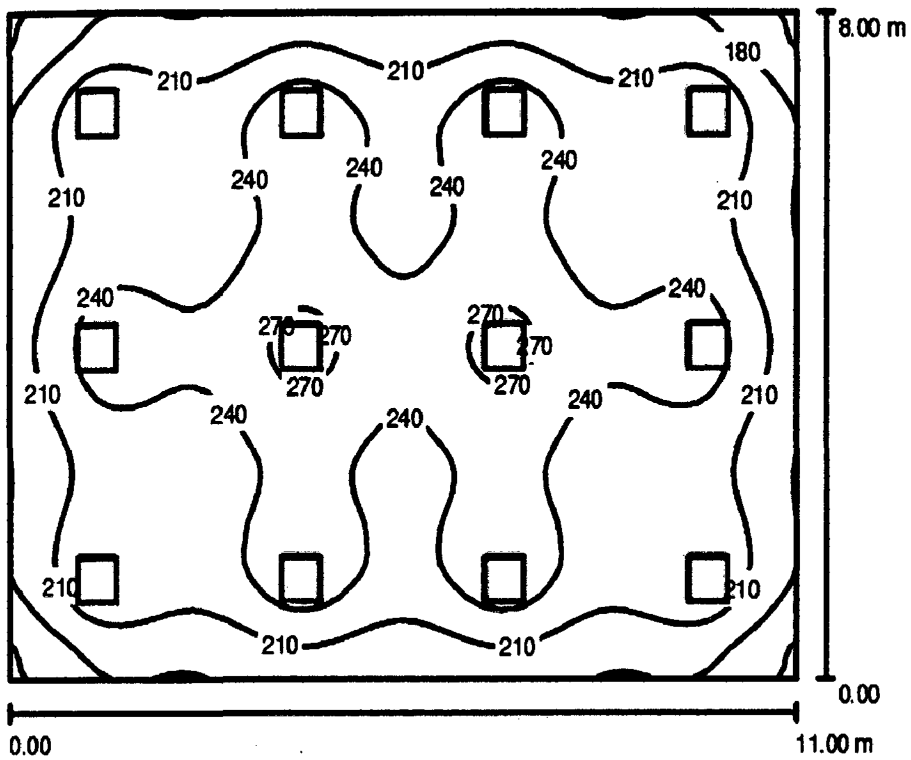
Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	10	SLE FP 19 11 R 1'x1 Flat Panel LED - 1' x 1 (Type 1)* (1.000)	900	19.0
		Total:	9000	190.0

*Modified Technical Specifications

Specific connected load: 1.81 W/m² = 2.77 W/m²/100 lx (Ground area: 105.00 m²)

Lecture Room



Height of Room: 3.000 m, Mounting Height: 3.000 m, Light loss factor: 0.95 Values in Lux, Scale 1:103

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	225	144	278	0.640
Floor	20	203	130	241	0.639
Ceiling	80	52	48	72	0.935
Walls (4)	50	132	60	206	/

Workplane:		**UGR**	Lengthways-	Across	to luminaire axis
Height:	0.760 m	Left Wall	19	19	
Grid:	64 x 64 Points	Lower Wall	19	19	
Boundary Zone:	0.000 m	(CIE, SHR = 0.25.)			

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.616, Ceiling / Working Plane: 0.230.

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	12	SLE FP R 39W 2'x2 Flat Panel LED - 2' x 2 (Type 1)* (1.000)	2000	50.3
		Total:	24000	603.6

*Modified Technical Specifications

Specific connected load: 6.86 W/m² = 3.04 W/m²/100 lx (Ground area: 88.00 m²)

Chapter 6: Energy Saving

6.1 Energy saving by use of LED fixtures:

For the purpose of energy saving the following data must be considered:

1. Lamp wattage
2. Total power consumption of fixture with lamp
3. Lumen output

The following steps are taken to determine energy saving.

- Determination of the power consumption @12hr/day by multiplying 12 with total power consumption of fixture.
- Determination of power consumption in a month by multiplying 30 with the power consumption @12hr/day
- Determination of cost of electricity/month@ Rs. n/unit which is comes out by multiplying power consumption in a month with 'n'. Where n is the cost of electricity per unit which may vary from state to state
- Saving per fixture is arrived at by subtracting the cost of fixture for which we are doing energy audit to the cost of reference fixture, comes out in previous steps
- Saving of energy bill per fixture per year is arrived at by multiplying 12 with the total saving per fixture

6.2 Energy saving in control room for a power plant

Table 6.1 Energy saving for a control room

SNo.	PARAMETERS	T12 FIXTURE	T5 FIXTURE	CFLs	LEDs
(1)	LAMP WATTAGE IN WATTS	40	28	18	50.3
(2)	TOTAL WATTAGE/LUMINAIRE IN WATTS	53	31.8	39	50.3
(3)	No. OF FIXTURE USED	48	42	42	20
(4)	TOLAL POWER CONSUMPTION OF FIXTURE WITH LAMP IN WATT((2)*(3))	2,544	1,335.6	1,638	1,006
(5)	POWER CONSUMPTION @12Hrs/DAY(12*(4)	30,528	1,6027.2	19,656	12,072
(6)	TOTAL UNITS OF ELECTRICITY PER MONTH IN KWH(30*(5)/1000)	915.84	480.81	589.68	362.16
(7)	COST OF ELECTRICITY/MONTH@Rs 5/UNIT(5*(6))	4,579	2,404	2,948	1,810
(8)	SAVING OF ENERGY BILL PER FIXTURE PER YEAR(12*(7))	54,950	28,848	35,380	21,729
(9)	**TOTAL ENERGY SAVING in Rs**		**26,102**	**19,570**	**33,220**

6.3 Energy saving in faculty office

Table 6.2 Energy saving in faculty office

SNo.	PARAMETERS	T12 FIXTURE	T5 FIXTURE	CFLs	LEDs
(1)	LAMP WATTAGE IN WATTS	40	28	18	50.3
(2)	TOTAL WATTAGE/LUMINAIRE IN WATTS	53	31.8	39	50.3
(3)	No. OF FIXTURE USED	6	5	6	2
(4)	TOLAL POWER CONSUMPTION OF FIXTURE WITH LAMP IN WATT((2)*(3))	318	159	234	136.6
(5)	POWER CONSUMPTION @12Hrs/DAY(12*(4)	3,816	1,908	2,808	1,639.2
(6)	TOTAL UNITS OF ELECTRICITY PER MONTH IN KWH(30*(5)/1000)	114.48	57.24	84.24	49.17
(7)	COST OF ELECTRICITY/MONTH@Rs 5/UNIT(5*(6))	572	286	421	245
(8)	SAVING OF ENERGY BILL PER FIXTURE PER YEAR(12*(7))	6,868	3,434	5,054	2,950
(9)	**TOTAL ENERGY SAVING in Rs**		**3,434**	**1,814**	**3,918**

