Illumination Evaluation of Lecture Theatre, Case Study of 1000 Seat Lecture Theatre, Federal University of Technology, Akure, Nigeria

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Abstract—Light, apart from making it possible for one to view objects clearly, can also be used for the beautification of any given space. Existing 1000 Seat Lecture Theatre auditorium lights lux level (115 lux) is below acceptable for an auditorium suitable for writing during examination. This paper focus on illumination evaluation of a lecture theatre, case study of 1000 Seat lecture theatre, Federal University of Technology, Akure, Nigeria. The auditorium is used for lecture and writing examination. Lumen method which is one of the methods for calculation the number of lamp for a space is used to determine the number of lamp needed for the studied area. The architectural design of the auditorium is not available, so, the dimensions of the floor of the studied area were measured with a measuring tape. The measured floor dimensions were used to produce model of the floor in autoCAD software in order to calculate the area of the floor because the auditorium was of irregular shape and different mounting heights. The obtained area is used to calculate the illuminance required for the auditorium using Lumen method, equation. Try and error method was used in selecting E, M, and U to arrive at 115 Lux of the studied area. Lumen method, putting into consideration standard maintenance factor (0.8) and utilization factor (0.7) of existing literatures and renowned consultancy firms were used. This paper submitted that the lux level of the 1000 Seat Lecture Theatre (SLT) is below acceptable international standard of 400lux (standard and the industrial practice) for a classroom-auditorium suitable for writing examination. The space is poorly illuminated (33.3% of the required illumination and 20% wattage contribution of the design,) using EDA 18W compact fluorescent lamp (CFL). The existing 2 x 18W CFL installed in the SLT should be replaced with 85W (5500lumen, 5500K, 10000Hrs) CFL because of its benefits. 400 Lux is adequate for Lecture Theatre Auditorium lux level; lighting designer should employ adequate lux level to avoid negative side effects of poor illumination.

Index Terms—Lumen, Lighting, Lamination, Luminance, Classroom-Auditorium Suitable, Mounting - Height

I. INTRODUCTION

The iris regulates itself to avoid damage if an excessive amount of light falls on it, hence the need for proper illumination to avoid damage to the eyes. Also, the nature of task for a particular space is a function of good lighting design [1].

Poor lighting has always been the problem of many spaces, just as we have in the 1000 Seat Lecture Theatre (SLT). This has caused poor vision which is affecting the activities been carried out in the place. The internal illumination of the 1000 SLT is poor and difficult to be used for examination purpose and even reading at night.

Good lighting is therefore needed in order to ensure the quality of work in reducing fatigue, it improves the effectiveness of workers, employees or students in a particular place and it ensures high prestige of an organization [1], [2]. Lighting does not only enable an occupant to work in a space, it is also used in the aesthetic or beautification of the spaces. The lighting designer will also consider design consideration and other matters which include purpose of installation, external influences which may affect it, budget of the client and its maintainability. These essentialities are lacking in 1000 SLT and as a result of these, internal lighting design evaluation is necessary to perform a required task in the auditorium under study like examination and the use of the auditorium as an event center during the day and night or cloudy days. This leads to determination of adequacy of the existing illumination of the1000 Seat Lecture theatre by calculate the number of luminaires which will meet the required illumination, compare the existing illumination with the required standard. This will solve the problem of poor illumination in 1000 SLT of Federal University of Technology Akure, thereby remove students’ inability to write examination and the its use as night class and also will increase the auditorium’s patronage for night events and thus generate more income for Federal University of Technology Akure, Ondo State, Nigeria. Considering the advantages of TLFL over incandescent bulb and advantages of CFL over TLFL as reviewed under literature in this research work, CFLs are used in this work [2], [3].

