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EFFICIENCY OF LED BULBS COMPARED TO CONVENTIONAL BULBS - ENERGY CONSUMPTION STUDY

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Abstract: *This study examines the energy efficiency of LED bulbs in comparison to more traditional lighting technologies, specifically focusing on incandescent and compact fluorescent lamps (CFLs). In today's world, where there is an increasing emphasis on environmental conservation and sustainable energy practices, the need for energy-efficient lighting has become more prominent. This paper aims to provide a detailed analysis of the energy consumption, light output, and overall operational performance of these three lighting technologies. By doing so, it offers deeper insights into their long-term sustainability, economic feasibility, and potential environmental impact. This research evaluates how LEDs, incandescent bulbs, and CFLs compare in terms of energy consumption and the amount of visible light they produce, measured in lumens. The primary objective of the study is to provide a quantitative comparison between these lighting options, enabling consumers and industries to make informed decisions based on their lighting requirements. The experimental design includes a range of wattages to ensure a comprehensive analysis. For incandescent bulbs, the study focuses on three common wattages: 60W, 75W, and 100W. These incandescent bulbs will be compared to equivalent LED and CFL counterparts, matched in terms of lumen output. This approach allows the research to assess not only how energy efficiency varies between different bulb types but also how wattage impacts performance within each lighting technology. By examining multiple wattages, the study provides insight into how various lighting sources perform under different conditions and lighting demands. For a detailed comparison, energy consumption will be carefully measured alongside light output at varying distances from the light source. This ensures that the analysis is not based solely on power consumption but also on the practical usability of the light produced. These findings are expected to support the global transition toward more energy-efficient and environmentally sustainable lighting systems, contributing to the broader objective of sustainable development.*

Keywords: *LED bulbs, energy consumption study, energy efficiency, green transition*

1. Introduction

Lighting efficiency plays a crucial role in global efforts to reduce energy consumption and conserve resources. In recent decades, LED bulbs have become a popular alternative to conventional incandescent bulbs and fluorescents bulbs due to their higher energy efficiency and longer lifespan. Among all the electric consumers, lighting has one of the highest shares in the residential and commercial sector. Lighting accounts for approximately 20% to 30% of the electricity consumption worldwide [1]. The first LED lamps that could replace traditional incandescent lamps appeared on the market as early as the late 1990s, but their light did not yet provide adequate visual comfort. Satisfactory results were obtained only at the beginning of the current century. At present, most of the lamps produced achieve luminous efficacy from 70 even to 205 lm/W [2]. Although the initial costs of LED bulbs are higher, the potential energy savings and lower operational costs make them an attractive choice for households and commercial spaces. In general, energy efficiency is defined as the consumption of less energy in the process of guaranteeing the same energy service. Figure 1 shows the energy efficiencies of selected major lamp technologies. Incandescent lamps have efficiencies ranging between 1.5% and 2.2%, while LEDs are much more efficient, with efficiencies varying between 19% and 29.2%. These differences in efficiency are related to the conversion efficiency of electricity into luminous flux in each technology, based on the different physical principles used. From Figure 1, the conversion efficiency is close to 30% for LED technology. [3]

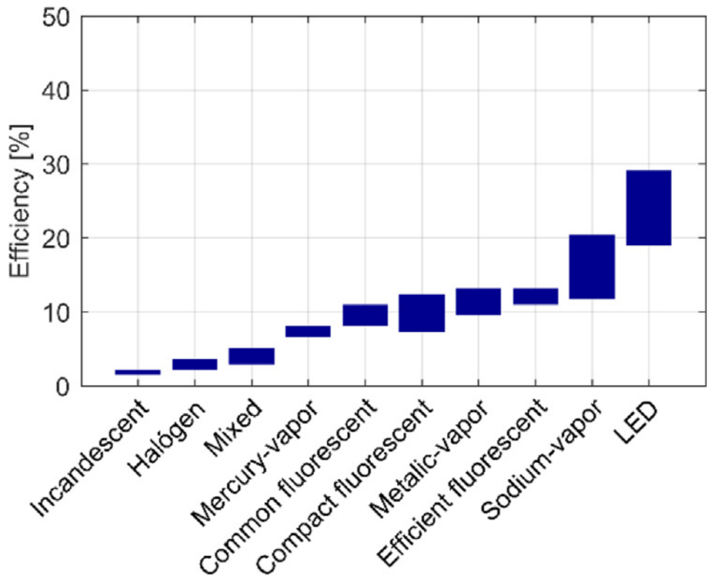

Fig. 1. Lamp technology efficiencies [1]