6.4 Energy saving in lecture room

Table 6.3 Energy saving in lecture room

SNo.	PARAMETERS	T12 FIXTURE	T5 FIXTURE	CFLs	LEDs
(1)	LAMP WATTAGE IN WATTS	40	28	18	50.3
(2)	TOTAL WATTAGE/LUMINAIRE IN WATTS	53	31.8	39	50.3
(3)	No. OF FIXTURE USED	25	24	30	12
(4)	TOLAL POWER CONSUMPTION OF FIXTURE WITH LAMP IN WATT((2)*(3))	1325	763.2	1170	603.6
(5)	POWER CONSUMPTION @12Hrs/DAY(12*(4)	15,900	9,158.4	14,040	7,243.2
(6)	TOTAL UNITS OF ELECTRICITY PER MONTH IN KWH(30*(5)/1000)	477	274.7	421.2	217.3
(7)	COST OF ELECTRICITY/MONTH@Rs 5/UNIT(5*(6))	2,385	1,373	2,105	1,086
(8)	SAVING OF ENERGY BILL PER FIXTURE PER YEAR(12*(7))	28,650	16,482	25,266	13,038
(9)	**TOTAL ENERGY SAVING in Rs**		**12,168**	**3,384**	**15,612**

6.5 Energy saving in corridors

Table 6.4 Energy saving in corridor

SNo.	PARAMETERS	T12 FIXTURE	T5 FIXTURE	CFLs	LEDs
(1)	LAMP WATTAGE IN WATTS	40	28	18	19
(2)	TOTAL WATTAGE/LUMINAIRE IN WATTS	53	31.8	39	19
(3)	No. OF FIXTURE USED	11	11	11	10
(4)	TOLAL POWER CONSUMPTION OF FIXTURE WITH LAMP IN WATT((2)*(3))	583	349.8	429	190
(5)	POWER CONSUMPTION @12Hrs/DAY(12*(4)	6,996	4,197.6	5,148	2,280
(6)	TOTAL UNITS OF ELECTRICITY PER MONTH in KWH(30*(5)/1000)	209.88	125.92	154.44	68.4
(7)	COST OF ELECTRICITY/MONTH@Rs 5/UNIT	1,049	692	772	342
(8)	SAVING OF ENERGY BILL PER FIXTURE/YEAR in Rs(12*(7))	12,592	7,555	9,266	4,104
(9)	**TOTAL ENERGY SAVING in Rs.**		**5,037**	**3,326**	**8,491**

Energy saving in the building of WRDM, IIT Roorkee per year:

12 Faculty Offices i.e.	12 x Rs 3,918 =	Rs 47,016
4 lecture room's i.e.	4 x Rs 15,612 =	Rs 62,448
3 corridors i.e.	3 x Rs 8,491 =	Rs 25,473
Total saving per year		**Rs 1,34,817**

6.6 Financial Evaluation

(i) Control room for power plant (size: 10m x 15m x 4m)

Table 6.5 financial evaluation table for control room in a power plant

	T-12 (1 x 40w)	LED (1 set of 50.3w)
Cost of fitting in Rs. Per fixture	400	10,000
Cost of lamp in Rs.	50	6,500
Total no. of fixtures required for an avg. 200LUX	48	20
Average Life of lamp in hours	5,000	50,000
No. of fixtures required in 10 years	10	1
Initial cost of fitting in Rs.	19,200	2,00,000
Total expenditure in 10 years in Rs.*	40,800	2,00,000

* Total expenditure = initial fitting cost + [(Total no. of fixtures required for an avg. horizontal LUX)*(Cost of lamp)*(No. of fixtures required in n years)*(n-1) years]

(ii) Faculty Office (size: 4.57m x 3m x 2.7m)

Table 6.6 financial evaluation table for Faculty Office

	T-12 (1 x 40w)	LED (1 set of 50.3w)
Cost of fitting in Rs. Per fixture	400	10,000
Cost of lamp in Rs.	50	6,500
Total no. of fixture required for an avg. 200LUX	6	2
Average Life of lamp in hours	5,000	50,000
No. of fixtures required in 10 years	10	1
Initial cost of fitting in Rs.	2,400	20,000
Total expenditure in 10 years in Rs.	5,100	20,000

(iii) Lecture Room (size: 11m x 8m x 3m)

Table 6.7 financial evaluation table for Lecture Room

	T-12 (1 x 40w)	LED (1 set of 50.3w)
Cost of fitting in Rs. Per fixture	400	10,000
Cost of lamp in Rs.	50	6,500
Total no. of fixtures required for an avg. 200LUX	25	12
Average Life of lamp in hours	5,000	50,000
No. of fixtures required in 10 years	10	1
Initial cost of fitting in Rs.	10,000	1,20,000
Total expenditure in 10 years in Rs.	21,250	1,20,000

(iv) Corridors (size: 35m x 3m x 2.7m)

Table 6.8 financial evaluation table for Corridors

	T-12 (1 x 40w)	LED (1 set of 19w)
Cost of fitting in Rs. Per fixture	400	5,000
Cost of lamp in Rs.	50	3,500
Total no. of fixtures required for an avg. 70LUX	11	10
Average Life of lamp in hours	5,000	50,000
No. of fixtures required in 10 years	10	1
Initial cost of fitting in Rs.	4,400	50,000
Total expenditure in 10 years in Rs.	9,350	50,000

<u>By replacement of the existing fluorescent tube light fittings by LED lamps, the estimate cost for the building of WRDM IITR is as follows:</u>

Total investment cost for the building of WRDM IITR=

(no. of faculty rooms)*(Total expenditure for Faculty rooms from table 6.6) + (no. of lecture rooms)*(Total expenditure for lecture rooms from table 6.7) + (no. of corridors)*(Total expenditure for corridors from table 6.8)

