IMPROVED LIGHTING DESIGN OF A TYPICAL UNIVERSITY LABORATORY BUILDING

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A DISSERTATION SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI

In Partial Fulfillment Of The Requirements For The Award Of The Degree Of Master Of Engineering In Electrical Power Systems Engineering

JULY, 2014

CERTIFICATION

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DEDICATION

This work is dedicated to God Almighty, the source and sustainer of life, and to all who contributed towards my education/training through all my years of studies, and professional practice/development

ACKNOWLEDGEMENT

My special appreciation goes to Engr. Prof. E.N.C Okafor for his encouragement and contribution to this work as my Project Supervisor and Engr. Dr D.O. Dike who helped me to make necessary corrections. I wish also to thank Engr. Prof. (Mrs.) G.A. Chukwudebe for her immense encouragement and advice, Engr. Dr. F.K. Okpara who inspired me to complete this work, Engr. Prof .S.O.E. Ogbogu, Engr. Dr. (Mrs.) G.N. Eze, Engr. Dr. F.I. Izuegbunam, Engr. Dr. C.C. Mbaocha, Engr. Dr. Laz Uzoechi, Engr. Dr N. Chukwuchekwa, Engr. J.O Onojo and Engr. Ray Opara for their useful contribution.

I am also grateful to the Chartered Institute of Building Services (CIBSE), UK whose materials enabled me immensely in this work. It is worthy of note that Late Engr. Prof. T.C. Nwodo facilitated my course work by undertaking to handle most of the courses at the time. May his soul rest in peace, Amen.

I am also indebted to Late Engr. Prof. J.I. Ejimanya and Engr. Prof. O.I. Okoro who handled some of the courses, and a host of others for their inspiring partnership during the course work.

Finally, I am grateful to my beloved wife, Mrs. E.N. Okeke and my children: Charles, Chinedu, Ezinne and Obianuju for their immense encouragement.

ABSTRACT

The Nigerian Electricity Act of 2005 brought in deregulation, unbundling and privatization of power industry. This has given rise to competition and commercialization aimed at increasing efficiency through enhanced quality service delivery. To realize the noble goals of this Act, there is dire-need to seek avenues of reducing energy consumption through the application of appropriate international standards and new technological advances in electrical designs. This dissertation, therefore, presents an improved lighting design of a typical university laboratory building. It specifies the use of energy-efficient luminaires and proper lighting standards. Furthermore, a model for energy savings was formulated for day lighting applications whereby respective switching cells follow isolux contours. Comparisons were made on the luminaires in terms of standards, efficacy, expected life, space illuminance levels and cost. While the new design excelled in the first four factors, the total initial cost of the existing design was approximately 60% lower. However, when postulated to one year of operation, the proposed design became cheaper by 20% as the result of excessive lamp replacement cost. For a special application in open halls (such as laboratories), there was a further reduction of energy demand ranging from 30% during very dull weather to 67% on very dry days due to introduction of day lighting applications.

Keywords: Efficacy, Illuminance, Isolux contours, Lighting standards, Luminaires and Switching model

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND INFORMATION

In general terms, light is defined as energy producing brightness: the energy producing a sensation of brightness that makes seeing possible. In the field of physics, light is defined as visible electromagnetic radiation: electromagnetic radiation in the range visible to the eye, between approximately, 4,000 and 7,700 angstroms [Microsoft Corporation, 2007].

All materials exhibit some degree of absorption, refraction and reflection of light.

Scientists use the units candela and lumen to measure the brightness of light as perceived by humans. These units account for the different responses of the eye to light of different colours. The lumen measures the total amount of energy in the light radiated in all directions; and the candela measures the amount radiated in a particular direction. The candela was originally called the candle, and it was defined in terms of the light produced by a standard candle. It is now defined as the energy flow in a given direction of a yellow-green light with a frequency of 540×10^{12} HZ and a radiant intensity, or energy output, of 1/683 watt into the opening of a cone of one steradian. The steradian is a measure of angle in three dimensions.

The lumen can be defined in terms of a source that radiates one candela uniformly in all directions. If one sphere with a radius of one foot were centred on the light source, then one square foot on the inside surface of the sphere would be illuminated with a flux of one lumen. Flux means the rate at which light energy is falling on the surface. The illumination or luminance of that one square foot is defined to be one foot-candle.

The illumination at a different distance from a source can be calculated from the inverse square law: One lumen of flux spreads out over an area that increases as the square of the distance from the centre of the source. This means that the light per square foot decreases as the inverse of the distance from the source. For instance, if one square foot of a surface that is one foot away from a source has an illumination of one foot-candle, then one square foot that is 4 feet away will have an illumination of the $^{1}/_{16}$ foot-candle. This is because 4 feet away from the source, the one lumen of flux landing on one square foot has had to spread out over 16 square feet. In the metric system, the unit of luminous flux is also called the lumen, the unit of illumination is defined in meters and is called lux [Marburger; Redmond, 2007].

Generally, we have natural and artificial lighting. Natural lighting comes from the sun and other natural luminous bodies. Light from the sun is used for day-lighting. Day-lighting can be used in buildings by means of light–pipes, façade systems and regular windows [Tulla, 2009c]

Artificial lighting has advanced from burning sticks, glowing coals, oil/wicks in vessels, open pot of stone/grease, illuminating gas etc to electric lighting innovations at the close of the 19th Century [Marburger; Redmond, 2007]. In 1878 and 1879 respectively, Englishman, Sir Joseph Swan and American, Thomas Edison both managed to develop a light source (the incandescent light bulb) which was affordable and suitable for domestic use. At the same time, Edmund Germer was conducting work on the mercury vapour fluorescent lamp. However, it was not until the 1940's that the first practical and visible fluorescent lamp was launched; General Electric bought the original patent and improved on the original design to make it suitable for the US market. From 1950 onwards, various new light sources were invented. See Fig 1. for graph showing the development and improvement in light output for given electrical light sources (Lighting Industry Federation [LIF, 2009]:

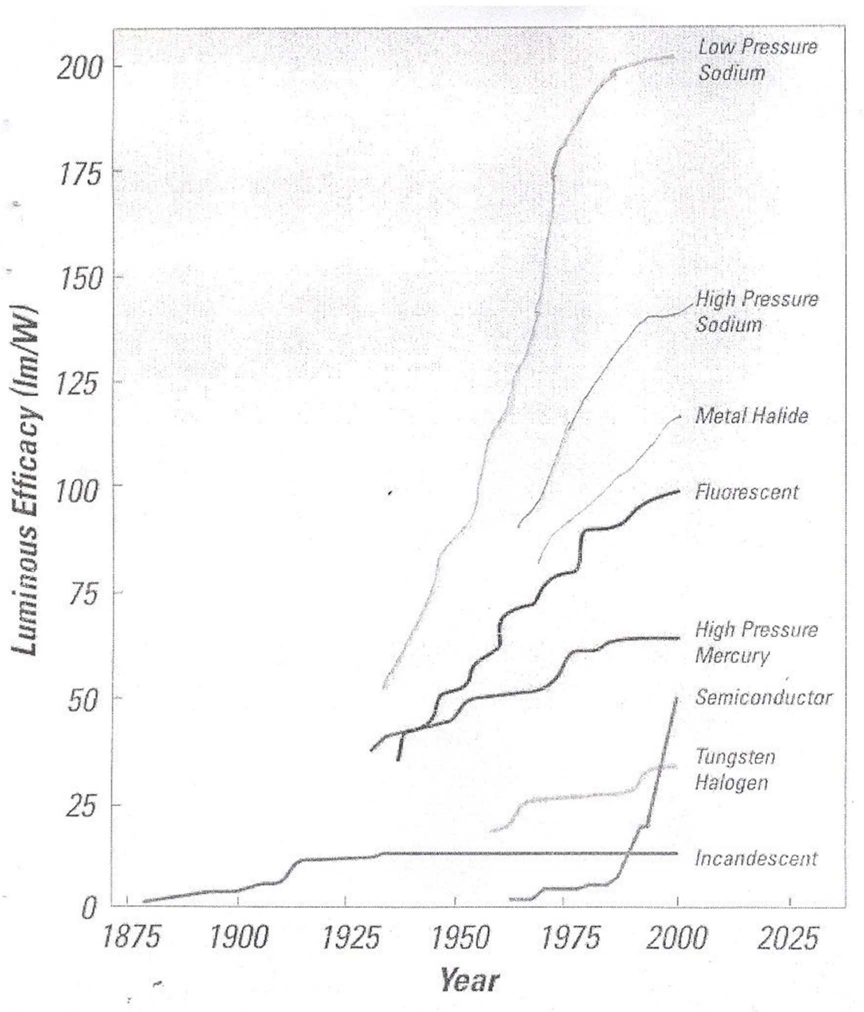

Fig. 1.1: Development of Electric Lamps [LIF, 2009]

Electric lighting is made possible by means of any of a number of devices that convert electrical energy into light. The types of electric lighting devices most commonly used are the incandescent lamp, the fluorescent lamp, the various types of arc and electric-discharge, vapour lamps and light-emitting diodes [Marburger; Redmond, 2007]

1.1.1 Incandescent Lamps(Tungsten-Filament):

Incandescent lamp is a device that produces light by heating a material to a high temperature. The most familiar example of an incandescent lamp is the common household (General Lighting Service, GLS) bulb. It consists of a stretched or coiled filament of tungsten material sealed inside a bulb filled with a gas that will not react with the tungsten or bulb. The inert gas is a combination of nitrogen and argon (or krypton) in a proportion designed to suit the wattage, or brightness, of the bulb. When electric current flows through the filament, it heats the filament to a temperature of about 3000^{o}C, causing the filament to glow and provide light. (tungsten has a melting point of 3422^{o}C) [Marburger; Redmond, 2007]. See fig 1.2.

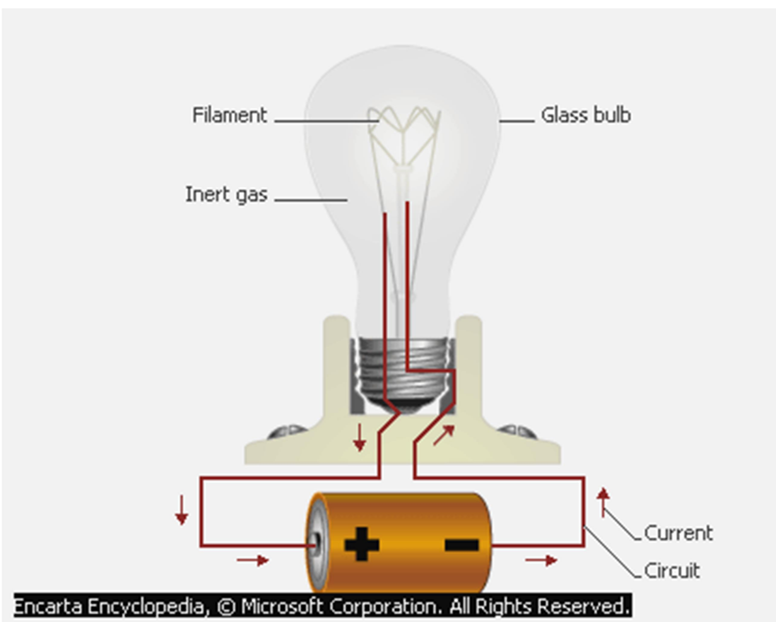

Fig1.2 Typical GLS Lamp [LIF, 2009]

The lamps have watt ratings ranging from 15 to 1000w and they may have different types of cap such as Bayonet Cap (BC), Edison Screw (ES) or Goliath Edison Screw (GES). GES is used for 300, 500 and 1000w lamps. Bulbs can be classified according to finish as clear (200w and above), pearl (from 150w downwards), Silica-Pearl (40-200w), reflector (25-150w) etc.

The usual life expectancy for GLS tungsten lamps is when approximately 50% of their installed number has failed and ranges from 1000-2500hours, least for single coil, more for coiled-coil and the longest for doublelife lamps. Doublelife lamps compromise slightly in lumen output to provide a rated life of up to 2500hours

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Table 1.1 shows the average lighting design lumen of GLS lamps [Newnes, 1988].

Table 1.1: Average Lighting Design Lumens of GLS Lamps [Newnes, 1988]

Watt	**Doublelife Lamps (Coiled-Coil) 240V**	**Neta-bulb (Coiled-Coil) 240V**	**GLS Lamps (Single Coil) 240V**	**GLS Lamps (Single Coil) 110V**
25	-	-	200	-
40	355	365	400	410
60	595	625	675	710
100	1160	1185	1290	1300
150	1860	1925	2070	2160
200	-	-	2730	2980
300	-	-	4300	4710
500	-	-	7700	8270
750	-	-	12,400	-
1000	-	-	17,300	-

The lamps are produced in different colours and shapes to suit numerous application such as decorative lighting and display lighting. White colour rendering is good and their low cost is an advantage. They are dimmable and perform best in the vertical cap-up position.

However, they suffer from having a poor efficacy (ranging from 3.3lm/W-13.4lm/W, classes E-G) and shorter life compared with other types of lamp. Moreover, according to Brian Jacobs of Philips Lighting, 100w GLS lamp in 30mins can produce Carbon Dioxide (CO_2) to fill a Party Balloon [Tulla, 2009c]. These characteristics place GLS lamps in disadvantaged position in this era of climate change. It has been reported already that Andris Pielbalgs, the European Commissioner for Energy banned the use of GLS lamps in Europe with effect from September, 2009 for the above reasons [Peck, 2009a].

1.1.2 Incandescent Lamps (Tungsten-Halogen):

Here, the tungsten filament is enclosed in a gas-filled quartz tube together with a carefully controlled amount of halogen, such as iodine or bromine. The halogen vapourises and controls the evaporation of the filament, thereby eliminating the blackening of the bulb as prevalent in GLS Lamps. TH lamp has a much higher efficacy (10-25lm/w) and longer life than the standard GLS lamps [Newnes, 1988]

Two types of TH lamps are linear double-ended and single-ended lamps. The former is operated within 5 degrees of the horizontal and finds application in display lighting, particularly floodlighting and office copying equipment requiring a linear light source. Single-ended lamps have various ratings up to 500W and can be used for display lighting, studios and theatre lighting, spotlights and traffic signals. See Figs.1.3(a) and 1.3(b) for the typical TH lamps.

Fig1.3 (a): Single-ended TH Lamp

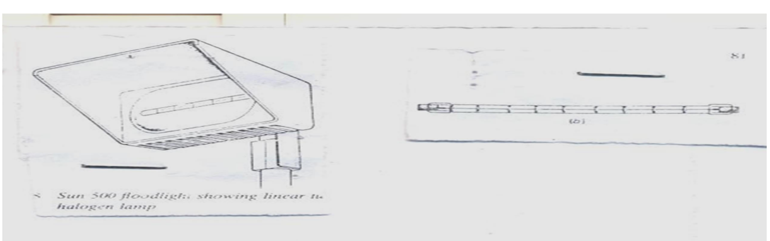


Fig1. 3(b): Linear Double-ended TH Lamp

Furthermore, Tables 2(a) and 2(b) display the data of the two TH lamps

Table1. 2(a): Linear double-ended lamps.

Type	Volts	Watts	Life (W)	No of Lumens	Burning Position
K9	240/250	300	2000	5,000	Horizontal
K1	240/250	500	2000	9,500	Horizontal
K2	240/250	750	2000	15,000	Horizontal
K3	240/250	750	2000	15,000	Horizontal
K4	240/250	1000	2000	21,000	Horizontal
K5	240/250	1500	2000	33,000	Horizontal
K8	240/250	2000	2000	44,000	Horizontal
K6	240/250	2000	2000	44,000	Horizontal

Table 1.2(b): Class M single-ended Lamps

Type	Volts	Watts	Life (h)	No of Lumens	Burning Position
M28	12	100	2000	2,150	Base Down/Base Horizontal
M32	12	50	2000	900	Any position
M34	6	20	2000	350	Any position
M36	24	250	2000	5,750	Base Down/Base Horizontal
M30	6	20	100	420	Any position
M29	6	10	100	210	Any position
M35	12/13.2	20	250	450	Any position
M37	12	55	750	-	Any position
M39	6	20	2000	-	Any position
M41	6	20	2000	-	Any position
M38	240/250	300	2000	5,000	Any position
M40	240/250	300	2000	8,500	Any position

1.1.3 Electric Discharge Lamps:

In this type of lamps, light is produced as a result of excitation of a gas or vapour inside a sealed glass tube containing two electrodes. When a typical lamp is connected in circuit with the supply, the voltage applied across its electrodes will cause ionization of the gas or vapour filling. To avoid continued ionization (which leads to excessive current), an inductor or high leakage transformer (known as choke) is inserted in the lamp circuit to limit the current to a designed safe value. On d.c supplies, a resistance may be used which, in most cases, consumes about as much power as the lamp itself and thus lowers the luminous efficacy compared with operation on a.c.

The choke is connected in series with the lamp and a power factor capacitor is placed across the mains on the mains side of the choke.

Generally speaking, there are two kinds of discharge lamps: one is called the Cold-Cathode type and the other the Hot-Cathode type. The former is normally referred to as a neon lamp, which requires a very high voltage to initiate the discharge. The latter is normally operated on low voltage supplies. Four of these are:

a) Low-pressure Mercury Vapour Fluorescent Lamps
b) High Pressure Mercury Vapour Fluorescent Lamps
c) Low Pressure Sodium Vapour Lamps
d) High Pressure Sodium Vapour Lamps.

With lengths ranging from 150mm to 2400mm, tubes ranging from 16mm to 38mm in diameter and colour appearance/colour rendering of various types, the low pressure mercury vapour fluorescent lamps (item a above) is used for general lighting with desirable efficacy. Item (b) is used for street lighting, industrial lighting, Show Rooms etc. while item (c) having poor colour rendering is used for street lighting and floodlighting. Item (d) is used for high-bar lighting, street lighting, swimming pools, modern shopping areas lighting etc.
For the purpose of this dissertation, Low-Pressure Mercury Vapour Fluorescent Lamps (called fluorescent lamps) are discussed in greater details.

1.1.3.1 Linear Fluorescent Lamps:

A fluorescent lamp consists of a phosphor-coated tube, starter, and ballast. The tube is filled with an inert gas (argon or krypton) plus a small amount of mercury vapour. At both ends of the tube are cathodes formed out of a single or multiple-coil of tungsten wire. These cathodes are coated with a special electron-emitting material, mounted on glass pinches and sealed into the ends of the lamp. The starter energizes the two filaments when the lamp is first turned on. The filaments supply electrons to ionize the argon or krypton, forming a plasma that conducts electricity. The ballast limits the amount of current that can flow through the tube. The plasma excites the mercury atoms, which then emit red, green, blue, and ultraviolet light. The light strikes the phosphors coating on the inside of the lamp, which converts the ultraviolet light into other colours. Different phosphors produce warmer or cooler colours [Marburger; Redmond, 2007]. See fig. 1.4

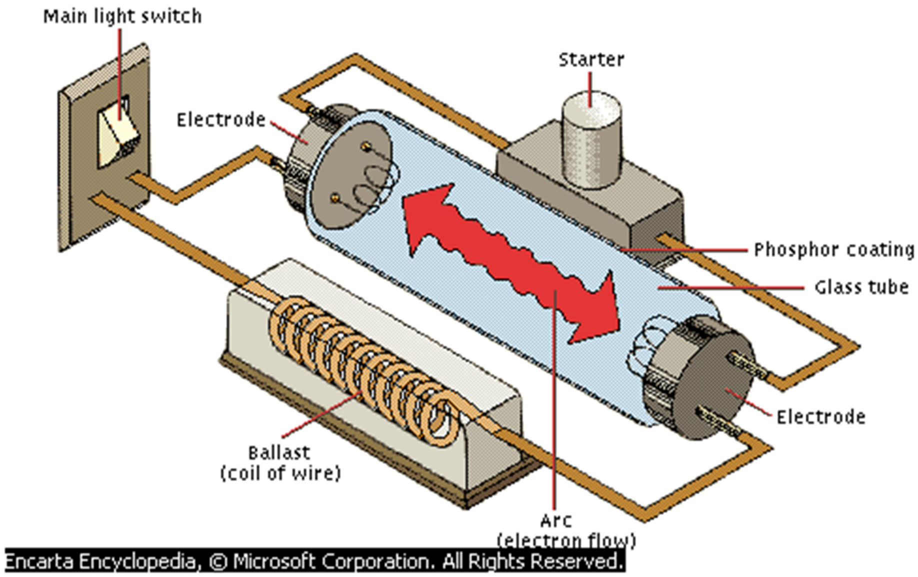


Fig1. 4: Components of a fluorescent lamp (Magnetic/Switch start Ballast, Type) [Microsoft Corporation, 2007b]

With the introduction of rare earth phosphors (triphosphors) in about 1980, it is now possible to have lamps with good colour rendering properties and high efficacy used in artificial daylighting, capable of using both switch-start and high frequency electronic ballasts. These phosphors can operate at higher temperatures and have permitted the development of a new generation of compact (fluorescent) lamps (eg. Thorn 2D Lamps)

Moreover, linear fluorescent lamps of higher efficacy, for example, 26mm and 16mm tubes (T8 and T5) have replaced the old T12 lamps which are 38mm in diameter [Newnes, 1988].

See Tables 1.3(a), 1.3(b) and 1.4 for characteristics of some fluorescent lamps.

Table1. 3(a): **Colour Appearance and Colour Rendering Properties of Fluorescent Lamps [Newnes, 1988]**

Tube Colour	Colour Rendering Quality	Colour Appearance	Applications
Polylux 2700	Very good	Warm	Tubes of various efficacies for use in social residential and domestic situations
Pluslux 3000	Fair	Warm	
Polylux 3500	Very good	Intermediate	Tubes of various efficacies for general illumination of work areas-shops, factories, warehouses etc.
Pluslux 3500	Fair	Intermediate	
Plus white	Good	Intermediate	
Polylux 4000	Very good	Cool	Tubes of various efficacies for work areas requiring illumination to blend with natural daylight – offices, shops etc.
Pluslux 4000	Very good	Cool	
Natural	Very good	Cool	
Deluxe natural	Good	Intermediate	Butchers, fishmongers, supermarkets. Enhances the appearance of red objects
Kolor-rite	Excellent	Cool	Complies with DHSS requirements for Hospital lighting
North light/colour matching	Very good	Cool	Areas for matching materials etc. Any application where a wintry effect or an impression of coolness is required
Artificial Daylight	Excellent	Cool	Areas for exact colour matching. Best colour rendering with cool appearance. Meets BS 950 Part 1.
Gro-Lux	-	-	For vivid colour effects on tropical fish or plant displays
Colours	Poor	-	Saturated colours for display floodlighting, stage lighting

Table 1.3(b) shows a selection from principal white colours, to demonstrate the relation between colour appearance and colour rendering, and to show systems of proprietary colour name.

Table 1.3(b): Relation between colour appearance and colour rendering for principal white colours [LIF, 2009]

Colour Appearance	**Colour Temperature**	**Triphosphor**	**Multi-phosphor**	**Applications**
		Colour Rendering Group	**Colour Rendering Group**	
		1b	**1a**	
Blue sky	17000k	8cx[1]	-	Alleviation
Sky light	8000-10000k	880	-	
North light/Cool Daylight	6000-6500k	860-865[2]	965	Dentists' practices, reprographic workshops, clothing retail market
Cool white	4000k	840[2]	940	Factories, workshops, offices, sportshalls, shops.
Intermediate	3500k	835	-	Offices
Warm white	3000k	830	930	Shops, schools, meeting rooms, offices, auditoriums
Very warm	2700k	827	-	Hotel foyers, Restaurants, theatres, homes

Notes: (1) There is no standard format (nomenclature) for this lamp series but CRI is > 80

(2) Special lower energy versions of these lamps are available

In the above table, CRI"XYZ" interpreted as follows: x represents Colour Rendering Index (eg.8 = Ra 80-89), white YZ represents Colour Temperature (eg. 27 = 2700K).

Where previously, colour appearance was largely a matter of taste, this has become a critical factor in lamp selection, particularly in the working environment. The general principle is to use cool colours for a business-like atmosphere and warm colours for a social atmosphere.

The performance of the following fluorescent fittings marketed by Thorn lighting is displayed in Table1. 4.

Table1. 4: **Photometric Data of some selected Thorn Lighting fluorescent fittings [Thorn, 2009]**

Range/SAP Description	**Lamp**	**Total Lamp Initial Lumens (lm)**	**Total Power (W)**	**LOR**	**Luminaire Lumens Per Watt**	**Lamp Lumens Per Watt**
AQUAF2 1x36w T26HF L840	T26	3350	36	0.68	63	93
Arroslim 1x35w	T16	3320	38	0.97	85	87
Arroslim 1x35w +Diffuser REAC	T16	3320	38	0.96	84	87
Arroslim 1x28w	T16	2640	31	0.97	83	85
Arroslim 1x28w +Diffuser REAC	T16	2640	31	0.96	82	85
Arroslim 1x21w	T16	1910	23	0.99	82	83
Arroslim 1x14w	T16	1230	16	0.99	76	77
Arroslim 1x14w +Diffuser REAC	T16	1230	16	0.98	75	77

Note: In the Thorn Light Sustainability Brochure [Thorn, 2009], there are T26 fittings ranging from 36w to 70w (both single and Twin Types) but for T16 fittings the ranges are from 14w to 80w (both single and Twin types). T16 (or T5) lamps are getting more popular while T26 (or T8) fittings are diminishing. T38 (or T12) fittings have been phased out. These developments are due to efficacy factors arising from emerging challenges of climate change.

The rated life of linear tubular fluorescent lamps can range from 6,000 hours up to 60,000 hours or more, depending on lamp type and control gear.

1.1.3.2 Compact Fluorescent Lamps

In this era of climate change, the compact fluorescent lamps (CFLs) are being used to replace the traditional GLS lamps due to the reasons stated earlier.

There are two types of compact fluorescent lamps [LIF, 2009]:

i) **Single-Capped CFLni-Compact Fluorescent Lamps Non-Integrated Ballast:**

These enable greater energy savings as well as control options such as dimming, daylight control and presence detection.

The wattage of a CFLni ranges from 5w for a ‘single’ 2-pin lamp, through the most popular 26w ‘double’, the most powerful 80w ‘long’,to 120w ‘multiple tube’ lamp. Efficacy ranges between 50lm/W and 70lm/W with IEC stipulated lumen maintenance of over 75% after 10,000 hours. However, such lamps can take approximately 1 second to light up initially and 1-2 minutes to run up to full brightness.

