LEDs : A STUDY FROM ILLUMINANCE PERSPECTIVE

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Abstract: *This paper intends to demonstrate the performance of commercially available Light Emitting Diodes (LED) and their comparison with Compact Fluorescent Lamps (CFL) with illuminance as the parameter. The paper addresses the problem of illumination from the end-user point of view in the sense that, illuminance or lux output is measured rather than considering the efficacy of the lamp. It is shown that for illumining a planar surface (a typical, representative of task lighting), performance of LED's as sources are far superior to that of a commercial CFL of similar wattage. An arrangement of 3 LED's of 1 W is compared with a 5 W CFL. Also results for illuminance of 3 LED's placed in different configurations are discussed and optimal arrangement is arrived at.*

Keywords*: Bright LED's, Compact Fluorescent Lamp, Efficacy, Illuminance, Optimization.*

1. Introduction

The lighting industry today is in a major state of transition. For more than a century incandescent bulbs have dominated the landscape of general illumination. With depleting non-renewable sources and threat of global warming, there has been an increasing awareness and need for energy efficiency together with conservation. Measures have been taken by several countries for the phased withdrawal of incandescent lamps [1]. The incandescent lamps are being replaced by Compact Fluorescent Lamps (CFL) which possess longer life and better efficiency. Certain problems though exist in CFLs including flicker, presence of mercury and slow start among others [2]. Solid-state lighting, primarily LEDs have come a long way in terms of light output and range of colours. They have already occupied some niche areas like traffic lamps and billboard lighting and are increasingly becoming competitive for home lighting also [3, 4]. With advantages ranging from higher energy efficiency, modularity, long life, no toxic mercury, no flickering, instant start and many more when compared to traditional lighting sources, LEDs are positioned to become the choice of lighting in the coming days [5]. However certain challenges exist including high capital cost, lack of measurement standards and uniform technical specifications, improper and inadequate driver and heat sink design that are hindering the commercial viability of LED products [5, 6].

Given the current energy crisis and increasing demand for efficient services the advantages of LEDs should be exploited in situations where they are viable.

Though it can be said that comparison between different sources of light like LED and CFL have certain limitations (due to the different frequency spectra), a comparison is presented in this paper considering illuminance on a predefined measurement plane in a dark room (fig. 1). The LED and CFL sources are of comparable wattage range. While currently, CFLs have higher efficacies when compared to LEDs [7], this paper intends to demonstrate that, for task lighting and similar applications LEDs provide far greater illuminance over the area of interest when compared to CFLs.

Due in part to the lesser light output and modularity of LEDs, an array of LEDs is used to meet lighting needs. There is scope for arranging the LEDs in the array to obtain uniform illumination or for obtaining any other intended objective by suitable optimal arrangement of the LEDs [8]. Uniform far field irradiance is obtained by arranging the LEDs on a spherical surface [9]. In the same spirit, some interesting observations about the arrangement of three LEDs and their impact on the uniformity / average illumination on the surface are made. The scope of the project is limited to arrangements of three LEDs, as a triangle is a polygon with least number of vertices and it can be used to fit any polygon of four or more vertices.

2. Methodology

2.1 Assumptions

The point source of light assumption for the LED source is not valid according to the standard CIE-127, as stated in reference [5]. A good approximation would be considering it as an imperfect Lambertian emitter [9]. For simulation purposes however, the LED is considered as an ideal point source of light (perfect Lambertian emitter). This is a simplistic model for small angles of illuminance, suitable as a first approximation, for task lighting applications. Assuming the LED to be a point source of light entails it to follow the inverse square law and Lambert's Cosine Law [10, 11].

2.2 Experimental Setup and Measurement

The experiment is setup in a dark room. The measurement plane is a circular area of 1 m in diameter on the ground plane. Three sets of measurement are taken for the following cases

(i) A single LED of 1 W, cool white color working at a rated current of 350 mA is placed over the ground, directly above the centre of the circular area at various heights (20 cm to 1m in intervals of 10 cm).

(ii) Three LEDs of similar rating are placed in an equilateral-triangle fashion with their centroid corresponding to directly above the centre of the circle marked on the ground (Fig. 1). Each of the 3 LEDs are at the same height above the ground. Measurements are made at different heights (40 cm to 1 m in intervals of 20 cm) and also for different distances of each of the LEDs from the centre.