While LED lamps are generally regarded as the most energy-efficient choice for lighting projects, followed by CFLs, the actual effectiveness of electrical energy usage can vary. This is because energy efficiency depends not only on the power rating of the lamps but also on their power factor. As a result, even with lower energy consumption, the desired level of illumination might not be achieved. To reach the necessary brightness, additional lamps of the same power might be required, leading to an overall increase in energy consumption, which contradicts initial estimates. In this study the main effort was to analyze the energy consumption of each type of light bulbs compared to their change of power factors. The power factor significantly affects the amount of energy required to deliver effective power at the point of consumption and indicates how much actual energy consumption exceeds the nominally declared amount [3].
This research was initiated following multiple case studies and energy audits which consistently highlighted significant reductions in electricity consumption after the installation of LED light bulbs. These findings demonstrated the potential for LED lighting to enhance energy efficiency, motivating a deeper investigation into the relationship between light intensity, energy usage, and bulb type across different environments [4,5].

2. Methodology

In this study, three different types of light bulbs were used: incandescent, fluorescent, and LED, with three tested lumens emitted. The experimental design includes a range of lumens to ensure a comprehensive analysis. By examining multiple wattages, the study provides insights into how various lighting sources perform under different conditions and lighting demands. For a detailed comparison, energy consumption will be carefully measured alongside light output at varying distances from the light source. Measurements were conducted at three different distances from the light source. This ensures that the analysis is not based solely on power consumption but also on the practical usability of the light produced. The goal is to determine how efficiently each lighting technology converts electrical energy into light and whether it provides sufficient illumination for different applications. This is particularly important in identifying which lighting technology is most suitable for residential, commercial, and industrial settings.

2.1. The experimental setup

The experiment was conducted under controlled conditions, where all other light sources were eliminated, and a constant room temperature was maintained. The light bulbs were positioned at a fixed height of 2m meters above the floor, while the measuring device i.e. lux meter was placed at three fixed distances (0.5, 1m, and 1.5m) from the light source. An energy meter was placed between the light bulb and the power source to accurately record energy consumption. Each type of light bulb was tested at three power levels: 60W, 75W, and 100W for the incandescent bulbs, while lumen equivalents were used for the LED and fluorescent bulbs, specifically 800 lm, 1000 lm, and 1500 lm. This means that for LED, bulbs which was used were 8W, 10W and 14W, while for fluorescent bulbs 15, 20, 25W. Each light bulb was placed in a controlled environment, without additional light sources. Measurements began after 15min, i.e. when the light bulb had been operating long enough to reach a stable state. The illustration of experimental setup can be seen in Figure 2, where H represents the distance of light body from the ground and h represents distance of working plane.