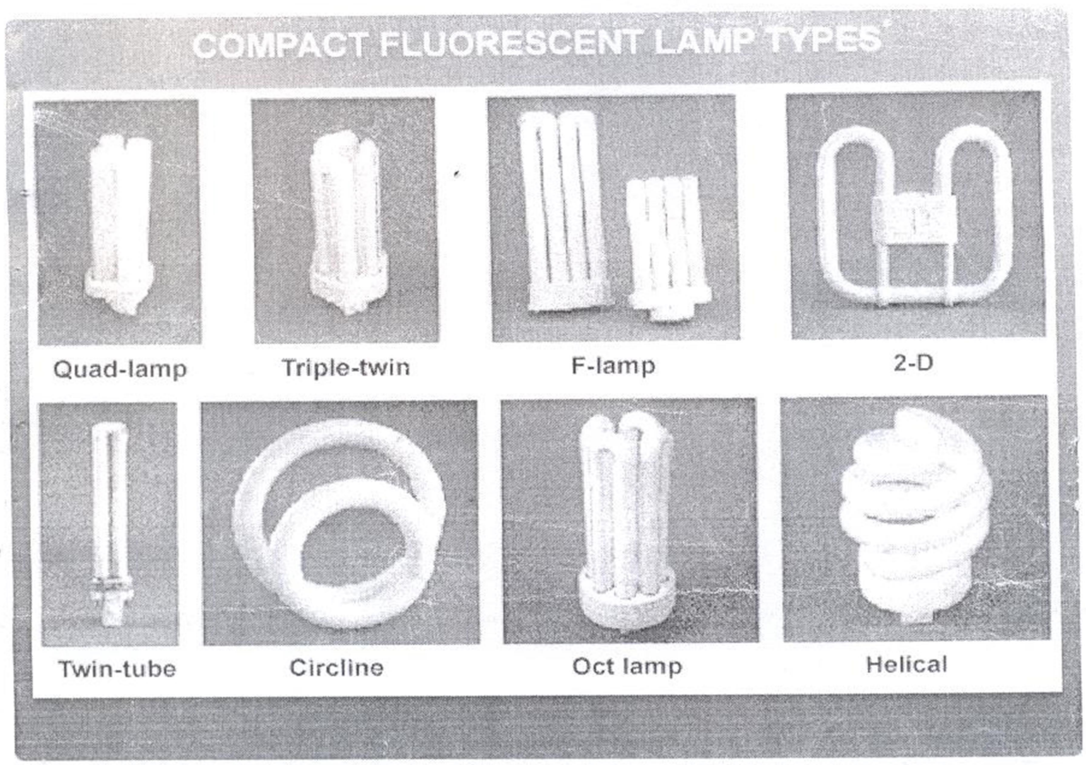


FIG1.5: COMPACT FUORESCENT LAMP TYPES [LIF, 2009]

ii) **Self-ballasted CFLi-Compact Fluorescent-Integrated Ballast:**

This is also commonly referred to as an energy-saving bulb. Many CFLi are designed to replace an incandescent lamp. Improved phosphor formulations have improved the subjective colour of the light emitted by CFLi’s such that the best ‘soft white’ CFLi’s available are subjectively similar in colour to standard incandescent lamps. It operates with electronic ballast and in either switch-dimmable and dimmer-dimmable versions. Tube diameters now range from T4 to T2 design, Wattages from 5W for a ‘candle’, through the popular 11W and 20W ‘stick’ types to as much as 36W ‘spiral’ or 42W ‘tube’ designed to replace double-ended halogen lamps. Efficacy would be from 45lm/W.

CFLi's tend to range in life from 3,000 hours up to 15,000 hours, with IEC stipulated lumen maintenance of over 75% after 10,000 hours. CFLi's are available in 3 main colours:

a) Warm white – Colour 827 – Ideal for homes and restaurants

b) Cool white – Colour 840 – Ideal for more business-like environments such as dental surgeries, opticians, pharmacists offices and for cooler light in modern homes.

c) Daylight – colour 860 or 865.

However, CFLi's have a higher purchase price, some types not being very aesthetic with exposed tubes and some delays in starting compared to incandescent lamps. Traditionally, CFLi's have a power factor of approximately 0.6 while later versions now offer up to 0.95 p.f. CFLi's are also affected by temperature of the environment.

However, a case study on the India CFL program shows that CFLs have a high failure rate due to lack of adherence to product specifications, especially in rural areas. Quality control and regulation are difficult as it is import-based. There is an added difficulty of regulating mercury in CFL and its final disposal [Tulla, 2009a]. Moreover, it has been discovered that not all CFLs have power factor correction. For example, many sold in the UK have only 0.3p.f so that the actual VA consumed is three times higher. Suddenly, 4 times energy savings over GLS almost disappear. Light from tungsten lamps appears even to be subjectively brighter, thereby making all the advantages to disappear [Tulla, 2009b].

It is necessary to further address the electromagnetic field effects of CFLs, potential problems stemming from installed CFLs usage and to properly analyse the actual installation system efficiencies before considering the ban of GLS lamps [Raynham, 2010]

1.1.4 **Light-Emitting Diodes (LED):**

Light–emitting Diodes (LEDs) are devices that emit visible light when an electric current passes through them. LEDs are made of semiconductors, or electrical conductors, mixed with **Phosphors**, substances that absorb electromagnetic radiation and re-emit it as visible light. When electrical current passes through the Diode, the Semiconductor emits infrared radiation, which the phosphors in the Diode absorb and re-emit as visible light. LEDs do not require heating of a filament to create light. Instead, electricity is passed through a chemical compound (crystal) that is excited and generates light [LIF, 2009]

In the largest available light diodes, their dimensions are represented by edges of only 1mm. LEDs thus belong to the smallest available, almost point-like, light sources.

An LED often has optics added directly on top of the chip to shape its radiation pattern and assist in reflection. The colour of the emitted light depends on the composition and condition of the semiconducting material used, and can be infrared, visible (red, orange, yellow, green and blue), or ultraviolet.

Table1. 5: Colour LEDs [LIF, 2009]

Semiconductor Material	Abbreviation	Colour
Aluminium-Gallium Arsenide	AlGaAs	Red
Aluminium Indium Gallium Phosphide	AllnGaP	Red, Orange, Yellow
Gallium Arsenide Phosophide	GaAsP	Red, Orange, Yellow
Indium Gallium Nitride	InGaN	Green, Blue

White light can be produced as a mixture of all wavelengths, for example, in LED modules. This arises through an additive mixture of the three RGB colours.

Dimming can be either by Analogue (with high energy loss) or Digital techniques. Average efficacy(affected by temperature) would be 50-100lm/W at present to achieve 70% lumen maintenance value at 50,000 hours life.

There are low Power LEDs (sizes from 2mm to 8mm and current ratings from 1mA to 20mA) with a luminous flux of approximately 1 lumen, used as indicators and high Power LEDs (ratings). LED drivers are designed to convert mains voltage to DC with Power factor pre-regulated for LED lighting, thereby avoiding problems of phase shift as in high wattage fluorescent circuits.

LEDs can now be used in street lighting, and as secondary light sources or in smaller rooms in lifts, railway carriages, corridors, etc. LEDs can be operated in any position and with instant start and restart.

There are two new competing LED technologies

a) OLEDs (Organic Light Emitting Diodes) are based on multiple layer devices (up to 16 layers) of evaporated low molecular weight molecules

b) PLEDs (Polymer Light Emitting Diodes) are solution processible structures based on a single white light emitting polymer, deposited by printing on to charge transport layers (3 or 4 thick).

Presently, OLEDs outperform PLED technology, on laboratory test samples, but due to the complexity of manufacturing multiple layer structures, it is widely believed that solution-processible PLED technology will be first to demonstrate high yield manufacturing levels.

Moreover, OLEDs are up to 75% more efficient than incandescent lamps at similar brightness. In 2006, scientists reported a breakthrough in OLED technology that could enable these LEDs to replace lamps and other types of lighting in homes and offices. Because they are made of wafer – thin layers of plastics and give off little or no heat on walls, ceilings, or even furniture, they could be used to light a room in place of the traditional lamp. The technology could achieve 100 percent efficiency in converting electricity to light [Redmond, 2009].

However, it has been discovered that the standard CIE CRI ratings given to white LED sources often contradict those given by users, hence a variation of CRI known as the colour harmony rendering index.

The pleasantness of an interior depends to a large degree on the harmonious appearance of the colours seen side by side. A descriptor of how strongly a light source distorts the colour harmony is therefore a logical further step in measuring light source quality.

White phosphor LEDs and RGB LEDs showed marked differences, with the later showing non-systematic colour shifts which differ not only in size but direction [Tulla, 2009d]. See Fig.1. 6 for details of a sample LED.

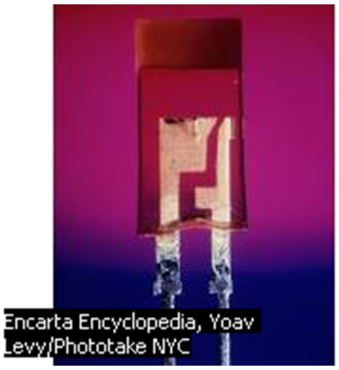


FIG1. 6: LIGHT EMITTING DIODE (LED) [LIF, 2009]

Moreover, further researches are going on to improve on the quality of CFLs, LEDs and other electric lamps for use, especially in this age of climate change [Knoop, 2010]

1.1.5 General:

The choice of lamp for a given task must be done carefully. This is influenced by the ambiance a designer wishes to create and the tasks being undertaken within the environment. It is best practice to use the highest efficacy lamps available and suitable for the task being undertaken. Colour rendering of lamps are important when choosing lamps for specific applications. Where lighting quality is of low priority, a low maintenance lamp may be used (eg. street lighting). When designing for an environment where people are retained for long periods of time, and create a warm social ambiance, a lamp emitting a warm appearance should be used (red/orange). When designing for an environment where a fast turn-around of people is required (Commercial/Supermarket), a lamp emitting a sharp cool/cold appearance (blue) should be used (University of [Strathclyde (ERSU), 2008].

Moreover, due to emerging climate change, lighting professionals have been tasked with how to reduce energy use in lighting [Boyce, 2009]. This has been accompanied with various standards in different countries to take care of this trend in design. Use of modern energy-efficient lamps, applications of daylighting and reviews of existing standard illuminances have been discovered to be effective ways of achieving energy-efficient designs.

Unlike Nigeria, electrical lighting development in Europe and America has advanced so much. For example, the illuminating Engineering Society was formed in Britain on 9th February, 1909 through an informal meeting of lighting professionals while the inaugural meeting was convened on 18th November, 1909. The Society of Light and Lighting (as it is now called) published the first Lighting Code over 70 years ago [Peck, 2009a]. Nigeria is yet to develop an indigenous lighting standard.

Lighting designers therefore resort to use of any available standard. Apart from the design of energy-efficient lighting scheme for a typical University Laboratory, this work goes further to take a closer look at an existing design of the Laboratory in order to ascertain the extent to which prevailing standards were adhered to.

1.2 STATEMENT OF THE PROBLEM

It is common knowledge that Nigeria is yet to have any indigenous lighting standard. Services Engineers therefore resort to adoption of any available foreign standards, a situation that does not allow for uniformity in design. There are also cases of arbitrariness in the use of design data. We now have the problem of adopting parameters for assessing the viability of lighting designs in the country.

The Nigerian Electricity Act of 2005 brought in deregulation, unbundling and privatization of power industry. This has given rise to competition and commercialization aimed at increasing efficiency through enhanced quality service delivery. To realize the noble goals of this Act, there is dire-need to seek avenues of reducing energy consumption through the application of appropriate international standards and new technological advances in electrical designs But lamps produced locally do not have elaborate and regulated photometric data. There is even no available local standard for assessing the quality of imported lamps and fittings.

Moreover, daylighting is being introduced worldwide as one of the measures in reducing power consumption in lighting designs. However, Nigeria is yet to have developed daylight factors in our areas and regions, an innovation which if achieved shall help to reduce lighting energy consumption in such an equatorial belt as Nigeria.

1.3 OBJECTIVES

This work was aimed at the following:

- To design an energy-efficient lighting scheme for a typical University Laboratory Building using available lighting standards. The laboratory room spaces are to serve as classrooms/lecture halls as well as for Laboratory Practical purposes, including preparatory rooms. There are few offices, toilet spaces, stores, lobbies, corridors/verandahs and two courtyards.

- To observe the effects of introduction of day-lighting and efficient control techniques in further reduction of energy consumption in lighting.

- To compare the existing (old) lighting design of the building handled by an external (indigenous) consultant with the above (new) design in terms of standards used, luminaires efficacy, expected life, space illuminance level and cost, and in view of day lighting applications.

- To compile an overview of all findings and make useful recommendations towards an improved lighting design.

1.4 JUSTIFICATION OF STUDY

Lighting designs in our country hardly contain specifications of expected illuminance levels (in lux). Apart from designing with specifications of illuminance and the use of available (foreign) standards, energy efficiency is emphasized in this work.

Further steps were taken to apply day lighting scheme in the improved design, using daylight factors to improve on the earlier results. A model for energy savings was formulated for day lighting applications whereby respective switching cells follow isolux contours. This was intended to open a window for a possible future daylight factors mapping of areas and regions of this country.

Moreover, the extent to which our local lighting designers stick to existing standards in design was investigated in this work, using an existing lighting design of a typical University Laboratory.

This work suggests the need for indigenous lighting standards in view of the competitiveness and commercialization of the power industry brought about by the de-regulation, unbundling and privatization, and our distinct ambient conditions of temperature, humidity etc.

1.5 SCOPE OF STUDY

This work covers the following:

- Design of an improved lighting scheme for a typical University Laboratory using available photometric data of some modern energy-efficient lamps/fittings, existing (foreign) standards, specified spaces dimensions and lighting design formulae.

- Tests of lighting energy efficiency in each space of the laboratory using some reviewed standards.

- Use of digital luxmeter to determine the daylight factors at a specified period of the day and incorporate the data obtained in extrapolating an improved energy-efficient lighting design of the Laboratory: A model for energy savings was formulated for day lighting applications whereby respective switching cells follow isolux contours. Possible ranges of energy savings at different periods of the day were calculated.

- Assessment of an existing (old) lighting design of the Laboratory (handled by an indigenous consultant) using some available photometric data and prevailing standards, to ascertain any case(s) of over-lighting/under-lighting: Comparisons were made on the luminaires between the old and the above (new) designs in terms of standards, luminaires efficacy, expected life, space illuminance levels and cost, and in view of day lighting applications.

- Use of DIALUX lighting design software to carry out comparative simulation of illuminanace levels of the old and new (improved) design.

CHAPTER TWO
LITERATURE REVIEW

2.1 LIGHTING DESIGN THEORIES AND APPLICATIONS

In this era of climate change, various professions have been tasked to find solution to the rate of carbon and other emissions into the atmosphere. The lighting profession is not left behind. The Society of Light and Lighting (SLL) celebrated her 100th (Centenary) Anniversary in 2009, having been inaugurated on 9th February, 1909 in Great Britain. Some of the Centenary Lectures raised vital issues in the profession that need to be reviewed to improve performance and as well contribute to the solution to the emerging challenges of climate change.

According to [Entwiste, 2010], lighting is invariably described as being a marriage of art and science, which of course, it is. Contributing further, [Hogett, 2010] advised, "Use light creatively … to invigorate, enliven, stimulate, excite, relax or calm as is appropriate for instances where duration of tasks are considered carefully"

In this chapter, the following issues on lighting design shall be discussed:

- Stages in the development of the Lighting Profession
- Climate Change: The need for a closer look at the standard illuminance values.
- Energy efficiency in lighting'
- Lighting design standards, data and formulae.

2.1.1 STAGES IN THE DEVELOPMENT OF THE LIGHTING PROFESSION

[Cuttle, 2009] reviewed the different stages of lighting design as follows:

a) **Engineering Approach:** At this initial stage, 'professionals wanted to produce uniform illuminance over large areas, a concept still very much with us and dominates our thinking. Modern light meters are technically sophisticated instruments which still measures exactly the same aspects and quality of lighting that they were trying to measure in the 19th Century – illuminance regardless of the direction of the incidence of light on a horizontal two dimensional plane'

b) **Determination of Illuminance Levels:** This stage emphasized on 'providing light for human need and the concept of visual performance. At that time, it made a lot of sense. Back in the 1920s and 1930s, there were eminent people in lighting saying that for a typical reading task, we need one foot-candle, approx. 10lux. Therefore, when we have different reading tasks, we provide additional illuminance in order to compensate for that. This is laughable now. We even now light corridors and plant rooms to much higher levels than that'.

c) Proposed Third Stage of the Lighting Profession: [Cuttle, 2009] during his SLL Centenary Lecture, contended that the obsession with measuring light only in relationship to the horizontal plane is outdated and no longer appropriate; advocated a move towards using mean room surface exitance (MRSE) as a measure in order to satisfy the expectation of an adequately lit space. He defined mean room surface exitance as follows: "While **Illuminance** is the density of lumens arriving at the surface, **Exitance** is the density of the lumens coming off the surface; this does not include direct light from the luminaires or from the windows but only light from room surfaces". He insisted that preoccupation with horizontal illuminance should end; instead we should be concerned with reflected light, the apparent brightness of a space, the light that reaches the eye rather than the horizontal plane, an idea which he called "the third stage of lighting design".

He expressed that the above two stages led to a misplaced concern with horizontal illuminance. According to him: 'the direct component of illuminance has no visual effect; it is not until the light has undergone a reflection that it has a visual effect upon the appearance of the things around us. Among the negative effect of the old approach is over-lighting. It overlooks the fact that technology has moved on. In the workplace, for example, most people use near-vertical, self-illuminated screens. In the supermarket, the person at the check-out no longer has to read the price because a bar code scanner does it for them. As soon as we start measuring light arriving at the eye, we get a completely different impression of what is effective lighting. With wallwashing and uplighting earlier seen as inefficient lighting, holding out a light meter on the horizontal plane gives inaccurate reading. Wallwashing can be an extremely effective way of giving people a sense of bright, well-lit space and a good sense of the ambient illumination'.

Crucial to Cuttle's theory, of course, are the nature and colour of the surfaces and objects within a space. Lighting design already accounts for the reflectance and colours of materials within a space, but many a scheme has been compromised because the Architect/Interior Designer subsequently changed their mind after the lighting has been predicated on different surfaces. There is therefore the need for co-operation between the Architects and Interior Designers with Lighting Engineers.

According to Cuttle, "Whether uplighting, downlighting, sidelighting, daylighting or electric lighting, MRSE gives a good indication of the overall impression of how brightly lit the space appears to be – how much reflected light is available".

Moreover, Cuttle added ‘But we need to have sound values by which we can specify what is perceived adequacy of ambient illumination ….. after which we revise our documents and teaching’.

The following should be noted with regards to the above proposal:
Already, the use of a Digital Camera is being speculated for Luminance Meter which takes only a single spot reading. Furthermore, there is High Dynamic Range Imaging (HDRI) which uses a computing software with embedded EXIF data (exchangeable Image File Format – ISO, exposure and aperture settings) to adjust the images to determine the actual luminance distribution within the photographed scene and produces an HDR Image [Peck, 2009b].

While commenting on Cuttle’s paper, [Hogett, 2010] remarked that it requires excellent knowledge of the materials and colours of surfaces at the design stage, which is often difficult to fix at the early stages of the project. If wrong assumptions are made, spaces could be left over- or under-lit. He also added that it should be ensured that the conceived lighting solutions are not so rigid that they leave the building owners/users with inflexible spaces, limited by the original colours. A reasonable level of flexibility should be achievable to allow for future changes.

2.1.2 CLIMATE CHANGE: THE NEED FOR A CLOSER LOOK ON STANDARD ILLUMINANCE VALUES

In his paper, [Boyce, 2010] argued that the current strategies for energy saving that are habitually trotted out – more daylight, more use of controls and so on – are completely inadequate. More radical and more immediate action is needed, he contends, if lighting is to meet energy saving pressures and carbon reduction goals.
He made it clear to the lighting community what makes lighting an attractive target for electricity savings as follows:

a) Lighting installations constitute a major user of electricity
b) They have a much shorter life than buildings.
c) They are easy to modify in existing buildings
d) They are conspicuous, so changes in lighting make it obvious that the authorities are doing something.

According to Boyce, the initial response of the lighting community is usually to emphasize the importance of maintaining lighting quality, and then to suggest three possibilities for lowering electricity consumption: a greater use of daylight combined with better controls on electric lighting, the development of more energy efficient lighting technology and a higher proportion of carbon-free electricity generation in the fuel mix. He felt that these three possibilities will not do because these options are too slow, too uncertain and too expensive to implement.

He went further to assert, ‘The honest answer to a demand for rapid and major reductions in the electricity consumed by lighting is a reduction in the illuminances used’. If asked whether this would be a disaster, he continued ‘The first thing to answer to this question is that illuminance recommendations are not written in stone. There have always been differences in illuminance recommendations between countries and, even for the same country, the recommendations have varied over the decade. The second is that, as regards visual performance, illuminance is a second-order effect relative to visual size and contrast. This means that if you are concerned that reducing illuminance will lead to deterioration in visual performance, you can always offset it by increasing either the size or contrast of the target details. The third is that for self-luminous computer displays, decreasing illuminance will improve visibility’.

Boyce viewed the argument that reduction in illuminance is a backward step as a mere conservatism. He asserted, ‘This objection might be overcome by ensuring the brightness of the space is maintained either by choosing an appropriate light spectrum or light distribution. In any case, it is important to appreciate that the reduction in illuminance need not be very large to have a significant effect on electricity use. The fact is, the response of the human visual system to illuminance is broadly logarithmic, while the influence of changing illuminance on electricity demand is broadly linear’.

He concluded by charging the lighting community to consider how it is going to respond to the pressure upon it; to fight for current standards, to accept defeat and take whatever the politicians impose, or to use our knowledge to maximize the benefits of lighting while minimizing the environmental costs.

Of course the last option seems the most reasonable. Lighting Engineers are working hard. Cuttle’s paper above is just one of the approaches. Phillips lighting Group recently announced “Phillips relights Welsh Castle using energy saving LED Technology”. In this exhibition, Phillips succeeded in relighting 18No of the Region’s most impressive castles with predicted energy savings of 50%, equating to saving 92 tons of CO_2 annually using state-of-art LED lighting technology. Phillips eW Reach LED floodlights were used, situated in the position as the former fittings, capable of projecting light some 500ft (150m) on both projected and recessed fascias [Philips Lighting Group, 2010].

2.1.3 ENERGY EFFICIENCY IN LIGHTING

[Actionenergy, 2003] provided an overview of energy efficiency in lighting, considering all the elements and how they inter-relate with one another. The elements were highlighted as follows:

2.1.3.1 Lighting Equipment

The following elements of the lighting equipment were highlighted:

a) **Lamp and Lamp Ballasts:** The following criteria were recommended for selection of lamps:

- Select the lamps for the application particularly with regard to its colour performance, and its operating characteristics.
- Use the most efficient ballast units, and for fluorescent lamps, use those with a CELMA energy rating of A or B and with the required control e.g. dimming. See Table 2.1
- Select lamp with highest efficacy. See Table 2.1

Table2.1: CE marking and energy labelling for Lamps [Actionenergy, 2003; Field; Soper, 2002].

Energy Efficiency Classification	Typical Lamp Types
A	Fluorescent Tubes, CFLs and LED
B	Halogen Energy Savers
C or D	Tungsten Halogen
E	Incandescent GLS (25w-200w)
F	Incandescent Candle Lamps
G	Incandescent Striplights

It should be noted that fluorescent lamp ballasts are classified by a CELMA Energy Class, marked on the ballast casing: either A, B, or C class unit, where A is the most efficient. Class C has been phased out from 21st November, 2005.

Table 2.2: Typical Lamp Efficacies [Actionenergy, 2003; LIF, 2009]

Lamp Type	Efficacy (Lumen/Watt)
Incandescent – Tungsten Filament	8-12
Incandescent – Tungsten Halogen	12-24
Compact Fluorescent	50-85
Tubular Fluorescent	65-100

Low Pressure Sodium	100-190
High Pressure Sodium	65-140
High Pressure Metal Halide	70-100
Light Emitting Diodes	50-100

.

Lamp manufacturers' catalogues shall be required for more accurate data on all aspects of lamp performance.

(b) Luminaires (Light Fittings): It is being recommended that to select the luminaire for the particular requirement, hence its light output distribution shape, and assess its efficiency in terms of either:

- Light Output Ratio using either LOR or Downward LOR and Upward LOR as appropriate. See Fig.2.1
- For luminaire to be used to provide a general illumination from a regular ceiling array, use Utilization Factor (UF).
- For spotlights and similar, use illumination performance data. See Fig.2.2

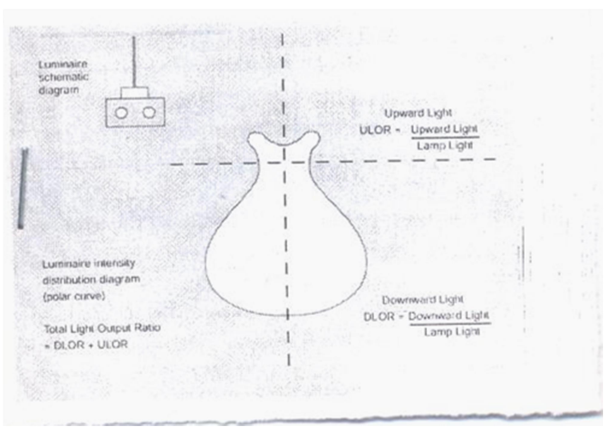


Fig.2.1: Typical Light Output Distribution(Polar Curve) of a diffuser-type Luminaire equipped with Fluorescent Lamps showing Upward and Downward Light Output Components [Actionenergy, 2003]

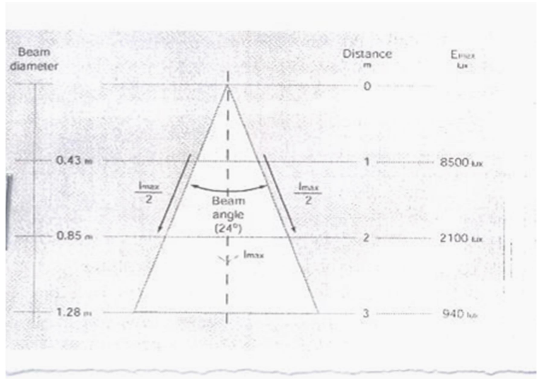


Fig2. 2: Typical Method of showing the Performance [Actionenergy, 2003]

However, these pieces of information are not usually contained within the standard catalogue, but in a publication which shows the photometric data, nowadays in an electronic form from a CD or on the Internet (except they are used for decorative purposes)

c) **Lighting Controls:** Good Lighting Controls, including switches and dimmers, operated either manually or automatically via light and occupancy sensors, can provide important benefits in terms of energy efficiency but must be user-friendly. In other words, they must be seen by the occupants as an important benefit and should hardly be noticeable in their operation.

2.1.3.2 Lighting Design and Operation

a) **Lighting Design:** The Lighting Design must provide conditions for the users to carry out their tasks safely, comfortably and with high productivity. This means following the recommendations provided by the Society of Light and Lighting. See Table 2.3. Here an illuminance uniformity recommendation of not less than 0.7 is assumed if uniform lighting is the aim of the designer (illuminance uniformity = minimum illuminance/average illuminance).

They are based on the following criteria:

- An average sized empty room (Room Index 2.5)
- High room surface reflectances (ceiling 0.7, Walls 0.5, Floor 0.2)
- High degree of installation maintenance (luminaires cleaned every year, room surfaces every three years, bulk lamp replacement every 10,000 hours)

It should be noted that the values could be higher or lower where variations in criteria are made.

Table 2.3: Lighting Energy Targets: Average Installed Power Density Per Application reprinted from CISBE Code of Lighting [Actionenergy, 2003]

Lamp Type	CIE General Colour Rendering Index (Ra)	Task Illuminance (Lux)	Average Installed Power Density (W/m^2)
Commercial and other similar application e.g offices, shops and schools			
Fluorescent – Triphosphor	80-90	300	7
Fluorescent – Triphosphor	80-90	500	11
Compact Fluorescent	80-90	300	8
Compact Fluorescent	80-90	500	14
Compact Fluorescent	80-90	750	21
Metal Halide	60-90	300	11
Metal Halide	60-90	500	18
Metal Halide	60-90	750	27
Industrial and Manufacturing Applications			
Fluorescent – Triphosphor	80-90	300	6
Fluorescent – Triphosphor	80-90	500	10
Fluorescent – Triphosphor	80-90	750	14
Fluorescent – Triphosphor	80-90	1000	19
Metal Halide	60-90	300	7
Metal Halide	60-90	500	12
Metal Halide	60-90	750	17
Metal Halide	60-90	1000	23
High Pressure Sodium	40-80	300	6
High Pressure Sodium	40-80	500	11
High Pressure Sodium	40-80	750	16
High Pressure Sodium	40-80	1000	21

The lit appearance of the building interior will also be important. These requirements will sometimes be possible through the use of non-uniform lighting that can also have energy saving benefits e.g. a task and building lighting design approach.

The use of experienced and qualified lighting designers is recommended for the best results.

b) **Daylight Availability and Electric Lighting Use:**

An important area of lighting energy efficiency is taking full advantage of the daylight availability and, therefore, reducing the need for electric lighting. It will be necessary, for optimum energy efficiency, to provide electric lighting to complement the daylighting to the best advantage. It will also be necessary to use lamps which have a colour appearance (CCT), of around 4000k so that the daylight and electric light will blend together reasonably well. However, it will never be perfect because the colour of daylight changes.

Daylight is often described in terms of the proportion of unobstructed daylight outside the building on a horizontal plane to that which will arrive inside a building at a particular point. This is called the Daylight factor, and can be translated into a likely minimum illuminance by knowing the proportion of a day, averaged throughout the year that a particular illuminance is likely to be exceeded. As an example, fig. 2.3 shows a plan of a room with windows in one side with Daylight factor contours across a horizontal plane at Desk height.