In accordance with [4], maximum mounting height of Fluorescent Lamp (FL) is considered in this work. Lumen method, putting into consideration standard maintenance factor (0.8) and utilization factor (0.7) of existing literatures and renowned consultancy firms were used. Average mounting heights was found since lamps were installed at different heights and the result was compared with recommended mounting height to ensure that CFLs were installed at specified mounting height. This is to ensure that CFL to be installed will perform better. Lamp of 5500lumen, 6500K, 10000Hrs was preferred for the proposed design which will be adequate for the concerned auditorium due to its benefits of colour rendering, high lumen and half-life [10]. Additionally, the proposed CFL used in the proposed design will be lower in quantity, save time of installation, reduce cost of installation in term of labour, and reduce the number of labour to be exposed to

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risk on site and thus reduce safety cost; 400 Lux is adequate for Lecture Theatre Auditorium lights lux level; lighting designer should employ adequate lux level to avoid negative side effect of poor illumination.

II. LITERATURE REVIEW

A. Light, Light Sources and Lighting Fixtures

Light is produced by both natural and artificial sources. A lighting system consists of lamps together with luminaires along with the control switch as well as other mechanism put in place to control the light for use in a particular situation [2], [4].

The human eye is sensitive to electromagnetic radiation with a wavelength between 380 and 720nm. The region between the 380nm and 720nm is where the visible light (the light that our naked eyes can accommodate) exists. If the wavelength is less than 380nm, it is called ultraviolet light, if the wavelength is higher than 720nm, it is called infra-red light (thermal radiation). These ultraviolet and infrared lights are dangerous. The ultraviolet light in large amount can cause skin burn and cancer and this effects should be avoided. Therefore, the lamp that will be installed in a building should be the devoid of the one that produces a great amount of visible light, ultraviolet or infrared radiations [5].

Light Sources are sources of light production. Sources of light can be divided into natural and artificial sources of light. Sources of light differ in how they provide energy to the charged particles, such as electrons, whose motion creates the light. If the energy comes from heat, then the source is called incandescent. If the energy comes from another source, such as chemical or electric energy, the source is called luminescent.

Lighting Fixture is a holder for the light source to provide directed light and to avoid visual glare. Lighting fixtures come in a wide variety of styles for various functions. Some are very plain and functional, while some are pieces of art in themselves. Nearly any material can be used, so long as it can tolerate the excess heat and is in keeping with safety codes. Extra fixtures are often placed in task areas; this is switch ON when it is needed. The necessary illuminance depends on the character of the task that is being performed [6].

B. Lamps, Reflectors and Fittings and Electrical Ballast

The term lamp is a generic name for a man-made light source often called a bulb or tube. Lamps are of various shapes and size, flux distribution patterns, colour spectra, and produce light deploying different schemes. There are two major categories of lamp which are the Incandescent lamps and Luminescent lamps [2], [4].

An incandescent light bulb is an electric light which produces light with a wire filament heated to a high temperature by an electric current passing through it, until it glows. Luminescent lamps (discharge lamps) do not produce light by means of an incandescent filament but by the excitation of a gas or metallic vapour contained within a glass envelope [2], [4].

Compact fluorescent lamp (CFL) is a smaller version of tubular fluorescent lamp (TLFL) long version. The quality of CFL light is higher than TLFL. CFL, like TLFF, lasts up to 10,000 hours as against 1,000hrs working hours of incandescent bulb. However, turning CFL on and off too frequently can reduce that lifetime substantially [2], [7]. The colour rendering of CFL (6500K) is higher than that of incandescent bulb (2700K)

Turning them on and off too frequently can reduce that lifetime substantially. They are unsuitable for places where you would turn on the light only briefly. These bulbs should be used only where they will be left on for a while without being turned on and off [7][8]. It is an energy saving light and produce lesser heat compare with incandescent lamp. It is designed to replace an incandescent light bulb where colour rendering is not of importance. CFLs produce light in the same manner as linear fluorescent lamps.

