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Leading Light: The Impact of Advanced Lighting Technologies on Indonesia's Office Industry

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Abstract

Addressing concerns over resource scarcity and environmental sustainability necessitates a global shift towards sustainable energy, notably facilitated by adopting Light-Emitting Diode (LED) lamps. This transition is pivotal for ensuring global energy security and aligning with sustainability goals. This study endeavors to comprehensively analyze potential energy savings achievable through the transition from Fluorescent (FL) lamps to LED lamps within industrial offices. Emphasis is placed on highlighting the central role of energy efficiency. Utilizing false color rendering as a visual guide, the study systematically identifies areas where FL lamps inadequately illuminate. The findings prompt recalculations for determining optimal room illumination achievable through implementing LED lamps. Lux calculations are then employed to showcase the superior illumination offered by LED lamps, revealing consistent monthly cost savings of 35%, particularly when harmonized with Building Management System (BMS) control in industrial office buildings. The study's results indicate that LED lamps provide superior illumination, yielding a noteworthy 35% monthly cost savings, especially when integrated with BMS control. Lamps contribute modestly (21-30%) to overall energy consumption, while air conditioning commands a substantial 60%, underscoring the critical need for advanced lighting technology. This need is emphasized, particularly with Solar PV as a sustainable energy source. Understanding technological developments, especially in BMS, is crucial to optimize energy efficiency in industrial offices. The imperative implementation of LED lighting technology is a critical solution to address resource scarcity and environmental concerns in industrial offices. The efficacy of LED lamps in achieving significant energy savings, especially when coupled with advanced systems like BMS and complemented by renewable energy sources such as Solar PV. The conclusion stresses the significance of staying abreast of technological advancements to foster sustained progress towards energy-efficient and environmentally conscious practices within industrial environments.

1. Introduction

Facing resource scarcity and environmental harm from reduced fossil energy use, a shift to sustainable energy is crucial. It not only safeguards global energy security but also aligns with sustainability goals [1–3]. In Indonesia's evolving office landscape, a transformative wave integrates advanced lighting technologies, illuminating workspaces and ushering in energy efficiency. Smart sensors, responsive controls, and sustainable LED solutions redefine office aesthetics and significantly contribute to reduced energy consumption [4]. As Indonesia's offices embrace this evolution, the luminous future promises innovation, efficiency, and a greener tomorrow.

Energy efficiency, especially through technologies like replacing Fluorescent (FL) lamps with light-emitting diode (LED) lamps, is pivotal for wiser and more economical energy use, making a positive environmental impact [5]. Switching from conventional to LED lighting is a pertinent choice for enhancing energy efficiency in industrial offices. This not only improves workspace quality but also yields significant energy savings. This transition, emphasizing cessation and strategic environmental impact reduction, is a crucial step in optimizing resource use.

While Indonesia has yet to fully embrace LED lighting, global case studies highlight its effectiveness. Rapid advancements in LED technology, offering lower energy consumption and extended service life, support the quest for greater efficiency. LED lights, with optimal brightness and customizable designs, are increasingly favored for their energy-saving potential. These advancements represent a proactive stride toward achieving energy efficiency in industrial offices, laying the groundwork for a sustainable future [6, 7].

LED lights outshine other types due to their extended lifespan, reaching approximately 30,000 to 50,000 hours, in stark contrast to fluorescent lights' 15,000 hours. Fluorescent lamps, with a mere 5,000 to 10,000-hour lifespan, are more susceptible to damage [8]. The use of light-emitting diodes (LEDs) in LED lamps ensures sustained brightness without burning out. Additionally, LED lights contribute positively to the environment by avoiding the hazardous mercury found in fluorescent lamps. Mercury, present in various artificial sources like batteries and paints, poses a threat to human health and ecosystems [9]. Switching from fluorescent to LED lights is a commendable step for environmental improvement.

Numerous prior studies extensively explored implementing LED lights in industrial offices to save electrical energy, covering key concepts like energy efficiency, system design, simulation, and optimization for maximum efficiency. Zou et al. [10] developed a study on a Wi-Fi-based lighting control system for Smart Buildings in order to reduce energy efficiency. A separate study delves deeply into the simulation, offering valuable insights into the performance of LED lighting across diverse situational scenarios in industrial office spaces. Manolis et al. [11] provided an example of a study of lamps on the market to reduce energy efficiency in office buildings. In the context of direct applications, several studies highlight the successful implementation of LED lighting in achieving significant energy savings in various types of industrial offices. Montoya et al. [12] and Gnana et al. [13] summarized that LED lamps have a big impact on energy efficiency in the office sector. Vandenbogaerde et al. [14] explore the incorporation of lighting technology through Building Management Systems (BMS), aiming to enhance energy efficiency in office buildings. This comprehensive literature review delves into diverse dimensions to provide a holistic perspective on the influence of LED lighting on optimizing electrical energy utilization within industrial office environments. Additionally, it examines strategies for curbing energy consumption in office settings, offering a thorough analysis of the subject.

Based on this review, many studies have discussed the energy-saving performance of lamps in industrial offices. This discussion focuses more on knowledge, comparisons, and frameworks to provide efficient measures to promote the sustainability of energy efficiency in LED lighting technology [15, 16]. However, no study in the office industry discusses in detail how to measure energy savings, especially using the method of energy con-sumed and comparison cost. Although Hemmerling et al. [17] and Vandenbogaerde et al. [14] have discussed energy-saving calculations using the software DIALux and the integration of lighting technologies with BMS, the discussion was, unfortunately, more about the individual process. Especially in the office industry, the elucidation currently lacks an incorporation of the expenditure cost comparison program.

To address these gaps, this paper discusses the sustainable energy savings measurement in the LED lighting parts in office industries to provide a comprehensive view of potential energy savings in transitioning from FL lamps to LED lamps in industrial offices, contributing to energy efficiency in these buildings. The aim of the study is to bridge a noticeable gap within existing literature concerning the lack of detailed methodologies for accurately measuring energy savings, particularly in the context of transitioning from FL lamps to LED lamps within industrial office environments. This research endeavors to introduce a sustainable energy savings measurement framework specifically tailored for LED lighting in office industries, aiming to provide a comprehensive understanding of the potential energy savings achievable through such a transition.