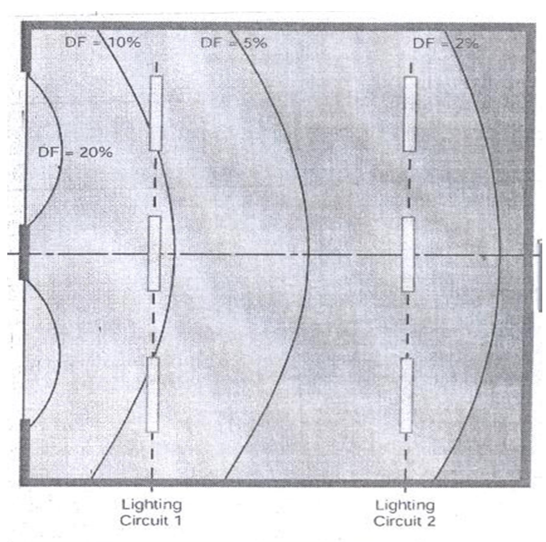


Fig. 2.3: Room Plan showing window positions and example daylight factor(DF) contours. Also ceiling-mounted luminaires and electric lighting circuits [Actionenergy, 2003]

The Diffuse Illuminance Availability for London and Edinburgh relative to a percentage of the working day is shown in fig. 2.4

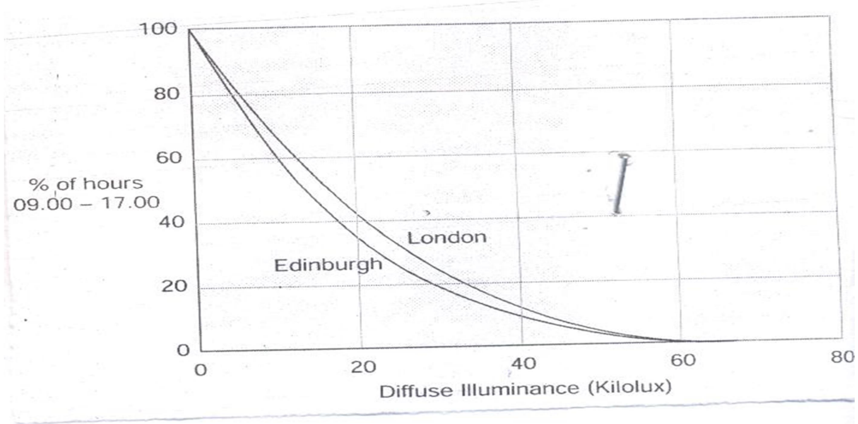


Fig. 2.4: Diffuse Daylight Illuminance for London and Edinburgh for a 09.00-17.00 hour day [Actionenergy,2003]

From this graph, it can be seen that for 60% of the year for a 09.00 – 17.00 length working day, in London, an illuminance of approximately 13 kilo lux will be exceeded. This will mean for the room shown in fig. 9 the area between the window and the 2% contour is likely to have an illuminance of at least 260 lux for 60% of the 09.00 – 17.00 day averaged throughout the year (i.e 13000x2/100 = 260 lux). From this, an estimate of the amount of electric light required for a particular illuminance can be found.

Daylight illuminance information can be calculated using one of a number of methods, usually using a computer, but as a simple rule-of-thumb, useful daylight will only penetrate into the room, a distance from the window of twice the window head height above the working plane level. This does not take account of a lot of parameters; so it should be used with great caution.

With these assessments, lights can switched on/off as appropriate either manually or automatically. It has been recommended that lights be switched off at a combined daylight/electric light of a least three times the required illuminance, to ensure that the switching action is not easily noticed.

Usually the lights are best switched on manually, but the circuits can be arranged to switch lights on when the illuminance level drops below a predetermined level, if this is seen to be appropriate. Automatically pre-set dimming techniques can be used as the best form of combined daylight and electric lighting control. Although this is more costly in terms of equipment, it may be cost effective if the installation lasts up to twenty years.

The following physical parameters of windows are necessary to assess in detail, the likely performance in providing useful energy efficiency benefits:

i) The window area

ii) Its position in the room

iii) The transmittance of the glass

iv) The orientation of the window

v) The degree of external obstruction to the window

Moreover, rooflights in single storey buildings and on the top floor of multi-storey buildings can be extremely effective in providing daylight, but with due consideration to prevent sun penetration.
Use of blinds can be used to reduce or eliminate glare if some measure of control can be put in place whether manually or automatically to ensure adequate handling.

c) **Occupancy and Electric Lighting Use:**

Occupancy or Presence/Absence controls are used to ensure that lights are not left on unnecessarily. This will make for an energy-efficient lighting installation and save the user money, provided that the controls are user-friendly.

2.1.3.3 Regulations and Incentives

The UK government, for example, has introduced regulations designed to improve the overall energy efficiency of lighting installations. It has also introduced tax incentives to further encourage energy efficiency through a system called Enhanced Capital Allowance (ECA). This allows a tax reduction when energy efficient equipment is purchased. Energy efficiency in lighting shall be encouraged if there are incentives from the government.

2.1.3.4 Important Highlights on Energy Efficiency in Lighting

Actionenergy (2003) recommended that calculating energy efficiency on the use of the total amount of electricity used for lighting (in kwh/year or kwh/m^2/year) in preference to power density (in W/m^2) will give the designer and user more flexibility in their approach to suit the particular requirements for the application.

By use of task and building lighting approach, it is possible from available statistics that over 50% savings can be achieved, with effective control to provide electric light only when they are needed. This would contribute to reductions in CO_2 emissions and their impact on climate change. However, such approach could lead to higher installation costs. It is expected that a well-designed installation that responds to the users' requirements and energy efficiency could well provide productivity benefits and lower operating costs. It is therefore necessary to consider a realistic time span with regard to overall cost effectiveness.

2.2 LIGHTING DESIGN STANDARDS, DATA AND FORMULAE

As highlighted earlier, electric lighting commenced at the close of 19th century. With the work of different professionals (lighting engineers/designers), lighting standards started to emerge after some years of experimentation. It was mentioned that Illuminating Engineering Society (now Society of Light and Lighting) was formed in Great Britain in 1909. Some years later (in 1913), the International Commission on Illumination (CIE) was formed to be a successor to the Commission International de Photometrie, which was formed few years earlier [Wikipedia, 2010]. The CIE has set up various lighting standards through her seven active divisions.

The SLL Code for Lighting first published more than 70 years ago and in CD-ROM format since 2002, is the primary guidance document on lighting in the UK. It was last updated in 2012. The new edition includes an additional section on road lighting as well as lighting guide 9: Lighting for Communal Residential Buildings. The SLL Code for Lighting encompasses all aspects of the design, installation and maintenance of Lighting. It covers both electric lighting and day lighting, as well as their integration (Peck, 2009a). The efficacy, illuminance and power density data of Tables 6-8 are part of this current edition, as it is an SLL submission to [Actionenergy, 2003]. SLL Code is also known as CIBSE Code for Lighting, as SLL is a division of CIBSE (Chartered Institute of Building Services Engineers). Moreover many other countries have their various indigenous lighting societies.

The CIE has branches spanning over 40 countries. However, South Africa was the only African Country in the list I glanced through [Halonen; Puolakka, 2010]. There are also other international professional lighting associations such as International Association of Lighting Designers (IALD), Professional Lighting Designers Association (PLDA) etc.

I must confess that Electrical Engineers in Nigeria have taken good strides in terms of coming up with standards (e.g. CAP 106, the NERC Codes, Electrical Installation in Public Buildings etc) but we are yet to have viable standards in lighting in the country. In this section, it will not be surprising, therefore, that the lighting standards to be discussed or utilized are either international or UK-based. Some US-based standards/agencies shall also be discussed.

2.2.1 Lighting Standards and Agencies

A work by [Field; Soper, 2002] compared various established methods for assessing or regulating buildings energy efficiency in the UK, USA and Sweden. A selection of approaches was compared and conclusions drawn about the type of approach and the benchmark standards set. It could be drawn from this work that system benchmarks, such as electrical power density and efficacy are becoming more widely used and could transcend national boundaries more easily than building energy consumption benchmarks. The following lighting energy standards were considered.

(a) California Title 24:

Title 24 is a detailed energy code and compliance is required generally for new buildings and major refurbishment in the State of California, USA. There are mandatory requirements for lighting controls including room controls, controls for day-lit areas and "bi-level" switching (allowing operation at 50% output or dimmed). The **prescriptive installed power approaches** include limiting the installed lighting for the whole building or by area such as **Hotel lobby (24 W/m^2)** and **General commercial work low bay (10.8.W/m^2)**. A further option includes standards for installed power based on **illuminance (quality)** categories.

This regulation was produced by an enforcing organization (California State). Emphasis was therefore placed on certification. For example, the system benchmarks (in W/m^2) cannot easily be related to annual energy use, thereby making it difficult for design intentions to be verified. It requires a full dynamic simulation

.

(b) American Society of Heating, Refrigeration and Air-conditioning Engineers, ASHRAE 90.1-1999,USA:

ASHRAE 90 is a US-wide energy code which can form the basis of local regulation. For lighting, there is a whole building approach in which interior lighting power allowance is derived from the building floor area and the lighting power densities – for example, offices are 14W/m^2 and a warehouse is 13W/m^2.

Alternatively, the interior lighting power allowance can also be made up from different areas within a building for example, as shown in Table 2.4 which shows that the lighting density for each space type normally does not change.

Additional lighting power is allowed for specific purposes as follows:

- Decorative chandelliers, 10.8W/m^2
- VDU lighting, 3.8 W/m^2
- Retail highlighting – 17W/m^2 for fine merchandise.

There are exterior lighting allowances based on linear or m^2 limits. Selected building types and space types are shown.

Table 2.4: lighting power density using the space-by-space method [Field; Soper, 2002]

Space Type Building Types	Lighting Power Density (W/m^2)		
	Office	Hospital Health Care	Hotel
Office – Enclosed	17	17	17
Office Open Plan	14	14	14
Conference Meeting/Multipurpose	16	16	16
Food Preparation	23	23	23
Restrooms	10	10	10
Corridors & Transition	8	17	8
Stairs – Active	10	10	10
Active Storage	12	31	12
Inactive Storage	4	4	4
Electrical/Mechanical	14	14	14
Building – Specific	Banking 26 Laboratory 20	Emergency 30 (etc various)	Guest rooms 26
Additional Power Allowance	Yes	Yes	Yes

This approach requires a full dynamic simulation.

(c) ASHRAE Standard 100-1995, USA:

This is system efficiency standard for existing buildings and, dating back to 1995, it has possibly been overtaken by current normal standards. Its approach to lighting is that a building's lighting power (adjusted for the level of automatic control) must be less than the lighting power allowance which is specified for each usage area with allowance for room shape. This must be achieved separately for interior and external lighting.

The controls factor is given for various combinations of controls rising to a maximum of 40% for occupancy sensing and daylight sensing with continuous dimming. Further requirements are that fluorescent lamp ballasts have specified minimum efficiencies, and the minimum number of control points, their types and accessibility are specified.

Examples of exterior connected lighting power allowances are 82 watts per linear metre of building exit door way and 2.7W/m^2 of external surface to be illuminated. This older code has higher allowances (e.g limiting system W/m^2)

(d) Energy Consumption Guide 19, UK (ECON 19): ECON 19

Energy Use in Offices provides annual energy consumption benchmarks for existing buildings – both at whole building and system level. Recent editions include system benchmarks for W/m^2, hours of use and KWH/m^2 for typical and Good Practice benchmarks in Table 2.5.

Table 2.5: Lighting Benchmarks for Offices, Econ 19 [Field; Soper, 2002]

Office Type	Type 1: Naturally Ventilated Cellular		Type 2: Naturally Ventilated Open Plan		Type 3: Standard Air conditional Office		Type 4: Prestige Air-conditioned Space	
	Good Practice	Typical	Good Practice	Typical	Good Practice	Typical	Good Practice	Typical
Connected Power, W/m^2	12	15	12	18	12	20	12	20
Occupied hours per year	2500	2500	3000	3000	3200	3200	3500	3500
Fraction on (%)	45%	60%	60%	70%	70%	85%	70%	85%
Lighting Energy Use, KWh/m^2/yr	14	23	22	38	27	54	29	60

The connected load of 12W/m^2 can be related to 400 lux and 3W/m^2 per 100 lux in offices.

This approach can therefore relate system installed powers to annual energy consumption benchmarks, and procedures for investigating this in existing buildings are specified in CIBSE Office Assessment Method. These procedures have no explicit allowance for exterior lighting; there is also a table for energy-related CO_2 emissions benchmarks.

(e) Energy Performance Indicator Method (EPIM), UK

EPIM provides a broad assessment of efficiency at the design stage based on installed loads and controls. In the EPIM, the lighting contribution to the total building electricity use is calculated from the connected power of lighting, the typical annual equivalent hours of full load operation (taken to be 2000 hours for a naturally ventilated office and 3000 hours for an air-conditioned office) and a control and management factor which has different values depending on the extent of monitoring and targeting, the proportion of the building with time and occupancy control and the proportion of the building with day lighting available which is fitted with lighting controls.

While the lighting performance is not separated, the overall building energy-related CO_2 emissions are compatible with ECON 19 targets. The inclusions of variability with time, occupancy, daylight and daylight control are achieved without undue complexity.

(f) CIBSE Energy Codes Part 1 and 2 1999, UK

The CIBSE Energy Codes provide a tool to assist with low energy design of buildings. The two codes use the same approach for lighting. The annual lighting energy is calculated from the floor area of each zone, the installed lighting load (as in Table 2.6), the lighting diversity factor for month (derived from annual diversity factor which are tabulated for required illuminance levels, room orientation, glazing percentage and glazing transmission factor). Allowances for occupancy diversity and task lighting are also included.

Table 2.6: Lighting Power Densities, CIBSE Energy Codes [Field; Soper, 2002]

LIGHTING POWER DENSITY (W/M^2)									
FLUORESCENT TUBE (WHITE)								TASK LIGHT	
Illuminance (lux)		Halogen Down Light 50W/12V	SON High Bay Reflector	MBF High Bay Reflection	Open Trough	Industrial	Enclosed Surface	Tungsten	Florescent
-	-	-	-	-	-	-	-	1.1	0.28
150	22	3	5	6	4	7	7	-	-
300	40	6	10	12	9	14	15	-	-
500	N/A	10	19	20	15	23	26	-	-
750	N/A	15	26	28	22	32	37	-	-

(g) CIBSE Interior Lighting Code, UK

This interior lighting Code has target ranges of installed power density (W/m^2 per 100 lux) for different lamp types and room index to be used with recommended lux levels.

(h) UK Building Regulations

The UK Building Regulations for lightings control and lamp efficacy or connected load requirements introduced and upgraded in 1995 have been considerably strengthened in later editions. The EPIM method described in item (e) above may be incorporated as a carbon performance index.

The following remarks should be noted when considering the above standards/agencies:

Most of the methods include basic installed lighting power per unit area limits or allowances. These generally get more onerous with time – the 1995 ASHRAE 100 allowances at 20 to 30 W/m^2 for offices are possibly no longer useful, and current ASHRAE 90 allowance at 14 W/m^2 can be compared with ECON 19 "Good Practice" and Title 24 levels of 10-12 W/m^2.

The need for explicit allowance of room (shape) factor appears to vary strongly between the methods – this introduces significant extra work for the user and the value is not obvious.

The US systems explicitly allow for external lighting. This would seem to be useful to reduce the imbalance between buildings with external lit facades, entrance and possibly parking lots.

The ECON 19 and ASHRAE 90 "simple" approach consider whole-building average lighting power density, which is a useful starting point in many cases.

The way in which codes are expected to be used differs-Title 24 is intended to be assessed by a professional engineer and certified accordingly – with the advantage of full support of California State in enforcing the requirements. The potentially complex allowances and whole-building approaches required considerable expertise and professional trust. The CIBSE Energy Codes and more detailed ASHRAE 90 procedures also require detailed appraisal, but these organizations cannot themselves enforce the Codes.

The ECON 19 and EPIM approaches can relate installed loads to annual energy benchmarks and annual energy consumption in use, without the use of complex calculations. It is a point of debate whether the simplifications required for this leave the results as useful when not used by highly experienced engineers.

For the purpose of this dissertation, any of the standards used at any point in the design shall be indicated and where necessary, further detailed tables shall be shown on the relevant data to be adopted.

2.2.2 Lighting Design Formulae and Photometric Data

Lighting design is an important component within the building design procedure. A designer should always aim to create a comfortable, pleasing environment within which the occupants can conduct their duties safely and to high levels of satisfaction. Poor lighting design leads to creation of problematic environment from a psychological, functional and practical perspective.

In the interest of reducing building energy utilization and the associated environmental impact, designer's efforts have focused on the use of daylight within new building designs. This is supported by natural daylight illumination being better suited to the sensitivity of the eye due to its tuned responsiveness to the wavelengths making up daylight.

The choice of lamp for a given task must be made carefully. This is influenced by the ambiance the designer wishes to create and the tasks being undertaken within the environment. It is best practice to use the highest efficacy lamp available and suitable for the task being undertaken.

$$Lamp\ efficacy = \text{Ø}/P\ (Lm/W)(1) \qquad (2.1)$$

Where Ø = Luminous flux (lm)

P = Lamp Power (W)

In practice, artificial lighting has to be designed into buildings to compensate for lack of daylight in either non-glazed locals or during night-time hours of operation. The design methods usually adopted either utilize the direct beam of light from a lamp when illuminating the working plane in large high ceiling (accent or task lighting) or outdoor spaces or direct, diffuse and reflected light when illuminating confined internal spaces.

Determining the luminance of a surface is the most precise part of lighting specification. In application, two basic situations arise when a surface is to be illuminated [ERSU, 2008]:

a. Direct illuminance at a specific point on a plane.
b. Average illuminance on a surface due to both the direct flux and diffused/reflected flux from other surfaces.

a. **Direct Illuminance:**

The illuminance at a small specific location in the room from a point light source can be determined either by [ERSU, 2008; Mitroy, 2009]:

i. Simply getting polar plot for the luminaire and working out the illumination on the surface for a given lamp.
ii. Using the Inverse Square Law:

$$Eo = \frac{I_0}{H^2} \qquad (2.2)$$

Where Eo = illuminance on measurement plane (lux)

I_o = intensity towards point A (cd)

H = height of light source above the plane (m).

(iii) Using the Cos^3 law of illumination:

$$E = \frac{I\emptyset \, \mathrm{Cos}^3 \, \emptyset}{H^2} \tag{2.3}$$

Where I = intensity towards another point B away from point A in item (ii) above

Ø = Angle of tilt of surface from the incident light.

The above methods are used for single point task lighting and typically used in large high ceiling areas (warehouses), sports halls and floodlighting applications.

b. Average Illuminance

When designing a lighting system for more confined but broad areas with low ceiling heights, a different method is required since the point of illuminance is illuminated by direct and diffused/reflected light from surrounding surfaces. The method for determining the illumination pattern is called the **total flux** method or **lumen** method. This is used to get rough and reasonable estimates of the lamps/luminaires needed. This method applies where a uniform light intensity is required in work area. It is used for rectangular rooms with gridded luminaire pattern. The variation of illuminance should not be less than 70% of the maximum illumination level [Mitroy, 2009].

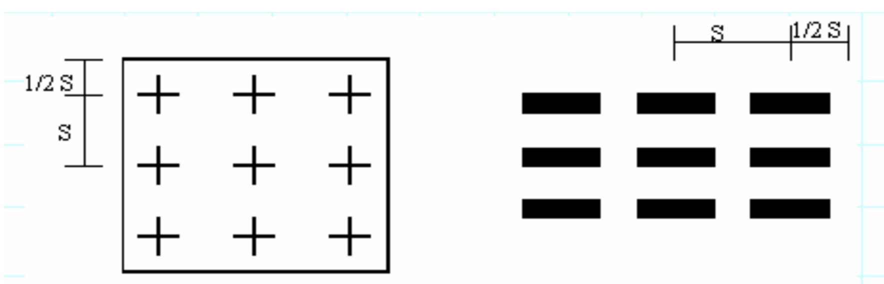


Fig. 2.5: Gridded Luminance pattern [Mitroy, 2009]

To determine the illumination level on a work plane for a lighting pattern in F:g. 2.5, the following equation applies:

$$E = \frac{\emptyset_{rec}}{A} \tag{2.4}$$

Where E is the illumination level required at the work plane

A = the total area of the plane

$\O_{rec}$ = the flux of light received on the plane

The main issue is to determine the how much flux needs to be installed i.e. $\O_{inst}$ to get the required amount of received flux $\O_{rec}$. First of all, determine how much flux is to be received:

$\O rec = EA$ (from eqn 2.4))

$\O_{rec}$ is related to the $\O_{inst}$ by a simple formula:

$$\O rec = MFxUFx\ \O inst \qquad (2.5)$$

Where MF = Maintenance Factor

UF = Utilization Factor.

The Maintenance Factor:

This gives an estimate of how the lighting conditions will deteriorate through use. Some Factors are:

i. Dust and dirt inside luminaire surfaces.

ii. Ageing of light bulbs, causing it to emit less light

iii. Cleaning of room surfaces e.g ceiling.

Without detailed knowledge of a maintenance plan one sets MF = 0.80

The Utilization Factor

This defines the proportion of lamp light output that reaches the work plane. It depends on the following:

i. The Luminaire Properties:

One needs to determine the amount of light emitted by the lamps that actually leaves the luminaire i.e the Light Output Ratio (LOR). For example, an enclosed lamp in a luminaire with low reflectivity will have lower LOR than a naked lamp.

ii. The Respective Values of Upward LOR (ULOR), and Downward LOR (DLOR):

The light emitted downwards will probably reach the work plane without reflections. However, the light emitted upwards can only reach the plane after reflection(s) from surfaces. A large DLOR usually means a higher UF.

iii. The Reflectance of the Room Surfaces:

This defines how light or dark in colour the surfaces (walls, ceilings) are. The larger the ULOR, the more important this factor becomes. Some typical reflectance values are:

Table 2.7: Reflectance Values Ranges for Various Colour Schedules [Mitroy,2009].

COLOUR	REFLECTANCE
White, off-white, light shades of grey, brown, blue	75-90%
Medium green, yellow, brown or grey	30-60%
Dark grey, medium blue	10-20%
Dark blue, green, wood paneling	5-10%

(A colour with strong chroma does not reflect other colours). Reflectances are available from manufacturers of paints and furniture finishings. It is usual to make the reflectance of the ceiling highest, walls, slightly lower and the floor, darker. The following values are recommended in office :

Table 2.8: Reflectance Values for Room Surfaces [Mitroy, 2009]

SURFACE	REFLECTANCE
Ceiling	70-90%
Wall	50-70%
Floor	20-50%
Desk	20-40%

Very dark wood or bright surfaces are not recommended for work planes.

iv. The Geometric Proportion of the Room:

A factor called the Room Index (RI) is defined from the horizontal and vertical areas of the room.

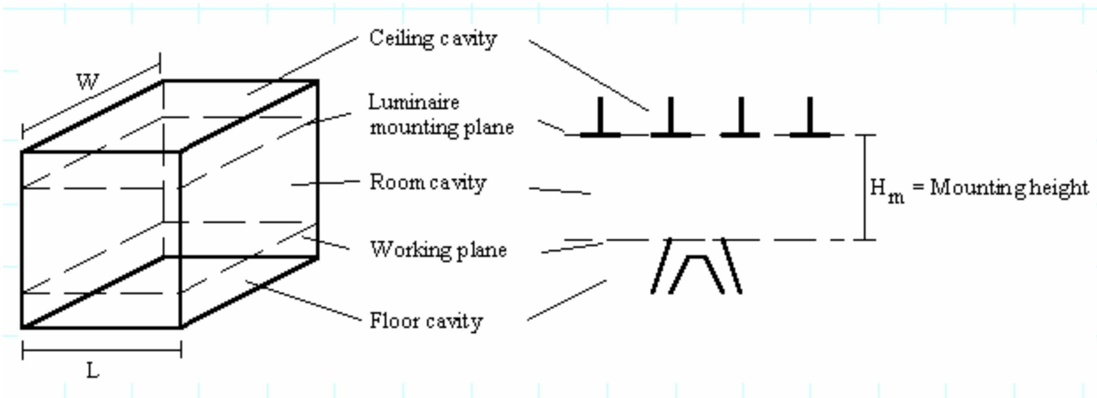


Fig 2.6: Typical Room Dimensions [Mitroy, 2009]

The horizontal areas are:

$$Area\ (H) = 2xLength\ x\ Width = 2xLxW \tag{2.6}$$

The vertical areas are:

$$\begin{aligned} Area\ (V) &= 2x\ (Length + Width)\ x\ Height\ (Lum) \\ &= 2x\ (L + W)x\ Hm \end{aligned} \tag{2.7}$$

The mounting height, H_m is the vertical distance from the work plane to the Luminaire. The RI (the factors of 2 cancel) is:

$$RI = \frac{Area(H)}{Area(V)} = \frac{LxW}{(L+W)xH_m} \tag{2.8}$$

v. **The Direct Ratio:**

This is the proportion of the downward luminous flux that reaches the work area directly without reflection. It depends on:

- **The Shape of the Room:**

  The Direct Ratio has a low value with a tall narrow room (small RI) and a high value for a wide room (large RI).

- **The Light Distribution from the Luminaires:**

  Luminaires that emit light through a larger solid angle will generally have a smaller Direct Ratio than ones that emit light in a narrower beam.

There exist data sheets of UF for rooms of different shapes and luminaires of a common type. Catalogues of luminaires often provide data sheets of UF for rooms.

Steps for Getting Uniform Illumination

As a rule-of-thumb, to achieve uniform lighting requires the spacing between the luminaires to be no larger than 1.5 times the mounting height:

$$Luminaire\ spacing\ <\ 1.5\ Hm \tag{2.9}$$

The following steps have been found useful for the calculations:

i. Decide on luminaire type and how many will be needed.

ii. Determine Room Index.

iii. Reflectance of ceiling, walls and floor estimated.

iv. Utilization factor for luminaire determined.

v. DLOR for luminaire determined

vi. Determine necessary flux.

$$\emptyset_{inst} = \frac{\emptyset_{rec}}{MFxUF} = \frac{ExA}{MFxUF} \tag{2.10}$$

vii. Work out the number and size of luminaires by trial and error method.

viii Test for uniformity of lighting using spacing-to-height ratio (SHR). SHR is the ratio of the centre-to-centre distance between adjacent luminaires, to their height above the working plane. For a rectangular luminaires arrangement:

$$SHR = \frac{1}{H_m}\sqrt{\frac{A}{N}} \tag{2.11}$$

$$A = total\ area$$
$$N = number\ of\ luminaires$$

Precisely, for uniform lighting:

- The SHR should not exceed maximum spacing-to-height ratio (SHRmax) of the given luminaire as quoted by the manufacturer, and
- The geometric mean SHR of the luminaire layout should be within the range of nominal SHR (SHRnom) of the given luminaire as quoted by the manufacturer, i.e

$$\sqrt{SHR(Length)xSHR(Width)} = \text{SHR}_{nom} \pm 0.5 \qquad (2.12)$$

Lighting Layouts

A regular arrangement of lights is advised for uniform lighting patterns. Generally, for linear luminaires, the long luminaire is kept parallel to the long room axis. Diffusers are recommended for production of flat lights. Provisions for general and task lighting respectively can be made where necessary. See the next section for further service illumination recommendations for various working spaces.

Further Details of Maintenance Factor

The details of the Maintenance Factor depends on a number of different inputs:

$$MF \ = \ LLMFx\ LMFx\ RSMF \qquad (2.13)$$

Where LLMF = Lamp Lumen Maintenance Factor, its light output as it ages, obtained from manufacturer catalogues.

LMF = Luminaire Maintenance Factor, defines how much dust or grime could be deposited on the luminaire surface.

RSMF = Room Surface Maintenance Factor, defines how clean the room is kept. Dirt on walls and ceilings reduce reflectivity and illumination.

