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# OPTIMAL DESIGN OF ROOM ILLUMINATION USING LED BULB FOR REDUCED ENERGY CONSUMPTION

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**Abstract:**
*This paper presents optimal design of room illumination using light emitting diode (LED) bulb using Matlab software. Three different scenarios were tested: (a) a single 68W LED bulb was used;(b) two 28W LED bulbs; (c) three 24W bulbs. An M-script program was written and run in the Matlab command window for the three different cases while varying the positions of the bulbs in cases (b) and (c). Locations of maximum illumination for the room were then determined. The advantage of this optimal design is to give the room maximum illumination while reducing energy consumption and consequently saving cost, particularly in developing countries.*

***Keywords:*** *LED, Lumens, Illumination, Wattage, Luminous Efficacy, Matlab.*

## INTRODUCTION

An LED (Light Emitting Diode) bulb is an electric light bulb used in light fixtures to generate light using light-emitting diodes (LEDs). Lighting or illumination is an important aspect of human life and can be described as the use of light for achieving practical or aesthetic phenomena. Globally, lighting is among the major consumers of energy and as such, designing ways of reducing the energy consuming monster becomes paramount (Obinna, Ikechukwu and Fidelis 2019).Lighting represents around 20% of global electric energy consumption, which is almost the same as the amount of electricity being generated by nuclear power. The latest IEA estimates predict the total savings potential in residential and commercial lighting at more than 2.4 EJ per year by 2030 (Dinar, et al. 2016).

Generally, lighting technology has changed very fast in the past 10 years, enabling replacement of the power consuming incandescent lamps with compact fluorescent lights (CFLs) and light emitting diode (LED) bulbs. The old days of selecting light bulbs by Watt is over, as the efficiency of lighting is now determined by its luminous efficacy, measured in lumens per Watt. The brightness or luminosity of a bulb is not determined by its rated power, rather by the lumens. Two LED bulbs with the same wattage may have different lumens, and this necessitates the need to check the lumens on the bulb before purchase (Mauludi and Wilyanti 2019).

The advantage of the LED bulbs is that they have a life expectancy and luminous efficacy several times greater than incandescent lamps, and are considerably more efficient than most fluorescent lamps. Energy-saving (LED) bulbs cost more than incandescent bulbs and compact fluorescent lamps but last much longer and save energy costs in the long-term (Khaliq, et al. 2017).

## METHODOLOGY

Matlab m-script window was used for coding the program that generates the illumination, based on number of lights used and their power ratings, in a form of contour lines. The research aimed at locating light fixtures on the ceiling of a standard living room, measuring 10 metres by 5 metres (dimension) by 3 metres (height).

In addition, the choice of type of bulb to be used is also paramount in obtaining a design with reduced cost and low energy consumption. The three types of bulbs currently being sold in the market are; incandescent bulb, compact fluorescent lamp (CFL) and light emitting diode (LED) bulb. Table 1 shows the breakdown for the three bulbs with their equivalent power ratings, luminance and warranty period.

Table 1: Breakdown of the Performance of Three Types of Bulbs

| **Lumens** | **Incandescent Wattage (W)** | **CFL Wattage (W)** | **LED Wattage (W)** |
|---|---|---|---|
| **≅460** | 40 | 7 | 6 |
| **≅830** | 60 | 13 | 11 |
| **≅1100** | 75 | 18 | 15 |

| | | | |
|---|---|---|---|
| **≅1800** | 100 | 28 | 24 |
| **≅2700** | 150 | 32 | 28 |
| **Rated Bulb Life** | 1.4 Years (1,000 hrs) | 14 Years (10,000 hrs) | 34 Years (25,000 hrs) |

Source: American Association of Physics Teachers 1996 and Energy Star Co. 2016

Among the three type of bulbs, LED can be seen (from Table 1) to have the lowest energy consumption, while maintaining the same intensity of light (Lumens). Although the incandescent lamp is always cheaper, but the guaranteed life span of the LEDs is far greater, which overshadows the cost in the long run.

The research questions considered in the paper are;

i. How the bulb(s) should be arranged so as to maximize intensity of light in the darkest part of the room
ii. How would the number of the bulb(s) used improve the light intensity?