![Incandescent bulb](image1)

![Compact Fluorescent Lamp](image2)

![Electric Ballast](image3)

**Table 1: Main difference between Bulbs and Lamps [2]**

<table>
<thead>
<tr>
<th>S/N</th>
<th>Luminescent lamps</th>
<th>Incandescent lamps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High luminous efficiency</td>
<td>Low luminous efficiency</td>
</tr>
<tr>
<td>2</td>
<td>Long life</td>
<td>Shorter life</td>
</tr>
<tr>
<td>3</td>
<td>Low running cost</td>
<td>High running cost</td>
</tr>
<tr>
<td>4</td>
<td>Low glare</td>
<td>High glare</td>
</tr>
<tr>
<td>5</td>
<td>Less heat output</td>
<td>More heat output</td>
</tr>
<tr>
<td>6</td>
<td>Stroboscopic effect</td>
<td>No Stroboscopic effect</td>
</tr>
<tr>
<td>7</td>
<td>High life of filament lamp</td>
<td>Low life of filament lamp</td>
</tr>
<tr>
<td>8</td>
<td>Initial cost per lamp is higher</td>
<td>Initial cost per lamp is lower</td>
</tr>
</tbody>
</table>

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per cent of the light output is in the lower hemisphere flashed opal glass is the reflecting and transmission medium.

In a fluorescent lighting system, the **ballast** regulates the current to the lamps and provides sufficient voltage to start the lamps. Without a ballast to limit its current, a fluorescent lamp connected directly to a high voltage power source would rapidly and uncontrollably increase its current draw, within a second the lamp would overheat and burn out. During lamp starting, the ballast must briefly supply high voltage to establish an arc between the two lamp electrodes. Once the arc is established, the ballast quickly reduces the voltage and regulates the electric current to produce a steady light output. A capacitor is connected across the circuit to improve the power factor in order to reduce cost of energy consumption [2], [4], [8].

C. **Luminous Flux (lm), Lumens per Watt, illuminance, Luminance**

The **luminous flux** is the amount of visible electromagnetic radiation (produced by a source and received by a surface), measured in lumens (1m). The lamp manufacturers specify the rated luminous flux of their lamps [2].

Lumen is the unit of visible light. Efficacy is measured in lumens per watt. To be rated as high efficacy, a lamp must produce a certain number of lumens for each watt of electrical power it consumes. Almost all fluorescent lamps equipped with electronic ballasts qualify as high efficacy light sources. For simplicity, the power used by the ballast is ignored when determining the lumens per watt for purposes of compliance with the residential lighting requirements. [7].

The illuminance refers to the incidence of the light flux on a surface, per unit of surface. The illuminance is expressed in lux (lx) and is measured with a lux meter, Figure 4.

![Fig. 4: Lux Meter](image)

**Luminance** indicates the degree of brightness with which the human eye perceives a light source or an illuminated surface. The luminance is expressed in candela per square meter (cd/m²) [9].

D. **Colour Temperature, Uniformity Ratio, Room Index, Maintenance Factor, Utilization Factor, Illumination per Space**

**Colour temperature** is the temperature of a certain object (black body) that radiates light of the same type of colour as the given light source. Incandescent lamps have a colour temperature of 2700 K, but halogens lamps have a higher colour temperature. Colour temperature is how cool or warm the light source appears. A high colour temperature is perceived as a “cooler” light. The colour temperature is expressed in Kelvin (K), Table 2.

**Table 2: Colour Temperature of Different Light Sources** [9], [10].

<table>
<thead>
<tr>
<th>LIGHT SOURCE</th>
<th>COLOUR TEMPERATURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candle</td>
<td>1900k</td>
</tr>
<tr>
<td>Incandescent</td>
<td>2700k</td>
</tr>
<tr>
<td>Halogen lamp</td>
<td>3000k</td>
</tr>
<tr>
<td>Fluorescent lamp</td>
<td>5000k</td>
</tr>
<tr>
<td>Direct sunlight</td>
<td>6000k -6500k</td>
</tr>
<tr>
<td>Daylight with cloudy sky</td>
<td>7000k</td>
</tr>
<tr>
<td>Daylight with clear sky</td>
<td>20000k</td>
</tr>
</tbody>
</table>

The **uniformity ratio** is the ratio between the minimum illuminance and the average illuminance on a surface. This a function of evenness of light uniformity on a plain. $E = 1$ indicates complete uniformity i.e. minimum illuminance is equal to the average illuminance. It is simply uniformity of evenly distribution of light on a plain [11].