= Rs ((12 x 20000) + (4 x 120000) + (3 x 50000))
= **Rs 8,70,000**

From Para 6.5, Energy saving in the building of WRDM IIT Roorkee per year = **Rs 1,34,817**

The financial evaluation has been carried out with the following input data:

(1) Total investment cost for the building of WRDM IITR
(2) Energy saving in WRDM IIT Roorkee per year
(3) Interest at the rate of 10% per annum

The results are presented in table:

Table 6.9 financial evaluation of replacement of existing FTL fixtures by equivalent LED fixtures in the building of WRDM IIT Roorkee

Year	Capital cost in Rs	Interest @ 10% p.a. in Rs	Total in Rs	Energy saving in Rs	Balance in Rs
1	8,70,000	87,000	9,57,000	1,34,817	-8,22,183
2	8,22,183	82,218	9,04,401	1,34,817	-7,69,584
3	7,69,584	76,958	8,46,542	1,34,817	-7,11,725
4	7,11,725	71,173	7,82,898	1,34,817	-6,48,081
5	6,48,081	64,808	7,12,889	1,34,817	-5,78,072
6	5,78,072	57,807	6,35,879	1,34,817	-5,01,062
7	5,01,062	50,106	5,51,168	1,34,817	-4,16,351
8	4,16,351	41,635	4,57,986	1,34,817	-3,23,169
9	3,23,169	32,317	3,55,486	1,34,817	-2,20,669
10	2,20,669	22,067	2,42,736	1,34,817	-1,07,919
11	1,07,919	10,792	1,18,711	1,34,817	16,106

From the above table the following conclusions are drawn:

1. The payback period comes in eleven years
2. As technology changes cost of LED will also decrease, which will results in decrease in capital cost. This will eventually increase the saving in cost

3. Energy saving calculation is determined by taking Rs 5per unit KWH, as the average cost of electricity between 2011-and 2020-21. If the value exceeds Rs 5per unit KWH, then the overall saving will increase.

By replacement of the existing fluorescent tube light fittings by LED lamps, the estimate cost of Control Room for a power plant is as follows:

From table 6.5 (8^{th} row, 3^{rd} column), Total investment cost for Control Room for a power plant = **Rs 2, 00,000**

From table 6.1 (10^{th} row, 5^{th} column), Energy saving for Control Room for a power plant for 10year = **Rs 32,220****

The financial evaluation has been carried out with the following input data:

(1) Total investment cost of Control Room for a power plant

(2) Energy saving in Control Room for a power plant

(3) Interest at the rate of 10% per annum

The results are presented in table:

Table 6.10 financial evaluation of replacement of existing FTL fixtures by equivalent LED fixtures in Control Room for a power plant

Year	Capital Cost in Rs	Interest@10%p.a. in Rs	Total in Rs	Energy saving in Rs	Balance in Rs
1	2,00,000	20,000	2,20,000	33,220	-186,780
2	1,86,780	18,678	2,05,458	33,220	-1,72,238
3	1,72,238	17,224	1,89,462	33,220	-1,56,242
4	1,56,242	15,624	1,71,866	33,220	-1,38,646
5	1,38,646	13,865	1,52,511	33,220	-1,19,291
6	1,19,291	11,929	1,31,220	33,220	-98,000
7	98,000	9,800	1,07,800	33,220	-74,580
8	74,580	7,458	82,038	33,220	-48,818
9	48,818	4,882	53,700	33,220	-20,480
10	20,480	2,048	22,528	33,220	10,692

Conclusion

LEDs use less power per unit of light generated. Also they don't produce UV radiation; it makes them ideal for illuminating objects. Hence, it helps in reduction of greenhouse gases.

The general lighting design approach is a good strategy, used to provide a fairly uniform amount of light throughout a room. This approach usually results in regular pattern of light fixtures that produces very even light levels, slightly higher than the average value in the center of the room and slightly lower in the outer corners of the room.

There is no comparison between the costs of LED lights vs. other options available in the market, which is clear from the energy saving exercise. If LED lighting is used, the total energy saving in a year is **Rs 33,220** in case of control room for a power plant. Cost of energy saving calculation is determined by taking Rs 5per unit KWH, as the average cost of electricity between 2011-and 2020-21. If the value exceeds Rs 5per unit KWH, then the overall saving will increase.

If T-12 fixtures were replaced by LEDs in the building of WRDM in IIT Roorkee, then the cost of energy saving is approx. **Rs 1,34,817** in a year.As technology improves cost of LED will also decrease, which will result in decrease in capital cost. This will eventually increase the saving in cost.

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Appendix I

Surya Roshni Limited
Luminaire Business Group
Padma Tower-1, Rajendra Place
New Delhi-110008

Customer:	*Power plant*
Project Code:	*Control room*

Calculation Area Details

Room Length:	*15.0 m*	**Ceiling Reflectance:**	*0.80*
Room Width:	*10.0 m*	**Wall Reflectance:**	*0.50*
Ceiling Height:	*4.00 m*	**Floor Reflectance:**	*0.20*
Workplane Height:	*0.70 m*	**Maintenance Factor:**	*1.00*

Type of Luminaire

Sr. No.	Photo	Luminaire Type	Luminaire Qty	Catalogue Number	Lamp Wattage	Lamp Type	Lamp Qty
1		Dainty-Junior	21	SCS 218 CF-D EB1 / P3	18.0W	CFL	42

Lighting Parameters

Avg. Horz. Illuminance (Eave)	=	*213 Lux*
Max. Horz. Illuminance (Emax)	=	*255 Lux*
Min. Horz. Illuminance (Emin)	=	*134 Lux*
Uniformity Ratio (Emin/Eavg)	=	*0.627 (1 : 1.59)*
Diversity Ratio (Emin/Emax)	=	*0.524 (1 : 1.91)*

Electrical Parameters

Total Wattage	=	*819 W*
Total Wattage/Luminaire	=	*39.0 W*
LPD (watt/squ.ft)	=	*0.51*
LPD (watt/squ.m)	=	*5.46*
Watt / squ.m / 100 lux	=	*2.57*

All calculation results are based on the nominal values of lamps, ballasts, luminaires and other design assumptions (M.F. / R.F.). Any deviations in these parameters may affect the illumination design.