The area illuminated by a single bulb, located on the room's ceiling is normally round in shape as shown in Figure 1.

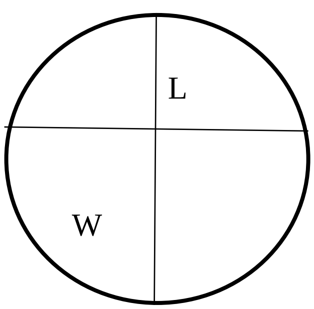


Figure 1: Area Covered by the bulb's illumination

The formula in Equation (1) is used to calculate the area of any round recesses.

$$A = \frac{(L/2 \times W)}{2}\pi \qquad \ldots(1)$$

Where L is the longest length of the recess, measured at the centre and W is the width of the recess.

Therefore,

$$A = \frac{WL}{2\pi} \times \frac{1}{2} = \frac{WL}{4\pi} \qquad \ldots(2)$$

Generally, LEDs are 4 times more efficient at producing light than the incandescent bulbs. Therefore, the 4:1 ratio gives a rough guide for the calculation of LED replacement for a rated incandescent bulb (Amanda 2005). Equation (2) can be rewritten, considering the 4:1 ratio as shown in Equation (3).

$$A_{|LED} = \frac{WL}{4\pi} \times 4 = \frac{WL}{\pi} \qquad \ldots(3)$$

Initially, single 68W LED bulb was used to illuminate the room, then two 28W LED bulbs, spaced at certain distance, d. The two bulbs were then replaced with three 24W LED bulbs at equal intervals. The intensity of light across the room was observed and discussed in each case.

**Single 68W LED bulb**

The bulb was placed at the centre of the ceiling. Coordinate x running from 0 to 10 was introduced to represent the length of the room, while the y axis ranges from 0 to 4, representing the width of the room. The intensity of illumination at a given point, measured in Watts per square metre, is the power of the bulb. Since the bulb is 3 metres above the point (5, 2) on the floor, at a point (x, y) on the floor, the intensity of illumination can be expressed as in Equation (4).

$$i = {}^{68}\!/\!_{(\pi((x-5)^2+(y-2)^2+3^2))} \qquad \ldots(4)$$

**Two 28W LED bulbs**

In this case, the two bulbs were arranged symmetrically along a line down the centre of the room in the direction of the length (along the line y = 2).

Equation (5) defines a function that gives the intensity of light at a point (x, y) on the floor due to the 28W LED bulb at a position (d, 2) on the ceiling.

$$l_2 = {}^{inline(vectorize('28}\!/\!_{(\pi((x-d)^2+(y-2)^2+3^2))'),\ 'x',\ 'y',\ 'd')} \qquad \ldots(5)$$

By placing one light at $d_1 = 3$ and the other at $d_2 = 7$, and by specifying the drawing of 20 contours, the illumination was further observed.

The locations of the two bulbs were later changed to $d_1 = 2$ and $d_2 = 8$. The new illumination was observed. The bulbs were then further moved apart at $d_1 = 1$ and $d_2 = 9$.

The process of changing the positions of the bulbs may not prove to be an optimal design. Generally, one bulb was placed at $x = d$ and the other symmetrically at $x = 10 - d$for d between 0 and 5. Judging from the three scenarios described above, the darkest spots were either at the corners or at the midpoints of the length of the room.

**a. Three 24W LED bulbs**

The intensity function for the 24W bulb is redefined as in Equation (6).

$$l_3 = {inline(vectorize('24} \Big/ {(\pi((x-d)^2 + (y-2)^2 + 3^2))'), 'x', 'y', 'd')} \quad \ldots(6)$$

In this case, the illumination of the floor when the off-centre bulbs are 1 metre away from the width of the room was shown.

If d is defined to be the distance of the bulbs from the widths of the room and a function giving the intensity at position x along the length of the room, then the intensity was graphed as a function of d for several values of x.

## RESULTS AND DISCUSSION

**a. Single 68W LED Bulb**

The result of using a single 68W bulb is represented by contour plot as shown in Figure 1.

