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# 55. Lighting Ergonomics (A Case Study towards Energy Conservation)

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## Abstract

Energy crises is getting worse situation in the developing countries. Measurements are being taken but they will take some time to overcome the power shortage. Besides these measures, Energy efficiency and conversation are one of the easiest and effective ways to minimize energy consumption hence reducing the power shortage. Among various energy consuming devices, Lighting constitutes a large but necessary portion of the electrical load in most facilities. Appropriate usage of lighting will not only minimize power shortage but also it gives pleasure and comfort to human sight.
This paper presents the detailed study of lighting system of HIET, Hamdard University, and proposed the efficient solution according to the illumination level needed for different classes of visual task as a case study. This paper also proposed the guidelines that will help the energy policy makers in establishing future energy conservative policy.



***Keywords:*** *" Energy Policy; Energy Efficiency; Energy Conservation; Lighting System ;"*

## 1. Introduction:

In the developing countries, where there is a gap between demand and supply, measures are being taken for reduction in electricity consumptions as a part of their demand side management. Among the different techniques for reduction in power consumption, replacement of energy inefficient lamps with energy efficient lamp is also one of them. [1].
In this paper, the comparison of performance of Linear Fluorescent tube lights (FL), Compact fluorescent lamps (CFL) and LED lamps on the basis of power consumption, lumens and lamp cost has been presented. HIET, Hamdard University Karachi was selected as case study and analysis of energy consumption in lighting with respect to recommended illumination level for various types of activities is confronted in this work.
This paper has been prepared on the measurements recorded & the data collected, compiled & recorded from initial months of 2015. The main focus of this study is to develop understanding and awareness among people in general of the nation to adopt latest energy management and conservative polices to overcome energy shortage of the country
The details are discussed in future sections.

## 2. Lighting Systems

Proper lighting makes all work tasks easier, whether in industrial or office settings. People receive about 85% of their information through their sense of sight. Appropriate lighting, without glare or shadows, can reduce eye fatigue and headaches; it can prevent workplace accidents by increasing the visibility of moving machinery and other safety hazards. Good quality lighting also reduces the chance of accidents and injuries from momentary blindness. [2]

## 3. HIET Electrical Energy Measurement

Initially a walk through audit of the building was conducted to identify the areas for energy conservation. Assessment of illumination requirement of the building and scope of improvement of illumination quality with an objective to reduce cost was also conducted.
HIET is an educational institute consisting of different sections e.g. conference room, class rooms, laboratories, workshops, library, canteen and offices. Total HIET electrical load is estimated to be **366kW**.
The layout of electrical appliances in a class room of HIET, Hamdard University is shown in the Fig. 1.