Control room

Surya Roshni Limited
Luminaire Business Group
Padma Tower-1, Rajendra Place
New Delhi-110008

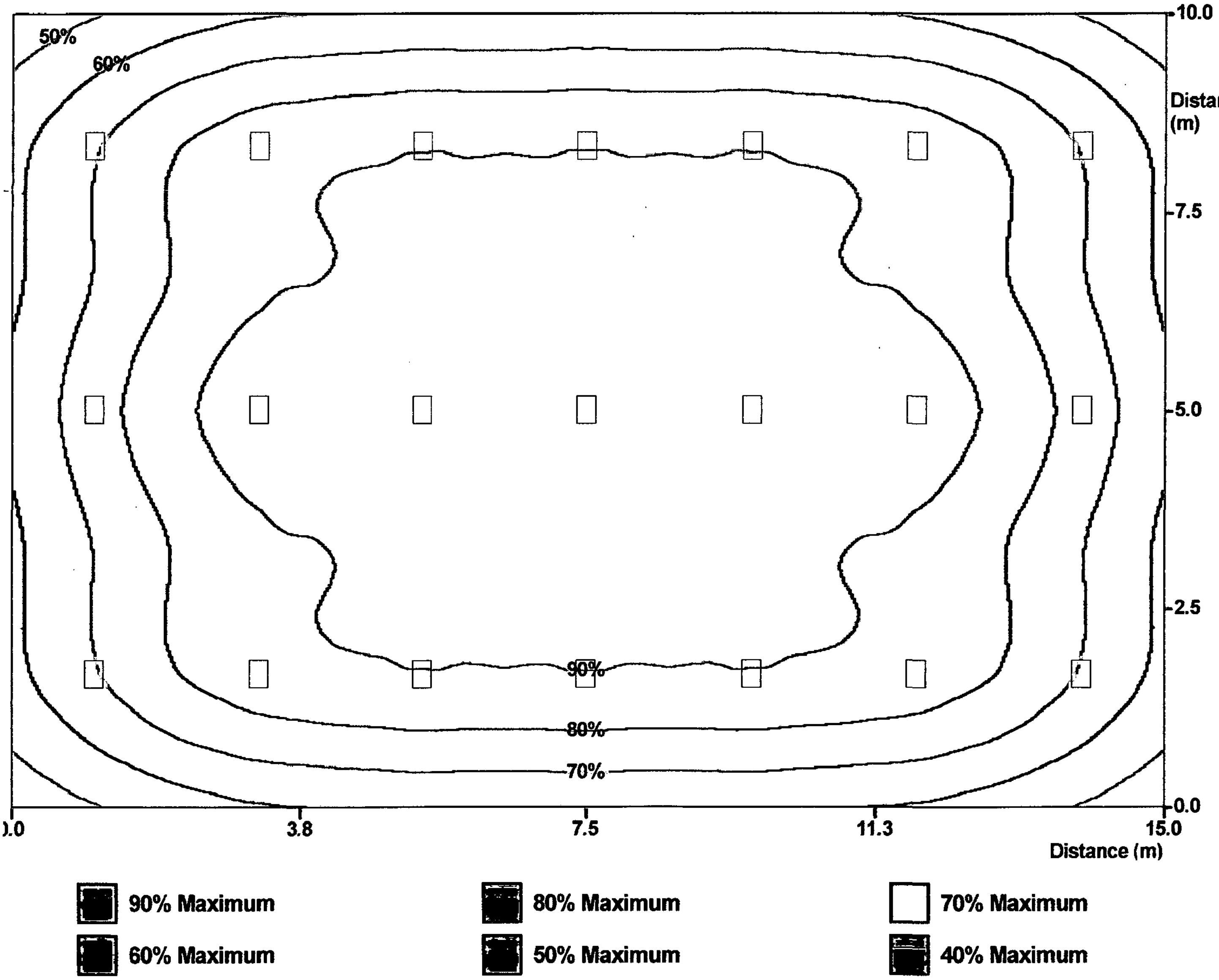
Illuminance Values:

Quick Estimat

Average	Minimum	Maximum	Min/Avg	Min/Max
213 Lux	134 Lux	255 Lux	0.627	0.524

Illuminance IsoLux Diagram:

Horizontal Illuminance (lx) on Workplane



Surya Roshni Limited
Luminaire Business Group
Padma Tower-1, Rajendra Place
New Delhi-110008

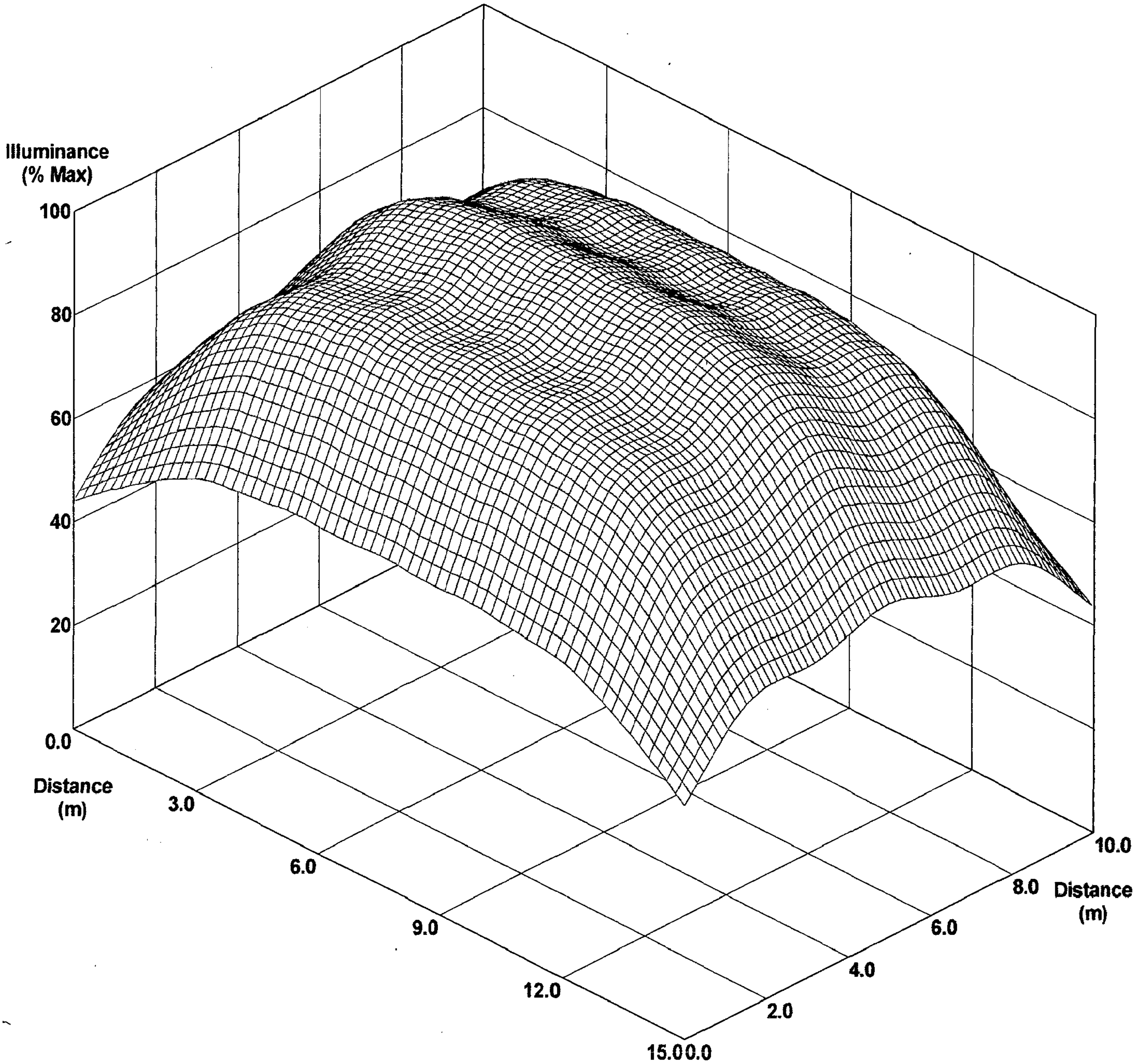
Illuminance Values:

Quick Estimat

Average	Minimum	Maximum	Min/Avg	Min/Max
213 Lux	134 Lux	255 Lux	0.627	0.524

3D Lux Web:

Horizontal Illuminance (lx) on Workplane



Appendix II

Faculty room

Surya Roshni Limited
Luminaire Business Group
Padma Tower-1, Rajendra Place
New Delhi-110008

Customer:	*WRDM*
Project Code:	*Faculty room*

Calculation Area Details

Room Length:	*4.57 m*	**Ceiling Reflectance:**	*0.80*
Room Width:	*3.00 m*	**Wall Reflectance:**	*0.50*
Ceiling Height:	*2.70 m*	**Floor Reflectance:**	*0.20*
Workplane Height:	*0.70 m*	**Maintenance Factor:**	*1.00*

Type of Luminaire

Sr. No.	Photo	Luminaire Type	Luminaire Qty	Catalogue Number	Lamp Wattage	Lamp Type	Lamp Qty
1		Dainty-Junior	3	SCS 218 CF-D EB1 / P3	18.0W	CFL	6

Lighting Parameters

Avg. Horz. Illuminance (Eave)	= *302 Lux*
Max. Horz. Illuminance (Emax)	= *377 Lux*
Min. Horz. Illuminance (Emin)	= *209 Lux*
Uniformity Ratio (Emin/Eavg)	= *0.690 (1 : 1.45)*
Diversity Ratio (Emin/Emax)	= *0.553 (1 : 1.81)*

Electrical Parameters

Total Wattage	= *117 W*
Total Wattage/Luminaire	= *39.0 W*
LPD (watt/squ.ft)	= *0.79*
LPD (watt/squ.m)	= *8.53*
Watt / squ.m / 100 lux	= *2.82*

All calculation results are based on the nominal values of lamps, ballasts, luminaires and other design assumptions (M.F. / R.F.). Any deviations in these parameters may affect the illumination design.

Surya Roshni Limited
Luminaire Business Group
Padma Tower-1, Rajendra Place
New Delhi-110008

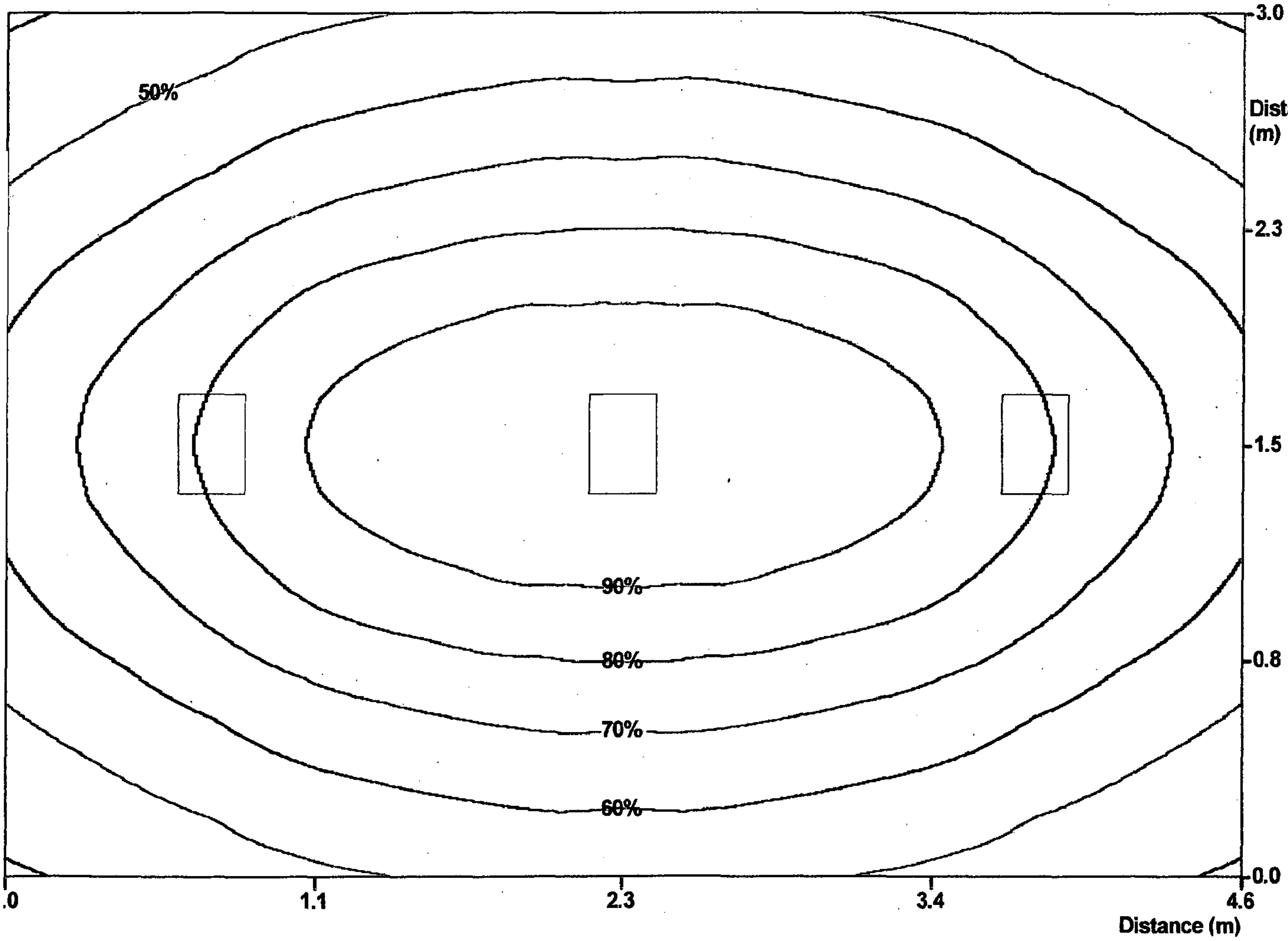
Illuminance Values:

Quick Estimate

Average	Minimum	Maximum	Min/Avg	Min/Max
302 Lux	209 Lux	377 Lux	0.690	0.553

Illuminance IsoLux Diagram:

Horizontal Illuminance (lx) on Workplane



90% Maximum | 80% Maximum | 70% Maximum
60% Maximum | 50% Maximum | 40% Maximum

Faculty room

Surya Roshni Limited
Luminaire Business Group
Padma Tower-1, Rajendra Place
New Delhi-110008

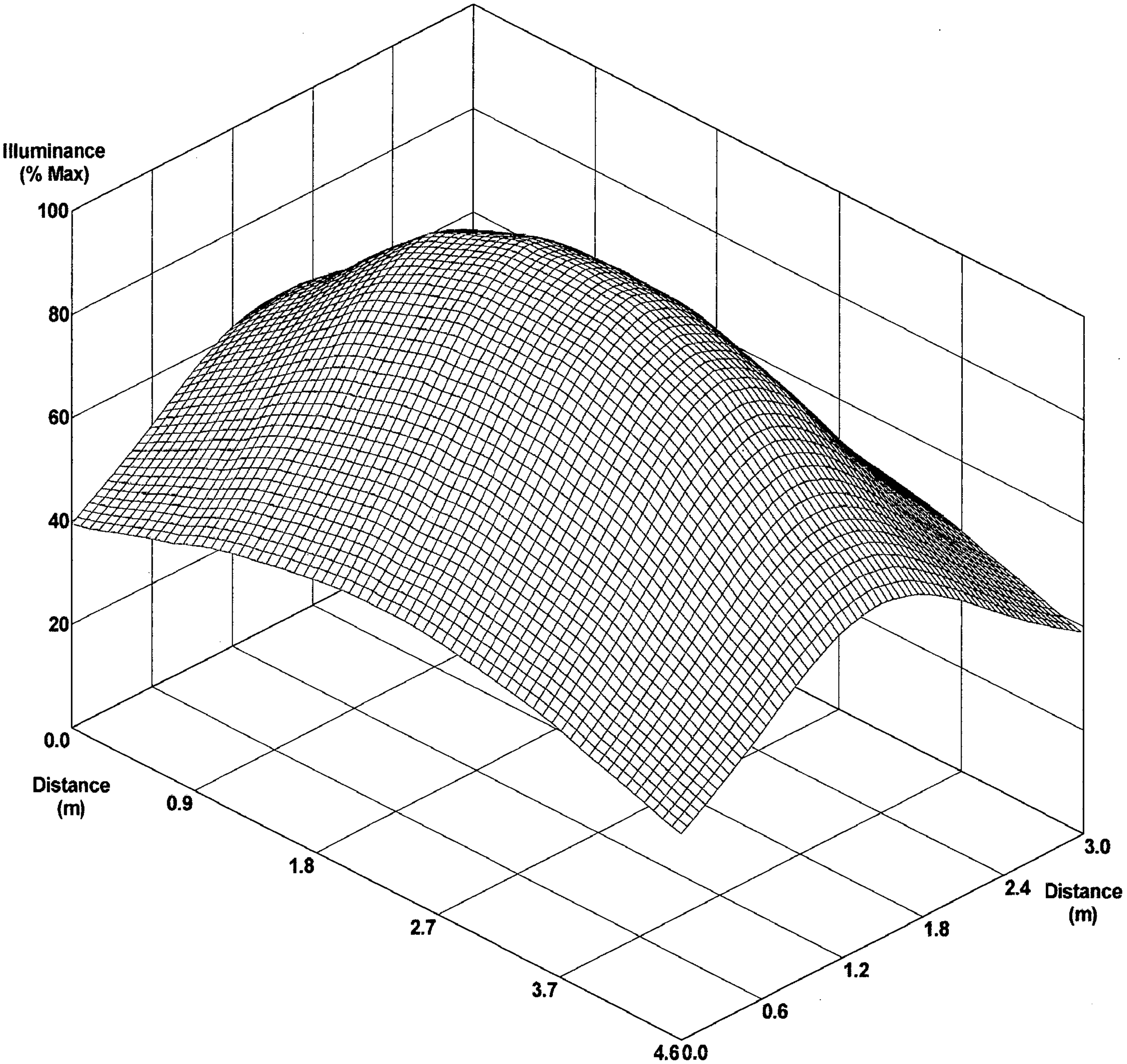
Illuminance Values:

Quick Estimat

Average	Minimum	Maximum	Min/Avg	Min/Max
302 Lux	209 Lux	377 Lux	0.690	0.553

3D Lux Web:

Horizontal Illuminance (lx) on Workplane



Appendix III

Surya Roshni Limited
Luminaire Business Group
Padma Tower-1, Rajendra Place
New Delhi-110008

Customer: *WRDM*
Project Code: *lecture room*

Calculation Area Details

Room Length:	*11.0 m*	Ceiling Reflectance:	*0.80*
Room Width:	*8.00 m*	Wall Reflectance:	*0.50*
Ceiling Height:	*3.00 m*	Floor Reflectance:	*0.20*
Workplane Height:	*0.70 m*	Maintenance Factor:	*1.00*