Table 1. Material datasheet comparison of TL lamps and LED lamps.

Lamp Type	Philips TL5 Essential 28W/840	Philips RC100B LED54S 840
Nominal Usage Per	15.000 hr	50.000 hr
Color Code	840 (CCT of 4000K)	4000K
Light Flux	2.900 lm x 2 (5.800lm)	5.400 lm
Lighting Power	94lm/W	122lm/W
Color Rendering Index	82	80
Power Consumption	27.8 W x 2 (55.6 W)	44 W
Driver/System	No	Dali driver, POE

(a) **(b)**

Figure 1. Material sample for TL 5 lamp and LED lamp, a). Philips FL TL5, b). Philips LED RC100B [18, 19].

2. Materials and Methods

2.1. Material

In this research, the author compared the types of lamps that were used in design simulations in industrial offices for the first type using TL5 Essential 28W/840 lamps and the second type using RC100B LED54S 840 lamps; material sample can be seen in Figure 1. Within the context of FL T5-type lamps, a notable distinction lies in the structural arrangement, where the armature and tube lamp panels manifest as different parts. In stark contrast, LED lamps exhibit a different configuration, wherein the armature and tube lamp panels seamlessly integrate into a singular unit. This design underscores a pivotal divergence between the two lighting lamp technologies.

Table 1 explained the datasheet material regarding the two lamps that were to be used, highlighting that the performance over time for LED lamps was longer than for FL lamps. While the power consumption of each lamp is listed in the table, LED is 44W and FL is 55.6W.

2.2. Layout: Result Assessment

As shown in Figure 2, a comprehensive layout plan is presented for an industrial office simulation, delineating the architectural features and configuration of the structure. The building's dimensions are specified, measuring 24.3 meters in length and 12 meters in width while reaching a height of 3 meters. Notably, the design of this industrial office building exhibits uniformity across each of its three floors, thereby ensuring a consistent and cohesive layout throughout the entire structure. This design is crafted using a simulation method facilitated by DIALux software.

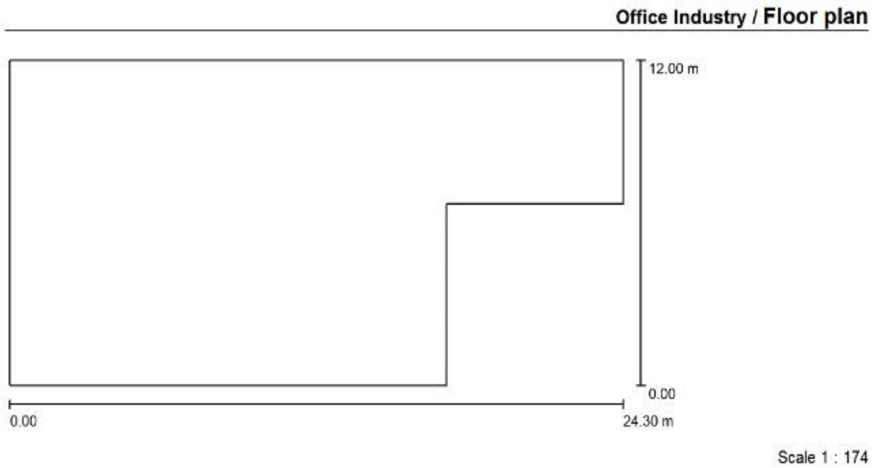
Based on the International Standard (IEC), specifically by "IEC 60598," and Indonesian National Standard (SNI) “SNI 6197: 2011," it is explicitly delineated that the prescribed luminance standards for office spaces fall within the range of 300 to 750 lux. The precise lux requirements are contingent upon the distinct nature of the room under consideration within which the simulation calculations are slated to transpire. To gain a comprehensive understanding of the average lighting levels mandated for the accurate emulation of illumination in industrial office settings, a detailed breakdown is provided in Table 2 for reference and further elucidation.

2.3. Simulation

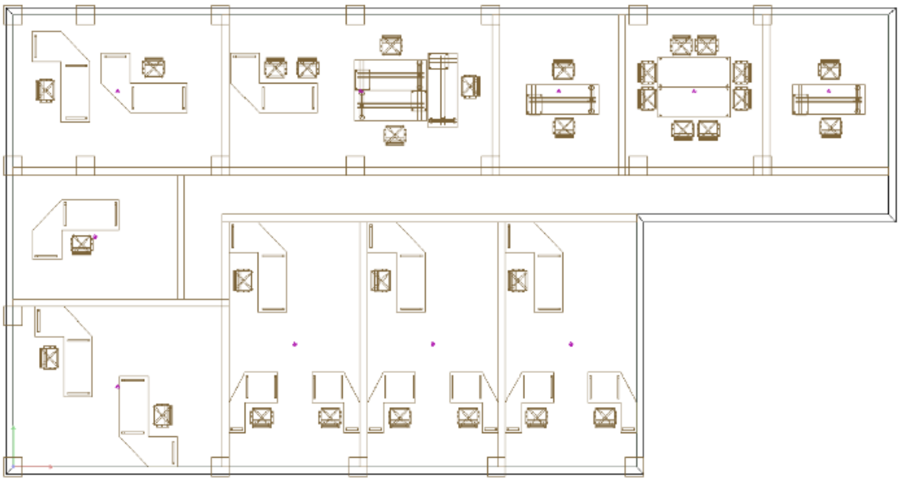
DIALux, a freely accessible and user-friendly computer software, is widely employed for simulating and visualizing lighting in various environments [20, 21]. This tool facilitates the creation of virtual spaces, encompassing both daylight and artificial light conditions, and offers versatile simulations for buildings, rooms, and outdoor areas [22–24]. Users can analyze lighting system performance in specific locations and object environments, presenting results through numerical data, graphs, and images [25, 26]. As exemplified by Moadab et al. [27]. Compared to Smart lighting versus conventional lighting in apartments using DIALux, the software proves valuable for assessing lighting quality and achieving energy cost savings. In summary, DIALux serves as an effective tool for comprehensive lighting evaluations.