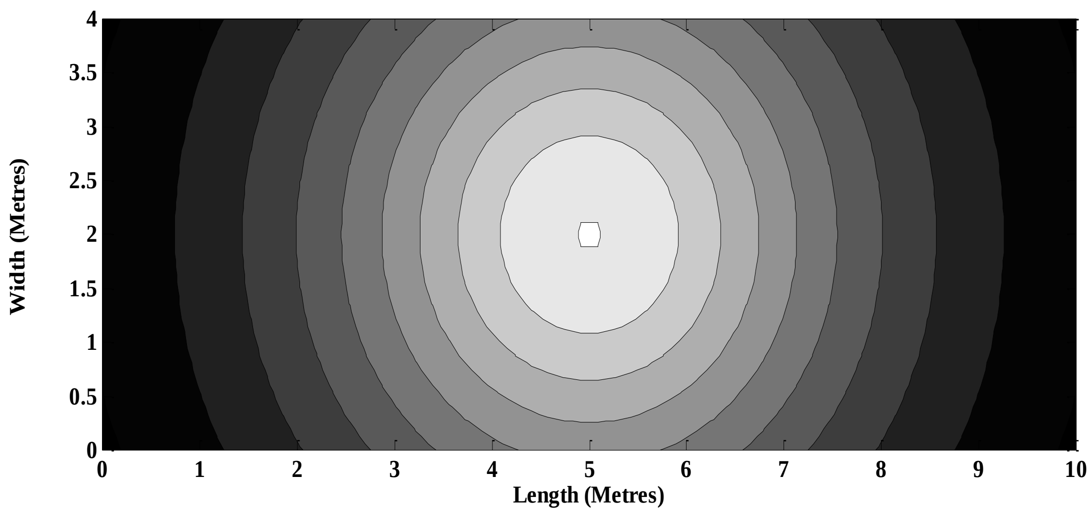


Figure 1: Room Illumination Using One 68W LED Bulb Placed at the Centre of the Ceiling

It could be observed that the darkest parts of the floor are the corners. The intensity of light at corners was found using the ‘subs’ command in the Matlab command window. The intensity at the corners and at the centre of the room were found out to be 0.57 and 2.41 respectively. The centre of the room, at floor level, is about 4 times as bright at the corners when there is only one bulb on the ceiling. The objective of this paper is to light the room more uniformly using more bulbs with the same total amount of power.

**Two 28 LED Bulbs**

In this case, the positioning of the two bulbs is necessary. The bulbs were initially arranged symmetrically at the centre along the length of the room (i.e. along y = 2). By defining a function that gives the intensity of light at a point (x, y) on the floor due to a 28W bulb at a position (d, 2) on the ceiling and one of the bulbs is placed at position $d_1 = 3$ and the other at $d_2 = 7$ and specifying the plot of 20 contours, the illumination pattern would be as shown in Figure 2.