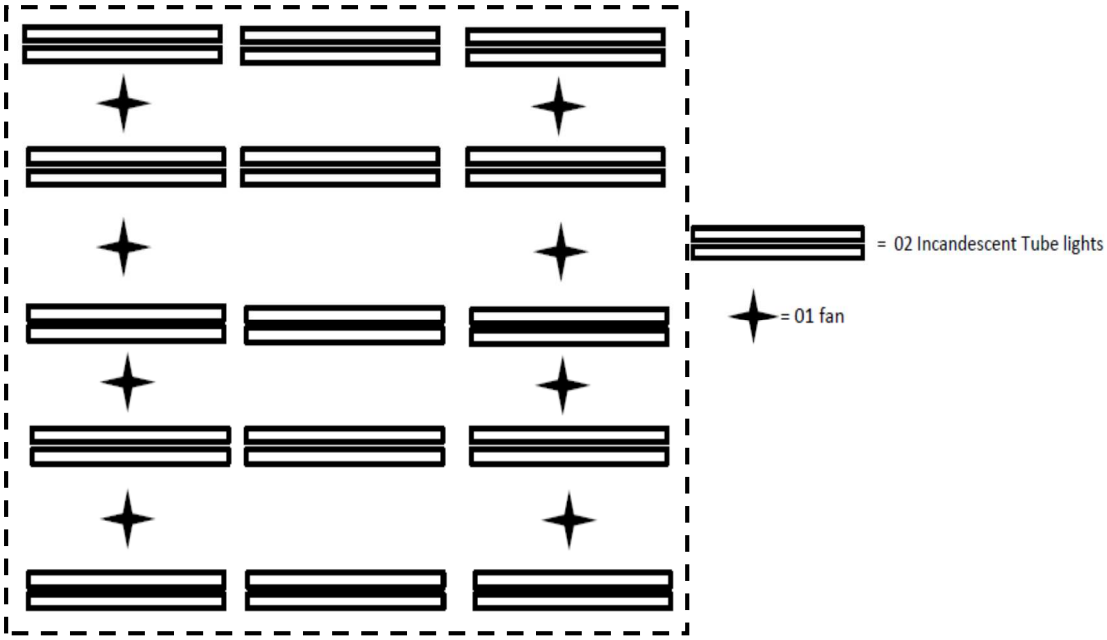


**Fig.-1: Layout of Electrical Appliances in a class room**

## 4. Lighting System at HIET Building

Lighting system of HIET, Hamdard University is 16% of the total electrical energy consumption as shown in Fig.-2.

