An approach to energy efficient lighting design for economic residential flats

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Abstract. The lighting design in a residential building now-a-days is not only limited to general lighting but also it is focused to provide quality lighting with the help of wide range of available luminaire with different orientations as well as colours with efficient use of energy, that opens up accurate characteristics of specific areas in any room of the building. The affordable housings in many states are some of the examples of residential building where most of the flats in a typical floor are using conventional lighting systems which are not energy efficient and light level is low compared to standards. This paper is mainly focused to provide a budget friendly as well as energy efficient lighting design with the help of new and energy efficient lamps using DIALux Software, which can be proposed to renovate the existing conventional lighting systems. In this paper effort has been made to reduce the power consumption in all rooms and lux levels has been achieved as per standard values along with good amount of energy saving with the use of newer technologies.

Keywords: Energy Efficient Lighting, Lighting Software, Payback Period, Residential Building.

1. Introduction

The physiological operations in the eyes are turned on by light, giving rise to the sensation of vision. Lighting must have both quality and quantity for two purposes; for bringing good environmental brightness which is comfortable for the occupant [¹] and for sanctioning a high degree of efficiency in seeing whatever is of special interest. In most economic flats, the lighting used are still conventional in nature that consumes high amount of power and also the lighting design is not scientific. For example, the use of fluorescent lights are not good for health as they increase the physical problems like diabetes, eye problems etc. Therefore, designing light in a residence needs careful and thoughtful planning.
2. Architectural and interior character of a residential building

An affordable housing at shrishtinagar in west bengal having 3bhk flats and 2bhk flats connected to a common lobby in a typical floor is taken as example for this paper. According to their project specification, the structure of the building is earthquake resistant R.C.C. framed construction with external walls of 250mm/200mm and internal walls of 125mm/100mm. Internal walls have plaster of Paris over the plastered surfaces and having 2 coats of acrylic plastic paint over a coat of primer over pop surfaces. External walls have 2 coats of weather shield paint over primer.

3. Interior lighting design steps of some typical areas of a flat

The beginning was on-site survey of the interior spaces like bedrooms, dining, kitchens, restrooms etc. of a flat. Then, proper study of Photometric quantities of the existing lighting has been done for individual spaces. The Next step was problem identification of conventional lighting plan in respect of energy efficiency and lighting requirements. Discover numbers lamps and luminaires which can be used for indoor lighting design of general areas of residential building. Last stage was redesigning the rooms and spaces depending up on energy-efficient, technical requirements, aesthetics and cost in obedience with applicable codes and corroborates proposed design with DIALux.

4. Physical survey and existing lighting plan of a 2bhk flat

![Diagram of a 2bhk flat](image_url)

**Figure 1.** Existing lighting positions of a 2BHK flat of the affordable housing.

The above picture represents the floor plan of one of the existing flats along with the lighting layout.

4.1. Existing lamp and luminaires in the 2bhk flat

The following table shows the types and details of the existing lamps and luminaires in a typical flat of the affordable housing.
Table 1. Various lamp types existing in the 2BHK flat.

| Room Type       | Lamp Type         | Luminaire    | Quantity          |
|-----------------|-------------------|--------------|-------------------|
| Bedroom         | T8 & CFL- 26 Watt | Wall Mounted | T8*1 & CFL*1      |
| Master Bedroom  | T8 & CFL- 32 Watt | Wall Mounted | T8*1 & CFL*1      |
| Living & Dining | T8                | Wall Mounted | T8*2              |
| Kitchen         | T8                | Wall Mounted | T8*1              |
| Toilet 1        | CFL- 26 Watt      | Recessed     | CFL*1             |
| Toilet 2        | CFL- 26 Watt      | Recessed     | CFL*1             |
| Balcony         | CFL- 26 Watt      | Ceiling Mounted | CFL*1         |

4.2. Measurement of photometric data of different areas

To estimate the Lux level at each space, firstly grid points are to be considered as per room areas. Lux meter is then put at the midpoint of every grid zone to measure illuminance values. Lastly, the average value for the space is calculated. This way the average illuminance (in Lux) of each area has been noted.