(iii) In the third case, a CFL lamp of 5 W, cool white color working on a nominal voltage of 240 V AC, 50 Hz and a power factor of 0.85 is placed hanging downwards, directly over and above the centre of the circular ground plane at various heights (h=40 cm to 1 m in intervals of 20 cm). The arrangement is similar to that shown in Fig.1 but CFL being at the center of the triangle instead of 3-LED arrangement.

(iv) A single LED of 3 W, cool white color working at a rated current of 700 mA is placed over the ground, directly above the centre of the circular area at various heights (20 cm to 1m in intervals of 10 cm).

Radial lines are drawn on the circle forming sectors of 30^o. On each of these radial lines illumination measurements are made at intervals of 10 cm. Digital Lux Meter of make KM-LUX-99 from KUSAM-MECO having range of 0-50000 Lux is used for measurement.

2.2 Simulation

Simulation is carried out in MATLAB to study the illumination of the three LEDs in different configurations. Further, it is attempted to find optimal distance between the LEDs for uniform illumination on the ground plane.

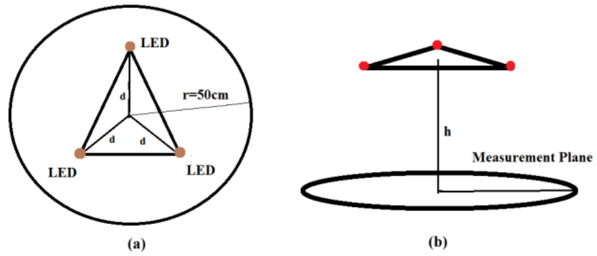

Fig. 1 Representation of experimental setup (a) Top View (b) Front View

The optimization is carried out using 'fminbnd' function of Optimization toolbox of MATLAB [12]. The objective of optimization is to have uniform illumination. The difference in illumination between the centre of the triangle and, the mid-point between a vertex and the centre of the triangle (fig. 1 ; d/2), projected on the ground surface is minimized. At a certain distance between the LEDs (corresponding to certain d) there will be flat (or nearly flat) region of illuminance on the ground within the co-ordinates of the LEDs. As the distance d decreases, the illumination pattern tends towards that of a point source of light. On the contrary when the distance d is greater than the optimal d, illumination at the centre reduces.

The surface plots for the experimental data are plotted using cubic interpolation method [12].

3. Results

3.1 CFL versus LED configurations

Relevant statistics derived from experimental data are shown in Table 1 comparing the performance of CFL and LEDs (and its configurations) placed at a height of 60 cm above the measuring plane.

From Table 1, the following observations are made. The illuminance from the LED arrangement is much greater than from that of a CFL with the average illumination on the area of interest being at least twice greater than that of the CFL and in some cases up to four times the average illumination of the CFL (fig. 2). The standard deviation for the CFL is

Table 1
Illuminance parameters of CFL and LED configurations

Properties / Case	Max (lx)	Min (lx)	Mean (lx)	Standard Deviation
CFL (5 W)	31	15	24	3.6
1-LED (1 W)	45	16	30	10.3
3-LEDs (1 W) d=40 cm	69	42	62	7.7
3-LEDs (1 W) d=30 cm	89	51	72	12.8
3-LEDs (1 W) d=20 cm	113	49	83	21.1
3-LEDs (1 W) d=10 cm	131	49	88	27.5
1-LED (3 W)	94	30	64	25.7

least when compared to the LEDs and this continues to be true for surfaces beyond the one that was examined currently (circle of diameter 1 m). The minimum illumination for the LEDs in all the configurations is about the same and is at the periphery of the area under consideration and this minimum illumination is twice the average illumination of the CFL lamp which further reinforces the superiority of LED sources for task lighting. The maximum illumination of the LEDs - each placed 10 cm from the centre, is twice the maximum illumination of the LEDs - each placed 40cm from the centre. However this is not reflected in the values of the average illumination where the former is only 40% greater than those for the latter. The minimum illumination of the 3 LEDs increases to a certain maximum and then decreases, though the changes in this case do not vary by a considerable margin. The maximum illumination and the average illumination increase steadily relatively, but there is a steep increase in the standard deviation of illuminance values for the case when the LEDs were 30 cm from the centre and for the case when each of the LEDs were 20 cm from the centre.

The tabulated statistics (max, min, mean illumination) for a single 3 W LED is approximately twice that of a single 1 W LED. An arrangement of three 1 W LEDs provide a better illumination in terms of uniformity or greater average illumination than that provided by the single 3 W LED.