Table 2.9: Typical LLMF for Lamps [Mitroy, 2009]

	Hours	6,000	10,000	12,000
Lamp Type				
Fluorescent, Tri-phosphor with electronic ballast	LLMF	0.99	0.96	0.95
Metal Halide	LLMF	0.72	0.66	0.63
High Pressure Sodium	LLMF	0.91	0.88	0.87

The LMF and RSMF depend on what is going on in the room.

According to SLL Handbook, rooms can be divided into a number of categories: very clean (VC), clean (C), medium (M), Dirty (D), very dirty (VD).

The LMF further depends on the type of luminaire: whether it is a naked bulb, whether it has diffusers, reflectors, uses louvres.

Table 2.10: LMF for Lamps [Mitroy, 2009]

Cleaning Interval	LMF	1 year			2 years			3 years		
Environment	LMF	C	N	D	C	N	D	C	N	
PERLUCE	LMF	0.94	0.90	0.86	0.91	0.86	0.81	0.90	0.84	0.79
IP 20 LUMINAIRE	LMF	0.88	0.82	0.77	0.83	0.77	0.71	0.79	0.73	0.65

C = Clean (clean rooms, computer centers, hospitals)

N = normal (offices, shops, schools, restaurants)

D = dirty (chemical plants, wood processing plants, welding shops)

According to CIE text 97 “Maintenance of indoor electrical lighting systems”, 1995 edition, ISBN 3 900 734 34 8:

Table 2.11: Maintenance Factors for Lamps [Mitroy, 2009]

Luminaire	Perluce	IP 20 Luminaire
Lamp lumen maintenance factor: LLMF	0.92	0.92
Lamp life survival factor: LSF	0.96	0.96
Room surface maintenance factor: RSMF	0.95	0.95
Luminaire maintenance factor: LMF	0.84	0.73
Maintenance factor: MF	0.70	0.61

Rough Estimation of Number of Luminaires

Majority of lighting engineers arrive at the minimum of fittings required by scaling them off on the plan. Alternatively, it can be derived from the formula [Newnes, 1988]:

$$N = \frac{L}{MS} x \frac{W}{MS} \tag{2.14}$$

Where L and W are the length and width of the room, and MS is the maximum space between fitting (m). Each part of the equation is worked out separately to the nearest whole number above the actual answer, There are also two simple equations for determining the grid layout of luminaires [Bentley, 2009]:

$$NL = \sqrt{Nx\, L/_W} \tag{2.15}$$

$$NW = \sqrt{Nx\, W/_L} \tag{2.16}$$

Where NL = Number of luminaires required for the length of the room

NW = Ditto width.

N = Total number of luminaires

L = Length of the room

W = Width of the room.

2.2.3 Standard Service Illuminance

The illumination of any lighting installation in confined areas is measured at the working surface which is an imaginary horizontal plane 0.85m above the floor level. The level of illumination required for any particular eye task depends upon the following factors [Bhatia, 2006].

i. **Type of Work:**
   Working may be sub-divided as minute, very small, ordinary and large.

ii. **Duration of Work:**
   The longer the working hours in artificial light, the higher the level of illumination required for doing the small job.

iii. **Contrast with the Background:**
   The higher the contrast, the smaller the level of illumination required, and vice versa.

iv. **Quality Requirements of Product:**
   The finer the quality, the higher the illumination required.

v. **Average Age of the Staff or the personnel** by whom light is to be used.

The following values of standard service illuminance were recommended in the CIBSE Code 1984 [Newnes, 1988]:

Table 2.12: CIBSE Code 1984- Standard Service Illuminance [Newnes, 1988]

Task Group and Typical Task or Interior	Standard Service Illuminance (lux)
Storage Areas and Plant Rooms with not continuous work	150
Casual work	200
Rough work: Rough Machinery and Assembly	300
Routine work: Offices, Control Rooms, Medium Machining and Assembly	500
Demanding work: Deep plan drawing, or business machine offices, inspection of Medium Machinery	750
Fine work: Colour discrimination, textile processing, fine machining and assembly	1000
Very fine work: Hand Engraving, inspection of fine machining and assembly	1500
Minute work: Inspection of very fine assembly	3000

There are also further detailed recommended levels of illumination for residential and non-residential places [Bhatia, 2006]. The illumination necessary for reading good print for different ages are given as follows:

Table 2.13 Age-based illuminance Requirements [Bhatia, 2006]

Age	**illumination**
10 years	175 Lux
40 years	500 Lux
60 years	2500 Lux

For comfortable working conditions, the contrast in brightness in the field of vision must not exceed the following ratios:

i Between visual task and working plane …………………......3:1

ii Between visual task and surroundings ……………………10:1

iii Between light source and background ……………………..20:1

iv Greatest Luminance difference in the field of vision………40:1

However, the desirable luminance ratios between the visual task, the immediate background and the general environment are 5:2:1. The ratios 10:3:1 as given above are to be taken as the outside limits.

From the preceding sections, it should be noted that much innovations have taken place in lighting designs which now necessitates some modifications in these standards. For example, for the sake of lighting efficacy, benchmarks are now placed in form of power densities. This implies that even if these standard values of illuminance are adopted, the amount of lighting energy demand should be minimized by choice of more energy-efficient lamps. The introduction of daylighting and optional controls have reduced the use of high artificial lighting illuminance values. [Cuttle, 2009] and [Boyce, 2010] advocated some reduction in values of these earlier prescribed standards of illuminance. Some of these views were also shared in the foregoing sections.

2.2.4 General Remarks

As stated in the concluding part of the preceding section, so many innovations have been introduced into lighting designs. But the general principles still hold. For example, the following principal considerations must be kept in view when planning a lighting installation:

i. Required level of illumination.

ii. Spatial distribution of light i.e direction of incidence, direct, diffuse or indirect lighting etc.

iii. Requirements of colour rendering, colour appearance etc.

iv. The choice of light sources and the fittings in view of life, shape, need for control gear, starting and re-starting time, effect of ambient temperature, relative cost (initial and running), accessibility.

In this era of climate change, item (iv) is considered in terms of energy efficacy. However, some new lamps and fittings have been invented such as LEDs (solid state lighting), T5 or T16 (now replacing old T8 and T12) fluorescent lamps, with electronic ballast (now replacing old Halophosphor lamps), CFLs (now replacing incandescent lamps in homes/offices) etc.

With the predominant use of computer screens, and other modern tasks, glare is becoming a major concern in lighting design. The discomfort glare constant is given by [Mitroy, 2009]:

$$G = 0.45 x \frac{{L_s}^{1.6} W^{0.8}}{L_B P^{1.16}} \tag{2.17}$$

Where Ls = Luminance of the source of glare

L_B = average luminance of the background sources.

P = position index (an indication of the position of where the light source is located in the field of view. P is small when light is in field of view)

$$W = \frac{Area\ of\ Glare\ Source}{(Distance\ from\ source)^2} = Solid\ angle\ of\ glare \tag{2.18}$$

Glare index is given by:

$$GI = 10\ log_{10}\ (G) \tag{2.19}$$

The following ranges of glare index are used as guides in lighting designs:

Table 2.14: Glare index Ranges [Mitroy, 2009]

Glare Index	Reaction
0-10	Imperceptible
10-16	Noticeable
16-22	Acceptable
22-28	Uncomfortable
28	Intolerable

The following limiting values of Glare Index are recommended for various tasks and working spaces:

Table 2.15: Limiting Values of Glare Index [Mitroy, 2009]

Limiting GI	Tasks/Working Spaces
16	Drawing offices, very fine visual inspections
19	Offices, Libraries, keyboards and VDT Work (reflections from screen)
22	Kitchen, Reception Area, Fine Assembly
25	Stock Rooms, Assembly Line for easy tasks
28	Indoor Car Park, Rough Industrial Work

Glare from all sources is additive:

$$GI = 10\, log_{10}\,(G1 + G2 + G3 + \cdots) \qquad (2.20)$$

The control of glare can be done by taking a close look at equation 2.17 above:

i Ls: Keep the illuminance of source down by use of diffusers, louvres etc. Instead of having one bright light source, have a number of dimmer luminaires. The background can be illuminated to reduce glare.

ii P: Keep the luminaires out of field of view. High ceilings are good. Field of view is roughly horizontal and about 1.2m above floor. Walls and floors should not have too high reflectance.

iii W: Keep area of source small.

iv Moreover, luminaires that emit light to sides (e.g batten luminaires with a diffuser at the sides) should be avoided. Light emitted more in downward direction avoids visual discomfort though it results in a darker ceiling which has an oppressive psychological effect.

v Uplighting and wallwashing can be used with luminance kept below 500 cd/m^2 average and 1500 cd/m^2 maximum. This is however an inefficient lighting technique.

vi High ceiling can be used to get an even illumination, using combinations of direct diffuse and indirect lighting.

The design techniques to be used in this work shall be described succinctly in the next chapter.

2.3 Special Case of External/Security Lighting

External/Security Lighting can be understood in terms of floodlighting, a unique lighting installation that provides never-ending 'daylight' for areas such as airline terminals in airports, restaurants, a hotel, retail shops, extensive parking lots and huge botanical garden [Microsoft Corporation, 2007b]. In this kind of lighting, [Bhatia, 2006] recommends the following considerations:

(i) An illuminance level of 10lux is used as applicable to parking lots

(ii) Efficiency factor is assumed as 0.4. The efficiency factor takes into considerations the depreciation in light output of lamps, soiling and loss of light in the working area etc.

(iii) Number of fittings are approximated to a quantity immediately above the decimals e.g. 0.4 = 1

$$No\ of\ fittings, Na = \frac{Area\ to\ be\ light\ \ (m^2)x\ Illuminance(lux)}{Light\ Output\ per\ fitting\ x\ Efficiency\ factor} \tag{2.21}$$

CHAPTER THREE

MATERIALS AND METHODS

3.1 CONSIDERATIONS FOR AN ENERGY-EFFICIENT LIGHTING DESIGN

The design of an energy-efficient lighting installation is a marriage of art and science [Entwiste, 2010]. It is a mix of considerations of energy efficiency, lighting and demand/supply economics, and facilitated by simple assumptions for effective approximations of some design functions. In this work, the following considerations were made:

3.1.1 ASSUMPTIONS

The following assumptions were made with respect to lighting designs inside the building:

a) The work plane is the desk/bench and the floors of rooms should be tiled grey (background)

(b) Each room space is of the same height

(c) There is no detailed knowledge of maintenance plan

(d) The Laboratory spaces are used for both practical work and other classroom exercises.

On the external surfaces, external/ security lighting around the building can be considered in terms of floodlighting with the following approximations:

(a) Projections on the walls and wardrobes, shelves, etc. of less than 1.0m is considered flat.

(b) Security lighting covers 10m from the light sources placed 3.4m above ground level, and on/above lintels and on walls as the case may be.

(c) An illuminance level of 10lux is used as applicable to parking lots [Bhatia, 2006].

3.1.2 CRITERIA FOR SELECTION OF LAMPS/FITTINGS

It is necessary at this point to point out the following techniques used in this design:

(i) The utilization of the space determined the type of lamps/fittings. For example, linear fluorescent fittings of high efficacy were selected for use in offices, Baseled ceiling fittings for toilet areas (good replacement for GLS lamps) etc.

(ii) Much effort was put into browsing of fittings produced by different manufacturers in order to make use of lamps of high efficacy. Adequate use of Tables 2.1 and 2.2 proved helpful.

(iii As much as possible, replication of lamps was encouraged, to enable orders to be placed easily. For example, by inspection, some fittings of same ratings and manufacturers were used.

(iv) One may observe that low-medium wattage lamps were used. This is to reduce glare. See some remarks under Equation 2.17 on the control of glare (L_s).

(v) Colour Rendering Index of lamps was considered. For example, Light Emitting Diodes were not used in offices because of their varying CRI. Lamps of Class 1B were selected for offices.

(vi) Correlated Colour Temperatures (CCT)**:** Lamps of CCT of 5000K range (COOL) recommended for offices were selected.

(vii) Safety**:** CFLs were not used in offices because its electromagnetic field effects have not been fully ascertained [Raynham, 2010].

(viii) In order to reduce cost, Plain Batten Fluorescent Fittings were used instead of ones with diffusers/louvers. With use of the latter, the number of fittings to be used per space increases. See Appendix A.

(ix) Thorn fittings are available, reliable and efficient. For ease of procurement, the installer could place orders through agents at the piping stage. By the repetitive specification of fittings of the same manufacturer, it is easy to achieve a quantity margin that would be acceptable to the distributors for packaging and haulage.

(x) This design emphasizes on energy-efficiency in view of climate change. Any increase in cost can be recovered through the period of use, with reduction in energy consumption bills. Moreover, modern Thorn fittings specified in this design have proven records of long life.

(xi) The degrees of protection (IP) were considered while selecting the type of fittings (encasement) in particular spaces. For example, IP20 fluorescent fittings were specified for offices (indoors) while IP65 fittings would be for security lighting. See Appendix B for details.

(xii) Dimmability of a lamp/fitting is a major factor in luminous control during daylighting applications. All lamps specified in sensitive areas in this design are dimmable.

(xiii) Only lighting was considered here. It does not mean that other accessories should not be incorporated in the services installation. The Distribution Boards here therefore take care of only the lighting installation, but with some provisions for other low-powered appliances as spares.

(xiv) Manual switching devices were specified at the first stage of this work while automated switching devices were incorporated for day-lighting application stage of the design.

3.1.3 THE PROJECT WORKSCOPE AND PROCEDURES

This work programme was broken down into the following stages, carefully arranged and executed using some standard formats:

(i) **Review of the principal characteristics of lamps in common use:** As discussed in Chapter 1, these include colour appearance and colour rendering, light output and efficacy, life (service period and lumen maintenance), energy use and dimmability, starting and re-starting time, effect of ambient temperature, need for control gear, relative cost, accessibility, etc.

(ii) **Review of some available lighting theories, standards and design formulae/lamps photometric data**: These were discussed in chapter 2. The key formulae used were as follows:

(a) Equation 2.5 with its derivatives for Building Interiors.

(b) Equation 2.21 with its derivatives for Building Exterior/Security.

(iii) **Compilation of the lab building design data per space**: These were taken from the available Architectural Drawing, including dimensions, colour schedules, usage, etc.

(iv) **Use of the design formulae and prevailing standards to establish the lumen ratings of lamps to be used**: Standards here include space use illuminance requirements, fittings types specifications, etc as discussed in the foregoing sections.

(v) **Browsing through manufacturers' catalogues to select the appropriate lamps/fittings to suit the task/application**: These involved the inspection of lamps/fittings types produced by different manufacturers in their respective websites, making comparison of their photometric data, usage, compactness, aesthetics, etc.

(vi) **Tests for energy efficiency in view of energy benchmarks of relevant standards**: Regulated energy efficacies of lamps/fittings produced in Europe are published in Voltimum website. For convenience and data integrity, such data and energy benchmarks (as in Tables 2.1- 2.12) were used for the analysis.

(vii) **Carry out load calculations and use AUTOCAD tools to present the design, including the Control/Distribution Boards Schematics**: Key Formula used for load calculation is:

$$Current\ per\ phase = \frac{P}{\sqrt{3}\ x\ V\ x\ 0.8} \tag{3.1}$$

Where P = Total Estimated Power(calculated from ratings of fittings)
V = Phase-Phase Voltage
0.8 = Nominal Power Factor

(viii) **Apply day-lighting and efficient control techniques in the design of a selected space and estimate possible energy savings**: Average daylight illuminance at different points in the space was obtained using Digital Luxmeter at mild daylight hours, relevant contours sketched and an average additional artificial illuminance estimated. Automated switching devices were specified based on the manufacturers' data.

(ix) **Assess an existing lighting design/installation of the space, using prevailing standards and observe any case of over-lighting/under-lighting**: The design was made by an external (indigenous) consultant. The assessment was facilitated by the available photometric data of fittings used (accessed over the web) and illuminance formulae in Equation 2.5.

(x) **Carry out comparisons on the luminaires between the old and the above (new) designs** in terms of standards used, luminaires efficacy, expected life, space illuminance levels and cost, and in view of day lighting applications.

(xi) **Use of DIALUX lighting design software to carry out comparative simulation of illuminance levels of the old and new designs** to observe the illuminance distribution.

(xii) **Statement of the findings/recommendations for an improved lighting design**: These were stated as applicable to our professional environment.

3.2 IMPROVED LIGHTING DESIGN OF A TYPICAL UNIVERSITY LABORATORY BUILDING

This work was handled under the following headings:

3.2.1 DIMENSIONS AND OTHER DESIGN DATA

The following Architectural design paint schedules and other available data of rooms and other spaces were collected:

Table 3.1: <u>Design Data for Lighting Design of a Typical University Laboratory Building</u>

S/N	SPACE DEFINITION	LENGTH (MM)	WIDTH (MM	HEIGHT (MM)	BENCH/DESK HEIGHT (MM)	PAINT SCHEDULES	
						WALLS	CEILING
1.	Undergraduate Lab	15,770	11,770	3,400	900	Off White	White
2.	Lab Store	3,770	2,770	3,400	900	Light Green	White
3.	Instrument Room	3,770	2,770	3,254	900	Light Green	White
4.	Office 1	3,770	2,770	3,256	770	Light Green/Off White	White
5.	Office 2	3,770	2,770	3,256	770	Ditto	White
6.	Office 3	4,189	2,770	3,256	770	Ditto	White
7.	General Store	3,770	4,310	3,256	770	Off White	White
8.	Toilet Lobby	1,695	2,770	3,256	-	Off White	White
9.	WC Room	1,845	1,270	3,256	-	Off White	White
10.	Lobby 1	1,350	4,785	3,256	-	Off White	White
11.	Verandah	27,000	1,770	3,556	-	Off White	White
12.	Courtyard	3,850	6,000	N/A	-	N/A	N/A
13.	Entrance Foyer	7,850	3,000	3,400	-	Off White	White
14.	Postgraduate Lab	11,770	11,770	3,256	900	Off White	White
15.	External Surfaces	N/A	N/A	N/A	-	Off White	N/A
16.	Lobbies 2, 3, 4	3,770	3,000	3,556	-	Off White	White

3.2.2 CALCULATION OF LIGHTING LAYOUT AND RESULTS

The following calculations were used to establish the desired energy-efficient lighting layout of each of the above spaces:

<u>Space 1:</u> **Undergraduate Lab**

(i) **Luminaire Type**: Thorn Arrowslim T_{16} 1200mm Plain Batten Fluorescent Fittings

$Hm = 3.4 - 0.9 = 2.5m$

$Spacing = 3m \ (Lum\ Spacing < 1.5\ x\ Hm\ (= 3.75m))$

$$N = \frac{15{,}770}{3{,}000}\ x\ \frac{11{,}770}{3{,}000}$$ (See Eqn 2.14)

$= 24\ Fittings.$

(ii) $$Room\ Index, K = \frac{15{,}770\ x\ 11{,}770}{(15{,}770+11{,}770)2500}$$ (See Eqn 2.8)

$\therefore \quad K = 2.7$

(iii) $Reflectance\ of\ Ceiling, rc = 70\%$

$Reflectance\ of\ Walls, rw = 50\%$

$Reflection\ of\ Desk, rd = 20\%$ (See Table 2.7)

(iv) From Table A4 of Appendix A,

$UF = 0.64$

(v) $MF = 0.8$ (Maintenance Schedule not certain)

(vi) $$\therefore\ \emptyset_{inst} = \frac{\emptyset_{rec}}{M_F\ x\ U_F} = \frac{E\ x\ A}{M_F\ x\ U_F}$$ (See Eqn 2.4, 2.5)

Based on ECON 19 (Table 2.5), $E = 400lux$

$400\ x\ 15.770\ x\ 11.770 = 0.8\ x\ 0.64\ x\ \phi inst$

$\therefore \emptyset_{inst} = 145{,}010\ lumens\ (Total)$

$$\therefore\ \emptyset_{inst}\ per\ fitting = \frac{145{,}010}{24}$$

$= 6{,}042\ lumens.$

From Thorn Brochure, 2010,

Thorn Arrowslim 2 x 35W HFD L840 = 6600 lumens.

(Thorn Product Ref: 96218621)

Connected Load = 75W

CELMA: A1, Dimming: DSI, 1 – 100%, λ= 0.99

CRI: 1B, IP Code: IP20.

(vii) **Luminaire Layout:**

$$NL = \sqrt{N\text{x}\,{}^{L}\!/_{W}} \qquad \text{(See Eqn 2.15)}$$

$$= \sqrt{24\text{x}\frac{15.77}{11.77}}$$

$$= 6$$

$$NW = \sqrt{24\text{x}\frac{11.77}{15.77}} \qquad \text{(See Eqn 2.16)}$$

$$= 4$$

(viii) **Energy-Compliance Tests**

$$Total\ Wattage = 75W \ \ X\ 24\ No\ fittings$$

$$= 1800W$$

$$\therefore \text{Power Density} = \frac{1800}{15.77\text{x}11.77}$$

$$= 9.7W/M2$$

$$= 2.4W/m2\ per\ 100lux.$$

This is in compliance with Tables 2.3 and 2.5. The improvement in energy efficiency should be due to further improvement on the quality of products by the manufacturers and design efficiency arising by proper selection of energy-efficient lamp/fitting.

From Eqn 2.4, 2.5: E_{final} = 437lux, $\emptyset_{instal,actual}$ = 6600 lumens per fitting, instead of 6,042 lumens calculated)

<u>Space 2:</u> Lab Store:

(i) **Luminaire Type:** Thorn Arrowslim T_{16}, 1200mm Plain Batten Fluorescent fitting

$$Hm = 2.5m$$

By inspection, $No\ of\ fittings = 2$

From Table 3.1,

$$K = 0.6$$

$$UF = 0.31$$

With MF = 0.8 (Maintenance Schedule not certain)

$$\emptyset_{inst} = \frac{150\text{x}3.77\text{x}2.77}{0.8\text{x}0.31} \quad \text{(From Table 2.11, E = 150lux)}$$

$$= 6{,}316\ lumens$$

$$\therefore \emptyset_{inst} \text{ per fitting} = \frac{6{,}316}{2} = 3{,}158 \text{ lumens}$$

Thorn Arrowslim 1 x 35W, Lum. SAP Code: 96211398 was selected

Total Lamp Initial Lumens = 3,320 lumens

Total Power = 38W

(ii) Luminaire Layout

$NL = 2$

$NW = 1$

$$\text{Power Density} = \frac{38\text{x}2}{3.77\text{x}2.77}$$

$$= 7.28W/\text{M}^2$$

This is within limits. See Table 2.6

Space 3: Instrument Room

(i) Luminaire Type: Thorn Arrowslim $T_{16,}$ 1200mm Plain Batten Flourescent Fitting

$Hm = 2.354m$

By inspection, $No\ of\ Fittings = 2$

$K = 0.7$

$UF = 0.34$

$MF = 0.8$

$$\emptyset_{inst} = \frac{150\ x\ 3.770\ x\ 2.770}{0.8\ x\ 0.34} \quad \text{(From Table 2.11, E = 150 lux)}$$

$$= 5759\ lumens.$$

$$\therefore \emptyset_{inst} \text{ per fittings} = \frac{5759}{2} = 2{,}880 \text{ lumens}$$

Thorn Arrowslim 1x35W, Lum. SAP Code. 96211398 was selected.

Other data as in space 2 above.

<u>Space 4:</u> Office 1

(i) Luminaire Type: Thorn Arrowslim T_{16} 1200mm Plain Batten Flourescent Fitting

$Hm = 2.486m$

By Inspection, $No\ of\ Fittings = 2$

$K = 0.6$

$\therefore\ UF = 0.31$

$MF = 0.8$

From Table 2.6, E = 300lux

$$\emptyset_{inst} = \frac{300x3.77x2.77}{0.8x0.31}$$

$$= 12{,}632.5\ lumens$$

$\emptyset_{inst}$ per fitting = 6,316 lumens

Thorn Arrowslim 2x35W, Product Ref: 96218621 is selected.

$Total\ lamp\ lumens = 6600\ lumens$

$Total\ Power = 75W$

(ii) Luminaire Layout

$NL = 2$

$NW = 1$

Power Density = $\frac{75x2}{3.77x2.77} = 14W/M2$

This conforms with Table 2.6 (Enclosed Surface)

<u>Space 5</u>: Office 2

Data and calculations/Results as in Space 4 above.

<u>Space 6</u>: Office 3

(i) Luminaire Type: Thorn Arrowslim $T_{16,}$ 1200mm Plain Batten Fluorescent fitting

$Hm = 2.486m$

By inspection, No of fittings = 2

K = 0.7

$\therefore\ UF = 0.34$

$MF = 0.8$

Using $E = 300lux$ (See Table 2.6)

$$\emptyset_{inst} = \frac{300x4.189x2.77}{0.8x0.34}$$

$= \ 12{,}798 \ lumens$

$\emptyset_{inst} \ per \ fitting \ = \ 6{,}399 \ lumens$

Thorn Arrowslim 2 x 35W, Product Ref: 96218621 was selected

Total Lamp Lumens = 6600 lumens

Total Power = 75W

(ii) Luminaire Layout:

$NL \ = \ 2$

$NW \ = \ 1$

Power Density = $\frac{75\text{x}2}{4.189\text{x}2.77} \ = \ 13W/\text{M}^2$

This is an improvement on Table 2.6 (Enclosed Surface)

<u>**Space 7**</u>**: General Store**

(i) Luminaire Type: Thorn Arrowslim $T_{16,}$1200mm Plain Batten Fluorescent fitting

Hm = 2.486m

Using an average spacing of 2m (Spacing <1.5xHm)

$N \ = \ 4$

$K \ = \ 0.8$

$\therefore UF \ = \ 0.37$

$MF \ = \ 0.8$

Using $E \ = \ 150lux$ (Tables 2.6/2.2.11)

$\emptyset_{inst} = \frac{150\text{x}3.77\text{x}4.31}{0.8\text{x}0.37}$

$= \ 8{,}234 \ lumens$

$\therefore \emptyset_{inst}$ per fitting = $\frac{8234}{4} \ = \ 2{,}059 \ lumens$

Thorn Arrowslim 1 x 28W, Lum. SAP Code = 96211396 was selected

Total Lamp Lumens = 2640 lumens

Total Power = 31W

(ii) Luminaire Layout:

$NL \ = \ 2$

$NW \ = \ 1$

$$\text{Power Density} = \frac{31\text{x}4}{4.31\text{x}3.770} = 7.96W/M^2$$

This is near the limits of Table 2.6 but is an improvement of Table 2.5

<u>Space 8</u>: Toilet Lobby

By experience, 1x60W GLS White Lamp which gives an illumination of 618 lumens (LIF, 2009) (Efficiency = 10.3 lumens/watts) has been found appropriate for lighting of lobbies of this magnitude. For the sake of energy-efficiency, 1No. Thorn BASELED 165 MRE 1 X 12W LED L927 Lamp, Product Ref: 96107294, Lamp Flux: 650 lumens is selected (CRI:90-100, CCT:6000, IP44).

Test of Contrast in Brightness in the field of Vision (Section 2.2.3: Standard Service Illuminance):

$$UF = 0.29$$

$$MF = 0.8$$

$$\therefore\ E_{background} = \frac{0.8\text{x}0.29\text{x}650}{1.695\text{x}2.77} = 32lux$$

$$E_{lightsource} = \frac{Lampflux\text{x}LOR}{A} = \frac{650\text{x}0.8}{1.695\text{x}2.77} = 111\text{lux}$$

$$\frac{E_{lightsource}}{E_{background}} = \frac{111}{32} = 4:1\ (\text{Max})$$

This is an improvement on the specified limit [Bhatia, 2006]

$$Watts/_{M^2} = 2.6W/_{M^2}\ (\text{Excellent: See Table 2.4})$$

<u>Space 9</u>: WC Room

By inspection, each WC Room is to be lit with 1 No Thorn BASELED 165 MRE 1 x 12W LEDL927 Lamp.

$$W/_{M^2} = 5.12W/_{M^2}$$

This is an improvement on ASHRAE 90.1-1999(Table 2.4) of $10W/M^2$ for Restrooms

<u>Space 10</u>: Lobby 1

By experience, 2 No. Thorn BASELED 165 MRE 1 x 12W LED L927 lamps can be used, at least for the sake of the aged and those with poor sight.

$$\text{Watts}/M^2 = \frac{2\text{x}12}{1.35\text{x}4.785}$$

$= 3.72W/M^2$

This is a very great improvement on the standards of ASHRAE 90.1 – 1999 ($8W/M^2$) arising from the innovation of LED lighting.