Type of Luminaire

Sr. No.	Photo	Luminaire Type	Luminaire Qty	Catalogue Number	Lamp Wattage	Lamp Type	Lamp Qty
1		Dainty-Junior	15	SCS 218 CF-D EB1 / P3	18.0W	CFL	30

Lighting Parameters

Avg. Horz. Illuminance (Eave) = *273 Lux*
Max. Horz. Illuminance (Emax) = *329 Lux*
Min. Horz. Illuminance (Emin) = *178 Lux*
Uniformity Ratio (Emin/Eavg) = *0.653 (1 : 1.53)*
Diversity Ratio (Emin/Emax) = *0.542 (1 : 1.85)*

Electrical Parameters

Total Wattage = *585 W*
Total Wattage/Luminaire = *39.0 W*
LPD (watt/squ.ft) = *0.62*
LPD (watt/squ.m) = *6.65*
Watt / squ.m / 100 lux = *2.44*

All calculation results are based on the nominal values of lamps, ballasts, luminaires and other design assumptions (M.F. / R.F.). Any deviations in these parameters may affect the illumination design.

Surya Roshni Limited
Luminaire Business Group
Padma Tower-1, Rajendra Place
New Delhi-110008

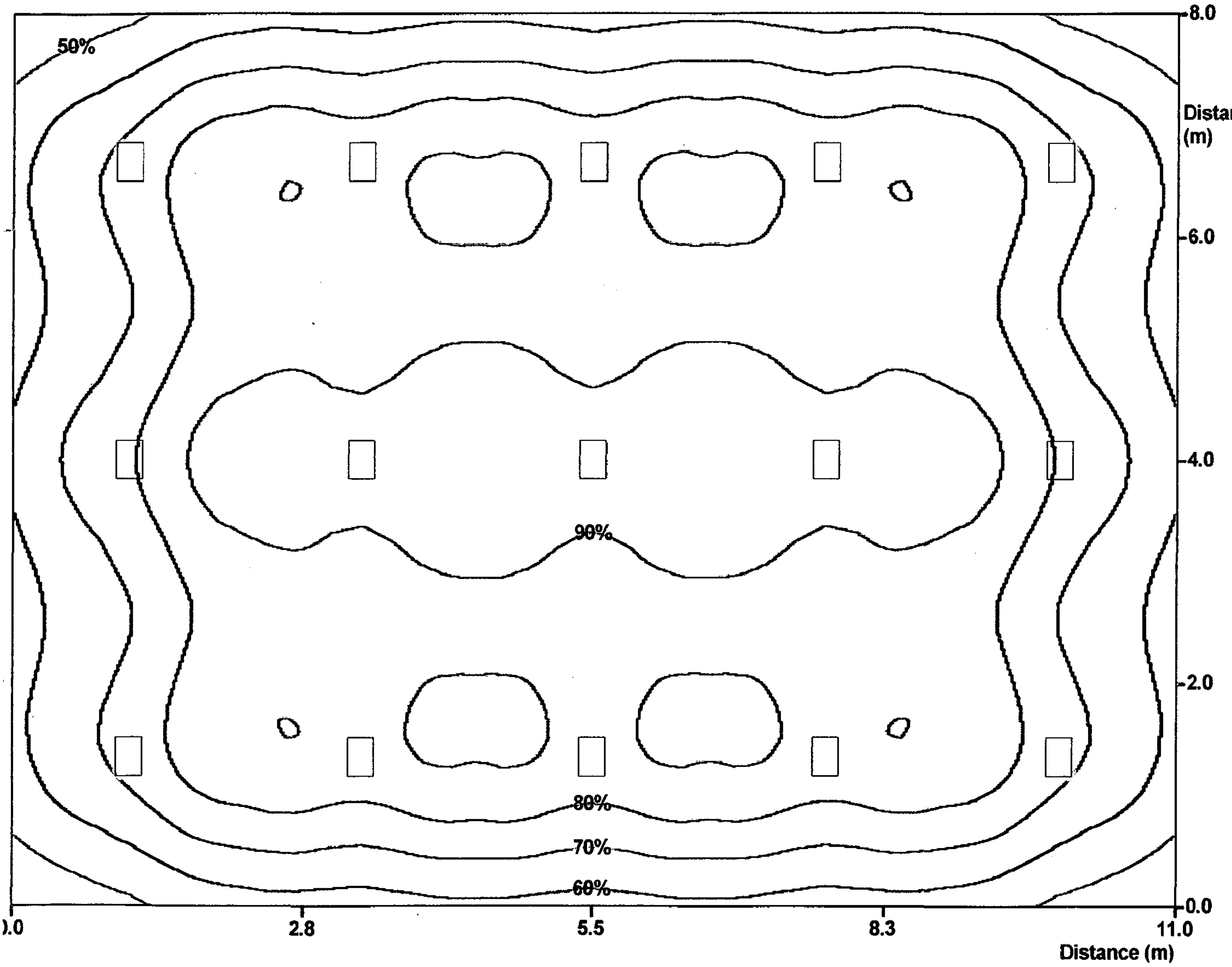
Illuminance Values:

Quick Estimat

Average	Minimum	Maximum	Min/Avg	Min/Max
273 Lux	178 Lux	329 Lux	0.653	0.542

Illuminance IsoLux Diagram:

Horizontal Illuminance (lx) on Workplane



90% Maximum
80% Maximum
70% Maximum
60% Maximum
50% Maximum
40% Maximum

lecture room

Surya Roshni Limited
Luminaire Business Group
Padma Tower-1, Rajendra Place
New Delhi-110008