These configurations of LEDs are case-specific. The experimental results of typical LED configurations are given in Fig. 3. A number of arrangements of LEDs are possible and generality can be brought about by identifying optimal locations. There can be several objectives for optimization depending on illuminating requirements. One of the desired objectives could be to provide uniform illumination over a plane surface.

3.2 Simulation and optimization

The comparison of illuminance between experimental and simulation studies of three LEDs each placed 20 cm (d) from the centre at 60 cm height is given in fig.4. It is observed that the experimental data (fig. 4(a)) closely matches the simulation results (fig. 4(b)) obtained from MATLAB.

The deviation from the ideality occurs at the periphery for increasing angle of illuminance and it is attributed to the assumptions made There exists an optimal distance ‘d’ for the triangular configuration of LEDs in order to obtain uniform illumination in a region within the periphery of the LEDs. The distance ‘d’ for uniform illumination obtained using ‘fmindbnd’ function in optimization toolbox of MATLAB is given in Table (2) for different heights (h; fig. 1); where h is the distance between the plane containing the LEDs and the ground plane.

A typical contour plot of illumination of three LEDs (placed at a height ‘h’= 1 m and distance ‘d’=0.751 m) is shown in fig. 5. Surface illumination plots for optimal distance‘d’ and for ‘d’ on either side of the optimal value are shown in fig. 6. Fig. 6(b) shows a flat region of illumination corresponding to the optimal ‘d’.

Table 2
Optimal ‘d’ and corresponding illumination for given ‘h’

h (m)	d (m)	Illuminance (lx)
1	0.751	25.268
0.9	0.676	31.192
0.8	0.603	39.348
0.7	0.527	51.421
0.6	0.453	69.749
0.5	0.378	100.123
0.4	0.305	155.387

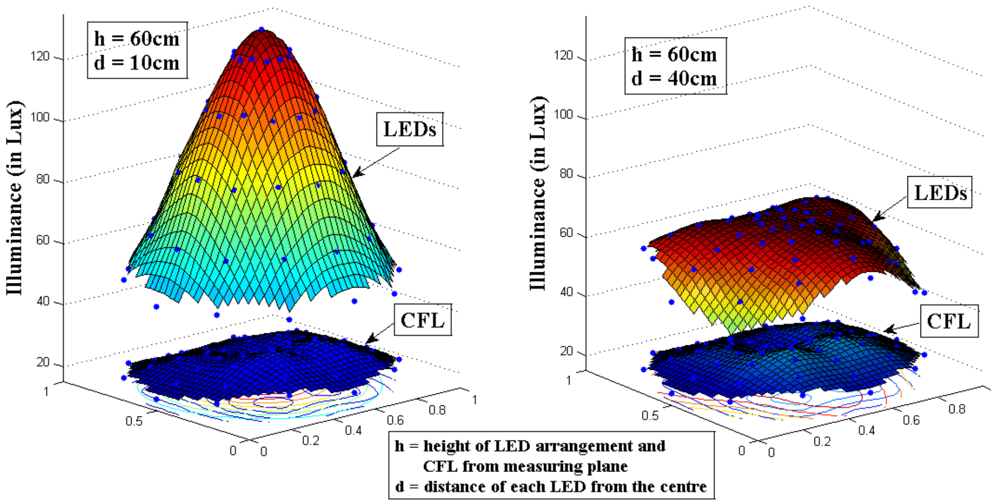

Fig. 2 Comparison of Illuminance of CFL and LED. (Note: Dots on the surface are experimental values).