The **room index** is the ratio between the surface of the working plane and the half surface of the adjacent walls. This indicates whether a room is narrow and high, or low and wide. This influences the amount of light that is reflected to the working plane from the walls. The narrower the room, the smaller the room index and vice versa. The mounting height is used to obtain utilization factor.

$$RI = \frac{a \times b}{h \times (a + b)}$$  \hspace{1cm} (1)

Where a is the length of the room; b is the width of the room, h is the height between the lighting fixtures and the working plane [2], [11].

**Maintenance factor (Mi).** As a result of communication of the lamp and fixture, plus degradation of the lamp, the illuminance reduces in the course of time. This must be taken into account during the lighting design. The maintenance factors depend on so many factors such as the frequency of cleaning the fixtures-daily, weekly, monthly, and so on; the neatness of the space, e.g. a classroom contrasted with a workshop. Normal maintenance factor should be 0.8 or higher. The value of Maintenance Factor is usually taken as 0.8. [4], [7], [12].

**Utilization Factor (Uj)** The utilization factor indicates how well a lighting installation uses the luminous flux of the lamps. This is indicated as the ratio between the luminous flux reaches the working plane and the light source of the bare lamps, expressed as a percentage.

$$Uj = \frac{\text{light falling on a given surface}}{\text{total light flux emitted}} \times 100\%$$  \hspace{1cm} (2)

Utilization factor, $Uj$, is given as 0.6-0.8(max) [13], [17], [19].

**Illumination per Space (E),** are different standards that give the minimum illumination level per space or activity. The illumination level requirement varies with the location or the standard that is employed by the designer. For this research, luminance values recommended by various bodies, consulting and practising firms is presented in Table 3.
TABLE 3: APPLICABLE STANDARDS OF ILLUMINANCE [2], [14], [15], [16], [17], [18], [19]

<table>
<thead>
<tr>
<th>S/N</th>
<th>APPLICABLE STANDARDS</th>
<th>LECTURE THEATRE RECOMMENDED LUX</th>
<th>AUTHOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PHILIP</td>
<td>400(Minimum)</td>
<td>[2]</td>
</tr>
<tr>
<td>2</td>
<td>MS 1525</td>
<td>300-500</td>
<td>[14]</td>
</tr>
<tr>
<td>3</td>
<td>IESNA</td>
<td>400</td>
<td>[15]</td>
</tr>
<tr>
<td>4</td>
<td>IES</td>
<td>500</td>
<td>[16]</td>
</tr>
<tr>
<td>5</td>
<td>PWO</td>
<td>400-500</td>
<td>[17]</td>
</tr>
<tr>
<td>6</td>
<td>IESNA</td>
<td>400</td>
<td>[18]</td>
</tr>
<tr>
<td>7</td>
<td>PROJECT</td>
<td>400</td>
<td>[19]</td>
</tr>
</tbody>
</table>

From Table 3, the illumination level of 400Lux is considered adequate for the lecture theatre.

E. Lighting Design Philosophy

According to [6], a good lighting design should reflect look good, provide the proper amount of light in every room, be built and constructed within budget, code and other constraints, be environmentally responsible, respond to the architecture and interior design, and produce good colour. In additionally, details of ceiling construction for the space, the service requirement of the space and the operating conditions such as temperature, humidity, dust, also count.

In order to achieve good lighting for a space, design consideration is very crucial. The design considerations include provision of adequate illumination, light distribution uniformity over the working plane, suitable light colour, glare avoidance and hard shadow as far as possible and colour of surrounding walls, ceiling and floor [2], [4].