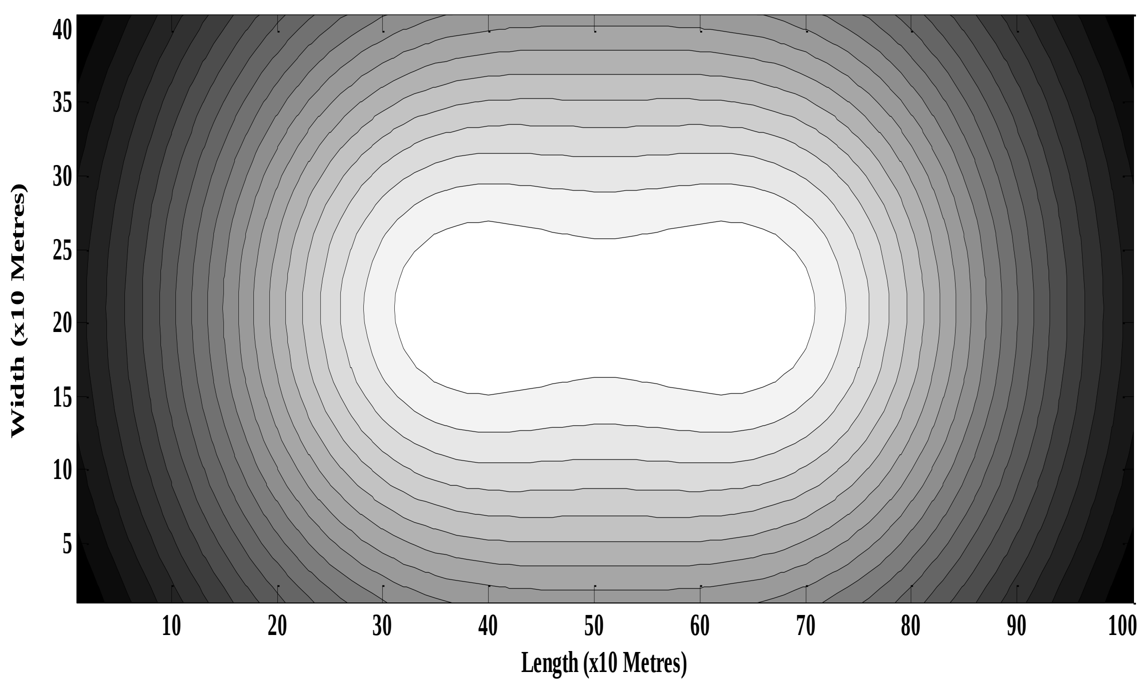


Figure 2: Room Illumination Using two 28W LED Bulbs Place at Positions $d_1 = 2$ and $d_2 = 7$

However, if one of the bulbs is placed at position $d_1 = 2$ and the other at $d_2 = 8$, the illumination pattern would be as shown in Figure 3.

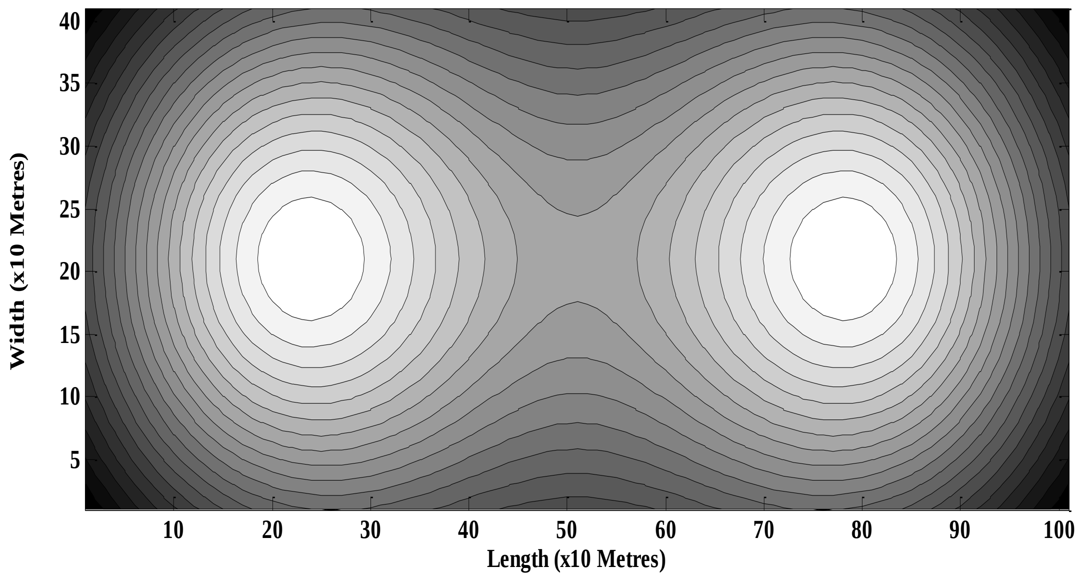


Figure 3: Room Illumination Using Two 28W LED Bulbs Place at Positions $d_1 = 2$ and $d_2 = 8$

The floor is more evenly lit than in Figure 2. The bulbs were further spaced at $d_1 = 1$ and $d_2 = 9$, and the illumination is shown in Figure 4.