2.4. Method

The determination of the number of light points required within a given space can be achieved through the application of the formula encapsulated in Equation 1, where various parameters and considerations are systematically integrated to ascertain an accurate and



(a)



(b)

Figure 2. Layout plan for industrial office simulation, a). Floor plan, b). Layout plan.

Table 2. Lux levels SNI 6197: 2011.

Room Function	Avg Lighting Level (E_{avg}) Min. (lux)	Min. Color rendering
Reception Room	300	80
Director Room	350	80
Workspace	350	80
Computer Room	150	80
Meeting Room	300	80
Image Space	750	80
Archive Room	150	80
Active Archive Room	350	80
Emergency Stairwell	100	80
Parking Space	100	80

optimal configuration for illuminating the designated room.

$$N = \frac{E_{lw}}{\theta . L_{lf} . CU_n} \quad (1)$$

Where, N is representing the number of light points, E [lux] is signifying the desired lighting intensity measured, lw [meter] is denote the length and width of the room, θ [lumen] is encapsulates the total lumen output of the lamps being considered a parameter readily available in the lamp catalogue earmarked for simulation, L_{lf} [0.7-0.8] is assumes a value within the range of 0.7 to 0.8, influencing the overall lighting equation, CU [50%-65%] is plays a pivotal role, fluctuating between 50% and 65%, and $n$is stands for the number of lamps essential to achieving the stipulated lighting conditions. This multifaceted formula integrates these diverse elements, ensuring a comprehensive and nuanced approach to determining the optimal lighting configuration for the specified room.

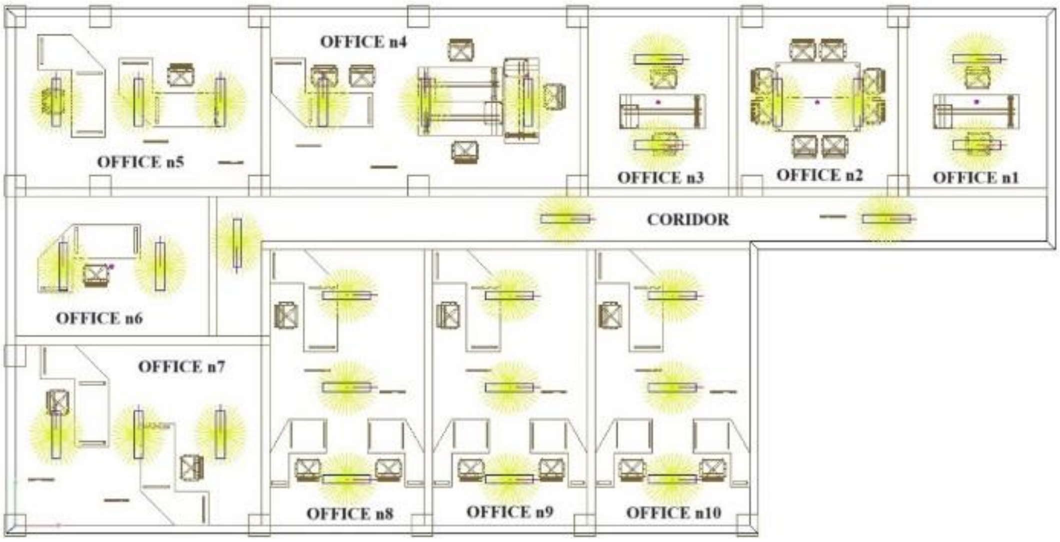


Figure 3. Plan of light points in an industrial office.

Table 3. Surface list Philips TL5 essential 28W x 2 840.

No	Room	Type	Grid	Eav [lx]	u0	Emin / Emax
1	Office - 5	Perpend.	128x128	301	0.336	0.213
2	Office - 4	Perpend.	128x128	253	0.323	0.188
3	Office - 3	Perpend.	128x128	308	0.641	0.421
4	Office - 2	Perpend.	128x128	273	0.334	0.199
5	Office - 1	Perpend.	128x128	310	0.658	0.432
6	Office - 6	Perpend.	32 x 32	288	0.674	0.427
7	Office - 7	Perpend.	128x128	295	0.314	0.195
8	Office - 8	Perpend.	128x128	296	0.480	0.305
9	Office - 9	Perpend.	128x128	296	0.488	0.310
10	Office - 10	Perpend.	128x128	300	0.367	0.234

Table 4. Surface list Philips RC100B LED 54S 840.

No	Room	Type	Grid	Eav [lx]	u0	Emin/Emax
1	Office - 5	Perpend.	128x128	479	0.292	0.203
2	Office - 4	Perpend.	128x128	400	0.343	0.240
3	Office - 3	Perpend.	128x128	495	0.654	0.496
4	Office - 2	Perpend.	128x128	440	0.337	0.226
5	Office - 1	Perpend.	128x128	500	0.662	0.505
6	Office - 6	Perpend.	32 x 32	462	0.645	0.497
7	Office - 7	Perpend.	128x128	470	0.303	0.206
8	Office - 8	Perpend.	128x128	472	0.475	0.349
9	Office - 9	Perpend.	128x128	472	0.493	0.363
10	Office - 10	Perpend.	128x128	476	0.360	0.265

As shown in Figure 3 illustrates the calculated distribution of light points for various rooms using DIALux software, such as 2 points for Offices n1, n2, and n3, 3 points for Offices n4, n5, n7, n8, n9, and n10, 2 points for Office n6, and 3 points for the corridor.

Table 3 presents the outcomes of calculations conducted through the DIALux software, referenced in Figure 3, offering insights into the lighting assessments for office spaces utilizing FL T5 lamps. Notably, the lux values for various offices are detailed, with Office n5 achieving an average of 301 lux, Office n4 registering 253 lux, Office n3 attaining 308 lux, Office n2 recording 273 lux, Office n1 reaching 310 lux, Office n6 maintaining 288 lux, Office n7 securing 295 lux, and Offices n8, n9, and n10 each registering 296 lux. It is noteworthy that the calculated average lux values for all offices mentioned align with the stipulated SNI standard criteria.