III. METHODOLOGY

A. Data collection

Design calculations used for lighting design was obtained from a renowned design and build practising firm, Popham Walter Odusote firm in Lagos, Nigeria.

B. Determination of the Existing Illumination Level of the Studied Area

To determine the existing illumination of the studied area, the type of light together with its specification were determined by removing one of the installed light and searching for it in the e-library (internet). The number of the installed lamps (2 x 18W) were physically counted. The lux meter will be needed to measure the lux level.

C. Evaluation of the Required Illumination Level

Lumen method which is one of the methods for calculation the number of lamp for a space is used to determine the number of lamp needed for the studied area as in equation (3).

\[
N = \frac{E \times A}{n \times L \times U_f \times M_f}
\]

Where N is the number of luminaires; n is the number of luminaires per lamp (n=1); E is the illumination; A is the area in square meter; \(U_f\) is the utilization factor; \(M_f\) is the maintenance factor and L is the lumen output of the lamp.

Dimensions of the studied area floor were measure with a measuring tape. The measurement of the floor dimensions was used to produce model of the floor in order to calculate the area of the floor because the auditorium was of irregular shape. The obtained area is used to calculate the illumination required for the auditorium using Lumen method, equation (3).

Try and error method was used for in selecting \(E\), \(M_f\) and \(U_f\) (1040lumen, 0.85 and 0.6 respectively) to arrive at 115 Lux of the studied area.

D. Determination of Luminaria which will meet the required Illumination

Maintenance factor of 0.8 is applied [4], [7], [12]. Utilization factor of 0.7 is applied [13], [17], [19].

1) Fluorescent lamp mounting height

Fluorescent lamp is mounted at 6 meter height for better performance [4]. Since compact light is a family of fluorescent light, the 6m mounting height is applied in this work. The 1000 SLT has irregular heights and mounting heights. As a result of this, the average fluorescent installation height, \(H_{amb}\), of the lecture theatre is obtained using equation (4).

\[
H_{amb} = \frac{H_{amh}}{A_v}
\]

Where \(H_{amh}\) is the average fluorescent installation height; and \(A_v\) is the numbers of mounting height.

The average fluorescent installation height is compared with maximum mounting height as in equation (5).

\[
H_{amh} < H_{mh}
\]

Where \(H_{mh}\) is the maximum fluorescent installation height.

Illuminance, \(E\), of 115 and 400 is applied as in Table 6. Lamp of 5500lumen, 6500K, 10000Hrs was preferred for the proposed design due to its benefits mentioned earlier.

The lumen method, equation (3), was used to compute the required luminaire. The number of required lights are thus calculated as presented in Table 6.

E. Comparism of Existing and the Required Illuminations Level and Wattage

Comparism of o Existing and the Required Illuminations Level Wattage

The number of installed lamps were counted. The counted number of installed lamps was compared with the number of designed lamps.

The existing wattage and design wattage were also compared using equation (6) and line chart.

\[
T_W = L_W \times L_n
\]

Where \(T_W\) is the total wattage output; \(L_W\) is the lumen per watt; and \(L_n\) is the number of lamp.

F. Comparism of Ratio of Existing and the Required Illuminations Wattage

Lux level is also compared using equation (7) and line chart.

\[
L_T = \frac{I_{existing}}{I_{designed}}
\]

Where \(L_T\) is the total number of types of luminaires; and L is the lumen output per lamp.
IV. RESULTS AND ANALYSIS

A. Result of Existing Luminaires at the CLT Auditorium by Physical Inspection

The result of the existing luminaires of the auditorium is presented in Table 4.

<table>
<thead>
<tr>
<th>SPACE CONSIDERED</th>
<th>DOUBLES</th>
<th>COMPACT</th>
<th>FLUORESCENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditorium</td>
<td>59</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The dimensions of 1000 Seat Capacity Auditorium is presented in Figure 5.