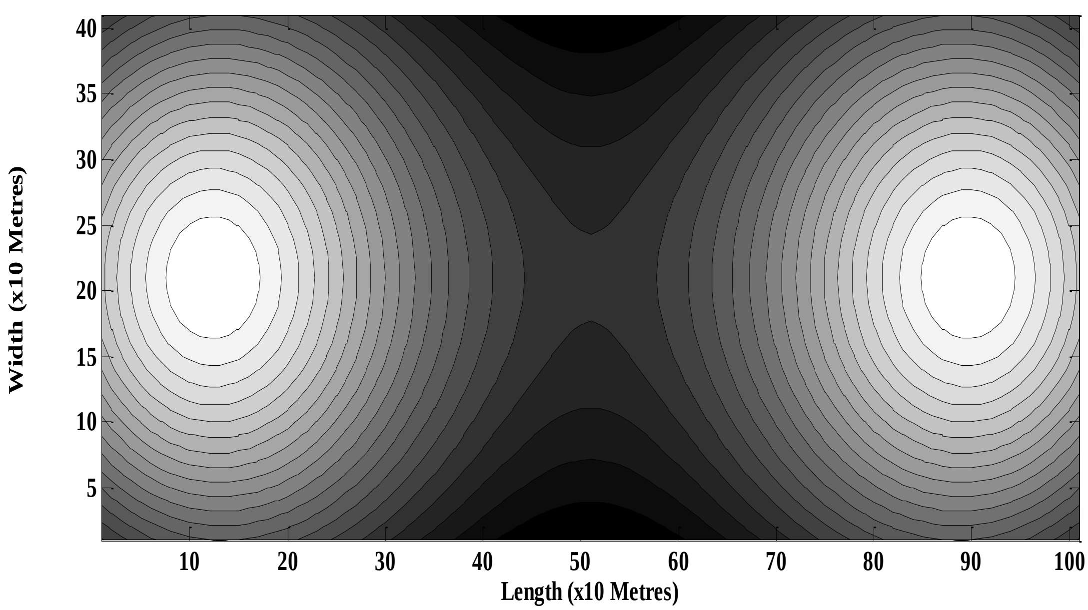


Figure 4: Room Illumination Using Two 28W LED Bulbs Place at Positions $d_1 = 1$ and $d_2 = 9$

To find the best position for the lights, one bulb was placed at x = d and the other symmetrically at (x = 10 – d), for d between 0 and 5. Judging from Figures (1) to (4), the darkest spots will be either at the corners or at the centre of the room. Figure 5 shows the intensity at one of the corners (0, 0) as a function of d.

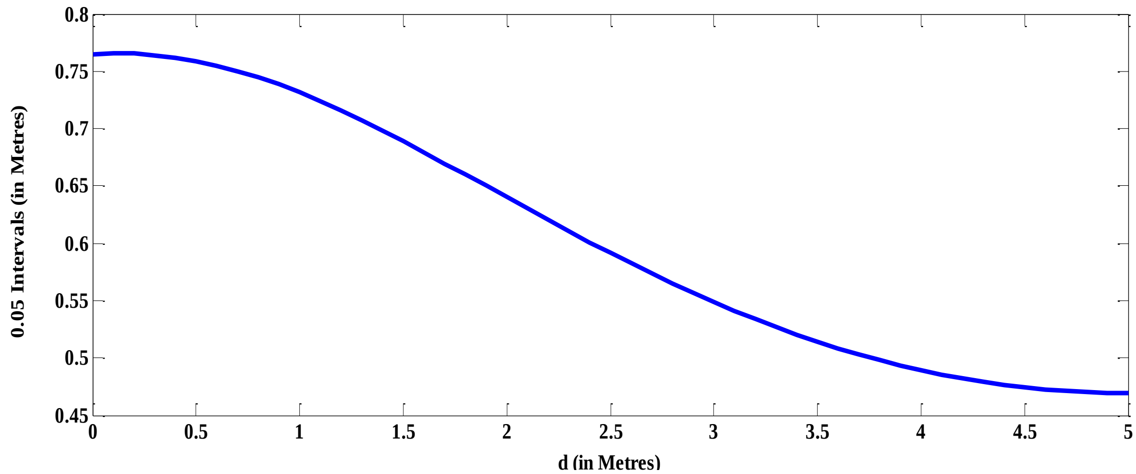


Figure 5: Intensity of Illumination at a corner (0, 0) of the Room as a Function of d

As expected, the smaller d is, the brighter the corners will be. In contrast, the graph for the intensity at the midpoint (5, 0) of the length of the room ought to increase with increase in d toward 5 as shown in Figure 6.