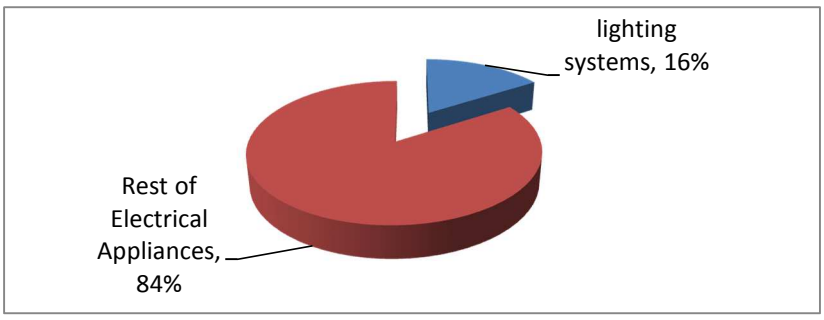


**Fig.-2: Percentage wise Electrical Energy Consumption by lighting system Vs. Rest of Appliances in HIET**

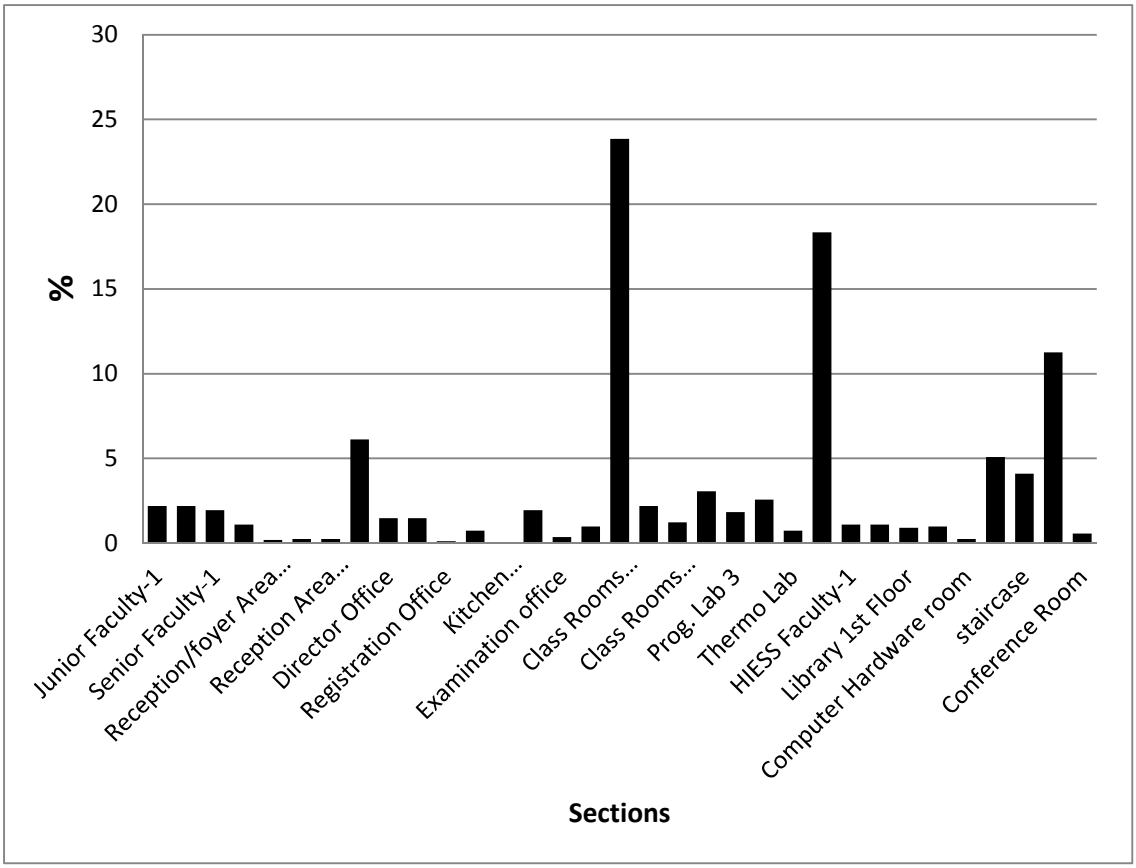


**Fig. 3: Percentage wise Light Energy Consumption at HIET**

## 5. Measuring Units Light Level – Illuminance [3]

Illuminance is measured in foot candles *(ftcd, fc, fcd)* (or *lux* in the metric SI system). A *foot candle* is actually *one lumen* of *light density per square foot*; *one lux* is *one lumen per square meter*.

### 5.1. Calculating Illumination [3]

Illumination is calculated as

$I = L_l C_u L_{LF} / A_l$ (1)

Where

I = illumination (lux, lumen/$m^2$)

$L_l$ = lumens per lamp (lumen)

$C_u$ = coefficient of utilization

$L_{LF}$ = light loss factor

$A_l$ = area per lamp ($m^2$)

#### 5.1.1. Light Loss Factor

The equation to determine LLF is simple: [4]

LLF= (LLD) (LDD) (BF)

Where;

LLD=Lamp Lumen Depreciation. LLD is determined by dividing mean, or average, lamp lumens by the initial lumen value.

LDD=Luminaire Dirt Depreciation. LDD is a factor relating to how dirty an environment is, and how much it affects the performance of a luminaire.

BF=Ballast Factor.

Higher LLFs = lower system cost, energy savings, but also potential for insufficient lighting
Lower LLFs = increased energy use, over lighting, glare etc.[5]

So, Light loss factor (LLF) of different devices are as under. [6]

| Appliances | LLF |
|---|---|
| 25W T8 Linear Fluorescent | 0.73 |
| 32W T8 Linear Fluorescent | 0.75 |
| 26W CFL | 0.77 |
| LED Lights [7] | 0.85 |

### 5.1.2 Coefficient of Utilization

The coefficient of utilization is defined as the percentage of lamp lumens reaching a work plane.
Due to the cylindrical design of a fluorescent tube lamp, only ~1/3 of the light output directly illuminates the intended surface. Thus the total zonal lumens from 0 to 120 degrees average 65 percent.
An LED is a directional light source. Most of the light is contained within a beam angle of 120 degrees, providing light where it's needed. A photometric data comparison validates this effect. [8]

So, Coefficient of Utilization (CU) of different devices are as under

| Appliances | CU |
|---|---|
| Linear Fluorescent Tube light [8] | 0.65 |
| LED Lamps [8] | 0.86 |
| CFL [9] | 0.54 |

## 5.2. Calculation of Illuminance of Current Linear Fluorescent Tube Lights and CFL and Proposed LED Lights

Consider Junior Faculty room,
Area is 12x07= 84 $m^2$
Power of each Tube light =36W
No. Of tube lights= 36
Total Wattage= 36x36 = 1296W
Per Tube light lumens=80
Total lumens spread in room=1296x80=103680
So lux is (CU=0.65, LLF=0.75)
$I = L_l C_u L_{LF} / A_l$
I=103680x0.65x0.75/84
I=602

The Existing lux measurements of various sections were also verified by using light intensity instrument, "lux meter"

For junior faculty room, we need 500 lux [Table2]

In this way, rest of the sections have been evaluated and Lux calculated as shown in table1