4.2.1 Measurement of light power density (LPD) and light level (lux) of bedroom and master bedroom

![Figure 2](image-url). Photometric view of Bedroom and Master Bedroom.

The above figures are the representation of Bedroom and Master bedroom with grid wise lux levels measured lux-meter to find out the average lux for these rooms.
BEDROOM (B)

- **Area of Calculation**: Total area of the room = (3.05*3.0) = 9.15 mt.²
- **Wattage Calculation**: Wattage of one T8 with electromagnetic ballast loss = (36+4) Watt = 40 Watt and wattage of one CFL with ballast loss = (26+2) Watt = 28 Watt. So, Total wattage = (40+28) watt = 68 Watt in Bedroom.
- **LPD (Light Power Density)**: Total wattage/Total area = 68/9.15 = 7.43 Watt/mt.²
- **Lux Calculation**: Average Lux = (2372.5/20) = 118.62 lux.

MASTER BEDROOM (MB)

- **Area of Calculation**: Total area of the room = (3.05*3.20) = 9.76 mt.²
- **Wattage Calculation**: Wattage of one T8 with electromagnetic ballast loss = (36+4) Watt = 40 Watt and wattage of one CFL with ballast loss = (32+4) Watt = 36 Watt. So, Total wattage = (40+36) watt = 76 Watt in Master Bedroom.
- **LPD (Light Power Density)**: Total wattage/Total area = 76/9.76 = 7.8 Watt/mt.²
- **Lux Calculation**: Average Lux = (2921.7/20) = 146.08 lux

4.2.2 Measurement of light power density (LPD) and light level (lux) of living room and kitchen

![Figure 3. Photometric view of Living Room and Kitchen.](image)

The above figures are the representation of Living Room and Kitchen with grid wise lux levels measured lux-meter to find out the average lux for these rooms.

KITCHEN (K)

- **Area of Calculation**: Total area of the room = (2.8*1.75) = 4.9 mt.²
- **Wattage Calculation**: Total wattage = (36+4) watt = 40 Watt in Kitchen.
- **LPD (Light Power Density)**: Total wattage/Total area = 40/4.9 = 8.16 Watt/mt.²
- **Lux Calculation**: Average Lux = (2774.4/19) = 146 lux.
LIVING ROOM (LR)

- **Area of Calculation**: Total area of the room = (5.35*2.75) = 14.7 $\text{mt.}^2$
- **Wattage Calculation**: Wattage of two T8 with Electromagnetic ballast loss = (36+4) *2 watt = 80 Watt.
- **LPD (Light Power Density)**: Total wattage/Total area = 80/14.7 = 5.4 Watt/mt.$^2$
- **Lux Calculation**: Average Lux = \((2155.4/16) + (2420.3/20))/2 = 127.8 lux.

4.2.3 Measurement of light power density (LPD) and light level (lux) of both toilets

**TOILET 1 (T1)**

- **Area of Calculation**: Total area of the room = (1.65*1.625) = 2.6 $\text{mt.}^2$
- **Wattage Calculation**: Total wattage = (26+2) watt = 28 Watt.
- **LPD (Light Power Density)**: Total wattage/Total area = 28/2.6 = 10.4 Watt/mt.$^2$
- **Lux Calculation**: Average Lux = (781.6/8) = 97.7 lux.

**TOILET 2 (T2)**

- **Area of Calculation**: Total area of the room = (1.65*1.6) = 2.6 $\text{mt.}^2$
- **Wattage Calculation**: Total wattage = (26+2) watt = 28 Watt.
- **LPD (Light Power Density)**: Total wattage/Total area = 28/2.6 = 10.6 Watt/mt.$^2$
- **Lux Calculation**: Average Lux = (774.3/8) = 96.7 lux.