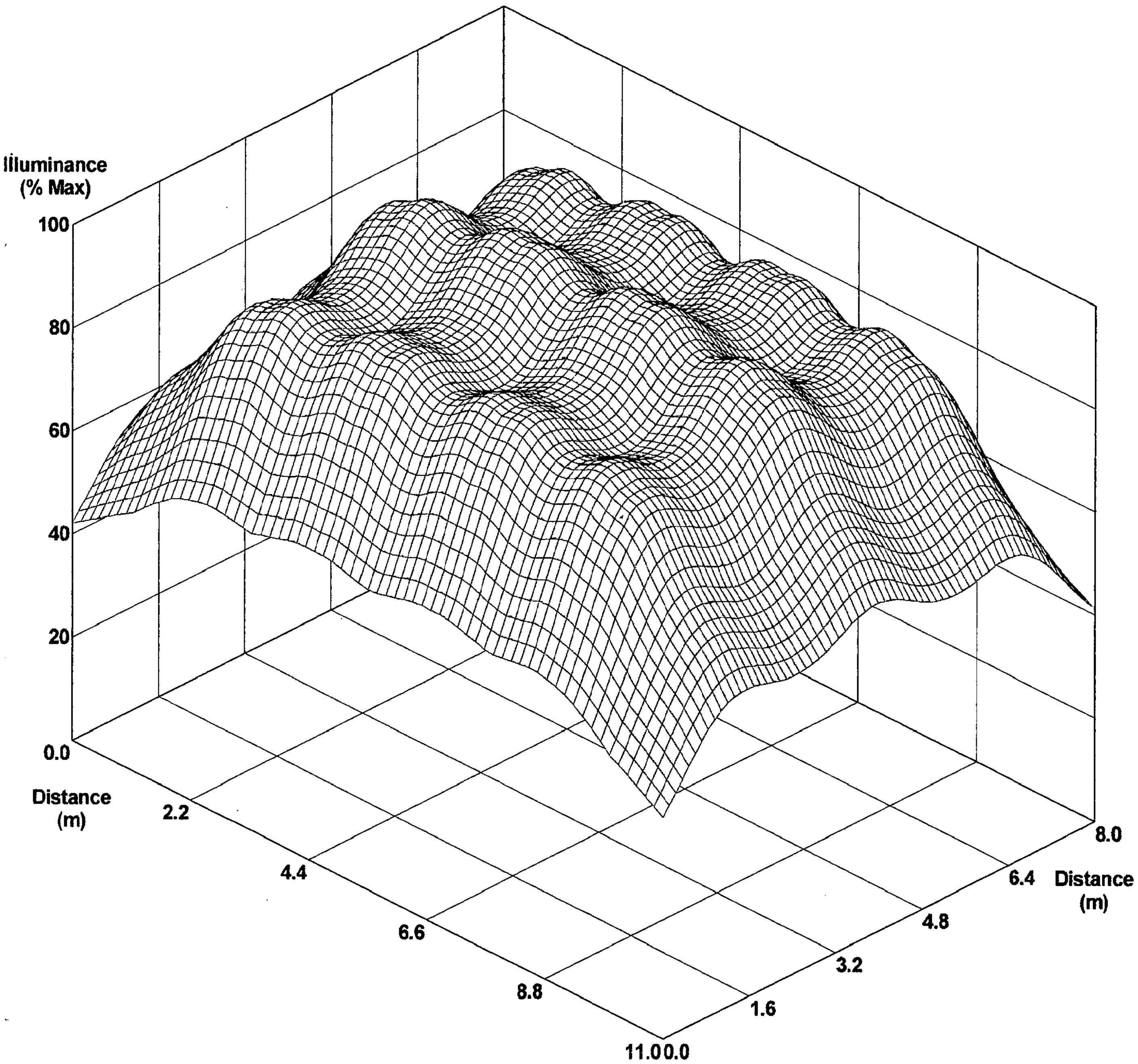
Illuminance Values:

Quick Estimat

Average	Minimum	Maximum	Min/Avg	Min/Max
273 Lux	178 Lux	329 Lux	0.653	0.542

3D Lux Web:

Horizontal Illuminance (lx) on Workplane



Appendix IV

INTERIOR LIGHTING POWER LIMIT **Space Function Method**

Recommended by Energy Conservation Building Code 20[illegible]

SPACE FUNCTION	LPD(W/m²)	SPACE FUNCTION	LPD(W/m²)
Office - Enclosed	11.8	Library	
Office - Open Plan	11.8	Card File and Cataloging	11.8
Conference/Meeting/Multipurpose	14	Stacks	18.3
Classroom/Lecture/Training	15.1	Reading Areas	12.9
Lobby	14	Hospital	
For Hotel	11.8	Emergency	29.1
For Performing ArtsTheater	35.5	Recovery	8.6
Audience/Seating Area	9.7	Exam Treatment	16.1
For Gymnasium	4.3	Pharmacy	12.9
For Exercise Centre	3.2	Patient Room	7.5
For Convention Centre	7.5	Operating Room	23.7
For Religious Building	18.3	Nursery	6.5
For Sports Arena	4.3	Medical Supply	15.1
For Performing Arts Theater	28	Physical Therapy	9.7
For Motion Picture Theater	12.9	Radiology	4.3
For Transportation	5.4	Laundry - Washing	6.5
Atrium - First Three Floors	6.5	Automotive - Service Repairs	7.5
Atrium - Each Additional Floor	2.2	Manufacturing	
Lounge/Recreation	12.9	Low Bay (<8m ceiling)	12.9
For Hospital	8.6	High Bay (>8m ceiling)	18.3
Dining Area	9.7	Detailed Manufacturing	22.6
For Hotel	14	Equipment Room	12.9
For Motel	12.9	Control Room	5.4
For Bar Lounge/Leisure Dining	15.1	Hotel/Motel Guest Rooms	11.8
For Family Dining	22.6	Dormitory - Living Quarters	11.8
Food Preparation	12.9	Museum	
Laboratory	15.1	General Exhibition	10.8
Restrooms	9.7	Restoration	18.3
Dressing/Locker/Fitting Room	6.5	Bank Office - Banking Activity Area	16.1
Corridor/Transition	5.4	Religious Buildings	
For Hospital	10.8	Worship - Pulpit, Choir	25.8
For Manufacturing Facility	5.4	Fellowship Hall	9.7
Stairs - Active	6.5	Retail	
Active Storage	8.6	Sales Area	18.3
For Hospital	9.7	Mall Concourse	18.3
Inactive Storage	3.2	Sports Arena	
For Museam	8.6	Ring Sports Area	29.1
Electrical/Mechanical	16.1	Court Sports Area	24.8
Workshop	20.5	Indoor Field Area	15.1
Sleeping Quarters	3.2	Warehouse	
Convention Centre - Exhibit space	14	Fine Material Storage	15.1
		Medium/Bulky Material Storage	9.7
		Parking Garage - Garage Area	2.2
		Transportation	
		Airport Concourse	6.5
		Air/Train/Bus - Baggage Area	10.8
		Terminal - Ticket Counter	16.1