<u>Space 11</u>: Verandah

By inspection, 4No fittings can be used, with spacing between fittings of 6.75m and spacing extreme walls of 3.375m

Thorn BASELED 165 MRE 1 X 12W LED L927 lamp, Product Ref: 96107294 was also selected.

$$Lamp\ flux\ =\ 650\ lumens$$

$$Quantity\ =\ 4No$$

$$Watts/Linear\ Metre\ =\ \frac{4x12}{27}\ =\ 1.8W/M$$

Due to improved efficacy with LED lamps, ASHRAE 100 – 1995 (Field; Soper, 2002 has been far exceeded.

However, with the provision of courtyard, natural daylight is sufficient during the day time along the verandah. As a general laboratory, night use may be rare. But still, the illumination is very adequate (See space 8 calculations).

<u>Space I2</u>: Courtyard

As IP 44 fitting, Thorn BASELED 165 MRE 1 x 12W LED L927 lamp, Product Ref: 96107294 was also selected.

$$NL\ =\ 2\ (1\ No\ per\ side)$$

$$NW\ =\ 2\ (1\ No\ per\ side)$$

$$Watts/M\ (Length) = \frac{12W}{3.85M}\ =\ 3.12W/M$$

$$Watts/M\ (Width) = \frac{12W}{6M} =\text{- } 2W/M$$

This is far above specifications (See space 11 above)

<u>Space 13</u>: Entrance Foyer

(i) **Luminaire Type:** Thorn LEOPARD TC-DDEL (CFL) LAMP

Hm = 2.630m

For the sake of aesthetics, 6 No lamps are recommended

$$NL\ =\ 3$$

$$NW\ =\ 2$$

$K = 0.8$

Choosing r_c = 0.7, r_w = 0.1 (Open spaces on sides)

$UF = 0.34;\ E = 140 lux$

$\therefore \emptyset_{inst} = \frac{140 \text{x} 7.85 \text{x} 3}{0.8 \text{x} 0.34}$

$= 12{,}121\ lumens$

$\therefore \emptyset_{inst}\ per\ fitting = 2{,}020\ lumens$

Thorn LEOPARD 1 X 28W TC-DDEL HF OP RD BLK L840

Product Ref: 96230493 was selected.

$Lamp\ Flux = 2050\ lumens$

$Connected\ load = 29W;\ \lambda = 0.96$

$CRI = 1B;\ CELMA =$ A3

$IP\ Code = 65;\ CCT = 5000K\ (Cool)$

This is ideal for an entrance foyer. IP65 characteristics ensure protection against ingress of dust and low pressure jets from all directions. (See Appendix B)

Watts/M^2 = $\frac{6 \text{x} 29}{7.85 \text{x} 3} = 7.39 W/\text{M}^2;\ W/M = 29/3 = 9.7 W/M$

Table 2.4 (ASHRAE 90.1 – 1999) recommends 8W/M^2 for Corridors/Transition while Table 2.5 (ASHRAE 100-1995) specifies 82W/Linear M for exit doorway. The use of the CFL fitting here is justified. Security Desk may be placed here.

Space 14: Postgraduate Lab

(i) Luminaire Type: Thorn Arrowslim T_{16} 1200mm Plain Batten Flourescent Fittings

$Hm = 2.356m$

$Spacing = 2.6\ (< 1.5\ x\ Hm)$

$N = \frac{11770}{2600} \text{x} \frac{11770}{2600}$

$= 25\ fittings$

Room Index, $K = \frac{11770 \text{x} 11770}{(11770 + 11770)2356}$

$= 2.5$

With $rc = 0.7,\ rw = 0.5,$

$UF = 0.63$ (See Appendix A, Table A4)

$MF = 0.8,\ E = 400Lux$

$$\therefore \emptyset_{inst} = \frac{400\text{x}11.770\text{x}11.770}{0.8\text{x}0.63}$$

$$= 109,947 lumens$$

$$\therefore \emptyset_{inst} \text{ per fitting} = \frac{109,947}{25}$$

$$= 4,398\ lumens$$

Thorn Arrowslim 1200mm 2x28W T_{16}, HFD L840 lamp/fitting, Product Ref: 96218619 was selected.

$Lamp\ lumens = 5200\ lumens$

$Connected\ load = 61W,\ \lambda = 0.99$

$CRI = 1B, CELMA = A1, CCT = 5000K\ (Cool)$

$Dimming: DSI, 1 - 100\%, IP\ Code = 20$

$NL = 5$

$NW = 5$

$$\text{Watts/m}^2 = \frac{25\text{x}61}{11.77\text{x}11.77} = 11.0 W/_{M^2}$$

This is within the limits of Table 2.3 but an improvement on Table 2.5

$Efinal = 473lux$

<u>Space 15</u>: External Surfaces

External/security lighting around the building can be considered in terms of floodlighting:
Thorn LEOPARD 1X28W TC-DDEL (CFL) HF OP RD BLK L840 lamps/fittings Product Ref: 96230493 were used throughout for the security lighting in view of its IP Code (65) and efficacy (70.7lm/W). Lamp Lumens = 2050 lumens, Power = 29W.

Using (Eqn 2. 21) with the associated parameters and the assumptions of Chapter 3, calculations were made for sides 1 to 17 as follows:

<u>Side 1</u>: $N_1 = \frac{12.265\text{x}10\text{x}10}{2050\text{x}0.4} = 1.50 = 2$

($N_2 - N_{17}$) were also derived as shown for Sides (1 – 17):

<u>Side 2</u>: $N_2 = 1$

<u>Side 3</u>: $N_3 = 1$

<u>Side 4</u>: $N_4 = 1$

<u>Side 5</u>: $N_5 = 2$

<u>Side 6</u>: $N_6 = 1$

<u>Side 7</u>: $N_7 = 1$

<u>Side 8</u>: $N_8 = 1$

<u>Side 9</u>: $N_9 = 1$

<u>Side 10</u>: $N_{10} = 1$

<u>Side 11</u>: $N_{11} = 1$

<u>Side 12</u>: $N_{12} = 1$

<u>Side 13</u>: $N_{13} = 1$

<u>Side 14</u>: $N_{14} = 1$

<u>Side 15</u>: $N_{15} = 1$

<u>Side 16</u>: $N_{16} = 1$

<u>Side 17</u>: $N_{17} = 2$

$$Total\ No\ of\ fittings\ = 19$$

$$Total\ Area\ to\ be\ illuminated\ = 1155.8m^2$$

$$Total\ Power\ (Load)\ to\ be\ connected\ =\ 19\ x\ 29W\ =\ 551W$$

$$\therefore \text{W/M}^2 = \frac{551}{1155.8} = 0.48W/_{M^2}$$

This is a great improvement on ASHRAE standard 100 – 1995 of 2.7W/M^2 of external surface to be illuminated. Efficient design and choice of lamps must be responsible for this observation.

<u>Space 16:</u> Lobbies 2, 3, 4

For the sake of design economics, only lobbies 2 and 3 were assigned 1 No Thorn BASELED 165 MRE 1 X 12W LED lamp each. See drawings (Figs.4.1 and 4.2).

<u>Summary:</u> See Tables 3.2 and 3.3 for summaries of design calculations/results and tests of lighting energy efficiency:

<u>Table 3.2: Design Calculations and Results</u>

SPACE	SPACE DEFINITION	NO. OF FITTINGS	TYPE OF FITTINGS
1	Undergraduate Lab	24	Thorn Arrowslim T16 2x35W HFD L840
2	Lab Store	2	Ditto 1x35W
3	Instrument Room	2	Ditto 1x35W
4	Office 1	2	Ditto 2x35W
5	Office 2	2	Ditto 2x35W
6	Office3	2	Ditto 2x35W
7	General Store	4	Ditto 1x28W
8	Toilet Lobby	1	Thorn Baseled 165 MRE 1x12W LED L927
9	WC Room	1	Ditto
10	Lobby 1	2	Ditto
11	Verandah	4	Ditto
12	Courtyard	4	Ditto
13	Entrance Foyer	6	Thorn Leopard 1x28W, TC-DDEL(CFL) L840
14	Postgraduate Lab	25	2x28W as in Space 1
15	External Surfaces	19	As in Space 13
16	Lobbies 2,3,4	2	As in Space 8

Table 3.3: Tests for Lighting Energy Efficiency

SPACE	SPACE DEFINITION	RESULT OBTAINED	SPECIFIED (STANDARD)
1	U/G LAB	$9.7W/M^2$	$12W/M^2$ (ECON 19)
2	LAB STORE	$7.28W/M^2$	$7.0W/M^2$ (CIBSE)
3	INSTR.ROOM	DITTO	DITTO
4	OFFICE 1	$14W/M^2$	$15W/M^2$ "
5	OFFICE 2	DITTO	DITTO
6	OFFICE 3	$13W/M^2$	DITTO
7	GENERAL STORE	$7.96W/M^2$	$7.0 W/M^2$(CIBSE)
8	TOILET LOBBY	$2.6W/M^2$	$8W/M^2$(ASHRAE 90.1)
9	W.C ROOM	$5.12W/M^2$	$10W/M^2$ "
10	LOBBY 1	$3.72W/M^2$	$8W/M^2$ "
11	VERANDAH	1.8W/M	2.7W/M (ASHRAE 100)
12	COURTYARD	2W/M	DITTO
13	ENTRANCE FOYER	$7.39W/M^2$	$8W/M^2$ (ASHRAE 90.1)
14	P.G LAB	$11.0W/M^2$	$11W/M^2$(CIBSE)
15	EXT. SURFACES	$0.48W/M^2$	$2.7W/M^2$(ASHRAE 100)

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 IMPLEMENTATION OF IMPROVED LIGHTING DESIGN OF A TYPICAL UNIVERSITY LABORATORY

In this chapter, the new (improved) design was presented complete with load calculations and schematics. Analysis of the old (existing) design was carried out using the photometric data of the luminaires/lamps used, in order to establish the parameters for relevant comparisons between the existing and improved lighting designs.

Furthermore, the illuminance levels of the two designs were simulated using DIALUX lighting design software and comparisons were made using the available displayed results.

Daylighting applications were also introduced to observe the extent of energy savings that could be achieved.

4.1.1 DESIGN PRESENTATION, LOAD CALCULATIONS AND SCHEMATICS

Lighting points are as represented in the drawing (See fig 4.1) and load schedules were as calculated in Tables 4.1and 4.2. Recommended Distribution Boards and Main Panel are as shown in foregoing analysis.

The Distribution Boards Schematics are as shown in Fig. 4.2.

It should be observed from Tables 4.1 and 4.2 that if the spares are excluded, the entire lighting installation shall consume only 9.18A per phase (equivalent to 5.28KW) ie less than 10A/phase. This is exciting.

The Distribution Boards and the Main Panel allow for connection of other load apart from lighting. The designs are in accordance with current Electricity Laws of Nigeria (CAP 106, B39-B63)

Table 4.1: Load Schedule for DB-A

			Load Distribution (W)			
CCT NO	**Load (W)**	**Diversity factor**	**Red Phase**	**Yellow Phase**	**Blue Phase**	**MCB Rating**
1	12 x 75 = 900	0.9	810			5A
2	12 x 75 = 900	0.9		810		5A
3	12 x 29 = 348	0.9			313.2	5A
4	9 x 12 + 2 x 38 = 184	0.9	165.6			5A
5	4 x 29 = 116	0.9		104.4		5A
6	2 x 38 + 4 x 75 + 2 x 12 = 400	0.9			360	5A
7	4 x 31 + 3 x 12 + 2 x 75 = 310	0.9	279			5A
8	Spare			300		10A
9	Spare				300	10A
10	Spare		300			10A
11	Spare			300		10A
12	Spare				300	10A
	Total		**1554.6**	**1514.4**	**1273.2**	**30A TPN MCCB**

Total Estimated Power at DB-A = 4342.2W

Nominal Power Factor = 0.8

Current per phase = $\dfrac{4342.2}{\sqrt{3}\ x 415 x 0.8}$ = 7.55A (See Eqn 3.1)

$\therefore$ 30A, 4-Way TPN MCB Distribution Board was recommended.

Table 4.2: Load Schedule for DB-B

			Load Distribution (W)			
CCT NO	**Load (W)**	**Diversity factor**	**Red Phase**	**Yellow Phase**	**Blue Phase**	**MCB Rating**
1	10 x 61 = 610	0.9	549			5A
2	Ditto	"		549		5A
3	5 x 61 = 305	"			274.5	5A
4	2 x 38 + 9 x 12 = 184	"	165.6			5A
5	10 x 29 = 290	"		261		5A
6	2 x 38 + 4 x 75 + 2 x 12 = 400	"			360	5A
7	4 x 31 + 3 x 2 x 75 = 310	"	279			5A
8	Spare			300		10A
9	Spare				300	10A
10	Spare		300			10A
11	Spare			300		10A
12	Spare				300	10A
	Total		**1293.6**	**1410**	**1234.5**	**30A TPN MCCB**

Total Estimated Power at DB-B = 3938.1W

Nominal Power Factor = 0.8

Current per phase = $\dfrac{3938.1}{\sqrt{3}\ \text{x}415\text{x}0.8} = 6.85\text{A}$

$\therefore$ 30A, 4-Way TPN MCB Distribution Board was recommended.

100A, 4-Way TPN MCCB Panel was recommended as Main Board.

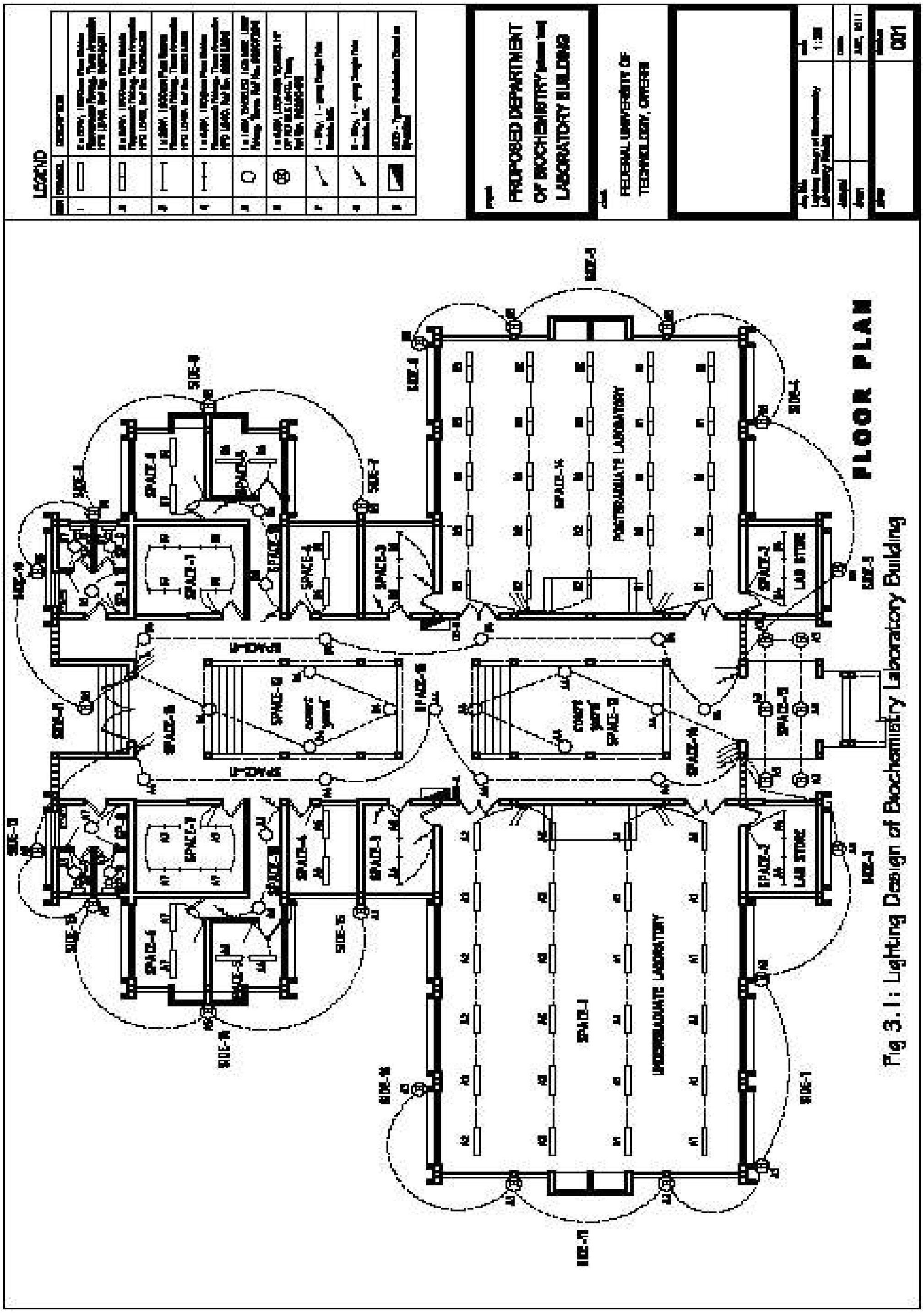


Fig. 4.1: Lighting Design of a Typical University Laboratory

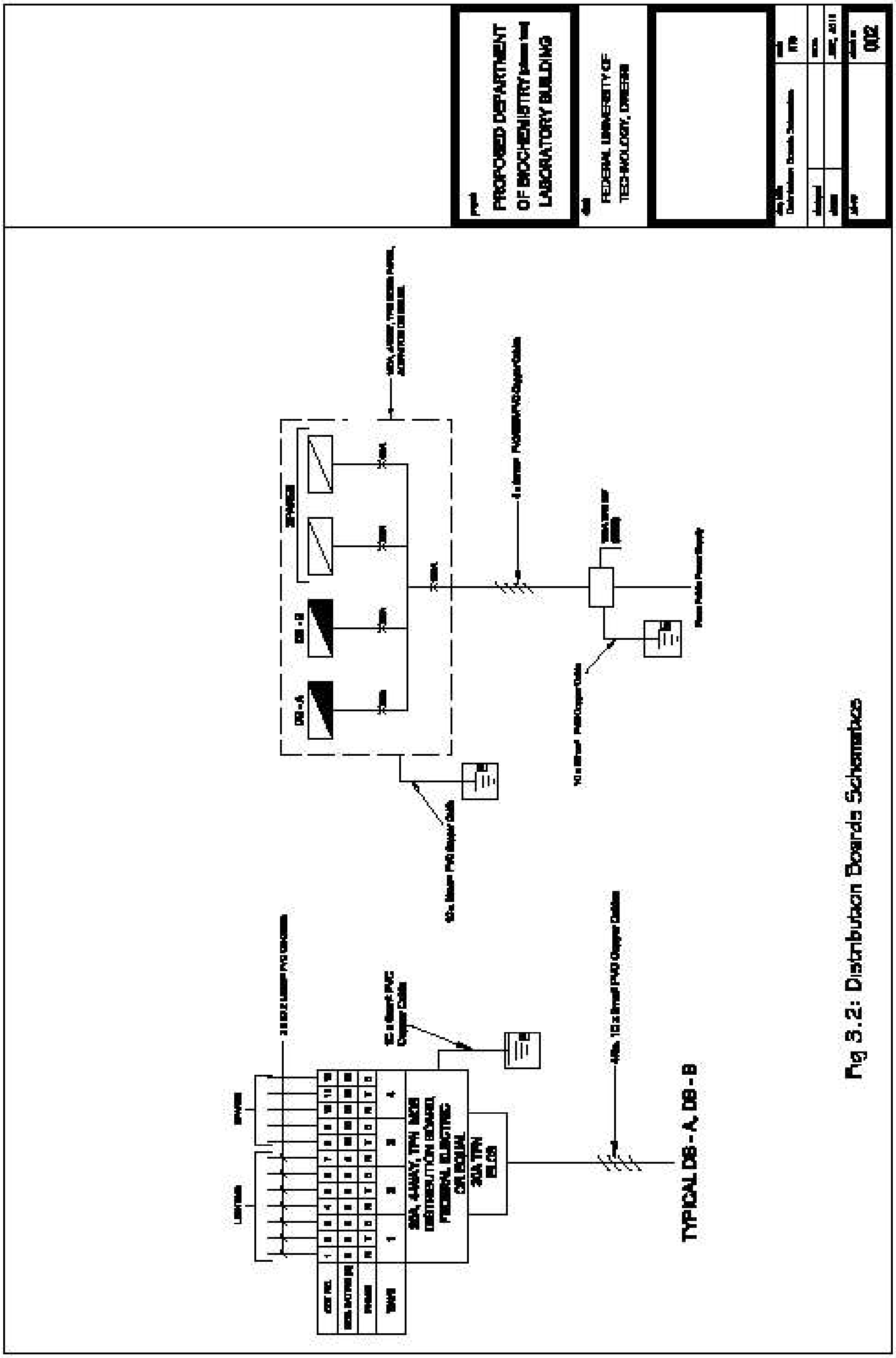


Fig. 4.2: Distribution Boards Schematics

4.2 COMPARISONS BETWEEN THE OLD AND NEW (IMPROVED) LIGHTING DESIGNS

Fig.4.16 and Table 4.5 display the old design of an external (indigenous) consultant.

At the Undergraduate Lab, the expected design illuminance was calculated as follows:

No of fittings = 18 (NL =6, NW=3)

Lamp wattage = 2x40w.

Make/Model:- Astra Nu-PAK England.

However, during the study, it was discovered that there wass no such registered luminaire/lamp manufacturer in Europe. In fact, there is no such name in the list of Voltimum- the regulatory body of European manufacturers (Check up: www. voltimum.co.uk). Only Astra China (http:www.astralux.com) could be found.

Here, 40w lamp gives 750 lumens/lamp.

With Diffuser, UF =0.52 (See Appendix A, Table A6)

$$\therefore\ E = \frac{0.8\ x\ 0.52\ x\ 1.8\ x\ 2\ x\ 750}{15.770\ x\ 11.770} \qquad \text{(See Eqn 2.4, 2.5)}$$

$$= 60.5 lux. \text{ (This is very poor)}$$

It should be noted that the design calculations of Space 1 was carried out with an illuminance level of 400lux in the new design. In this same way, other required data were generated for the old design to enable comparisons made between it and the new design as follows:

4.2.1 COMPARISON IN TERMS OF EXPECTED LIFE, EFFICACY AND COST

(A) OLD DESIGN

Table 4.3(a): Expected Lamp Life, Luminaire Efficacy and Cost of Old Design.

L	Type of Luminaire	Expected Life(hrs)	Efficacy (lm/W)	Qty	Unit Price Initial (N)	Total Cost Initial (N)	Unit Price 1st Yr (N)	Total Cost 1st Yr (N)
1	60W GLS/ Ceiling-mounted	1100	10.3	22No	800	17,600	1,500	33,000
2	60W GLS/Bowl Water-proof	1100	10.3	6No	850	5,100	1,550	9,300
3	60W GLS/Escort Bulkhead	1100	10.3	29No	800	23,200	1,500	43,500
4	1x40W,1200mm Fluorescent(T26)	1200	18.75	12No	1,990	23,880	3,590	43,080
5	2x40W, Ditto	1200	18.75	34No	3,180	108,120	6,380	216,920
Grand Total						177,900		345,800

(B) NEW DESIGN

Table 4.3(b):): Expected Lamp Life, Luminaire Efficacy and Cost of New Design

L	Type of Luminaire	Expected Life(hrs)	Efficacy (lm/W)	Qty	Unit Price Initial (N)	Total Cost Initial (N)	Unit Price 1st Yr (N)	Total Cost 1st Yr (N)
1	12W LED/ Downlighter	40,000	54.17	18No	2,500	45,000	2,500	45,000
2	28W CFL/Escort Bulkhead	12,500	70.71	26No	1,200	31,200	1,200	31,200
3	1x28W,1200mm Fluorescent(T16)	50,000	85.16	2No	2,030	4,060	2,030	4,060
4	2x28W, Ditto	50,000	85.25	25No	4,060	101,500	4,060	101,500
5	1x35W, Ditto	50,000	87.37	4No	2,080	8,320	2,080	8,320
6	2x35W	50,000	88.00	24No	4,160	99,840	4,160	99,840
Grand Total						289,920		289,920

RESULTS USING BAR CHARTS

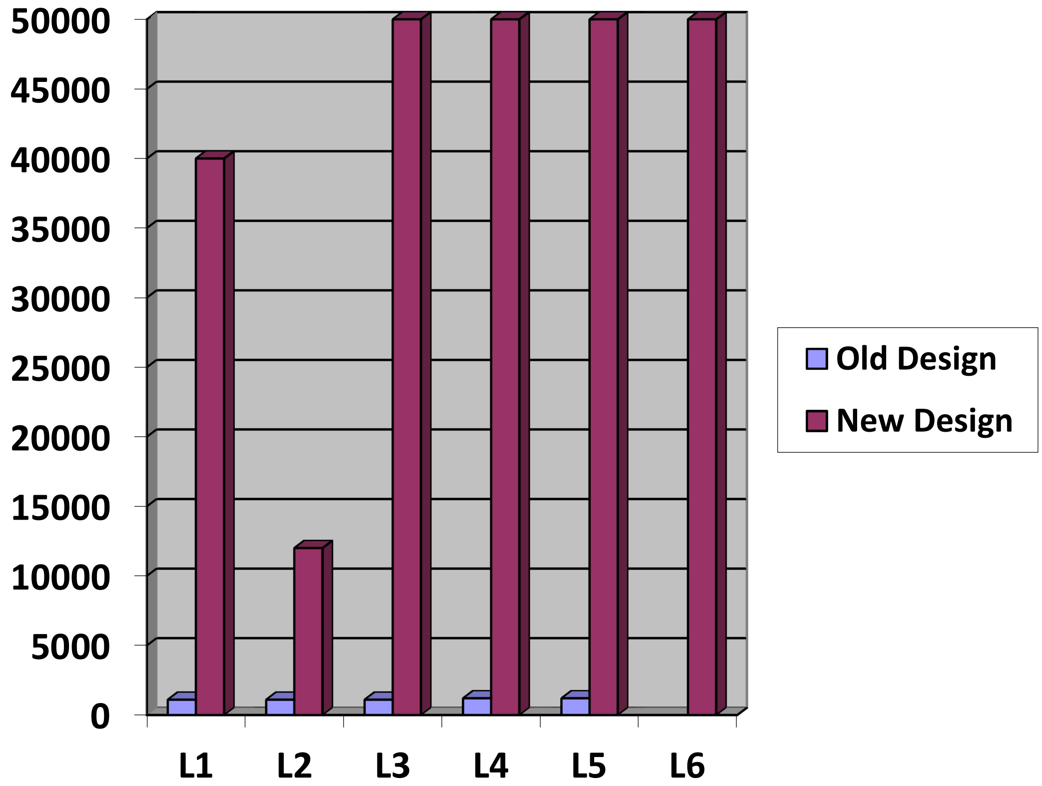


Figure 4.3: COMPARISON IN TERMS OF EXPECTED LIFE

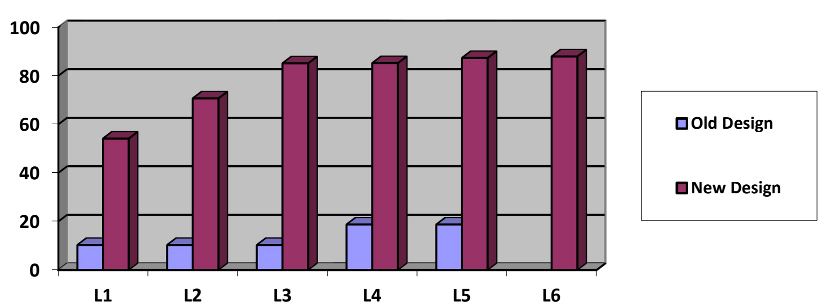


Figure 4.4: COMPARISON IN TERMS OF LUMINAIRE EFFICACY

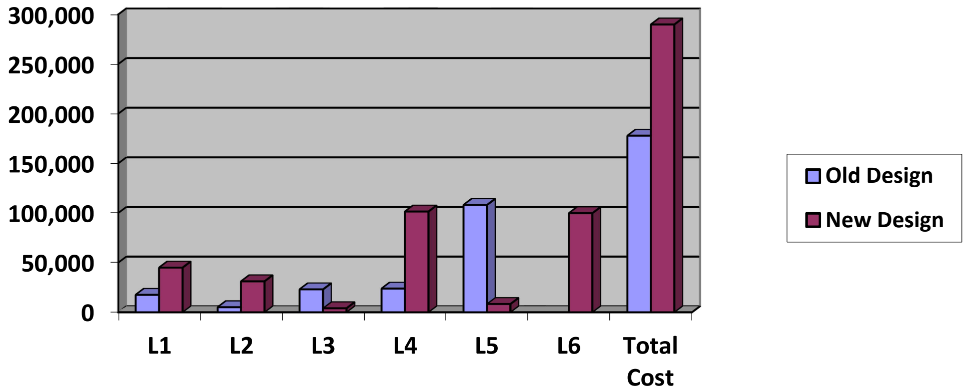


Figure 4.5: COMPARISON IN TERMS OF INITIAL COST

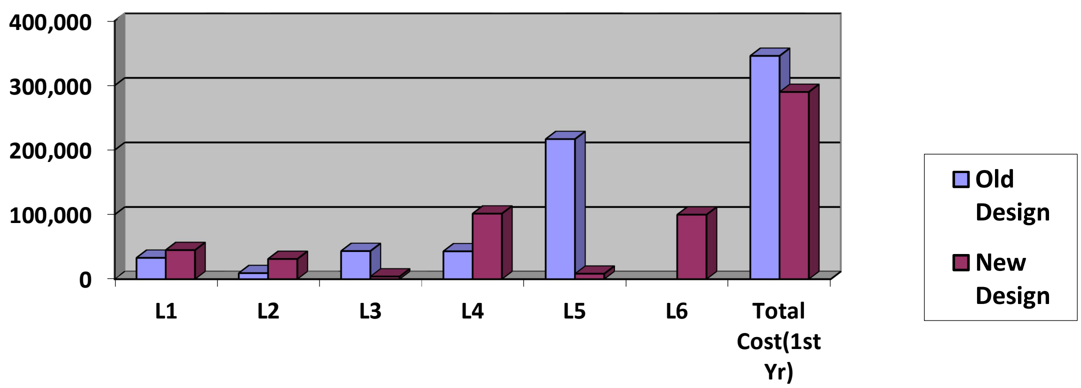


Figure 4.6: **COMPARISON IN TERMS OF COST AT THE END OF FIRST YEAR**

The following findings were made:

It could be seen that the initial cost of the new design was less than two times (about 1.6 times) that of the old design but this was justified by the life of lamps in the former being over 30 to 40 times that of the latter. . However, at the end of the first year, while the cost of the new design remained the same, that of old design increased about 1.94 times (almost doubled), thereby rising to about 1.2 times that of the former due to excessive lamps replacement cost. The efficacy of luminaires also improved over 4 to 7 times in the new design.