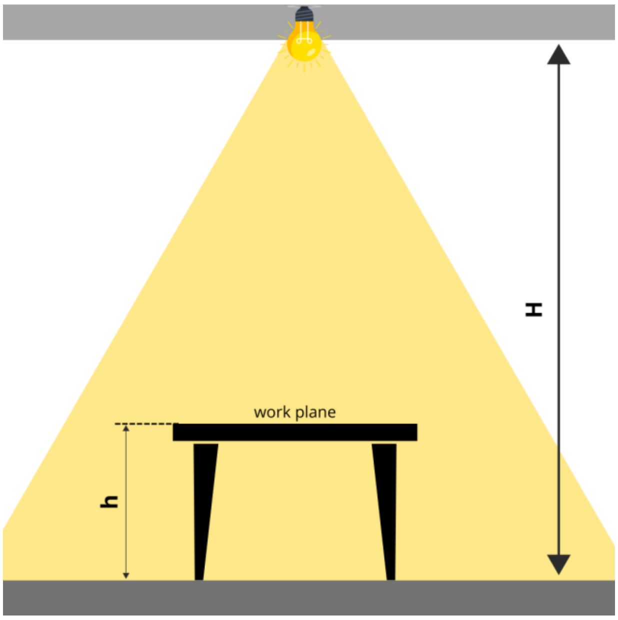

Fig. 2. Illustration of experimental setup

For maintaining the controlled conditions (room temperature and humidity) as well as measuring light intensity in lumens, it was used the device PCE-222 - digital thermometer shown in Figure 3a, while for measuring the energy consumption the smart plug which was connected to the mobile app Smart Life in order to measure real time energy consumption while the lights bulbs were working, as shown in Figure 3b. By using all input parameters, the experiment was conducted using a 3x3x3 factorial design (3 types of lights bulbs x 3 x power levels x 3 distances) which means total of 27 measurements combinations were performed. For each combination (type of bulb, power, and distance), measurements were repeated three times to obtain average values. Measurements were conducted sequentially for all three distances, starting from the closest. In Table 1. is shown a plan of experiment.

Fig. 3. Instruments used for the experiment; 3a. PCE-222 3b. Smart life app for energy consumption measurements

Table 1: Plan of experiment

Type of light bulb	Lumen value [lm]	Lux [lm/m^2]			Energy Consumption
		Distance 0,5m	Distance 1m	Distance 1,5m	
Incandescent	800	Measurement 1	Measurement 2	Measurement 3	Measurement X1
Incandescent	1000	Measurement 4	Measurement 5	Measurement 6	Measurement X2
Incandescent	1500	Measurement 7	Measurement 8	Measurement 9	Measurement X3
Fluorescent	800	Measurement 10	Measurement 11	Measurement 12	Measurement X4
Fluorescent	1000	Measurement 13	Measurement 14	Measurement 15	Measurement X5
Fluorescent	1500	Measurement 16	Measurement 17	Measurement 18	Measurement X6
LED	800	Measurement 19	Measurement 20	Measurement 21	Measurement X7
LED	1000	Measurement 22	Measurement 23	Measurement 24	Measurement X8
LED	1500	Measurement 25	Measurement 26	Measurement 27	Measurement X9

3. Results and data processing

The main goal of this experiment was to compare the performance of three different types of bulbs across various power levels and distances. Key parameters such as light intensity and energy consumption were measured to evaluate the efficiency and effectiveness of each bulb type. The collected data provides valuable insights into how different lighting technologies perform under specific conditions, allowing for a detailed analysis of their practical applications. The following section presents the results of the measurements and outlines the steps taken in data processing to ensure accurate and reliable finding.

3.1. Results

After conducting measurements for all combinations of bulb types, power, and distances, the collected data includes values for light intensity and energy consumption is shown in Table 2. The experiment was conducted under controlled conditions (room temperature 20^{o}C and humidity 46%).

Table 2: Results of experiment

Type of light bulb	Lumen value [lm]	Lux (lm/m^2)			Energy Consumption [W]
		Distance 0.5m	Distance 1m	Distance 1.5m	
Incandescent	800	524	125	52	62.1
Incandescent	1000	657	223	87	78.1
Incandescent	1500	1001	337	129	93.4
Fluorescent	800	543	153	37	9
Fluorescent	1000	688	306	68	10.3
Fluorescent	1500	841	431	103	16.2
LED	800	643	213	98	8.3
LED	1000	887	435	124	10.2
LED	1500	1020	520	179	11.8

3.2. Data processing

To address the research objectives, a detailed statistical analysis was conducted to evaluate the differences in light output (lux) between different types of light bulbs (incandescent, fluorescent, and LED), to assess the effect of distance on light intensity, and to analyse the energy efficiency of each bulb type. The analysis involved four major components:

- Comparison between light bulbs types: Using a one-way ANOVA to compare the lux values between incandescent, fluorescent and LED bulbs across different distances;
- Effect of distance on lux: Perform a linear regression analysis to see how distance affects lux values for each type of bulb and visualize the trend.
- Energy efficiency comparison: Compute the ratio of lux to energy consumption (lux per watt) for each type of bulb to measure their energy efficiency.
- Comparison of measured vs. specified power levels.