**Table: 1. Current Lighting illumination levels at various Sections of HIET**

| Sections | Area (Sq. m) | Appliance(s) | Tube light Lumens/Watt | Total Lumens | Lux (Lumen/sq..m) | Recommended Lux | Comment on Illumination Level |
|---|---|---|---|---|---|---|---|
| Junior Faculy-1 | 84 | Tube Light | 80 | 103680 | 602 | 500 | Ok |
| Junior Faculty-2 | 84 | Tube Light | 80 | 103680 | 602 | 500 | Ok |
| Senior Faculty-1 | 84 | Tube Light | 110 | 126720 | 735 | 500 | Ok |
| Senior Faculty-2 | 84 | Tube Light | 110 | 71280 | 414 | 500 | Not Ok |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Reception Area/Ground Floor | 42 | Tube Light | 110 | 11880 | 138 | 200 | Not Ok |
| Reception Area First Floor | 42 | Tube Light | 110 | 15840 | 184 | 200 | Not Ok |
| Reception Area Second Floor | 42 | Tube Light | 110 | 15840 | 184 | 200 | Not Ok |
| HIET Library | 336 | Tube Light | 80 | 288000 | 418 | 300 | Ok |
| Director Office | 84 | Tube Light | 80 | 69120 | 401 | 500 | Not Ok |
| Admin Office | 84 | Tube Light | 80 | 69120 | 401 | 500 | Not Ok |
| Registration Office | 42 | Tube Light | 80 | 5760 | 67 | 500 | Not Ok |
| Dining Room ground floor | 42 | Tube Light | 80 | 34560 | 401 | 200 | Ok |
| Kitchen ground floor | 42 | Tube Light | 80 | 2880 | 33 | 500 | Not Ok |
| Bathrooms | 54 | Tube Light | 110 | 126720 | 143 | 150 | Not Ok |
| Examination Office | 84 | Tube Light | 80 | 17280 | 100 | 500 | Not Ok |
| Research Lab | 84 | Tube Light | 110 | 63360 | 368 | 750 | Not Ok |
| Classrooms A, B, C, D, E, F, G, H, J, K, L, M, P | 84 | Tube Light | 80 | 1123200 | 501 | 300 | Ok |
| Classrooms I, O, N | 84 | Tube Light | 80 | 103680 | 201 | 300 | Not Ok |
| Classrooms R, Q, T, S & girls common room | 42 | Tube Light | 110 | 79200 | 184 | 300 | Not Ok |
| Programming Lab 1 & 2 | 336 | Tube Light | 80 | 144000 | 209 | 500 | Not Ok |
| Programming Lab 3 | 84 | Tube Light | 80 | 86400 | 501 | 500 | Ok |
| Dirt Lab & SnS Lab | 84 | Tube Light | 80 | 120960 | 702 | 500 | Ok |
| Thermo Lab | 84 | Tube Light | 80 | 34560 | 201 | 500 | Not Ok |
| Labs (BE, MPES, EDC, Physics, Bio, ICE, CE, DCCN, E&N , Environmental) | 84 | Tube Light | 80 | 864000 | 501 | 750 | Not Ok |
| HIESS Faculty-1 | 84 | Tube Light | 110 | 71280 | 414 | 500 | Not Ok |
| HIESS Faculty-2 | 84 | Tube Light | 110 | 71280 | 414 | 500 | Not Ok |
| Library First Floor | 84 | Tube Light | 80 | 43200 | 251 | 300 | Not Ok |
| Server Room | 42 | Tube Light | 110 | 63360 | 735 | 500 | Ok |
| Computer Hardware room | 42 | Tube Light | 80 | 11520 | 134 | 500 | Not Ok |
| Server Room Ext | 42 | Tube Light | 110 | 95040 | 1103 | 500 | Ok |
| Staircase & corridor | 1062 | CFL | 50 | 120750 | 178 | 100 | Ok |
| Stair case & Corridor (Ext) | 1062 | CFL | 50 | 331200 | | | |
| Conference Room | 84 | CFL | 50 | 16800 | 83 | 300 | Not Ok |

## 6. Comfortable Illumination Levels [10]

These levels are usually measured on a working surface in the building.

**Table: 2. Recommended Lighting Levels** [10]

| Type of Activity | Characteristics of Activity | Standard Maintained Illuminance (lux) |
|---|---|---|
| Cable tunnels, nighttime sidewalk, parking lots | **Interiors rarely used for visual tasks** (no perception of detail) | 50 |
| Corridors, changing rooms, loading bay | **Interiors with minimal demand for visual acuity** (limited perception of detail) | 100 - 150 |
| Foyers and entrances, dining rooms, warehouses, restrooms | **Interiors with low demand for visual acuity** (some perception of detail) | 200 |

| | | |
|---|---|---|
| Libraries, sports and assembly halls, teaching spaces, lecture theaters | **Interior with some demand for visual acuity** (frequently occupied spaces) | 300 |
| Computer work, reading & writing, general offices, retail shops, kitchens | **Interior with moderate demand for visual acuity** (some low contrast, color judgment tasks) | 500 |
| Drawing offices, chain stores, general electronics work | **Interior with demand for good visual acuity** (good color judgment, inviting interior) | 750 |
| Detailed electronics assembly, drafting, cabinet making, supermarkets | **Interior with demand for superior visual acuity** (accurate color judgment & low contrast) | 1000 |
| Hand tailoring, precision assembly, detailed drafting, assembly of minute mechanisms | **Interior with demand for maximum visual acuity** (low contrast, optical aids & local lighting will be of advantage) | 1500 -2000+ |