4.3. Comparative studies with respect to ECBC 2017 and IS-3646

**Table 2.** Comparison of LPD and Lux value with standard code.

| Area | Calculated LPD Value (Watt/m$^2$) | Recommended LPD Value as per ECBC (Watt/m$^2$) | Remarks | Calculated Illuminance Value (Lux) | Recommended Illuminance Value as per IS-3646 (Lux) | Remark |
|------|---------------------------------|-----------------------------------------------|---------|-----------------------------------|-----------------------------------------------|--------|
| B    | 7.43                            | 9.10                                          | Within limit | 118.62                           | 200                                           | Very low |

Figure 4. Photometric view of both Toilets.

The above figures are the representation of Toilet 1 and Toilet 2 with grid wise lux levels measured lux-meter to find out the average lux for these rooms.
5. Proposals of modification on existing lighting design in the interior of the building

After proper physical survey along with measurement of light levels and power consumptions for each room, many problems were identified. The following solutions for each problem has been proposed for a better indoor lighting design in residential buildings [2], [3], [4]:

- **Problem 1**: The existing illumination level is not satisfactory and it is very low as per IS-3646.

  **Solution**: T8 lamps with 36 watt that use electronic ballast which includes 4 watts more power loss. So total power consumption of individual T8 lamp is (36+4) = 40 watt. Also, the CFL lamps along with its lamp wattage include extra integrated ballast loss like 26-watt CFL includes extra 2 watts due to its ballast. In 2BHK flats the bedrooms have one T8 fluorescent lamp along with one CFL lamp, but overall lux level is not achieved as per standard. So, it can be replaced by LED tube/batten and bulb which are efficient in terms of energy consumption along with higher lumen package. The Living and Dining of the 2BHK flats has two T8 fluorescent lamps of 36 watts and a one CFL lamp of 26 watts at the entrance from corridor and the combination failed to provide required lux level compared to their overall power consumption. So, the T8 tubes can be replaced by LED tube or LED batten of higher lumen and at the entrance CFL can be replaced by recessed LED luminaire that can provide energy efficient renovation.

- **Problem 2**: Light distribution is not satisfactory with poor uniformity.

  **Solution**: Distribution of light on the bed of bedrooms due to the combination of T8 fluorescent lamp and CFL lamp is not having uniformity. Lux level is very high at the centre of the room due the combination of these lamps. Therefore, overall uniformity of the room is poor. Replacement of T8 and CFL by LED lights having proper distribution of light intensity (polar curve) can be done.

- **Problem 3**: LPD value is not within limit as per ECBC-2017 [6].

  **Solution**: In the toilets or restrooms of both the 2BHK flats, the power consumption by the CFL lamp along with the recessed luminaire is very high and measured LPD is 10.45 W/m² for toilet 1 and 10.60 W/m² for toilet 2 and they are high compared to the ECBE 2017.
recommended LPD value of 7.7 W/m$^2$. These luminaires can be replaced by efficient recessed LED luminaires of 13.4W.

So, new LPD is $13.4W/2.68m^2 = 5 W/m^2$.

This value is within specified limit in ECBC 2017.

- **Problem 4**: Objects are not clearly visible due to imperfect lighting arrangement \[7\].

- **Solution**: In both the 2BHK flats the combination of T8 and CFL lamp (along with the recessed luminaire) has failed to provide the required average illuminance compared to the IS-3646\[5\] recommended lux value due to which the objects within the rooms are not properly visualized. So, redesigning with efficient recessed LED \[8\] luminaires with higher lumen distribution can be done.

6. Studies with energy efficient lamp to be used in the flats

LED (Light Emitting Diode), is a solidstate, non-toxic & fully dimmable lamp in modern lighting era. It has efficacy up-to 200 lumen/watt, which is a very high compared to other artificial light sources. It has approximately 50000 hrs of life-span. They are used in indoor lighting \[9\],[10],[11] as well as outdoorlighting due to their less energy consumption compare to the conventional ones. As LEDs comes in less voltage and wattage rating, they can operate with battery source for emergency cases. LEDs can emit wide range of colours direct from source with its combination of different metal and semiconductor without the use of colour filters. LEDs are well known for their robustness and can easily with-stand external force due to drop. Start-up time of LED lamps is very less. LEDs come in small sizes as they acquire very less space on the chip or board.