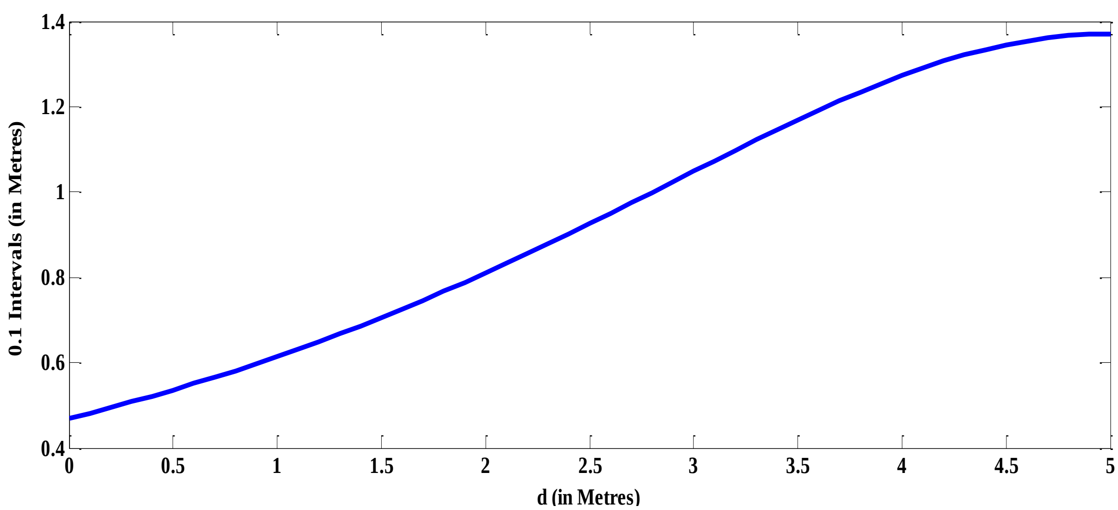


Figure 6: Intensity of Illumination at the midpoint (5, 0) of the Room as a Function of d

The optimal value of d is at the point of intersection of the two curves, as shown in Figure 7, near 1.4, with minimum intensity a little under 1. The 'inline' and 'fzero' Matlab functions were used to get the exact point where the two curves meet. The exact point of intersection was found out to be at 1.441.
Therefore, the two LED bulbs should be placed at about 1.44 metres from the widths of the room for maximum intensity at the corners. For this configuration, the approximate intensity at the darkest spots on the floor was found out to be 0.74. The darkest spots in the room have intensity around 0.74, an improvement of 0.17 as opposed to 0.57 for single bulb of 68W.