Table 4 presents the subsequent simulation results employing a distinct luminaire, specifically the RC100B LED lamp, utilizing the DIALux software with reference to Figure 3. The outcomes encompass various office spaces, revealing average lux values such as 479 for Office n5,400

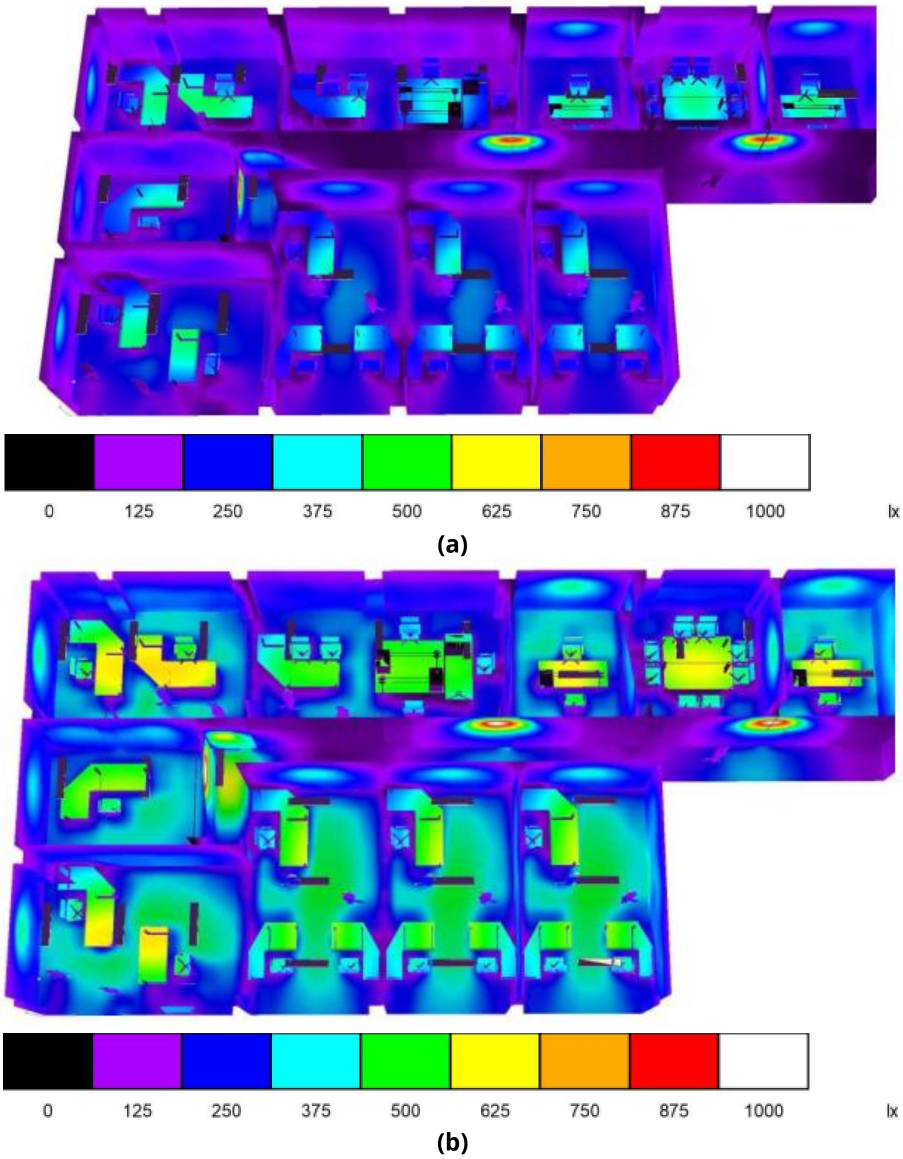


Figure 4. False lux color rendering at office: (a) TL5 28W x 2, (b) RC100B LED 54S.

for Office n4, 495 for Office n3, 440 for Office n2, 500 for Office n1, 462 for Office n6, 470 for Office n7, and 472 for Offices n8, n9, and n10. Notably, these calculated average lux values consistently adhere to the stipulated SNI standard criteria.

Figure 4a provides an insightful depiction of the color rendering outcomes for industrial office buildings employing FL T5 lamps. This representation elucidates the distribution of lighting within the space by grouping it on an illumination or luminance scale and visually presenting it through an array of colors.

Figure 4b visually presents the color rendering outcomes for industrial office buildings utilizing RC 100B LED lamps. These results underscore the superior quality of lighting distribution compared to FL T5 lamps, demonstrating an enhanced and commendable color rendering performance.

The false color rendering depicted in both Figure 4a and 4b serves as a visual indicator of the lighting spectrum's effectiveness in achieving optimal distribution within a room. A visual cue is provided, where black hues signify areas where the lights fail to adequately illuminate corner points. In such instances, recalculations become imperative to ensure that each room receives adequate illumination from the lamps.

Smart buildings employ a myriad of automated processes that seamlessly collaborate to oversee and manage essential building systems, encompassing HVAC, lighting, electricity, utility consumption, and closed-circuit cameras. At the core of this technology are interconnected devices and a BMS capable of effective

Figure 5. Topology BMS for lighting control.

communication and execution of intricate instructions tailored to the real-time conditions of diverse subsystems. Facilitating this dynamic communication network necessitates advanced software and hardware solutions that enable the coordination, monitoring, and control of various building elements over the interconnected network. Illustrated in Figure 5 is the technological advancement in the industrial office building, highlighting the implementation of an upgraded lighting control system through the BMS. Notably, this BMS enables dynamic control of the lighting system in real time, facilitating adjustments based on a predetermined schedule mutually agreed upon by the building owner.

Employing BMS for lighting control, the author presents a simulation outlining temporal constraints, restricting the operation of lights from 8:00 am to 8:00 pm within a 12-hour timeframe.