4. Results discussion

A one-way analysis of variance (ANOVA) was performed to compare the lux values produced by incandescent, fluorescent, and LED bulbs at different distances. This statistical test was chosen to determine whether there were significant differences in the brightness levels (lux) emitted by the three types of bulbs. The null hypothesis for this test was that there is no significant difference in lux output between the bulb types, while the alternative hypothesis posited that at least one group had a significantly different mean lux value. The results indicated that at all distances, the p-values were greater than 0.05, suggesting that the differences in lux values between the bulb types were not statistically significant. Therefore, it can be concluded that incandescent, fluorescent, and LED bulbs produce similar levels of brightness at these measured distances. To further investigate the impact of distance on the intensity of light (lux), a linear regression analysis was performed for each type of bulb. The regression analysis aimed to quantify the relationship between the lux values at three measured distances and to determine how distance affects the light intensity for each bulb type. For all three bulb types, the results showed a clear negative slope, indicating that lux values decrease as the distance from the light source increases. LED bulbs exhibited the steepest decline in lux levels with distance, followed by incandescent and fluorescent bulbs, as shown in Figure 4.

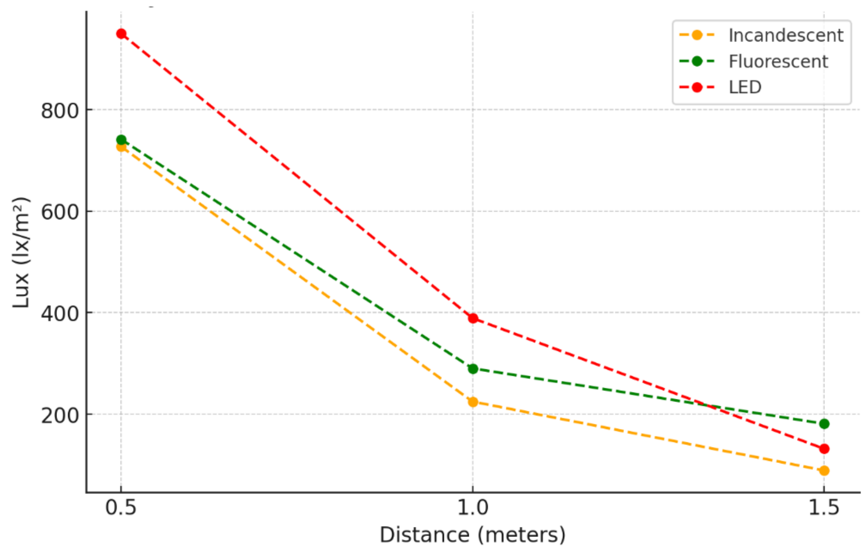

Fig. 4. Effect of Distance on Lux for Different Bulb Types

Energy efficiency is a critical factor when evaluating lighting systems. To measure the energy efficiency of each type of bulb, the ratio of lux per watt (lux divided by energy consumption) was calculated at all three distances. This metric provides a standardized way to compare how much light (lux) each bulb produces per unit of energy consumed, as shown in Table 3. The analysis revealed that LED bulbs were the most energy-efficient, producing the highest lux per watt across all distances. Fluorescent bulbs were moderately efficient, while incandescent bulbs had the lowest energy efficiency, consuming significantly more power to produce the same level of brightness. This finding is consistent with the well-documented superiority of LED and fluorescent technology in terms of energy savings compared to traditional incandescent bulbs.