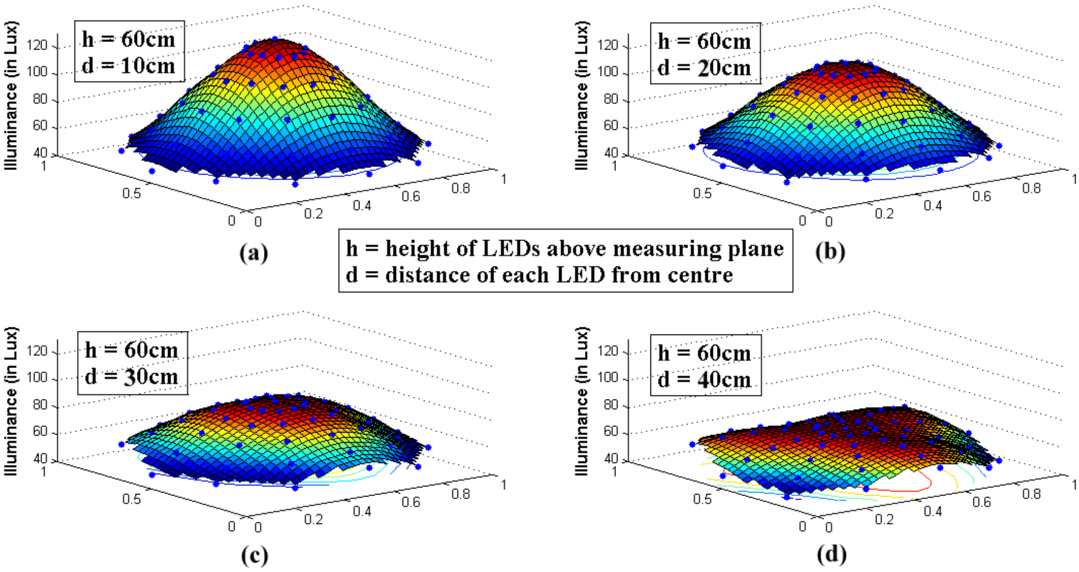

Fig. 3 Comparison of illuminance of three LEDs placed symmetrically about the centre. (Note: Dots on the surface are experimental values).

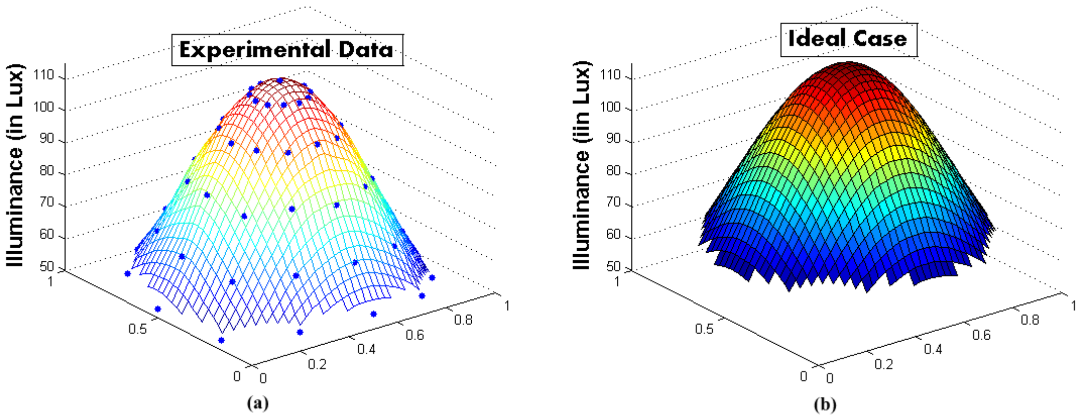

Fig. 4 Comparison of illuminance between experimental and simulation studies of three LEDs each placed 20 cm (d) from the centre at 60 cm height. (Note: Dots on the surface are experimental values).

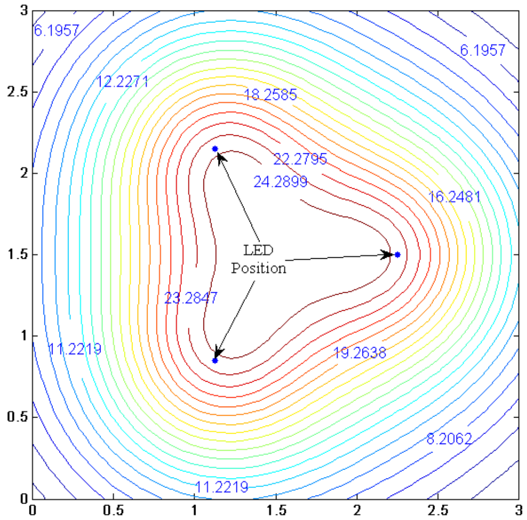

Fig. 5 Contour plot of illuminance of 3 LEDs placed in equilateral triangular fashion.