3. Results and Discussion

3.1. Results

This study conducts a comparative analysis between FL lamps and LED lamps, as illustrated in Figure 1 for a sample of the lamps. Additionally, the research presents the findings of a cost comparison between FL lamps and LED lamps over a one-year duration and also provides a cost comparison of LED lamps using BMS and without BMS.

The graphical representation in Figure 6a. delineates the lux calculations for FL lamps versus LED lamps, delineates the lux calculations for FL lamps versus LED lamps, revealing that LED lamps offer superior illumination compared to FL lamps. Importantly, the lux values for each lamp in this comparison consistently adhere to the national and international standard criteria.

In Figure 6b, the comparison of load consumption between FL lamps and LED lamps reveals that the latter demonstrates commendable energy efficiency. The graph illustrates that LED lamps exhibit superior energy consumption values in contrast to FL lamps, with an average improvement of 21%. Emphasizing the potential for energy savings, especially in lamp load utilization, adopting LED lamps is recommended for enhanced energy efficiency within the building.

The subsequent phase involves a detailed analysis of monthly cost expenditures, focusing on the comparison between FL lamps and LED lamps. Illustrated in Figure 6c. The yearly cost projection reflects an average daily light usage of approximately 18 hours, spanning from 6:00 am to 1:00 am. Notably, the lighting system employs conventional control methods, with lights being switched on or off using a simple ON/OFF mechanism. This operational approach translates into an average monthly cost savings of 21%.

As shown in Table 5 are the outcomes of a meticulous monthly cost comparison between FL lamps and LED lamps, referencing the light point data outlined in Figure 3. Notably, the results demonstrate a consistent pattern where the monthly cost associated with FL lamps surpasses that of LED lamps. This discrepancy can be

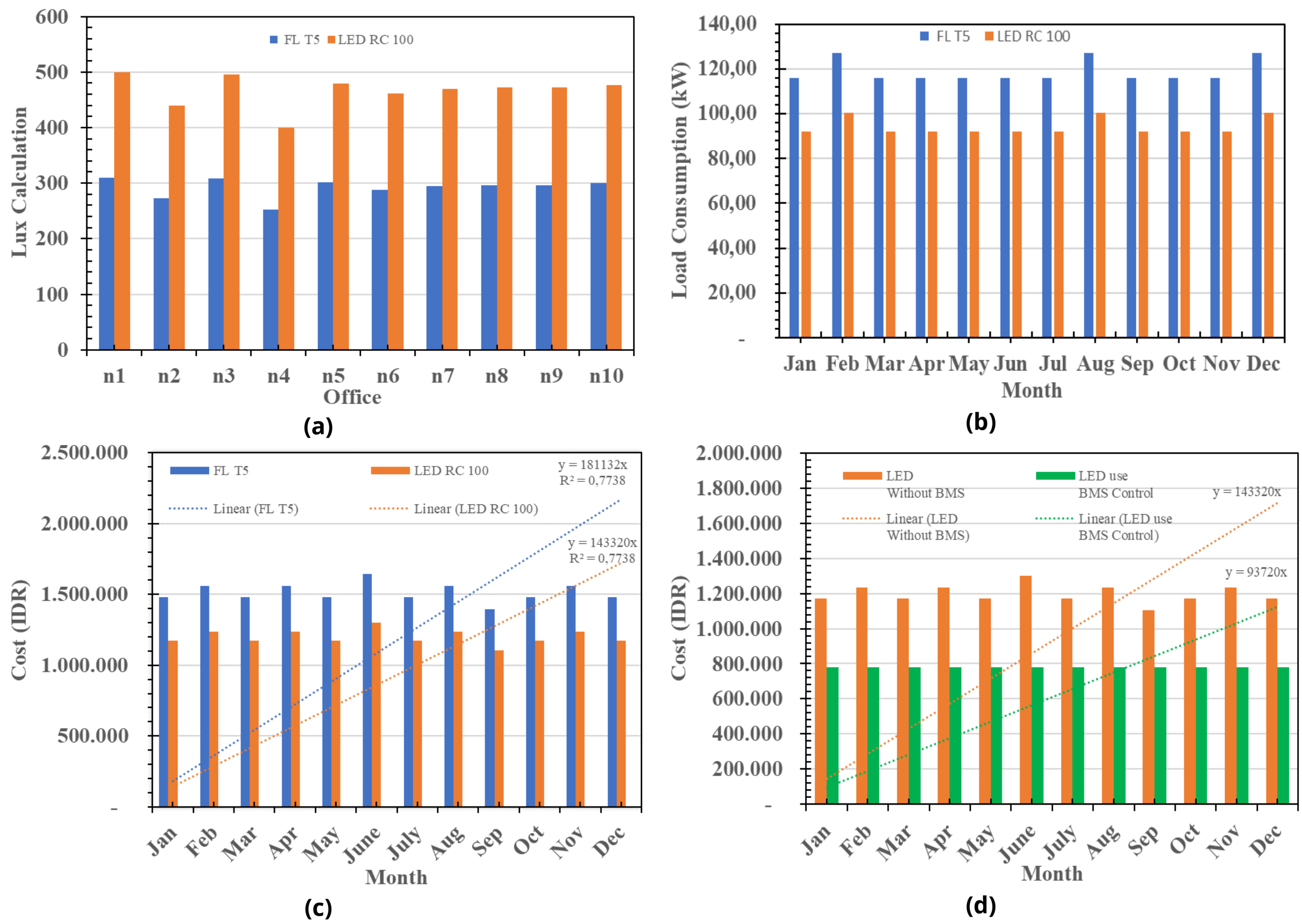


Figure 6. Comparison bar graph. (a) Lux comparison table for FL lamp and LED lamp, (b) Load consumption comparison table for FL lamp and LED lamp (c) Cost comparison FL lamp and LED lamp, (d) Cost comparison LED lamp without BMS and LED lamp with BMS system.

attributed to the higher power output of FL lamps as opposed to LED light a distinction further elucidated in Table 1.

The next discussion shown in Figure 6d. show illustrates the comparison graph, showcasing notably substantial outcomes of advanced lighting control systems utilizing BMS operations, as opposed to conventional counterparts use switch on/off. The cost efficiency of LED lamps integrated with BMS surpasses that of controlled LED lamps in conventional systems.