4.2.2 SPACE-BY-SPACE COMPARISON OF OLD AND NEW DESIGNS IN TERMS OF ILLUMINANCE LEVELS, ENERGY EFFICIENCY(POWER DENSITY) AND LIGHTING STANDARDS USED

Table 4.4: Comparison of illuminance Levels, Energy efficiency and Lighting Standards Used

SP	Space Definition	Illuminance Level (lux)		Power Density (W/m^2)		Lighting Standard Benchmark		Standard Met? (Yes/No)	
		Old	New	Old	New	Old	New	Old	New
1	Undergraduate Lab	60.5	400	9.7	9.7	Not stated	ECON (UK) (12w/m2)	Not certain	Yes
2	Lab Store	14.68	150	5.7	7.28	Ditto	CIBSE ($7w/m^2$)	Ditto	Yes
3	Instrument Room	16.10	150	5.7	7.28	Ditto	Ditto ($7w/m^2$)	Ditto	Yes
4	Office 1	35.62	300	5.7	14.0	Ditto	Ditto ($15w/m^2$)	Ditto	Yes
5	Office 2	35.62	300	5.7	14.0	Ditto	Ditto ($15w/m^2$)	Ditto	Yes
6	Office 3	70.32	300	17.24	13.0	Ditto	Ditto ($15w/m^2$)	Ditto	Yes
7	General Store	27,33	150	6.15	7.96	Ditto	Ditto ($7w/m^2$)	Ditto	Yes
8	Toilet Lobby	-	-	12.78	2.6	Ditto	ASHRAE90.1 ($8w/m^2$)	Ditto	Yes
9	W.C Room	-	-	25.6	5.12	Ditto	Ditto ($10w/m^2$)	Ditto	Yes
10	Lobby 1	-	-	9.29	3.72	Ditto	Ditto ($8w/m^2$)	Ditto	Yes
11	Verandah	-	-	37.78 w/m	1.8 w/m	Ditto	ASHRAE100 ($2.7w/m^2$)	Ditto	Yes
12	Courtyard	-	-	10 w/m	2 w/m	Ditto	Ditto	Ditto	Yes
13	Entrance Foyer	0.69	140	2.55	7.39	Ditto	ASHRAE90.1 ($8w/m^2$)	Ditto	Yes
14	Postgraduate Lab	65.5	400	8.66	11.0	Ditto	CIBSE($11w/m^2$)	Ditto	Yes
15	External Surfaces	N/A	10	1.40	0.48	Ditto	ASHRAE100 ($2.7w/m^2$)	Ditto	Yes

RESULTS USING BAR CHARTS

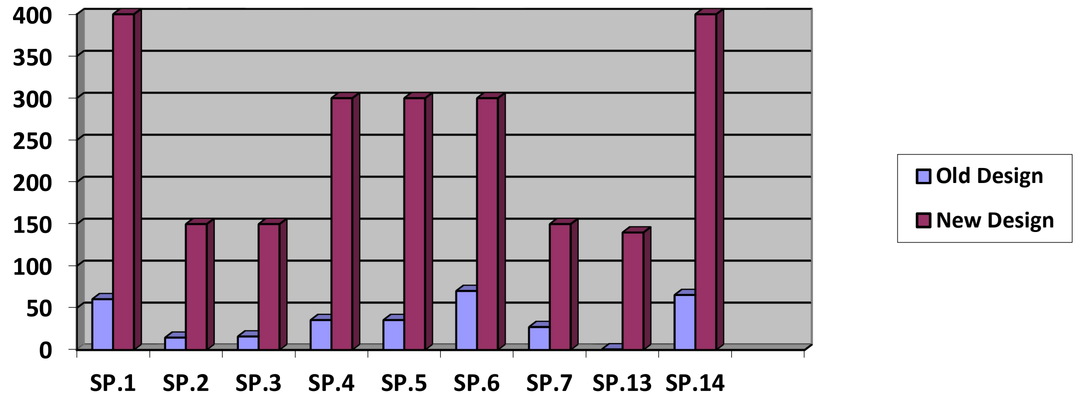


Figure 4.7: COMPARISON IN TERMS OF ILLUMINANCE LEVELS IN VITAL SPACES

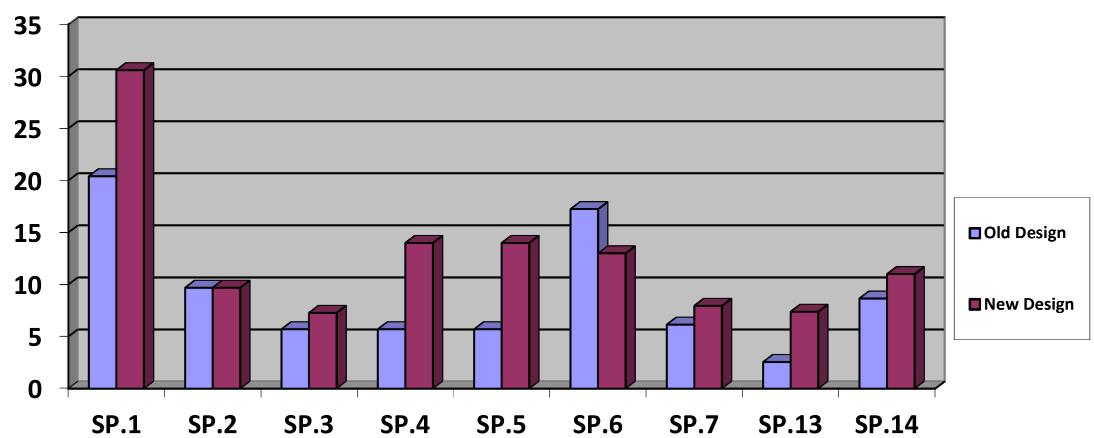


Figure 4.8: COMPARISON IN TERMS OF ENERGY EFFICIENCY(POWER DENSITY) IN VITAL SPACES

The comparisons could be viewed under the following headings:

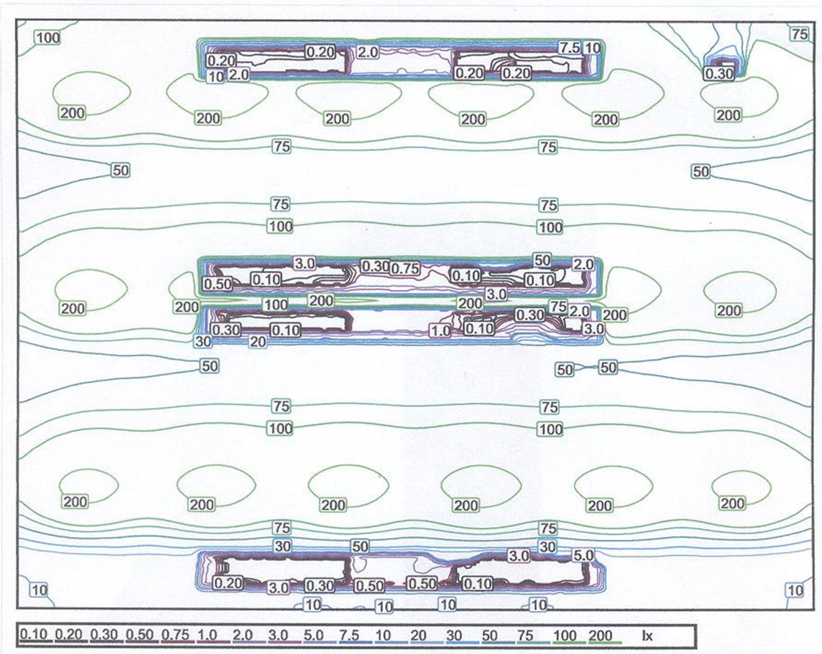
(i) **Illuminance Levels:** This was found to be very poor in the old compared to the new deign which used specified standard illuminance levels.

(ii) **Power Density (Energy Efficiency):** This might not be a good measure of comparison because where the power density of the old design was lower, the required illuminance levels could not be attained. Insignificant illuminance was mostly achieved in the former with so much luminaire power.

(iii) **Compliance with Lighting Standards:** The old design did not refer to any lighting standard. It was not therefore possible to assess its viability but from simple analysis, the specifications were generally poor.

4.2.3 SIMULATION OF ILLUMINANCE LEVELS OF OLD (EXISTING) AND NEW (IMPROVED) DESIGNS – A CASE STUDY OF UNDERGRADUATE AND POSTGRADUATE LABS

Using the luminaire/lamp data and building design data, the illuminance levels of the two designs were simulated using DIALUX lighting design software as shown in Figs. 21-24



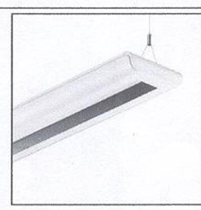
Scale: 1 : 100

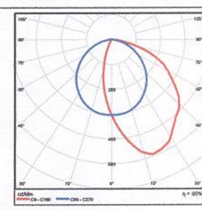
Perpendicular illuminance (adaptive)

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Workplane 1	94	0.02	262	0.000	0.000	256 x 256 (all)

Height of room: 3.400 m, Height of working plane: 0.800 m, Wall zone: 0.000 m, Reflection factors: Ceiling 70.0%, Walls 50.0%, Floor 30.0%, Light loss factor: 0.80

No.	Quantity	
1	18	Philips Lighting TPS460 1xTL5-20W HFP A Light output ratio: 84.71% Luminous flux: 1398 lm, Power: 24.0 W





Total luminous flux: 25158 lm, Total Load: 432 W

Specific connection value: 2.33 W/m² = 2.48 W/m²/100 lx (Ground area 185.61 m²)

Figure 4.9(a): SIMULATED ILLUMINANCE CONTOURS OF OLD DESIGN OF UNDERGRADUATE LAB

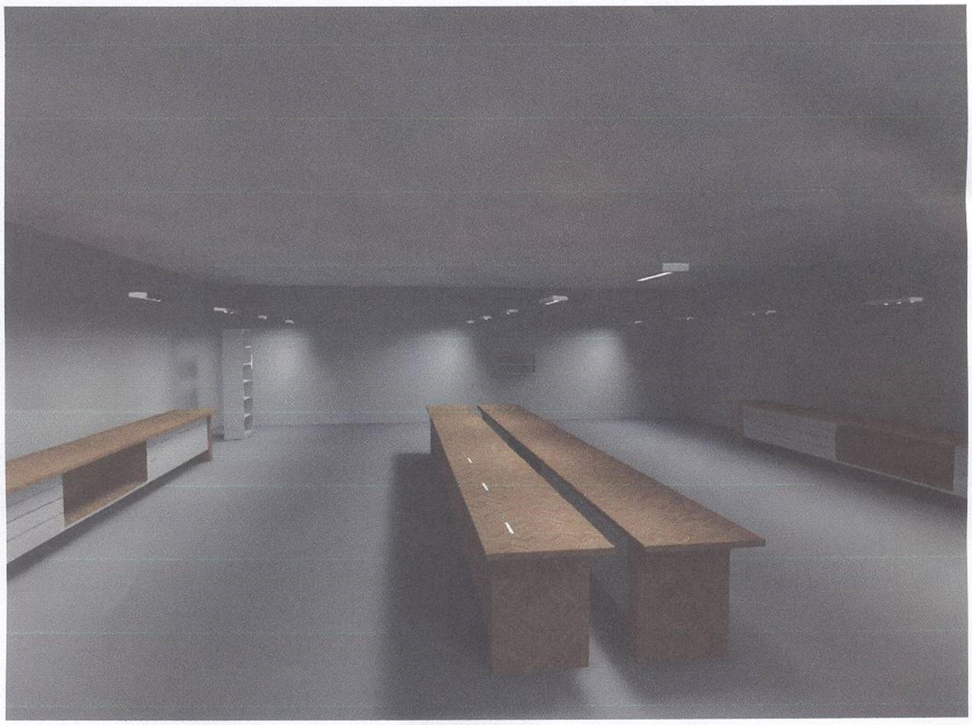


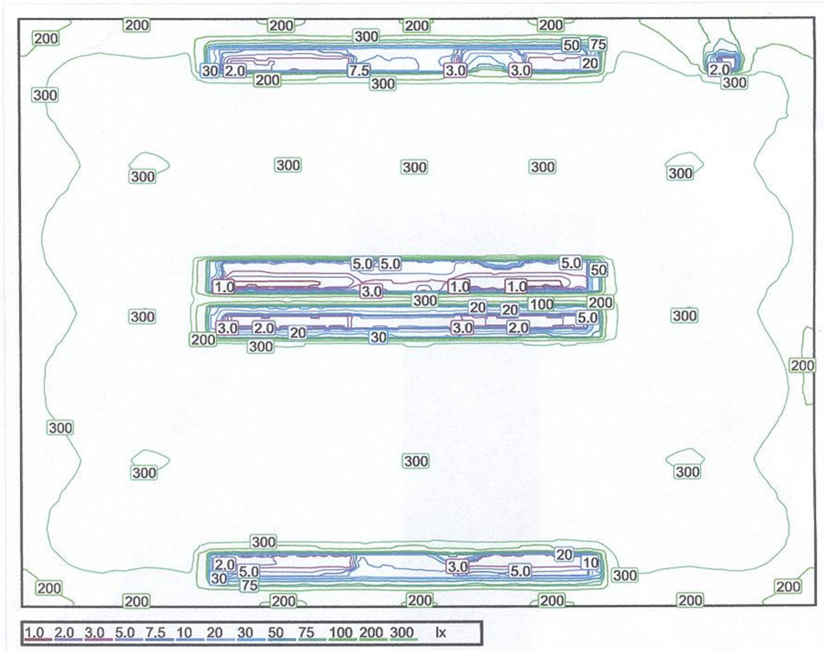
Figure 4.9(b): SIMULATED LIGHTING MODEL OF OLD DESIGN OF UNDERGRADUATE LAB

Perpendicular illuminance (adaptive)

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Workplane 1	94	0.02	262	0.000	0.000	256 x 256 (all)

Height of room: 3.400 m, Height of working plane: 0.800 m, Wall zone: 0.000 m, Reflection factors: Ceiling 70.0%, Walls 50.0%, Floor 30.0%, Light loss factor: 0.80

Relevant points are points in a surface that are not covered by room elements. The summarised results are based exclusively on these relevant points, as the remaining points would falsify the results.



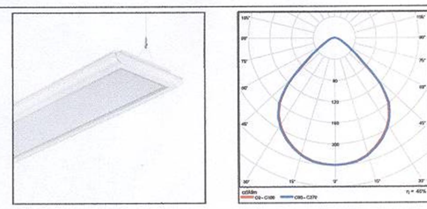
Scale: 1 : 100

Perpendicular illuminance (adaptive)

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Workplane 1	283	0.88	419	0.003	0.002	256 x 256 (all)

Height of room: 3.400 m, Height of working plane: 0.800 m, Wall zone: 0.000 m, Reflection factors: Ceiling 70.0%, Walls 50.0%, Floor 30.0%, Light loss factor: 0.80

No.	Quantity	
1	24	Philips Lighting TPS461 2xTL5-35W HFP AC-MLO Light output ratio: 45.90% Luminous flux: 3053 lm, Power: 77.0 W



Total luminous flux: 73261 lm, Total Load: 1848 W

Specific connection value: 9.96 W/m² = 3.51 W/m²/100 lx (Ground area 185.61 m²)

Figure 4.10(a): SIMULATED ILLUMINANCE CONTOURS OF NEW DESIGN OF UNDERGRADUATE LAB

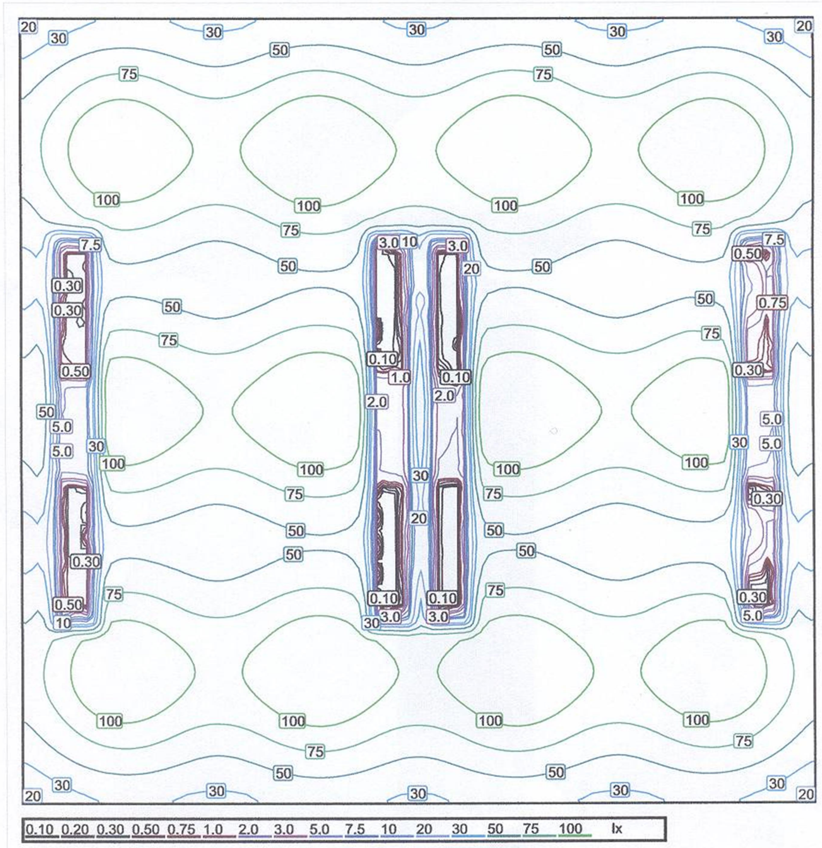
Figure 4.10(b): SIMULATED LIGHTING MODEL OF NEW DESIGN OF UNDERGRADUATE LAB

Perpendicular illuminance (adaptive)

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Workplane 1	283	0.88	419	0.003	0.002	256 x 256 (all)

Height of room: 3.400 m, Height of working plane: 0.800 m, Wall zone: 0.000 m, Reflection factors: Ceiling 70.0%, Walls 50.0%, Floor 30.0%, Light loss factor: 0.80

Relevant points are points in a surface that are not covered by room elements. The summarised results are based exclusively on these relevant points, as the remaining points would falsify the results.



Scale: 1 : 75

Perpendicular illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Wall calculation object 1	35	0.00	94	0.000	0.000	28 x 7 (all)
Wall calculation object 2	30	13	52	0.433	0.250	28 x 7 (all)
Wall calculation object 3	35	0.00	94	0.000	0.000	28 x 7 (all)
Wall calculation object 4	30	13	51	0.433	0.255	28 x 7 (all)
Summary	33	0.00	94	0.00	0.00	

Perpendicular illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Ceiling calculation object 1	19	15	23	0.789	0.652	10 x 10 (all)

Figure 4.11(a): SIMULATED ILLUMINANCE CONTOURS OF OLD DESIGN OF POSTGRADUATE LAB

Perpendicular illuminance (adaptive)

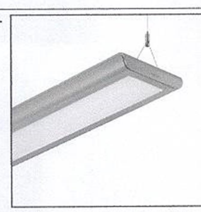
Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Workplane 1	67	0.01	137	0.000	0.000	128 x 128 (all)

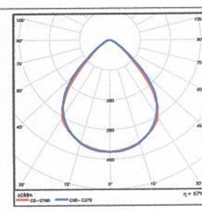
Horizontal illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Calculation surface 1	46	39	64	0.848	0.609	5 x 5 (all)

Height of room: 3.400 m, Height of working plane: 0.800 m, Wall zone: 0.000 m, Reflection factors: Ceiling 70.0%, Walls 50.0%, Floor 30.0%, Light loss factor: 0.80

No.	Quantity	
1	12	Philips Lighting TPS460 H2L 1xTL5-20W HFP MLO-PC Light output ratio: 66.62% Luminous flux: 999 lm, Power: 104.0 W





Total luminous flux: 11992 lm, Total Load: 1248 W

Specific connection value: 9.01 W/m² = 13.49 W/m²/100 lx (Ground area 138.53 m²)

Figure 4.11(b): SIMULATED LIGHTING MODEL OF OLD DESIGN OF POSTGRADUATE LAB

Perpendicular illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Wall calculation object 1	35	0.00	94	0.000	0.000	28 x 7 (all)
Wall calculation object 2	30	13	52	0.433	0.250	28 x 7 (all)
Wall calculation object 3	35	0.00	94	0.000	0.000	28 x 7 (all)
Wall calculation object 4	30	13	51	0.433	0.255	28 x 7 (all)
Summary	33	0.00	94	0.00	0.00	

Perpendicular illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Ceiling calculation object 1	19	15	23	0.789	0.652	10 x 10 (all)

Perpendicular illuminance (adaptive)

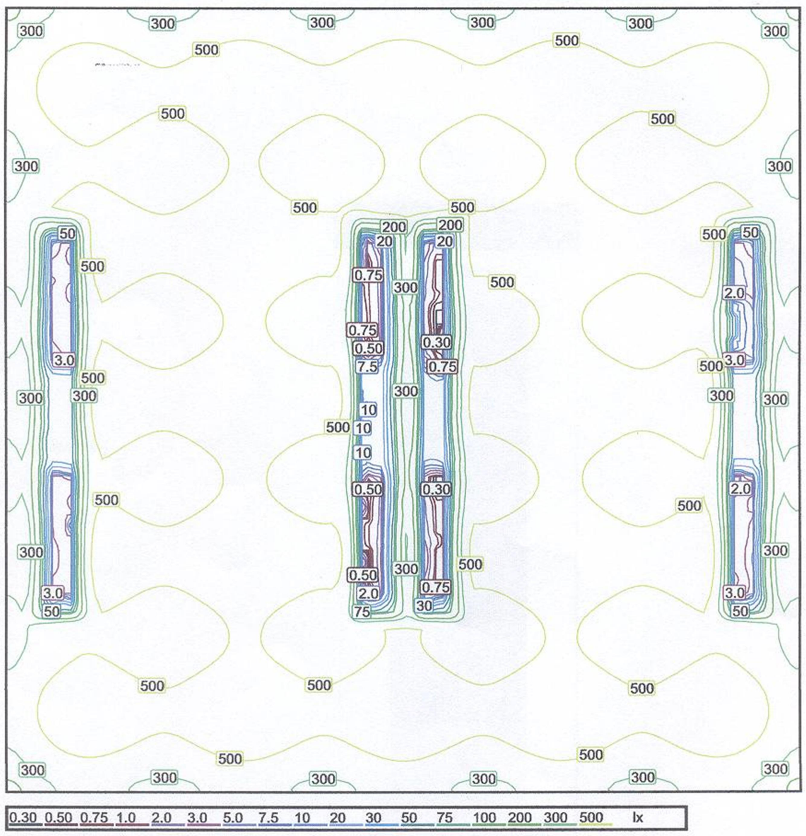
Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Workplane 1	67	0.01	137	0.000	0.000	128 x 128 (all)

Horizontal illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Calculation surface 1	46	39	64	0.848	0.609	5 x 5 (all)

Height of room: 3.400 m, Height of working plane: 0.800 m, Wall zone: 0.000 m, Reflection factors: Ceiling 70.0%, Walls 50.0%, Floor 30.0%, Light loss factor: 0.80

Relevant points are points in a surface that are not covered by room elements. The summarised results are based exclusively on these relevant points, as the remaining points would falsify the results.



Scale: 1 : 75

Perpendicular illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Wall calculation object 1	224	0.00	1150	0.000	0.000	28 x 7 (all)
Wall calculation object 2	223	79	516	0.354	0.153	28 x 7 (all)
Wall calculation object 3	224	0.00	1151	0.000	0.000	28 x 7 (all)
Wall calculation object 4	223	80	516	0.359	0.155	28 x 7 (all)
Summary	223	0.00	1151	0.00	0.00	

Perpendicular illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Ceiling calculation object 1	128	97	159	0.758	0.610	10 x 10 (all)

Figure 4.12(a): SIMULATED ILLUMINANCE CONTOURS OF NEW DESIGN OF POSTGRADUATE LAB

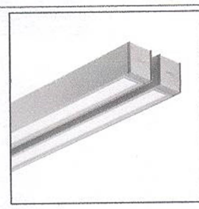
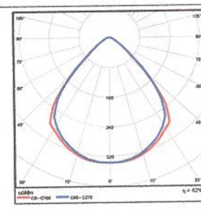
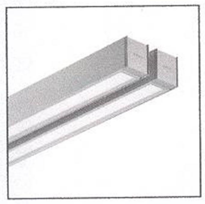
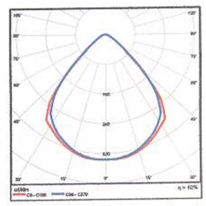
Perpendicular illuminance (adaptive)

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Workplane 1	434	0.23	717	0.001	0.000	128 x 128 (all)

Horizontal illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Calculation surface 1	571	427	722	0.748	0.591	5 x 5 (all)

Height of room: 3.400 m, Height of working plane: 0.800 m, Wall zone: 0.000 m, Reflection factors: Ceiling 70.0%, Walls 50.0%, Floor 30.0%, Light loss factor: 0.80

No.	Quantity			
1	1	Philips Lighting TPS680 2xTL5-28W HFP AC-MLO Light output ratio: 61.87% Luminous flux: 3217 lm, Power: 118.0 W		
2	24	Philips Lighting TPS680 2xTL5-28W HFP AC-MLO Light output ratio: 61.87% Luminous flux: 3217 lm, Power: 118.0 W		

Total luminous flux: 80426 lm, Total Load: 2950 W

Specific connection value: 21.29 W/m² = 4.91 W/m²/100 lx (Ground area 138.53 m²)

Figure 4.12(b): SIMULATED LIGHTING MODEL OF NEW DESIGN OFPOSTGRADUATE LAB

Perpendicular illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Wall calculation object 1	224	0.00	1150	0.000	0.000	28 x 7 (all)
Wall calculation object 2	223	79	516	0.354	0.153	28 x 7 (all)
Wall calculation object 3	224	0.00	1151	0.000	0.000	28 x 7 (all)
Wall calculation object 4	223	80	516	0.359	0.155	28 x 7 (all)
Summary	223	0.00	1151	0.00	0.00	

Perpendicular illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Ceiling calculation object 1	128	97	159	0.758	0.610	10 x 10 (all)

Perpendicular illuminance (adaptive)

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Workplane 1	434	0.23	717	0.001	0.000	128 x 128 (all)

Horizontal illuminance

Name	Average [lx]	Min [lx]	Max [lx]	Min/average	Min/max	Points (Relevant)
Calculation surface 1	571	427	722	0.748	0.591	5 x 5 (all)

Height of room: 3.400 m, Height of working plane: 0.800 m, Wall zone: 0.000 m, Reflection factors: Ceiling 70.0%, Walls 50.0%, Floor 30.0%, Light loss factor: 0.80

Relevant points are points in a surface that are not covered by room elements. The summarised results are based exclusively on these relevant points, as the remaining points would falsify the results.