**Table: 3. Lumen Output: Comparing LED Vs Linear Fluorescent Lamps Wattage** [11]

| Column 1 | Costs | Payback | Life | Efficiency |
|---|---|---|---|---|
| T-8 LED Tube light | Rs. 1600-2000 | 3-4 years | 10-15 years | About 110-120 limens per watt |
| T-5 Fluorescent Tube light | Rs. 500 | 6 months to 01 year | 3-4 years | 110 limens per watt |
| T-8 Fluorescent Tube light (Regular Fluorescent) | Rs. 100 | - | 3-4 years | 60-80 lumens per watt (lower for one with electromagnetic ballast) |

**Table-4: Lumen Output: Comparing LED vs. CFL vs. Incandescent Wattage** [12, 13]

| Light Output | Light Emitting Diodes (LEDs) | Incandescent Light Bulbs | Compact Fluorescents (CFLs) |
|---|---|---|---|
| **Lumens** | **Watts** | **Watts** | **Watts** |
| 450 | 4-5 | 40 | 9-13 |
| 800 | 6-8 | 60 | 13-15 |
| 1100 | 9-13 | 75 | 18-25 |
| 1600 | 16-20 | 100 | 23-30 |
| 2600 | 25-28 | 150 | 30-55 |

## 7. Factors affecting the amount of light [14]

Quantity of number of LED lights required per room also depends on following factors:

- **Colour shade:** Dark shade of wall requires more lights
- **Height of ceiling:** More heights require more lights.
- **Objects:** Lots of furniture, display items, complex geometry requires more lights.
- **Wastage:** Light very close to wall will waste more amount of light by reflection. You have to install more lights in this case
- **Amount:** More small lights distributed in room can give good illumination than one big light.

## 8. Identifying Energy Management Opportunities (EMO's) Proposed Replacement with LED

Considering LED lights: A typical LED light gives provide 100-120 Lumens per watt [11], let's consider 100 lumens.
Area is 12x07= 84 $m^2$
No. Of proposed LED tube lights= 36 (same quantity with mean gap)
CU=0.86, LLF=0.85

Lumens needed
$L_l = I\ A_l / C_u\ L_{LF}$
Total lumens spread in room=57456
Total watt needed in room =57456/ (100lumens/watt)
Watt per LED lamp in replacement of same quantities of linear fluorescent tube light=Total watt/no. of LED=574.56/36=**16Watt LED Lamp**
In this way, rest of the sections have been evaluated and Wattage of Lamps calculated as shown in table: 5