Examining Table 6 reveals a noteworthy average cost savings of 35% when comparing the use of LED lights with BMS control to LED lights with conventional control. This approach proves highly advantageous for achieving cost reductions, particularly in the context of LED lighting technology implementation within industrial office buildings.

3.2. Discussion

The strategic selection of LED technology aligned with needs, coupled with technological advancements on a BMS basis integrated with the Internet of Things (IoT). As per research [28], energy conservation is achievable by leveraging IoT to create smart offices, aiding remotely in electricity monitoring. Consequently, studying technological advancements becomes imperative for optimizing energy efficiency. Furthermore, various technologies are emerging that integrate smart lighting with the IoT, enabling the monitoring of electricity usage to facilitate energy conservation [29].

Involves a strategic emphasis on energy efficiency within industrial offices beyond the lighting system, encompassing discussions on other integral systems such as HVAC [30]. This strategic approach stems from the recognition that the energy efficiency percentage within the lighting system discussion, while significant, does not constitute a substantial portion due to the predominant load imposed by air conditioning in industrial office buildings. The rationale behind this emphasis is rooted in the overarching goal of attaining optimal energy efficiency throughout the entirety of a building. Moreover, it is crucial to underscore the significance of optimizing other energy-consuming

Table 5. Cost comparison FL T5 and LED RC 100.

Month	Time Usage/days	Energy Cost/Month FL T5 Lamp (IDR)	Energy Cost/Month LED RC 100 (IDR)	Saving Energy (%)
Jan	18	1.480.000	1.171.000	21%
Feb	19	1.562.000	1.236.000	21%
Mar	18	1.480.000	1.171.000	21%
Apr	19	1.562.000	1.236.000	21%
May	18	1.480.000	1.171.000	21%
June	20	1.644.000	1.301.000	21%
July	18	1.480.000	1.171.000	21%
Aug	19	1.562.000	1.236.000	21%
Sep	17	1.398.000	1.106.000	21%
Oct	18	1.480.000	1.171.000	21%
Nov	19	1.562.000	1.236.000	21%
Dec	18	1.480.000	1.171.000	21%
Avg	18	1.514.000	1.198.000	21%

Table 6. Cost comparison Lighting LED without BMS and LED with BMS system.

Month	Op. Time w/o BMS	Op. Time Use w/ BMS	Cost sum. LED w/o BMS (IDR)	Cost sum. LED w/ BMS (IDR)	E. Saved (%)
Jan	18	12	1.171.000	781.000	33%
Feb	19	12	1.236.000	781.000	37%
Mar	18	12	1.171.000	781.000	33%
Apr	19	12	1.236.000	781.000	37%
May	18	12	1.171.000	781.000	33%
June	20	12	1.301.000	781.000	40%
July	18	12	1.171.000	781.000	33%
Aug	19	12	1.236.000	781.000	37%
Sep	17	12	1.106.000	781.000	29%
Oct	18	12	1.171.000	781.000	33%
Nov	19	12	1.236.000	781.000	37%
Dec	18	12	1.171.000	781.000	33%
Avg	18	12	1.514.000	781.000	35%

systems, such as air conditioning, for overall efficiency [30].

Imperative to delve into discussions concerning strategic technological advancements about Lighting Technologies seamlessly integrated with PV Solar as the primary power source. This discussion assumes paramount importance in the contemporary epoch marked by the transition from fossil energy reliance to the adoption of renewable energy sources [31]. Furthermore, advancements in the utilization of solar photovoltaic (PV) technology within buildings not only contribute to energy cost savings but also yield environmentally beneficial effects, promoting a greener impact on the surrounding environment [32]. The research outcomes offer a comprehensive perspective, shedding light on the intricacies of energy efficiency endeavors. The initiative to transition from FL lamps to LED lamps, particularly within industrial offices and across various industries, yields profoundly positive impacts. This shift towards environmentally friendly and energy-efficient lighting not only contributes positively to the environment but also enhances economic sustainability [28].

The practical application of this research is not only in the office industry but can also be applied to other industries and building management with adjustments as necessary. This research contributes to achieving energy savings with a proper energy management control system (EMCS) and energy goal setting. Concept of Information Control Systems for Green Manufacturing Industries with IoT-Based Energy Efficiency and Productivity [33]. Reducing energy and water consumption in the textile dyeing Industry with reuse wastewater [34], Potential energy efficiency and solar energy applications in a small industrial [35], and energy efficiency in aluminum parts industries with EMCS as well as energy efficiency with exhaust hot air for the scrap process [36, 37].

4. Conclusions

The development of energy-saving baselines for measurements in industrial offices has been comprehensively discussed. Basic data development must analyze process flows and data extensively for better understanding. Baseline uses the ratio of energy consumed per month and year by comparison. Some of the main findings can be summarized. First, based on comparative calculations between the energy consumption of TL lamps and LED lamps, LED lamps have a better efficiency value of 21%. However, the impact of lamps on energy efficiency is relatively modest, constituting only 21% to 30% of energy consumption on average. In contrast, air conditioning exerts the most significant influence, accounting for 60% of energy consumption, with elevators and other systems making up 6% and 4%, respectively. Beyond these considerations, there is a pressing need for the advancement of lighting technology in industrial office buildings, particularly in conjunction with Solar PV as an energy source.

Apart from that, technological developments in industrial office spaces are very important; with BMS as the main example. BMS by efficiently monitoring and controlling various systems through the building network empowers precise regulation of time utilization within the electrical infrastructure of office industries, notably optimizing energy consumption in vital components such as AC and lighting systems. This system will help achieve energy efficiency in an industrial office building.