The following observations could be made from the outcome of the simulation of illuminance levels of the two lab spaces using the old and new (improved) designs:

In the existing design of the undergraduate lab, the illuminanace levels around the luminaires recorded 200 lux while it dipped from as low as 100 lux to 50 lux between the luminaires (about 50% to 25% of the maximum). This is below the specified standard dip of not below 70% (Mitroy, 2009). In the new design of the same lab, the illuminanace levels were fairly distributed at 300 lux (acceptable).

Moreover, in the old design of the postgraduate lab, the illuminance levels around the luminaires recorded 100 lux (poor) and dipped as low as 50 lux (50%) between the luminaires, also below the acceptable limit of 70%. On the other hand, in the new design of the postgraduate lab, the illuminance levels were fairly distributed at 500 lux (acceptable).

4.2.4 COMPARISON IN TERMS OF DAYLIGHTING APPLICATION- A CASE STUDY OF UNDERGRADUATE LABORATORY

Daylighting data were collected at about 1:40pm on 28/06/11 and 01/07/11 respectively using digital luxmeter and an attempt was made to create daylighting contours in the Undergraduate Laboratory of the Building only. This is just a rough demonstration of how daylighting application can further enable energy savings. See Fig 15 for the rough sketch of Daylight Contours obtained, based on a mild cloudy day and desk height of 900mm

External illuminance was read at 30, 000 lux (average)

:. Contour 1 (5%) = average of 1500 lux (ie 5% of 30, 000)

Contour 2 (2%) = average of 600 lux

Contour 3 (1%) = average of 300 lux

Contour 4 (0.4%) = average of 120 lux

With a specified illuminance of 400lux (See space 1 data), the following automatic controls were specified:

(a) Thorn Switchlite MWA SLD IP64 BLK, Product Ref 96233649. This wall-mounted device shall link the switchable luminaires to presence/absence and daylight detectors. The presence /absence detector shall be set at a delay of 3mins (adjustable to 10s – 3mins). The daylight detectors shall be set at 1500 lux, minimum specification of three times the required illuminance (Actionenergy, 2003).This is best mountable near the platform for wide range of coverage (up to contour 2 extremes).

(b) Thorn LSD Daylight Sensor: Product Ref 96111028, ceiling-mounted and centralized one-third the distance away from the platform (wall). This shall be connected to 4 No Dimmers to take care of Circuits. 1 to 4 as follows:

(i) Dimmer, D1 to dim lamps from 0 – 100% for illuminance fluctuations from 400-1500lux, combined daylight and electric light.

(ii) Dimmer, D2 ditto but for 400 – 1200 lux

(iii) Dimmer, D3 ditto but for 400 – 1000 lux

(iv) Dimmer D4 ditto but for 400 – 800 lux

Manually operated switches can be used when people are coming in but even if they do not switch off while leaving, it can be done automatically by Switchlite. See drawing/schematics for proposed wiring logic (Figs 16 and 17)

The energy savings work in the following ways: If energy savings per day are CCT.1 (40%), CCT. 2(25%), CCT.3 (10%) and CCT. 4 (5%),

:. CCT. 1 : $0.4x4x75 \ = \ 120W$

CCT 2: $0.25x8x75 \ = 150W$

CCT. 3: $0.1x4x75 \ = \ 30W$

CCT. 4: $0.05x8x75 \ = \ 30W$

Total = <u>330W</u>

In KWh/month, $total\ savings \ = \ 330x24x30/1000$

$$= 237.6kW/h$$

From the foregoing it could be observed that switching cells were formed from respective isolux contours.

Let proportions of savings achieved by dimming vary from 1 to 0, and be represented by Xs1, Xs2, Xs3, Xs4 and P1, P2, P3, P4 be total power rating of lamps per switching cell in CCT1, CCT2, CCT3, CCT4 respectively.

(a**) In terms of Energy Savings:**

$$X_{s1}P_1 \ + \ X_{s2}P_2 + X_{s3}P_3 + \ X_{s4}P_4 \ = \ P_s$$

$$\therefore Total\ KWH\ saved \ = \ \frac{P_S H}{1000} \ = \ Es$$

Where H = Number of hours; Es = Energy saved (KWH); Ps = Total Power saved (W)

$\therefore$ Generally, $Es \ = \ \frac{(X_{s1}P_1 \ + X_{s2}P_2 + X_{s3}P_3 + \ .....)}{1000} H$

$$Total\ amount\ of\ money\ saved \ = \ N(Es \ * \ R)$$

Where R = KWH billing rate in Naira (N).

(b**) In terms of Energy Consumed:**

Let proportions of consumption at dimming vary from 1 to 0, and be represented by Xc1, Xc2, Xc3, Xc4 and P1, P2, P3, P4 be total power rating of lamps per switching cell in CCT1, CCT2, CCT3, CCT4 respectively:

$$\therefore \; X_{c1}P_1 + X_{c2}P_2 + X_{c3}P_3 + X_{c4}P_4 = P_c$$

$$Total\ KWH\ consumed = \frac{P_cH}{1000}$$

$$\therefore \; Ec = \frac{(X_{c1}P_1 + X_{c2}P_2 + X_{c3}P_3 + \ldots..)}{1000}H$$

$$Total\ amount\ of\ money\ to\ be\ paid = Ec * R$$

When switching cell CCT1 is off, $X_{c1}P_1 = 0, etc.$

This is better known as the daylight switching model.

This device/model will find application in the following areas for energy savings:

(i) **Automated Daylight Control:** This enables lamps in a particular isolux contour to be dimmed fairly uniformly, even to zero at some level of daylight illuminance.

(ii) **In large spaces such as laboratories, lecture halls/theatres, etc**. in developing areas, a user of smaller generating sets can conveniently decide on the switching cells to be put off without creating shades of low illuminances in less bright portions, so as to utilize the power of the generator.

NOTE: Day lighting application was not applied in the old design for any of the spaces.

From the daylight illuminance readings taken, energy savings can range from 30% during very dull weather to 67% on very dry days.

This is quite understandable in Europe and America where energy certification is now being demanded in buildings/estates [Actionenergy, 2003]

The contours here are just for demonstrations from only two days readings. More extensive studies are required over a period of time, coupled with programming, to establish daylight contours of specific mapped areas.

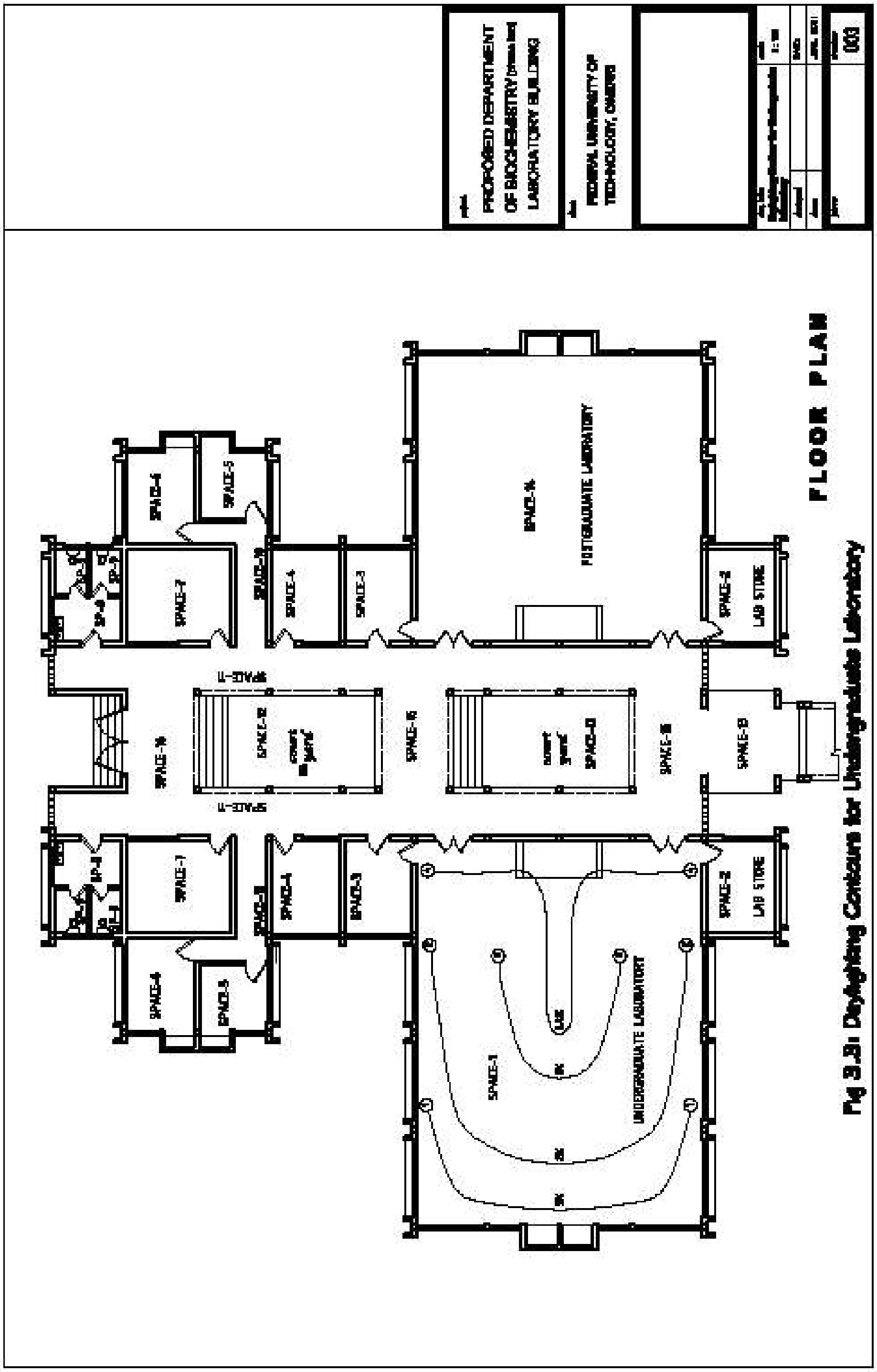


Fig. 4.13: Daylighting Contours for Undergraduate Laboratory

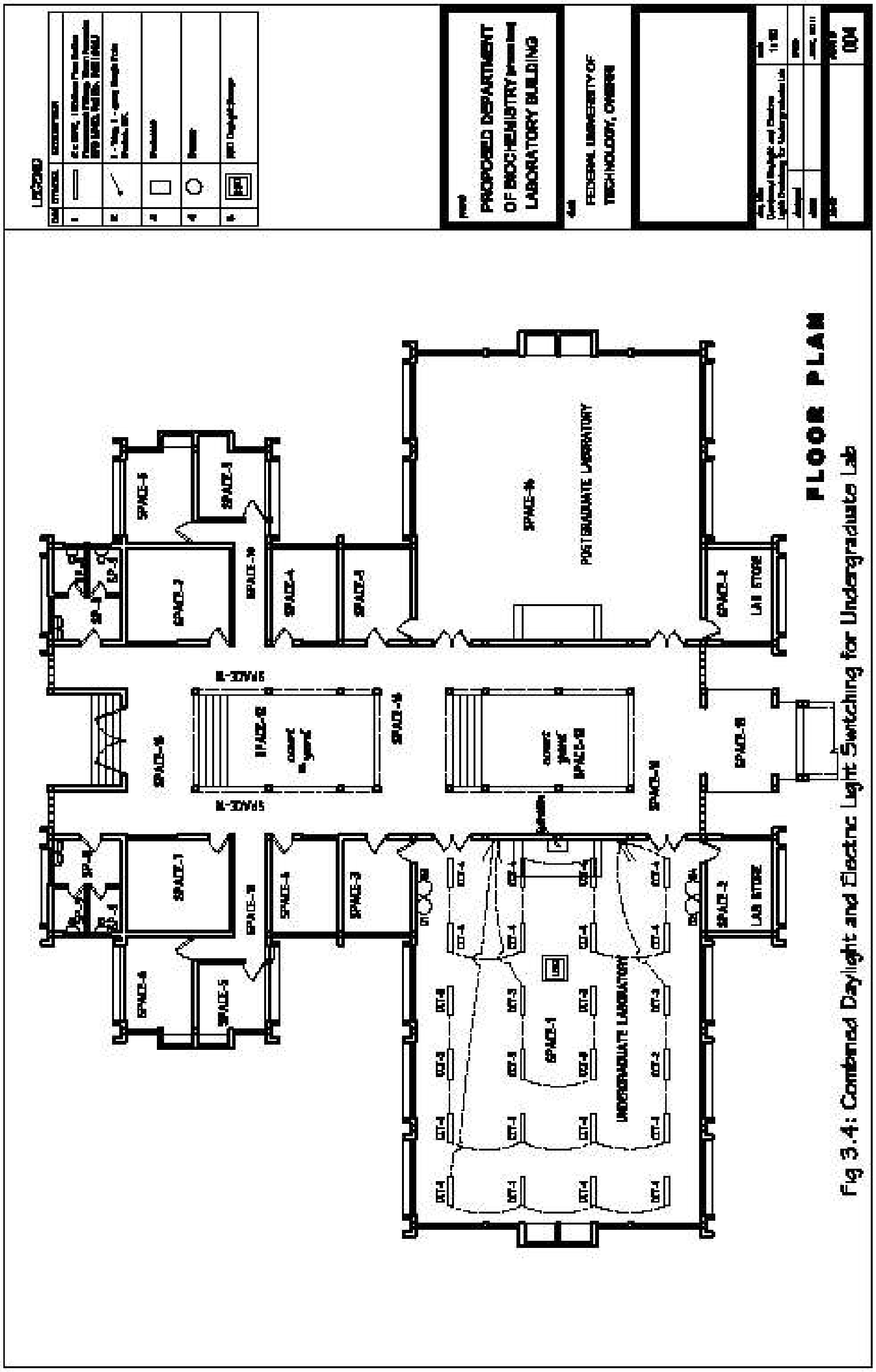


Fig. 4.14: Combined Daylight and Electric Light Switching for Undergraduate Lab

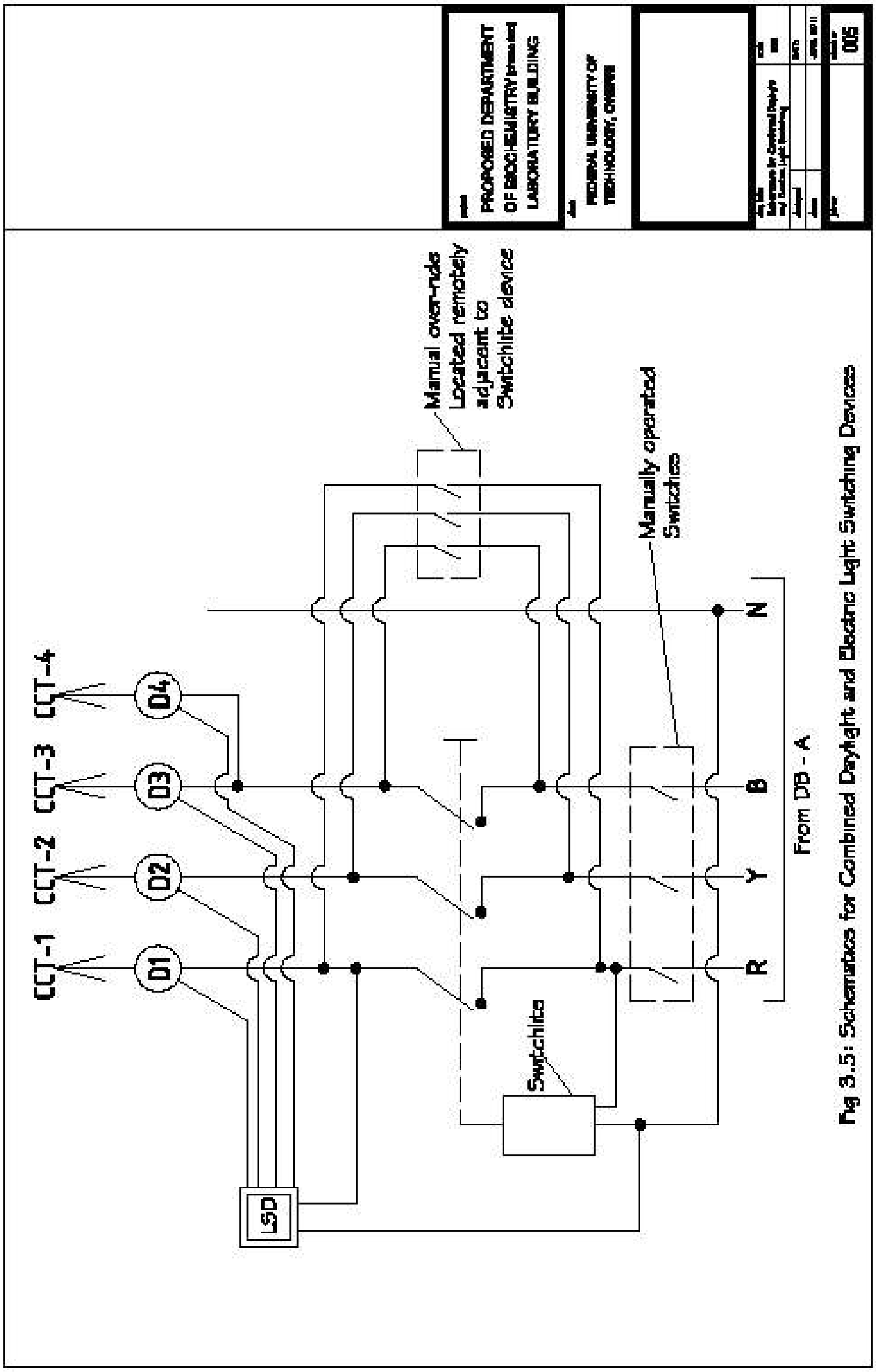


Fig. 4.15: Schematics for Combined Daylight and Electric Light Switching Devices

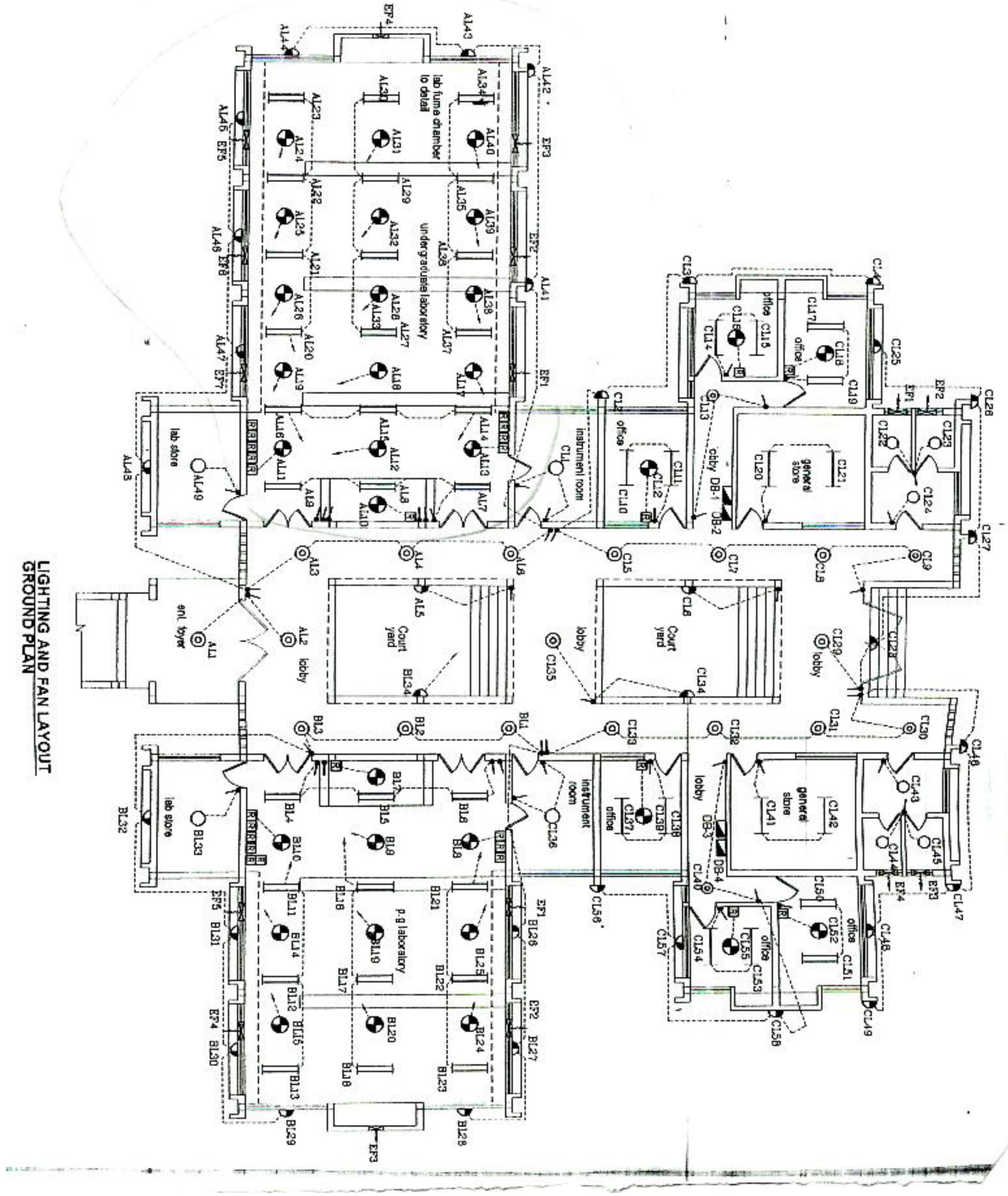


Figure 4.16: Lighting/Fan Design by an External (Indigenous) Consultant

LEGEND

SYMBOL	DESCRIPTION
	1x40w FLUORESCENT LIGHTING FITTING COMPLETE WITH PRISMATIC DIFFUSERS BY ASTRA NU-PAK ENGLAND
	2x40w FLUORESCENT LIGHTING FITTING COMPLETE WITH PRISMATIC DIFFUSERS BY ASTRA NU-PAK ENGLAND
	CAR PORT LIGHTING FITTING
◎	1x60w BOWL FITTING C/W PLASTIC GALLER AND SCREWED NECK
	13A FLUSH MOUNTED SWITCHED SOCKET OUTLET
	15A, FLUSH MOUNTED SWITCHED SOCKET OUTLET
	1 GANG 1-WAY FLUSH MOUNTED SWITCH
	1 GANG 2-WAY FLUSH MOUNTED SWITCH
2	2 GANG 2-WAY FLUSH MOUNTED SWITCH
2	2 GANG 1-WAY FLUSH MOUNTED SWITCH
R	1x400mm SWEEP CEILING FAN NEW CLIME OR EQUAL AND FAN REGULATOR
○	1x60w CEILING MOUNTED FITTING C/W CIRCULAR WHITE OPAQUE PLASTIC DIFFUSER
	TV. ANTENNA
	MCB- TYPE DISTRIBUTION BOARD AS SPECIFIED
▲	TELEPHONE OUTLET (MK 5665D5 WH1)
△	TELEPHONE INTERNAL (MK 5665D5 WH1)
	NETWORK OUTLET
	24 POT NETWORK HUB
	COMPUTER SYSTEM

Table 4.5: Legend of Fig. 4.16

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

As earlier highlighted, this work was aimed at designing an improved lighting installation at a typical University Laboratory Building. From the results obtained, the following targets have been achieved so far:

- Design of energy-efficient lighting scheme using modern energy-efficient lamps/fittings: The analysis carried out showed that the prevailing standards were met with significant improvements. Standards used include ECON(UK), CIBSE(UK) and ASHRAE(USA).

- With the use of digital luxmeter in a mild/cool day, the daylight factors were plotted in contour form for the typical University laboratory. This result was superimposed on the above designed lighting scheme, while automated/regulated switching devices were specified to control the use of the lamps, as total illuminance values were set at predetermined ranges. Daylight switching model was formulated whereby switching cells follow isolux contours. From daylight illuminance readings and with the use of dimmable lamps, energy savings could range from 30% during very dull weather to 67% on very dry days.

- The assessment of the existing lighting design handled by an indigenous consultant was facilitated by available photometric data of the lamps/fittings from the web. Comparisons were made between old (existing) and the new designs in terms of standards used, luminaires efficacy, expected life, illuminance levels and cost. While the new design excelled in the first four factors, the total initial cost of the existing design was lower. Efficacy of luminaires improved over 4 to 7 times, expected life 30 to 40 times in the new design while illuminance levels were found to be very poor in the old compared to the new design which used specified standard illuminance levels. The initial cost of the new design was less than two times (about 1.6 times) that of the old design but at the end of the first year, while the cost of the new design remained the same, that of old design increased about 1.94 times (almost doubled), thereby rising to about 1.2 times that of the former due to excessive lamps replacement cost. It was clear that the old design carried out on unregulated platforms was unguided. Some luminaires imported into the country are as unregulated as the local designs.

- Simulation of illuminanace levels of the old and new (improved) designs were also carried out for both undergraduate and postgraduate labs using DIALUX lighting design software. Apart from recording illuminance dip between the luminaires below the acceptable limit of 70% in the labs, the old design did not meet with the required minimum design illuminance of 300 lux, even around the luminaires. The new design for both labs excelled in recording 300 lux and 500 lux fair distribution in the lab spaces.

- The original design which is typical of many indigenous lighting designs did not specify appropriate photometric data. It is a fact that luminaires utilize electric power but a lighting design should specify expected illuminance levels (in lux) and for energy efficiency purposes, must include power density benchmarks for the relevant spaces. Both of these parameters were not specified in the existing design under review.

5.2 RECOMMENDATIONS

The following recommendations for improvement on contemporary lighting designs in Nigeria were as listed below:

(1) Nigeria is in dire need of lighting standards in view of the Nigerian Electricity Act of 2005 which brought in deregulation, unbundling and privatization of power industry with the associated competition and commercialization aimed at increasing efficiency through enhanced quality service delivery. It should be observed that some Engineering Services Consultants design at convenience. Luminaires either manufactured in or imported into the country are not regulated by any indigenous lighting standards. No wonder, Nigeria is seen as a dumping ground by different nations. A little overview of lamp manufacturers in Nigeria shows that photometric data of lamps are hardly available. But even if there are, who confirms such data?

(2) Energy efficiency in lighting is now being emphasized worldwide. Even though lighting consumes about 20% of electrical energy generated, the lighting profession/industry is under pressure to indicate their own efforts in reducing sizes of our generating stations and thereby reducing rate of carbon emissions. With choice of lamps of adequate efficacy and long life, this is achievable.