Table 3: Energy efficiency of light bulbs

Type of light bulb	Lux per Watt		
	Distance 0.5m	Distance 1m	Distance 1.5m
Incandescent	9.189213	2.825444	1.110823
Fluorescent	59.681010	24.437892	5.690359
LED	83.623780	37.459168	13.044527

To assess the accuracy of manufacturer-reported power levels, the measured energy consumption of each bulb type was compared to the specified (nominal) consumption provided by the manufacturer. This analysis aimed to quantify any discrepancies between the actual energy consumption and the expected values, providing insights into how closely each type of bulb adheres to its nominal specifications**.** Table 4 shows the average measured energy consumption, expected energy consumption, and the difference (discrepancy) between the two for each type of light bulb.

Table 4: Comparison of measured energy consumption vs. producer specified

Type of light bulb	Measured consumption [Wh]	Expected Consumption [Wh]	Difference [Wh]
Incandescent	11.83	20.00	-8.17
Fluorescent	77.87	78.33	-0.47
LED	10.10	10.67	-0.57

The results indicate that fluorescent bulbs exhibit the largest discrepancy, with an average measured consumption of 11.83Wh, which is 8.17Wh lower than the expected 20Wh. This substantial deviation suggests that the actual energy use of fluorescent bulbs in the tested conditions is considerably more efficient than specified by the manufacturer. In contrast, incandescent bulbs demonstrated a much smaller deviation, with a measured consumption of 77.87Wh, only 0.47Wh lower than the expected average of 78.33Wh. This near-perfect alignment suggests that incandescent bulbs perform as expected in terms of energy consumption. Similarly, LED bulbs showed only a slight deviation from their specified power levels, consuming 10.10Wh on average, 0.57Wh lower than the expected value of 10.67Wh. The close match between the measured and expected values for LED bulbs reinforces their reliability and energy efficiency. The lower-than-expected consumption of fluorescent bulbs could be attributed to variations in testing conditions or improvements in the energy efficiency of modern fluorescent technologies. However, this differences can vary from different producers.

5. Conclusions

This study aimed to evaluate and compare the performance of three different types of light bulbs—incandescent, fluorescent, and LED—across various power levels and distances. The primary goal was to assess the light output (lux), energy consumption, and energy efficiency of each bulb type, while also examining any discrepancies between measured energy consumption and manufacturer-reported power levels. The analysis revealed several key insights:

- Lux Output and Distance: A one-way ANOVA showed no statistically significant differences in lux output between the bulb types at various distances. While the lux values decreased with increasing distance for all bulb types, the rate of decline was most pronounced for LED bulbs, followed by incandescent and fluorescent bulbs. This indicates that distance significantly impacts the effectiveness of each lighting technology, particularly for LED bulbs.
- Energy Efficiency: LED bulbs were found to be the most energy-efficient, producing the highest lux per watt across all distances. Fluorescent bulbs were moderately efficient, while incandescent bulbs were the least efficient, consuming significantly more energy to produce the same level of brightness. These findings align with previous studies, highlighting the energy-saving potential of LED and fluorescent technologies compared to traditional incandescent lighting.
- Measured vs. Specified Power Levels: The comparison between measured and specified power levels revealed some discrepancies, particularly for fluorescent bulbs, which consumed 8,17Wh less on average than the manufacturer-specified 20Wh. This suggests that fluorescent bulbs may be more energy-efficient in real-world applications than reported. In contrast, incandescent and LED bulbs showed minimal deviations from their specified power levels, reinforcing the reliability of their reported energy consumption.

In conclusion, LED bulbs offer the greatest energy efficiency and light output per watt, making them an ideal choice for both residential and commercial lighting applications. Fluorescent bulbs provide a moderate level of efficiency but may offer unexpected energy savings in certain conditions. Incandescent bulbs, while performing close to their expected power levels, remain the least energy-efficient option. As the global emphasis on energy conservation and sustainability continues to grow, this study reinforces the importance of selecting appropriate lighting technologies to reduce energy consumption and operational costs. Further research could explore how these findings translate to larger-scale lighting systems and different usage.

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