![Figure 5: 1000 Capacity Auditorium Floor Plan](image)

The result of the existing luminaires of the auditorium is presented in Figure 6 for easy digestion and understanding.

![Figure 6: Comparison of Existing and Proposed 1000 Seat Lecture Theatre](image)

The area is obtained from the Figure 5 and the result is presented in Table 5.

<table>
<thead>
<tr>
<th>TABLE 5: 1000 SEAT CAPACITY FLOOR AREA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPACE</td>
</tr>
<tr>
<td>Auditorium</td>
</tr>
</tbody>
</table>

From equation (4), average mounting height is obtained:

\[ H_{amh} = \frac{5+5.7+6.3}{3} = 5.7 \]

The average mounting is confirmed to be less than or equal to maximum mounting height:

\[ H_{amh} < 5.7 \]

B. Result of the Designed Lamps

The result of the designed lamps for the auditorium is presented in Table 6.

Table 6 shows the number of CFLs lamps which will meet the required illumination, 400 Lux, for every part of the auditorium used in the design.

| TABLE 6: 1000 SLT DESIGNED LIGHTS AND COMPARISON OF PERCENTAGE OF ILLUMINATION |
|----------------------|-----------------|-----------------|
| Type of Lamps        | Wattage (W)     | Lux Ratio       |
| CFL 18               | 541.7           | 0.7             |
| CFL 18               | 541.7           | 0.7             |
| CFL 85               | 541.7           | 0.7             |

The percentage contribution line chart of Table 6 is presented in Fig. 6 for easy digestion and understanding.

![Figure 6: Comparison of Existing and Proposed 1000 Seat Lecture Theatre](image)

C. Analysis

From Table 5, 0.6 utilisation factor and 0.85 maintenance factor were used to arrive at 59 numbers of 2 x 18W EDA lamp for 1000 Seat Lecture Theatre. 0.7 utilisation factor and 0.8 maintenance factor from existing literature and consulting firms were used to arrive at 70 numbers of 1 x 85W lamp same Lecture Theatre. Considering irregularity of the lecture theatre which made the refractive index difficult to be used and maximum mounting height of fluorescent lamp (6m), utilization factor of 0.7 was used.

The ratio of existing and expected design is 1:3. This indicated that the existing installation design is 33.3% of the required standard. From Figure 3, this is about 20% wattage contribution of the design.

The wattage and lux ratio of series 2 and 3 are the same. This means that either of both can be used for the required design. However, 186 numbers of 2 x 18W EDA lamps with be too many compare to 70 numbers of 85W lamp (Table 6). Also, the percentage contribution of 186 numbers of 2 x 18W EDA lamps for required design is about 80% while that of 70 numbers of 85W lamp is 100%. 70 numbers of 85W lamp is lower in quantity in comparism with 186 numbers of 2 x 18W EDA lamps. This amount to saving of money in term of reduced labour cost, timing installation of the lamps and saving in labour insurance.

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V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

I. Existing 1000 Seat Lecture Theatre auditorium lights lux level (115 lux) is below acceptable of 400Lux (standard and the industrial practice) for an auditorium suitable for writing examination. This spaces are poorly illuminated (33.3% of the required illumination) using EDA 18W compact fluorescent lamp.

II. Average mounting height is proposed in this work for irregular shape and different mounting heights in order to establish that maximum mounting height recommendation is not violated for better performance of the installed fluorescent lamps.

III. 2 x 18W installed in the 1000 seat auditorium should be replaced with 85W (5500lumen, 5500, 10000Hrs) compact florescent lamp owing to its benefits mention earlier.

B. Recommendations

I. 400 Lux is adequate for Lecture Theatre Auditorium lux level.

II. Lighting designer should employ adequate lux level to avoid negative side effect of poor illumination.

III. Average mounting height algorithm should be employed for fluorescent lamp installed at different mounting heights of an irregular shape.

REFERENCES