(3) Choice of lamps is no more done at convenience. Considerations such as efficacy, colour rendering index, correlated colour temperature, life etc should now be made.

(4) Nigeria is in equatorial region where there is much sunshine. This benefit can be appropriated in lighting design. There is no need wasting electric energy by use of artificial lighting when some homes/offices can benefit from use of day lighting due to their location.

(5) Lighting has not become a profession in Nigeria. Some Electrical Services Engineers just try to design from sample designs of others. It is not surprising therefore to discover obsolete specifications in many drawings. In fact, many designers in our country are not yet ICT-compliant. Brochures/catalogues are now better accessed through the web for updateness. Lighting profession should be developed by carving out a curriculum in either Electrical Engineering, or a combination of Electrical Engineering and Architecture.

5.3 TOWARDS DEVELOPMENT OF A NATIONAL BUILDING LIGHTING STANDARD

At this point, it might be helpful to propose the following building lighting standard as an interim guide for lighting designers in Nigeria:

Table 5.1(a): Recommended Standard Illuminance Levels and Power Densities For Some Selected Building Spaces

SPACE TYPE	OFFICE		HOSPITALS/HEALTH CARE		HOTEL	
	Illuminance (lux)	Power Density (W/m^2)	Illuminance (lux)	Power Density (W/m^2)	Illuminance (lux)	Power Density (W/m^2)
Office- Enclosed	300	11	300	11	300	11
Office- Open Plan	400	12	400	12	400	12
Conference Hall	300-500	14	300-500	14	300-500	14
Food Preparation	300	11	400	12	450	13

Rest Rooms	150	8	150	8	150	8
Corridor/Transition	100	7	100	7	100	7
Stairs- Active	100	7	150	8	150	8
Active Storage	150	8	400	12	150	8
Inactive Storage	70	4	120	7	70	4
Elect/Mech. Control Rooms	450	13	500	14	450	13
Canteen, Cafeteria, Dining Rooms	200	9	200	9	200	9
Computer Work Stations	200	9	200	9	200	9
Reception Desk	300	11	300	11	300	11
Bed Rooms	-	-	100	7	100	7

Table 5.1(b): Recommended Standard Illuminance Levels and Power Densities For Special Spaces

SPACE TYPE	ILLUMINANACE (lux)	POWER DENSITY (W/m$^{2)}$
Banking Halls	400	12
Laboratories/Classrooms	400	12
Theatre/Emergency (e.g. Hospitals, etc.)	500	14
Fashion	500	14
Supermarket/Superstore	750	16
Bookshop, Chemist, Jeweller	500	14

Arcades/Malls	300	11
Cinema/Theatre Foyer	200	9
Auditoria	150	8
Library	300	11
Museum Art Gallery	300	11
Church	300	11

5.4 SUGGESTIONS FOR FURTHER WORK

Further work may still be carried out in the following areas:

- Daylight factors of regions/areas in Nigeria can be ascertained through research and proper mapping/programming. This can be used by lighting designers for energy-efficient designs.
- It should be noted that the use of conventional Luxmeter does not take care of real light that enters the eye through reflection. All the readings in this work were taken with the Meter in vertical position. Lighting designers should seek to lay hold of modern luminance meters to enhance lighting design accuracy. Some adequate standards that should take care of reflected light are required. Let us move into the third stage of the lighting profession.
- Confirmatory physical readings could not be taken with the Luxmeter due to the state of power supply in the country. Further work may need to include such on-site readings to enable comparison to be made between design and real time data.

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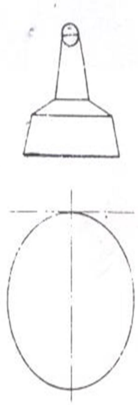
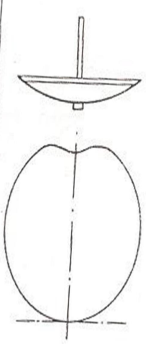
APPENDIX A: UTILIZATION FACTORS TABLE [BHATIA, 2006]

Incandescent Lamps			*Utilisation Facto New Condition*									*Maintenance Factor*	
Type of Fitting	*Efficiency %*	*K*	$r_c = 0.7$ r_w			$r_c = 0.5$ r_w			$r_c = 0.3$ r_w			*Cleaned once yearly*	*Cleaned once every 2 years*
			0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1		
		0.5	0.27	0.21	0.17	0.26	0.21	0.17	0.26	0.21	0.17	Soiling rate low	
		0.6	0.32	0.26	0.21	0.31	0.25	0.21	0.30	0.25	0.21,		
		0.75	0.38	0.32	0.32	0.37	0.32	0.27	0.36	0.31	0.27	X	X
		1.0	0.46	0.40	0.40	0.45	0.40	0.36	0.44	0.39	0.36		
		1.2	0.51	0.46	0.46	0.50	0.46	0.42	0.49	0.45	0.42		
		1.5	0.55	0.50	0.50	0.54	0.50	0.46	0.53	0.49	0.46	Soiling rate normal	
	0 ↑ 80 ↓ 80	2.0	0.61	0.56	0.56	0.60	0.56	0.53	0.59	0.55	0.53		
		2.5	0.64	0.60	0.60	0.63	0.60	0.57	0.62	0.69	0.57	1.35	1.55
		3.0	0.67	0.63	0.63	0.66	0.63	0.60	0.65	0.62	0.60,		
		4.0	0.70	0.67	0.67	0.69	0.67	0.65	0.68	0.66	0.65	Soiling rate high	
		5.0	0.72	0.70	0.70	0.71	0.69	0.67	0.71	0.69	0.67	1.65	2.15
		Fittings at centre of room											
		0.5	0.29	0.23	0.19	0.28	0.23	0.19	0.28	0.23	0.19,		
		0.6	0.35	0.20	0.25	0.34	0.29	0.25	0.33	0.28	0.25		
		0.75	0.42	0.37	0.33	0.41	0.36	0.33	0.41	0.36	0.33		
		1.0	0.52	0.47	0.44	0.51	0.47	0.44	0.50	0.47	0.44,		

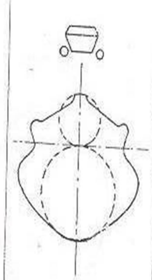
A 1

Incandescent Lamps			*Utilisation Factor, New Condition*										
Type of Fitting	*Efficiency %*	*K*	$r_c = 0.7$ r_w			$r_c = 0.5$ r_w			$r_c = 0.3$ r_w			*Cleaned once yearly*	*Cleaned once every 2 years*
			0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1		
Diffuser		0.5	0.20	0.15	0.12	0.18	0.13	0.10	0.15	0.11	0.19	Soiling rate low	
		0.6	0.24	0.18	0.15	0.21	0.16	0.13	0.17	0.14	0.11	1.25	1.40
		0.8	0.28	0.23	0.19	0.24	0.21	0.16	0.21	0.17	0.14	Soiling rate normal	
		1.0	0.34	0.29	0.25	0.30	0.25	0.21	0.25	0.21	0.18	1.45	1.80
		1.2	0.39	0.33	0.29	0.33	0.29	0.25	0.28	0.25	0.22	Soling rate high	
		1.5	0.42	0.37	0.32	0.36	0.32	0.28	0.31	0.27	0.24	X	X
	35 ↑ 79 ↓	2.0	0.46	0.42	0.38	0.40	0.36	0.33	0.34	0.31	0.29		
		2.5	0.50	0.45	0.42	0.43	0.40	0.37	0.37	0.34	0.32		
		3.0	0.52	0.48	0.45	0.45	0.42	0.39	0.39	0.36	0.34		
		4.0	0.55	0.52	[illegible]	0.48	0.45	0.43	0.42	0.39	0.37		
		5.0	0.57	0.54	0.51	0.50	0.48	0.46	0.43	0.41	0.40		
		Fittings at centre of room											
		0.5	0.21	0.16	0.12	0.18	0.14	0.11	0.15	0.12	0.09		
		0.6	0.25	0.19	0.16	0.21	0.17	0.14	0.18	0.14	0.12		
		0.8	0.30	0.24	0.20	0.26	0.21	0.18	0.22	0.18	0.15		
		1.0	0.36	0.31	0.27	0.32	0.27	0.24	0.27	0.24	0.21		

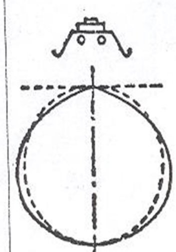
A 2

Incandescent Lamps			*Utilisation Factor, new Condition*									*Maintenance Factor*	
Type of Fitting	*Efficiency %*	*K*	$r_c = 0.7$ r_w			$r_c = 0.5$ r_w			$r_c = 0.3$ r_w			*Cleaned once yearly*	*Cleaned once every 2 years*
			0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1		
Indirect fitting		0.5	0.19	0.15	0.12	0.13	0.11	0.09	0.08	0.06	0.05	Soiling rate low	
		0.6	0.23	0.19	0.16	0.16	0.13	0.11	0.09	0.08	0.07	1.35	1.55
		0.8	0.27	0.23	0.20	0.19	0.16	0.14	0.11	0.09	0.08	Soiling rate normal	
		1.0	0.32	0.28	0.25	0.22	0.20	0.18	0.13	0.12	0.11	1.65	2.15
		1.3	0.35	0.32	0.29	0.25	0.22	0.21	0.15	0.13	0.12	Soiling rate high	
		1.5	0.38	0.35	0.32	0.27	0.25	0.23	0.16	0.15	0.14	X	X
		2.0	0.42	0.39	0.37	0.30	0.28	0.26	0.18	0.17	0.16		
	80 ↑ 80 ↓ 0	2.5	0.45	0.42	0.49	0.31	0.30	0.28	0.19	0.18	0.17		
		3.0	0.46	0.44	0.42	0.33	0.31	0.30	0.19	0.19	0.18		
		4.0	0.49	0.47	0.45	0.34	0.33	0.32	0.20	0.20	0.19		
		5.0	0.50	0.49	0.47	0.35	0.34	0.34	0.21	0.21	0.20		
		Fittings at centre of room											
		0.5	0.19	0.15	0.13	0.14	0.11	0.09	0.08	0.07	0.06		
		0.6	0.23	0.19	0.16	0.16	0.14	0.12	0.10	0.08	0.07		
		0.8	0.28	0.24	0.20	0.19	0.17	0.15	0.11	0.10	0.09		
		1.0	0.33	0.21	0.26	0.23	0.21	0.19	0.14	0.13	0.11		

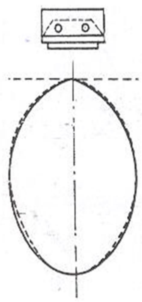
A 3

Fluorescent Lamps			Utilisation Factor, New Condition									Maintenance Factor	
Type of Fitting	Efficiency %	K	$r_c = 0.7$ r_w			$r_c = 0.5$ r_w			$r_c = 0.3$ r_w			Cleaned once yearly	Cleaned once every 2 years
			0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1		
Flourescent lamp on mounting rail		0.5	0.27	0.20	0.16	0.24	0.18	0.15	0.21	0.16	0.13	Soiling rate low	
		0.6	0.31	0.25	0.20	0.28	0.22	0.18	0.25	0.20	0.16	1.25	1.10
		0.8	0.37	0.31	0.26	0.33	0.28	0.23	0.29	0.25	0.21	Soiling rate normal	
		1.0	0.45	0.39	0.31	0.40	0.35	0.31	0.35	0.31	0.28	1.45	1.80
		1.3	0.50	0.44	0.39	0.45	0.40	0.36	0.40	0.36	0.32	Soiling rate high	
	33 ↑ 93 ↓ 60	1.5	0.54	0.48	0.44	0.48	0.44	0.40	0.43	0.39	0.36	X	X
		2.0	0.60	0.55	0.50	0.54	0.50	0.46	0.48	0.44	0.41		
		2.5	0.63	0.59	0.55	0.57	0.53	0.50	0.51	0.48	0.45		
		3.0	0.66	0.62	0.59	0.60	0.56	0.53	0.53	0.51	0.48		
		4.0	0.70	0.66	0.63	0.63	0.60	0.58	0.57	0.54	0.52		
		5.0	0.72	0.69	0.66	0.65	0.63	0.61	0.59	0.57	0.55		
		Fitting at centre of room											
		0.5	0.28	0.22	0.17	0.25	0.20	0.16	0.22	0.18	0.14		
		0.6	0.33	0.27	0.22	0.29	0.24	0.20	0.26	0.22	0.18		
		0.8	0.40	0.34	0.29	0.36	0.30	0.27	0.32	0.28	0.24		
		1.0	0.49	0.43	0.38	0.44	0.39	0.35	0.39	0.36	0.32		

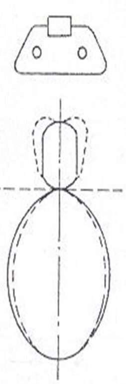
A 4

Fluorescent Lamps			Utilisation factor, New Condition									Maintenance Factor	
Type of Fitting	Efficiency %	K	$r_c = 0.7$ r_w			$r_c = 0.5$ r_w			$r_c = 0.3$ r_w			Cleaned once yearly	Cleaned once every 2 years
			0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1		
Direct trough fitting with fluorescent lamps.		0.5	0.29	0.24	0.20	0.29	0.23	0.20	0.28	0.23	0.20		
		0.6	0.35	0.29	0.25	0.34	0.28	0.25	0.33	0.28	0.24		
		0.8	0.41	0.36	0.31	0.41	0.35	0.31	0.40	0.35	0.31	Soiling rate low	
		1.0	0.50	0.45	0.41	0.49	0.44	0.41	0.48	0.44	0.41		
		1.3	0.55	0.50	0.47	0.54	0.50	0.46	0.48	0.50	0.46	X	X
	0 ↑ 82 ↓ 82	1.5	0.59	0.55	0.51	0.58	0.54	0.51	0.53	0.54	0.51	Soiling rate normal	
		2.0	0.65	0.61	0.58	0.64	0.60	0.58	0.58	0.60	0.57		
		2.5	0.68	0.65	0.62	0.67	0.64	0.62	0.63	0.64	0.62	1.40	1.70
		3.0	0.70	0.67	0.65	0.69	0.67	0.65	0.66	0.67	0.65		
		4.0	0.73	0.71	0.69	0.72	0.71	0.69	0.72	0.70	0.69	Soiling rate high	
		5.0	0.75	0.73	0.71	0.74	0.73	0.71	0.74	0.72	0.71	1.85	2.85
		Fittings at centre of room											
		0.5	0.32	0.26	0.22	0.31	0.23	0.22	0.30	0.26	0.22		
		0.6	0.38	0.33	0.29	0.37	0.32	0.29	0.37	0.32	0.29		
		0.8	0.46	0.41	0.33	0.46	0.41	0.38	0.45	0.41	0.38		
		1.0	0.57	0.53	0.50	0.57	0.53	0.50	0.56	0.53	0.50		

A 5

Fluorescent lamps		Utilisation Factor, New Condition										Maintenance Factor	
Type of Fitting	*Efficiency %*	*K*	$r_c = 0.7$ r_w			$r_c = 0.5$ r_w			$r_c = 0.3$ r_w			*Cleaned once yearly*	*Cleaned once every 2 years*
			0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1		
Direct with louvres		0.5	0.24	0.21	0.18	0.24	0.20	0.18	0.24	0.20	0.18	Soiling Rate low	
		0.6	0.29	0.25	0.22	0.28	0.24	0.22	0.28	0.24	0.22		
		0.8	0.34	0.30	0.27	0.33	0.30	0.27	0.33	0.29	0.27	1.30	1.45
		1.0	0.40	0.37	0.34	0.39	0.36	0.34	0.39	0.36	0.34		
	0	1.3	0.43	0.40	0.38	0.43	0.40	0.38	0.42	0.40	0.38	Soiling rate normal	
	↑	1.5	0.46	0.43	0.41	0.45	0.43	0.41	0.45	0.43	0.41		
		2.0	0.49	0.47	0.45	0.49	0.47	0.45	0.48	0.46	0.45	1.55	1.90
	60	2.5	0.51	0.49	0.48	0.51	0.49	0.47	0.50	0.49	0.47		
	↓	3.0	0.53	0.51	0.49	0.52	0.51	0.49	0.52	0.50	0.49	Soiling rate high	
	60	4.0	0.54	0.53	0.52	0.54	0.53	0.52	0.54	0.53	0.52		
		5.0	0.56	0.54	0.53	0.55	0.54	0.53	0.55	0.54	0.53	X	X
		Fittings at Centre of Room											
		0.5	0.27	0.23	0.21	0.26	0.23	0.21	0.26	0.23	0.21		
		0.6	0.32	0.29	0.26	0.32	0.28	0.26	0.31	0.28	0.26		
		0.8	0.39	0.36	0.33	0.38	0.35	0.33	0.38	0.35	0.33		
		1.0	0.46	0.44	0.42	0.46	0.44	0.42	0.45	0.44	0.42		

A 6

Fluorescent lamps		Utilisation Factor, New Condition										Maintenance Factor	
Type of Fitting	*Efficiency %*	*K*	$r_c = 0.7$ r_w			$r_c = 0.5$ r_w			$r_c = 0.3$ r_w			*Cleaned once yearly*	*Cleaned once every 2 years*
			0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1		
Semi direct with louvres		0.5	0.25	0.20	0.17	0.23	0.19	0.16	0.21	0.17	0.15	Soiling Rate low	
		0.6	0.30	0.25	0.21	0.27	0.23	0.20	0.25	0.21	0.19	1.30	1.50
		0.8	0.35	0.30	0.27	0.34	0.28	0.25	0.29	0.26	0.23	Soiling rate normal	
		1.0	0.42	0.38	0.34	0.39	0.35	0.32	0.35	0.32	0.30	1.60	200
	24	1.3	0.46	0.42	0.39	0.43	0.39	0.36	0.39	0.36	0.34	Soiling rate high	
	↑	1.5	0.49	0.46	0.43	0.45	0.42	0.40	0.42	0.39	0.37	X	X
	76	2.0	0.54	0.50	0.48	0.49	0.47	0.44	0.45	0.43	0.41		
	↓	2.5	0.56	0.53	0.51	0.52	0.50	0.48	0.48	0.46	0.44		
	52	3.0	0.58	0.56	0.53	0.54	0.52	0.50	0.49	0.48	0.46		
		4.0	0.61	0.59	0.57	0.56	0.54	0.53	0.51	0.50	0.49		
		5.0	0.62	0.60	0.59	0.57	0.56	0.55	0.53	0.52	0.51		
		Fittings at Centre of room											
		0.5	0.27	0.22	0.19	0.25	0.21	0.18	0.23	0.19	0.17		
		0.6	0.32	0.27	0.24	0.29	0.26	0.23	0.27	0.24	0.21		
		0.8	0.39	0.34	0.34	0.36	0.32	0.29	0.33	0.30	0.28		
		1.0	0.47	0.43	0.43	0.43	0.38	0.40	0.40	0.38	0.36		

A7

APPENDIX B: UNDERSTANDING IP RATINGS

The protection of enclosures against ingress of dirt or against the ingress of water is defined in IEC529 (BSEN60529:1991). Conversely, an enclosure which protects equipment against ingress of particles will also protect a person from potential hazards within that enclosure, and this degree of protection is also defined as a standard.

The degrees of protection are most commonly expressed as "IP" followed by two numbers, e.g. IP65, where the numbers define the degree of protection. The first digit (Foreign Bodies Protection)shows the extent to which the equipment is protected against particles, or to which persons are protected from enclosed hazards. The second digit (Water Protection) indicates the extent of protection against water. The wording in the table is not exactly as used in the standards document, but the dimensions are accurate.

The first digit in the rating is the protection against contact and foreign bodies. The second digit in the rating is the water protection factor. The third digit in the impact protection factor It is normally displayed in the format below.

IP s l (i)

s = solids, l=liquids and i= impact (optional)

First Index - Foreign Bodies Protection, Solids		
Index	**Protection against Human/Tool Contact**	**Protection against solid objects (foreign bodies)**
0	No special protection	
1	Back of hand, Fist	Large foreign bodies, diam. >50mm
2	Finger	Medium-sized foreign bodies, diam. >12

3	Tools and wires etc with a thickness >2.5mm	Small foreign bodies, diam. >2.5mm
4	Tools and wires etc with a thickness >1mm	Granular foreign bodies, diam. >1mm
5	Complete protection, (limited ingress permitted)	Dust protected; dust deposits are permitted, but their volume must not affect the function of the unit.
6	Complete protection	Dust-proof

Second Index - Water Protection, Liquids		
Index	**Protection against water**	**Protection from condition**
0	No special protection	
1	Water dripping/falling vertically	Condensation/Light rain
2	Water sprayed at an angle (up to 15º degrees from the vertical)	Light rain with wind
3	Spray water (any direction up to 60º degrees from the vertical)	Heavy rainstorm
4	Spray water from all directions, (limited ingress permitted)	Splashing
5	Low pressure water jets from all directions, (limited ingress permitted)	Hose down, residential
6	High pressure jets from all directions, (limited ingress permitted)	Hose down, commercial. eg. Ship decks
7	Temporary immersion, 15 cm to 1m	Immersion in tank
8	Permanent Immersion, under pressure	For use on Titanic recovery vehicle

Third Index - Impact Protection, Impact		
Index	**Protection against impact**	**Equivalent mass impact**
0	No special protection	
1	Protected against 0.225J impact	eg. 150g weight falling from 15cm height
2	Protected against 0.375J impact	eg. 250g weight falling from 15cm height
3	Protected against 0.5J impact	eg. 250g weight falling from 20cm height

4	Protected against 2.0J impact	eg. 500g weight falling from 40cm height
5	Protected against 6.0J impact	eg. 0.61183kg weight falling from 1m height
6	Protected against 20.0J impact	eg. 2.0394kg weight falling from 1m height

Retrieved From: escreen- http//www.escreen.com/ip_ratings.htm

APPENDIX C: DEFINITION OF TERMS

Apart from some basic definitions in section 1.0, the following further definition of terms shall be useful [Newnes,1988; Actionenergy, 2003]

Illuminance and Maintained Illuminance (Lumens/M^2 or Lux)

Illuminance is the term used to describe the level of light on a surface in lumens/square metre or lux. Maintained illuminance is the term used to describe the average illuminance on a reference surface e.g desktop, at the time maintenance has to be carried out.

Standard Service Illuminance (Lumens/M^2 or Lux)

This is the service illuminance throughout the life of an installation and averaged over the relevant area. This area may be the whole area of the working plane in an interior or the area of the visual task and its immediate surround. Table 2.11 shows the standard service illuminance for specific areas.

Luminance (Lumens/M^2 or apostilbs)

This is a term which expresses the intensity of the light emitted in a given direction by unit area of luminous or reflecting surface. It is the luminous flux emitted in the given direction from a surface element, divided by the product of the projected area of that element perpendicular to the prescribed direction and the solid angle containing the direction. It is expressed in lumens per square metre. In interior lighting design, it is the product of the illuminance and the luminance factor for the particular conditions of illumination and viewing. If the surface can be assumed without too much error to be perfectly matt, its luminance in any direction is the product of surface illuminance and its reflectance.

Room Surface Reflectance:

This is ratio of the light reflected from a surface to the light incident on it. Except for matt surfaces, this will depend on how the surface is illuminated. The value is always less than unity.

Glare:

This is the discomfort or impairment of vision experienced when parts of the visual field are excessively bright in relation to the general surroundings. There are a number of terms to express the amount of glare. For example, a disability glare which prevents seeing detail; discomfort glare which causes visual discomfort but might not impair ability to see detail; direct glare caused when excessively bright parts of the visual field are seen directly i.e unshielded light sources. Glare index enables discomfort glare to be ranked in order of severity, thereby determining the permissible limit

Efficacy (Lumens/Watt)

This is used to describe the energy efficiency of a lamp. It is described by the amount of light it produces in lumens with respect to the power it consumes in watts. The term efficacy is used, rather than efficiency, because it is comparing dissimilar units.

Task Lighting

This describes task illumination and it will encompass the amount of light (illuminance) and the type of light, including its colour performance and its ability to express the task for easy and comfortable accomplishment.

Building Lighting:

This describes the illumination of the building interior, which needs to complement the architecture and the application.

Colour Appearance (Correlated Colour Temperature CCT in Kelvin)

This is used to describe the colour of the light emitted and in particular its degree of warmth or ‘coolness’. This is described by its CCT. Lamps that have a CCT below 3300K are classed as ‘warm’, 3500K (intermediate), above 4000K (cool) and lamps that are above 5300K are classed as ‘cold’.

Colour Rendering Index (CIE Ra)

The CIE general colour rendering index (Ra) describes the accuracy by which a lamp can show surface colours

If a lamp has an Ra between 90-100, the lamp is described as having accurate colour rendering properties, and is appropriate for accurate colour matching tasks. If a lamp has an Ra between 80-90, then it is appropriate for situations where accurate colour judgments are necessary e.g. shops and offices. When a lamp's Ra is below 80, then colour judgments may be impaired. For normal offices, colour rendering group will be 1B or 2 which is easily achieved with normal fluorescent lamps.

Daylight Factor and Average Daylight Factor

Because daylight illuminance is constantly changing, daylight levels are described by the term Daylight Factor (DF). This is the ratio of a point daylight illuminance within a building relative to the unobstructive daylight illuminance outside. Both values exclude direct sunlight and apply to diffuse sky light under the same sky conditions and at the same time. Average Daylight Factor can be calculated and gives an indication of the likely amount of daylight within a room.

Luminaire (Light Fitting)

This describes the apparatus that supports a lamp(s) and enables it to be connected to an electrical supply. It also incorporates the light controlling elements and the lamp protection. Colloquially, it is often referred to as a light fitting.

Ballast (Control gear)

All discharge lamps require circuitry to start the discharge and to limit the current while the lamp is operating. These circuits consume energy, so consider using low loss, high frequency and dimmable units.

CELMA Ballast Energy Classes A, B and C

CELMA, the European lighting manufacturers association, has developed a system where the energy consumption of ballasts can be graded. The system has a set of letter grades A to C with A consuming the least energy. The energy class should be marked on the ballast casing.

Light Output Ratio (LOR)

This is the ratio of the total light output of a luminaire, relative to the total light output of the lamp(s) under reference conditions. Total LOR can be divided into downward and upward light output ratios if appropriate.

Luminous Intensity Distribution (Polar Curve)

The luminous intensity distribution, often termed the polar curve, is a graphical representation of the distribution of intensity (candela) of a luminaire and indicates the directions in which light is projected.

Utilization Factor (UF)

For a particular installation, the UF is the proportion of lamp light output that reaches the working plane e.g desktop, including both direct and reflected light.

Maintenance Factor (MF)

This is defined as the ratio of the illuminance provided by an installation in the average condition of dirtiness expected in service, to the illuminance from the same installation when clean. Selection of maintenance factor is rather complicated and requires guidance by appropriate standards e.g. SLL Light Code.

Room Index

This is related to the dimensions of a room and used when calculating the utilization factor and the characteristics of the lighting installation. It is given by:

$$Room\ Index = \frac{LxW}{Hm(L+W)}$$

Where L is the length, W is the width of the room and Hm is the height of the luminaires above the working plane.

Power Density (W/M^2)

The power density of a lighting installation is the total power it consumes measured in watts, and includes the lamps and lamp ballasts, divided by the total floor area of the installation in square metres.

International Commission on Illumination (CIE)

The International Commission on Illumination (usually abbreviated CIE for its French name, Commission Internationale de L' enclairage) is the international authority on light, illumination, colour and colour spaces. It was established in 1913 as a successor to the Commission Internationale de Photometrie and is today based in Vienna, Austria.

The CIE has seven active divisions, each of which establishes technical committees to carry out its program under the supervision of the Division's Director (Wikipedia, 2010):

1. Vision and colour.
2. Measurement of Light and Radiation

3. Interior Environment and Lighting Design
4. Lighting and Signaling for Transport
6. Photobiology and Photochemistry
7. Image Technology.

CE

By affixing the CE mark, the manufacturer declares their compliance with the essential requirements of the relevant EU directives. CE is an abbreviation which stands for communaute Europeene or conformite Europeene (French for "European Conformity").