7. Use of lighting software for interior lighting design

DIALux, three-dimensional graphics software \[12\] was launched for lighting plan in interior and exterior spaces and available in free of charge. The world’s leading manufacturers of lamps-luminaires provide plugins for their products to make the photometric properties available in DIALux allowing the freedom to the design exercise. Merits of DIALux software in lighting design: Plan the lighting in simple but professional way with luminaire details of the world’s leading manufacturers, availability of light scenes along with location and date-time for daylight visualization and incorporates control groups \[13\],[14] to control the lighting scheme in different areas and energy evaluation within seconds.

8. Results of proposed lighting design from DIALux software

![Figure 5](image_url)

*Figure 5. Floor plan of (a) Bedroom and (b) Master Bedroom.*
The above figures are the simulated two dimensional views of the Bedroom and Master bedroom from DIALux.

![Simulation Result of Bedroom and Master Bedroom](image)

Figure 6. Simulation Result of Bedroom and Master Bedroom.

The above figures are the simulated result with Isolux diagrams of the Bedroom and Master bedroom from DIALux.

**Height of Room: 2.5m  Light loss factor 0.80  Values in Lux, Scale 1:25**

|   | $E_h$ [lx] | $E_I$ [lx] | $E_{tot}$ [lx] | $\mu_0$ | $E_{ill} / E_{ill}$ |
|---|-----------|------------|----------------|--------|------------------|
| Grid: 128 x 128 Points | 213 | 140 | 276 | 0.666 | 0.528 |
| Grid: 128 x 128 Points | 222 | 139 | 292 | 0.644 | 0.493 |

![Floor plan of Living Room and Kitchen](image)

Figure 7. Floor plan of Living Room and Kitchen.

The above figures are the simulated two dimensional views of the Living Room and Kitchen from DIALux.
Figure 8. Simulation Result of Living Room and Kitchen.

The above figures are the simulated result with Isolux diagrams of the Living Room and Kitchen from DIALux.

Height of Room: 2.5m Light loss factor 0.80 Values in Lux, Scale 1:21

| Grid: 129 x 129 Points | E_{min} [N] | E_{max} [N] | E_{rms} [M] | u0  | E_{min}/E_{max} |
|------------------------|-------------|-------------|-------------|-----|-----------------|
|                        | 119         | 225         | 329         | 0.51| 0.301           |

| Grid: 128 x 128 Points | E_{min} [N] | E_{max} [N] | E_{rms} [M] | u0  | E_{min}/E_{max} |
|------------------------|-------------|-------------|-------------|-----|-----------------|
|                        | 125         | 235         | 331         | 0.52| 0.379           |

Figure 9. Floor plan of Toilet 1 and Toilet 2.

The above figures are the simulated two dimensional views of the Toilet 1 and Toilet 2 from DIALux.
The above figures are the simulated result with Isolux diagrams of the Toilet 1 and Toilet 2 from DIALux.

**Height of Room: 2.5m  Light loss factor 0.80  Values in Lux, Scale 1:13**

| Grid: 32 x 32 Parts | \( E_{\text{LPD}} \) (Watt/m\(^2\)) | \( E_{\text{Lux}} \) (Lux) | \( E_{\text{LPD}} \) (Watt/m\(^2\)) | \( E_{\text{Lux}} \) (Lux) | \( \delta \) | \( \frac{E_{\text{LPD}}}{E_{\text{Lux}}} \) |
|---------------------|-----------------|-----------------|-----------------|-----------------|------|-----------------|
|                     | 149             | 110             | 174             | 0.739           | 0.654|
| Grid: 32 x 32 Points| \( E_{\text{LPD}} \) (Watt/m\(^2\)) | \( E_{\text{Lux}} \) (Lux) | \( E_{\text{LPD}} \) (Watt/m\(^2\)) | \( E_{\text{Lux}} \) (Lux) | \( \delta \) | \( \frac{E_{\text{LPD}}}{E_{\text{Lux}}} \) |
|                     | 150             | 113             | 175             | 0.754           | 0.645|

**Comparison of results of proposed design with existing lighting plan**

In the following table calculated LPD and Lux values are compared with standards and guidelines after redesigning with DIALux software.