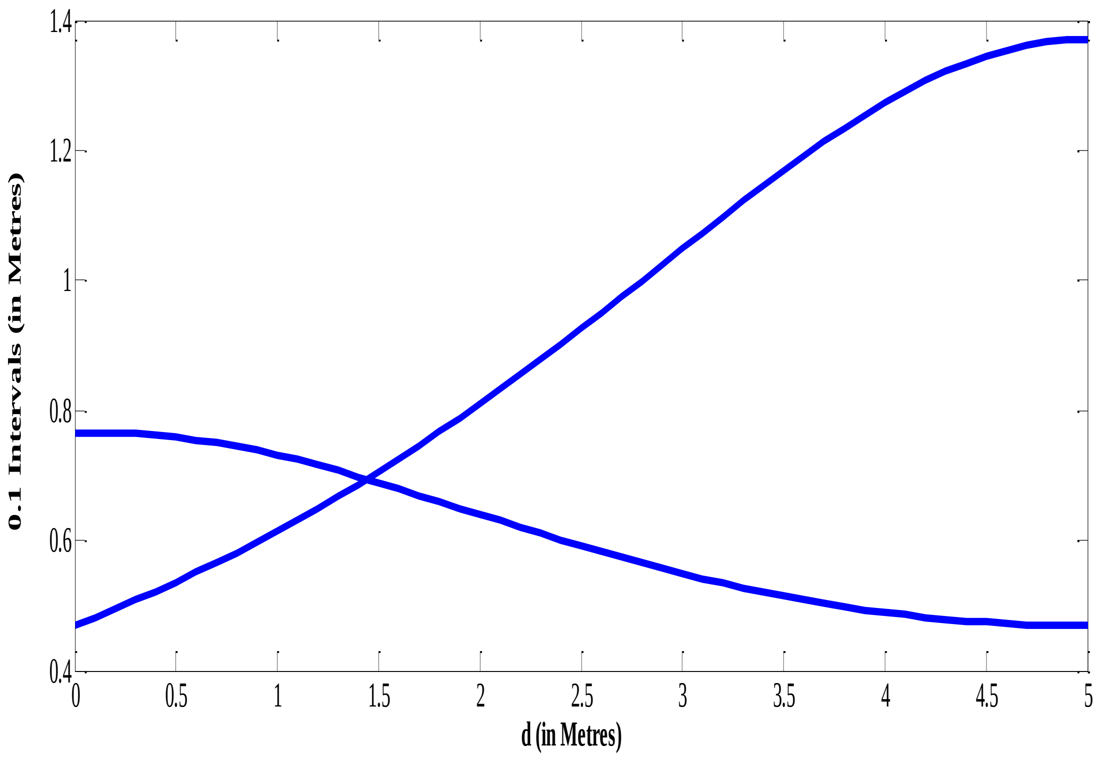


Figure 7: Intensity of Illumination at the corner (0, 0) and at midpoint (5, 0)

### Three 24W LED Bulbs

The intensity of illumination using three 24W bulbs is shown in Figure 8. The bulbs still seemed to be a bit farther away from the wall (room's widths).

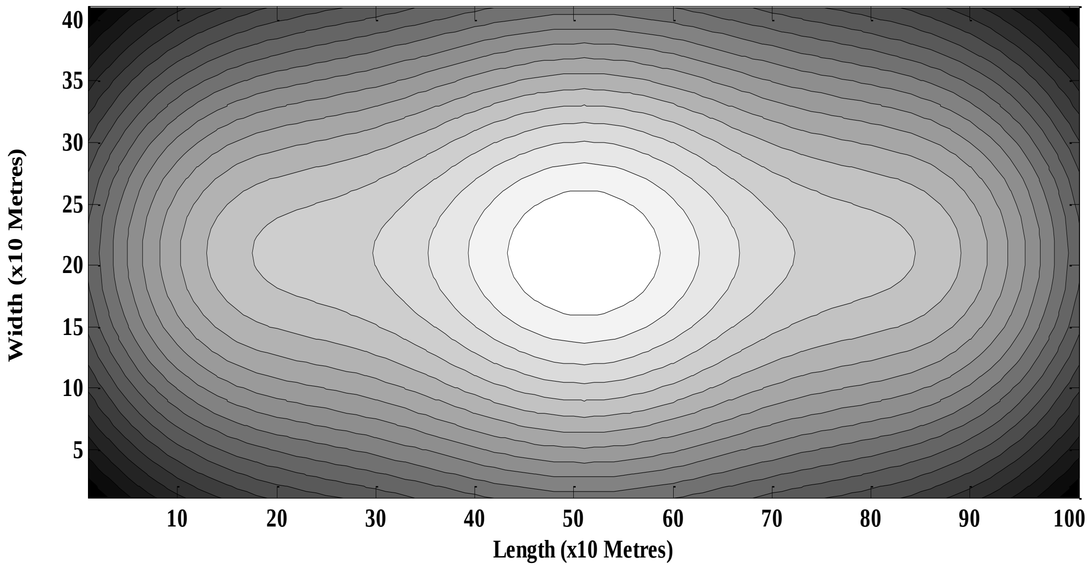


Figure 8: Room Illumination Using Three 24W LED Bulbs Place at the Midpoint and Positions $d_1 = 1$ and $d_2 = 9$

A function giving the intensity at position x along the Length of the room can be defined. Then the intensity is graphed as a function of d for several values of x, as shown in Figure 9.