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References

1. Moey, L. K., Goh, K. S., Tong, D. L., Chong, P. L., Adam, N. M., and Ahmad, K. A. (2020). A Review on Current Energy Usage and Potential of Sustainable Energy in Southeast Asia Countries, *Journal of Sustainability Science and Management*, Vol. 15, No. 2, 89–107.
2. Najjar, M., Figueiredo, K., Hammad, A. W. A., and Haddad, A. (2019). Integrated Optimization with Building Information Modeling and Life Cycle Assessment for Generating Energy Efficient Buildings, *Applied Energy*, Vol. 250, No. January, 1366–1382. doi:10.1016/j.apenergy.2019.05.101.
3. Idroes, G. M., Hardi, I., Noviandy, T. R., Sasmita, N. R., Hilal, I. S., Kusumo, F., and Idroes, R. (2023). A Deep Dive into Indonesia's CO2 Emissions: The Role of Energy Consumption, Economic Growth and Natural Disasters, *Ekonomikalia Journal of Economics*, Vol. 1, No. 2, 69–81. doi:10.60084/eje.v1i2.115.
4. Wagiman, K. R., Abdullah, M. N., Hassan, M. Y., Mohammad Radzi, N. H., Abu Bakar, A. H., and Kwang, T. C. (2020). Lighting System Control Techniques in Commercial Buildings: Current Trends and Future Directions, *Journal of Building Engineering*, Vol. 31, No. March, 101342. doi:10.1016/j.jobe.2020.101342.
5. Byun, J., and Shin, T. (2018). Design and Implementation of an Energy-Saving Lighting Control System Considering User Satisfaction, *IEEE Transactions on Consumer Electronics*, Vol. 64, No. 1, 61–68. doi:10.1109/TCE.2018.2812061.
6. Duwal, I. (2019). Case Study for Replacement of Conventional Lights by Led Lights, *Journal of Science and Engineering*, Vol. 7, No. November, 44–51. doi:10.3126/jsce.v7i0.26789.
7. Bhattacharya, S., Satvaya, P., and Roy, S. (2024). Predictive Modelling of Lighting Quality Parameters and Energy Efficiency of Light Emitting Diode-Based General Road Illumination Systems with Special Emphasis on Luminaire Tilt and Bracket Length, *Sadhana - Academy Proceedings in Engineering Sciences*, Vol. 49, No. 1. doi:10.1007/s12046-023-02382-y.
8. Hoang, T. T. L., Do, T. G., Nguyen, V. T., Nguyen, H. C., and Phan, H. K. (2020). Environmental Impacts of Photoluminescence and Light-Emitting Diode (LED) Lighting Technologies in Horticulture: Case Study on Compact Fluorescent Lamp (CFL) and LED Lights for "Night Break" of Chrysanthemum Cultivation, *Sustainability*, Vol. 12, No. 19, 7969. doi:10.3390/su12197969.
9. Kadam, A. R., Nair, G. B., and Dhoble, S. J. (2019). Insights into the Extraction of Mercury from Fluorescent Lamps: A Review, *Journal of Environmental Chemical Engineering*, Vol. 7, No. 4, 103279. doi:10.1016/j.jece.2019.103279.
10. Zou, H., Zhou, Y., Jiang, H., Chien, S. C., Xie, L., and Spanos, C. J. (2018). WinLight: A WiFi-Based Occupancy-Driven Lighting Control System for Smart Building, *Energy and Buildings*, Vol. 158, 924–938. doi:10.1016/j.enbuild.2017.09.001.
11. Manolis, E., Doulos, L. T., Niavis, S., and Canale, L. (2019). The Impact of Energy Efficiency Indicators on the Office Lighting Planning and Its Implications for Office Lighting Market, *Proceedings - 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe, EEEIC/I and CPS Europe 2019*. doi:10.1109/EEEIC.2019.8783856.
12. Montoya, F. G., Peña-García, A., Juaidi, A., and Manzano-Agugliaro, F. (2017). Indoor Lighting Techniques: An Overview of Evolution and New Trends for Energy Saving, *Energy and Buildings*, Vol. 140, 50–60. doi:10.1016/j.enbuild.2017.01.028.
13. Gnana Swathika, O. V., Karthikeyan, K., Subramaniam, U., Udayanga Hemapala, K. T. M., and Bhaskar, S. M. (2022). Energy Efficient Outdoor Lighting System Design: Case Study of IT Campus, *IOP Conference Series: Earth and Environmental Science*, Vol. 1026, No. 1. doi:10.1088/1755-1315/1026/1/012029.
14. Vandenbogaerde, L., Verbeke, S., and Audenaert, A. (2023). Optimizing Building Energy Consumption in Office Buildings: A Review of Building Automation and Control Systems and Factors Influencing Energy Savings, *Journal of Building Engineering*, Vol. 76. doi:10.1016/j.jobe.2023.107233.
15. Morgan Pattison, P., Hansen, M., and Tsao, J. Y. (2018). LED Lighting Efficacy: Status and Directions, *Comptes Rendus Physique*, Vol. 19, No. 3, 134–145. doi:10.1016/j.crhy.2017.10.013.
16. Beccali, M., Bonomolo, M., Lo Brano, V., Ciulla, G., Di Dio, V., Massaro, F., and Favuzza, S. (2019). Energy Saving and User Satisfaction for a New Advanced Public Lighting System, *Energy Conversion and Management*, Vol. 195, 943–957. doi:10.1016/j.enconman.2019.05.070.

17. Hemmerling, M., Seegers, M., and Witzel, D. (2023). Calculation of Energy Saving Potential for Lighting with DIALux Evo, *Energy and Buildings*, Vol. 278. doi:10.1016/j.enbuild.2022.112475.

18. Philips. (2022). Lighting TL5 Essential HE, 27–29.

19. Highbay, G., Cw, B. Y. P. L. E. D., Wb, P. S. U., and Gm, G. (2020). Lighting GreenPerform.

20. Mandala, A. (2019). Lighting Quality in the Architectural Design Studio (Case Study: Architecture Design Studio at Universitas Katolik Parahyangan, Bandung, Indonesia), *IOP Conference Series: Earth and Environmental Science*, Vol. 238, No. 1. doi:10.1088/1755-1315/238/1/012032.