**Table 3.** Comparison between LPD and Lux value of new design with standards.

| Area | Calculated LPD Value (Watt/m\(^2\)) | Recommended LPD Value as per ECBC (Watt/m\(^2\)) | Remarks | Calculated Illuminance Value (Lux) | Recommended Illuminance Value as per IS-3646 (Lux) | Remark |
|------|------------------------------------|-----------------------------------------------|---------|----------------------------------|-----------------------------------------------|--------|
| B    | 5.30                               | 9.10                                         | Within limit | 222                             | 200                                         | Satisfactory |
| MB   | 4.97                               | 9.10                                         | Within limit | 213                             | 200                                         | Satisfactory |
| K    | 4.76                               | 10.9                                         | Within limit | 233.5                           | 200                                         | Satisfactory |
| LR   | 4.89                               | 12.1                                         | Within limit | 233                             | 200                                         | Satisfactory |
| T1   | 5.00                               | 7.7                                          | Within limit | 149                             | 150                                         | Satisfactory |
| T2   | 5.07                               | 7.7                                          | Within limit | 150                             | 150                                         | Satisfactory |
So, from the above table it can be easily seen that the results from simulation are satisfactory as well as energy efficient. Therefore, the proposed lighting can be installed in the flat which is not only budget friendly but also an energy efficient solution for economic flats.

9. **Used lamp and luminaire for proposed designing**

| AREA            | LAMP AND LUMINAIRE TYPE                   | QUANTITY |
|-----------------|-------------------------------------------|----------|
| Bedroom & Master Bedroom | Endura Next Batten BN308C LED40S-6500 L120 PSU WH & Standard LED bulbs 19W E27 6500K W A25 1PF/6 MX | 1 & 1 |
| Living Room     | CoreLine Downlight DN140B LED10S/840 PSU WR PL6 Endura Next Batten BN308C LED40S-6500 L120 PSU WH | 1 & 2 |
| Kitchen         | MASTER LEDtube EM/Mains T8 UO 24W 865 T8 | 1 |
| Toilet          | GreenPerform Sleek DN296B LED15S-6500 PSU WH | 1 |

10. **Load calculations of existing and proposed**

| Area            | Wattage in Each Room-Existing Lights (Watt) | Wattage in Each Room-Proposed Lights (Watt) |
|-----------------|---------------------------------------------|--------------------------------------------|
| Bedroom         | 68                                          | 48.5                                       |
| Master Bedroom  | 76                                          | 48.5                                       |
| Living Room     | 80                                          | 70.1                                       |
| Kitchen         | 40                                          | 24                                         |
| Toilet 1        | 28                                          | 13.4                                       |
| Toilet 2        | 28                                          | 13.4                                       |
| TOTAL           | 320                                         | 217.9                                      |

11. **Total energy saving for the proposed design**

Power consumption with existing lights = 320 Watts and power consumption with proposed lights = 217.9 Watts.
So, total power savings = (320-217.9) = 102.1 Watts.
**Percentage of energy savings** = (102.1/320) * 100 % = 31.9%
12. Conclusion

This paper, focused on the Indoor Lighting Design of a Residential Building, the main objectives of which were to suggest energy efficient, aesthetic and new lighting design with help of modern and energy efficient lamp. The design has been simulated for all the flats in a typical floor, because there was scope of new lighting design as well as option of renovation of the existing lights in some flat areas to offer scientific and energy efficient lighting design. The beginning of this paper work was physical survey, followed by study of the existing lighting plan and position of furniture and then, identifies the flaws of the existing lighting design with respect to energy efficiency and technical requirements. The design exercise incorporated discussion of various applicable standards, codes and guidelines as redesigning depended on aesthetics, energy-efficiency, technical requirements and economy in compliance with those codes.

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