4. Discussion

The analysis of the data from simulation some relevant observations are drawn. For the point directly below the lamp it is seen that a single LED is capable of greater illuminance when compared to the CFL. For the selected area of interest, the arrangement of three LEDs in any configuration gives a much better illuminance than the CFL. However it must be remembered that LEDs can emit light only in a hemispherical region and the intensity decreases rapidly for large angles. Thus beyond a certain point (about 0.75 m from the centre for this particular case) the illumination of the three LEDs will be about less than that of the CFL lamp and continue to decrease further. The CFL is able to provide uniform illumination for a larger area. With three LEDs itself, there are a variety of configurations in which they could be placed. For the case discussed in this paper, for the three LEDs placed close to the center, the minimum illumination provided at the periphery is still about the same as the minimum illumination provided by the other configurations. Hence, since the average illumination of this configuration is better than the other cases this may get a preference for a given problem. However the illuminance perceived by the human eye is sensitive to the changes in illumination. Hence configuration which yields uniform illumination is desirable. In that respect, the configuration of LEDs corresponding to standard deviation of 7.7 in Table 1, may be preferred. Incidentally this configuration corresponds to a situation of near optimal ‘d’ arrived by simulation.

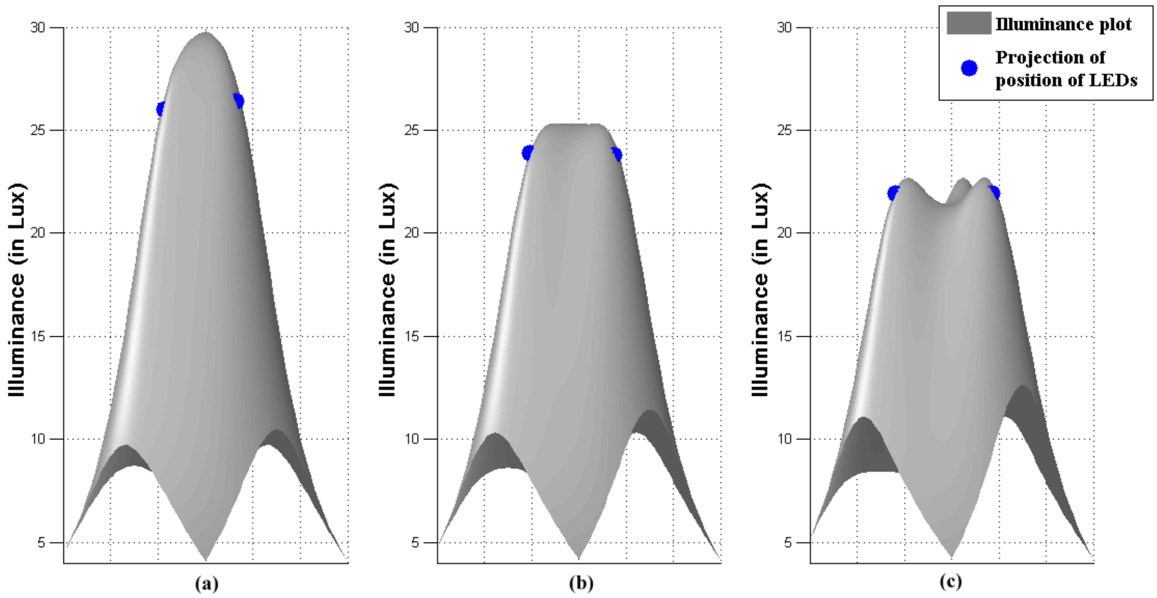

Fig. 6 Illuminance plot of 3-LEDs placed in an equitriangular fashion about the centre (height of 1 m), each at a distance d from the centre, viewed at an angle of 45^0 from –ve Y Axis. (a) d = 0.635 m (b) d = 0.751 m (c) d = 0.866.

5. Conclusions

- 1 W LED compares well with a 5 W CFL and The average illumination of the CFL is about the same as that of a single LED placed at the same height, over a circular plane region of 1 m diameter.
- Average Illumination of 3 W LED is (approximate) only twice of that single 1 W LED.
- The average illumination of three LEDs arranged in any configuration is more than twice the average illumination of CFL for all heights over the range of study (0.4 m to 1 m).

For applications such as task lighting or spot lighting (where the area of illumination is small) the above points based on experimental results have shown that LEDs of smaller wattage (to the corresponding CFL) is able to provide much better illumination.

- There exists an optimal arrangement of 3-LEDs configurations which yield uniform illumination (within the periphery of the area projected by the LEDs on the ground plane).
- The experimental results are validated using the simulations. In general simulated results match well with those of the experimental results keeping in view the assumptions made.
- The distance 'd' of each LED from the centre of an equilateral triangle (LED's placed at the vertices), for uniform illumination is obtained by optimization.

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