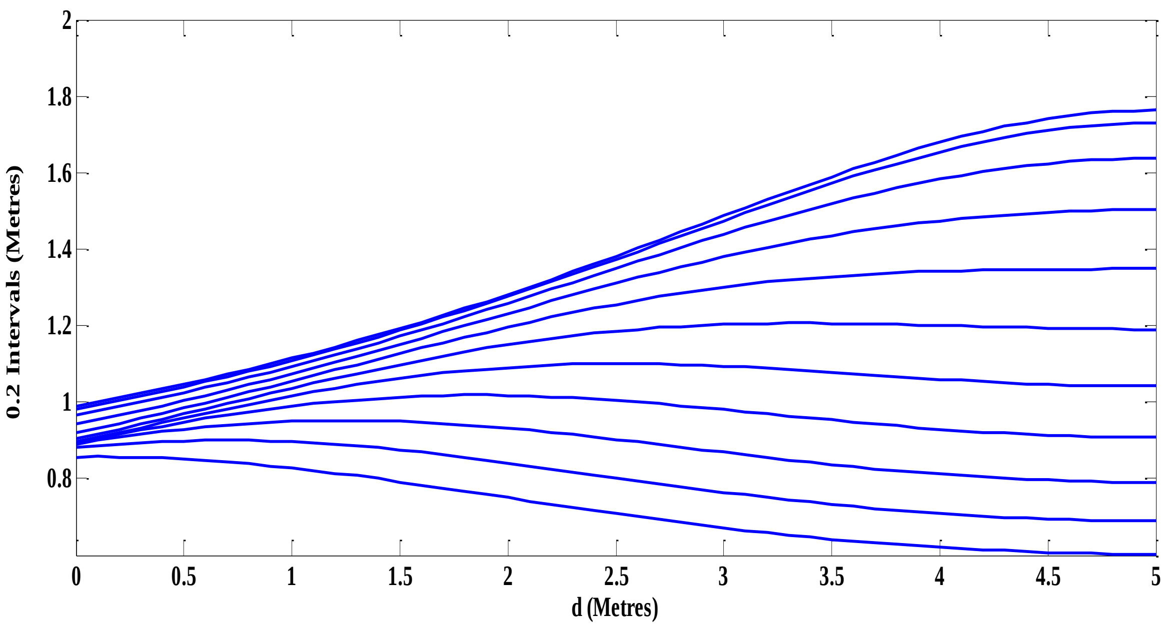


Figure 9: Intensity of Illumination as a Function of d for Several Values of x

As discussed above, for d near 5, the intensity is supposed to increase as x increases from 0 to 5. So the bottom curve corresponds to x = 0 and the top curve to x =5 (with x = 0 curve being the lowest for all d, and rises as d decreases). Therefore, d = 0 maximizes the intensity of the darkest spots in the room, which are the corners. The intensity was found out to be 0.86.

## CONCLUSION

The optimal design of room illumination using LED bulbs was presented. The results of simulation of the three different scenarios; from using single bulb to two and then to three bulbs equivalent in power to the single bulb shows considerable improvements. The intensity of illumination at the corners of the room, going from one 68W bulb to two 28W bulbs and then three 24W bulbs, with respect to the intensity of illumination at the corners, having respective intensities of 0.57, 0.74 and 0.86.

As discussed earlier, the intensity of illumination is not determined by the power of the bulb, but by its luminous efficacy. The luminous efficacy of the LED bulb is about 4 times that of the normally used incandescent bulb with an equivalent power rating. As discussed earlier, even two LED bulbs with the same power rating may have different luminous efficacy, thus, by choosing the one with highest lumens, the design could be significantly improved.

## REFERENCES

Amanda, S. 2005. "A Technology Assessment of Light Emitting Diode (LED) Solid-State Lighting for General Illumination." Working Paper Series, Rochester Institute of Technology.

Dinar, B, Z. Akhtar, M.A. Romero, and K. Strelets. 2016. "LED Light Bulbs as a Source of Electricity Saving in Buildings." *MATEC Web Conferences.*

Khaliq, A., M. iqbal, R. Fahad, and J. shafique. 2017. "Study of Energy Saving in a Commercial Setup by Replacing Conventional Bulbs with LED Lights." *International Journal of Advancements in Technology* 8 (4): 1 - 5.

Mauludi, M., and S. Wilyanti. 2019. "LED Efficacy as a Key Indicator to Evaluate Bulb Lighting." *AIP Conference Proceedings 2169.*

Obinna, O.C., O. O. Ikechukwu, and E. I Fidelis. 2019. "Estimation of Lighting Cost and Energy Saved from LED (Light Emitting Diode) Bulbs." *OOU Journal of Physical Sciences* 1 (2): 105 - 111.