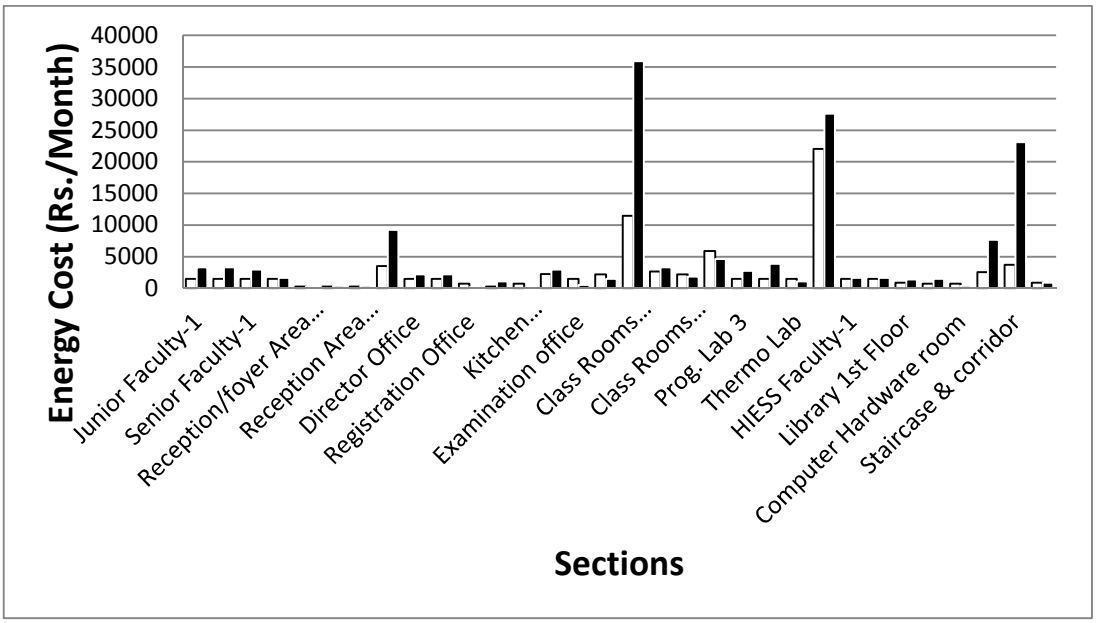


**Fig. 4: Comparison graph showing difference in Energy Cost (in PKR.) per month before and after EMO and using recommended illumination level as required by different sections. Black colour corresponds to Energy costs before EMO, and white colour represents Energy cost after EMO and using recommended illumination level**

**Table: 5: After selected recommended illumination levels and using EMO**

| Sections | Area (Sq. m) | Appliance(s) | LED Tube light Lumens/Watt | Recommend Lux | Total Lumens needed for section | Total Watt | Wattage/ LED Tube light |
|---|---|---|---|---|---|---|---|
| Junior Faculy-1 | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 16 |
| Junior Faculty-2 | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 16 |
| Senior Faculty-1 | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 9 |
| Senior Faculty-2 | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 16 |
| Reception Area/Ground Floor | 42 | LED Tube light | 100 | 200 | 11491 | 115 | 19 |
| Reception Area First Floor | 42 | LED Tube light | 100 | 200 | 11491 | 115 | 14 |
| Reception Area Second Floor | 42 | LED Tube light | 100 | 200 | 11491 | 115 | 14 |
| HIET Library | 336 | LED Tube light | 100 | 300 | 137893 | 1379 | 14 |
| Director Office | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 24 |
| Admin Office | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 24 |
| Registration Office | 42 | LED Tube light | 100 | 500 | 28728 | 287 | 144 |
| Dining Room ground floor | 42 | LED Tube light | 100 | 200 | 11491 | 115 | 10 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Kitchen ground floor | 42 | LED Tube light | 100 | 500 | 28728 | 287 | 287 |
| Bathrooms | 54 | LED Tube light | 100 | 150 | 88646 | 886 | 14 |
| Examination Office | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 96 |
| Research Lab | 84 | LED Tube light | 100 | 750 | 86183 | 862 | 27 |
| Classrooms A, B, C, D, E, F, G, H, J, K, L, M, P | 84 | LED Tube light | 100 | 300 | 448153 | 4482 | 11 |
| Classrooms I, O, N | 84 | LED Tube light | 100 | 300 | 103420 | 1034 | 29 |
| Classrooms R, Q, T, S & girls common room | 42 | LED Tube light | 100 | 300 | 86183 | 862 | 22 |
| Programming Lab 1 & 2 | 336 | LED Tube light | 100 | 500 | 229822 | 2298 | 46 |
| Programming Lab 3 | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 19 |
| Dirt Lab & SnS Lab | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 14 |
| Thermo Lab | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 48 |
| Labs (BE, MPES, EDC, Physics, Bio, ICE, CE, DCCN, E&N , Environmental) | 84 | LED Tube light | 100 | 750 | 861833 | 8618 | 29 |
| HIESS Faculty-1 | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 16 |
| HIESS Faculty-2 | 84 | LED Tube light | 100 | 500 | 57456 | 575 | 16 |
| Library First Floor | 84 | LED Tube light | 100 | 300 | 34473 | 345 | 23 |
| Server Room | 42 | LED Tube light | 100 | 500 | 28728 | 287 | 9 |
| Computer Hardware room | 42 | LED Tube light | 100 | 500 | 28728 | 287 | 72 |
| Server Room Ext | 42 | LED Tube light | 100 | 500 | 28728 | 287 | 6 |
| Staircase & corridor | 1062 | CFL | 100 | 100 | 145280 | 1453 | 3 |
| Conference Room | 84 | CFL | 100 | 300 | 34473 | 345 | 25 |