21. Wijaya, D. D. A., Utami, S. S., Adi, G. S., and Prayitno, B. (2019). Optimization of Natural and Artificial Lighting System Design in the Library of the Faculty of Economics and Business, Universitas Gadjah Mada, *ICETAS 2019 - 2019 6th IEEE International Conference on Engineering, Technologies and Applied Sciences*. doi:10.1109/ICETAS48360.2019.9117347.

22. Mohd Husini, E., Raja Md Yazit, R. N. S., Arabi, F., Wan Ismail, W. N., and Jaafar, N. H. (2018). Light, Daylighting and Fluctuation of Illuminance Level in Office Buildings, *IOP Conference Series: Materials Science and Engineering*, Vol. 401, No. 1. doi:10.1088/1757-899X/401/1/012021.

23. Standar Nasional Indonesia, B. S. N. (2001). SNI 03-6575-2001 Tentang Tata Cara Perancangan Sistem Pencahayaan Buatan pada Bangunan Gedung, *SNI 03-6575-2001 Tentang Tata Cara Perancangan Sistem Pencahayaan Buatan Pada Bangunan Gedung*, 1–32.

24. Sardar, S., Ganguly, A., Roy, A., Banerjee, S., and Kumar, S. (2023). Energy-Efficient Railway Lighting Design—A Case Study, *Lecture Notes in Electrical Engineering*, Vol. 926, 597–605. doi:10.1007/978-981-19-4971-5_43.

25. Idrus, I. (2019). Evaluasi Kondisi Pencahayaan Integrasi Manual Pada Ruang Kantor Menara Balaikota Makassar, *Jurnal Linears*, Vol. 1, No. 1, 1–11. doi:10.26618/j-linears.v1i1.1312.

26. Zhang, L., Yuan, L., Zhang, W., and Guo, P. (2021). General Classroom Lighting Design and Simulation Based on DIALux evo software, *2021 International Conference on Electronic Information Engineering and Computer Science, EIECS 2021*, 994–997. doi:10.1109/EIECS53707.2021.9587908.

27. Hafezparast Moadab, N., Olsson, T., Fischl, G., and Aries, M. (2021). Smart versus Conventional Lighting in Apartments – Electric Lighting Energy Consumption Simulation for Three Different Households, *Energy and Buildings*, Vol. 244, 111009. doi:10.1016/j.enbuild.2021.111009.

28. Berawi, M. A., Kim, A. A., Naomi, F., Basten, V., Miraj, P., Medal, L. A., and Sari, M. (2023). Designing a Smart Integrated Workspace to Improve Building Energy Efficiency: An Indonesian Case Study, *International Journal of Construction Management*, Vol. 23, No. 3, 410–422. doi:10.1080/15623599.2021.1882747.

29. Soheilian, M., Fischl, G., and Aries, M. (2021). Smart Lighting Application for Energy Saving and User Well-Being in the Residential Environment, *Sustainability (Switzerland)*, Vol. 13, No. 11. doi:10.3390/su13116198.

30. Yandri, E., Ariati, R., Uyun, A. S., Setyobudi, R. H., Anne, O., Susanto, H., and Vincevica-Gaile, Z. (2020). Implementation of walk-through audits for designing energy management system: A first step towards an efficient campus, *IOP Conference Series: Earth and Environmental Science*, Vol. 490, No. 1. doi:10.1088/1755-1315/490/1/012005.

31. Pintér, G., Baranyai, N. H., Wiliams, A., and Zsiborács, H. (2018). Study of Photovoltaics and LED Energy Efficiency: Case Study in Hungary, *Energies*, Vol. 11, No. 4, 1–13. doi:10.3390/en11040790.

32. Rudationo, C. B., Novianto, B., Yandri, E., Susanto, H., Setyobudi, R. H., Uyun, A. S., Nur, S. M., Wahono, S. K., Widodo, W., Zekker, I., and Lomi, A. (2021). Techno-Economic Analysis of Rooftop Photovoltaic System (RPVS) Using Thin-Frameless Solar Panels for Household Customers in Indonesia, *Proceedings of the Pakistan Academy of Sciences: Part A*, Vol. 58, No. Special Issue, 131–139. doi:10.53560/PPASA(58-SP1)750.

33. Yandri, E., Idroes, R., Maulana, A., and Zahriah, Z. (2023). Design Concept of Information Control Systems for Green Manufacturing Industries with IoT-Based Energy Efficiency and Productivity, *Leuser Journal of Environmental Studies*, Vol. 1, No. 1, 9–17. doi:10.60084/ljes.v1i1.36.

34. Yandri, E., Idroes, R., Setyobudi, R. H., Rudationo, C. B., Wahono, S. K., Mahaswa, R. K., Burlakovs, J., and Susanto, H. (2021). Reducing Energy and Water Consumption in Textile Dyeing Industry with Cleaner Production by Inlet-Outlet Modification to Reuse Wastewater, *Proceedings of the Pakistan Academy of Sciences: Part A*, Vol. 58, No. S, 49–58. doi:10.53560/PPASA(58-sp1)732.

35. Yandri, E., Ariati, R., Saepul Uyun, A., Hendroko Setyobudi, R., Susanto, H., Abdullah, K., Krido Wahono, S., Adhi Nugroho, Y., Yaro, A., and Burlakovs, J. (2020). Potential Energy Efficiency and Solar Energy Applications in a Small Industrial Laundry: A Practical Study of Energy Audit, *E3S Web of Conferences*, Vol. 190. doi:10.1051/e3sconf/202019000008.

36. Yandri, E., Suherman, S., Lomi, A., Setyobudi, R. H., Ariati, R., Pramudito, P., Ronald, R., Ardiani, Y., Burlakovs, J., Zahoor, M., Shah, L. A., Fauzi, A., Tonda, R., and Iswahyudi, I. (2024). Sustainable Energy Efficiency in Aluminium Parts Industries Utilizing Waste Heat and Equivalent Volume with Energy Management Control System, *Proceedings of the Estonian Academy of Sciences*, Vol. 73, No. 1, 29–42. doi:10.3176/proc.2024.1.04.

37. Yandri, E., Pramudito, P., Ronald, R., Ardiani, Y., Ariati, R., Setyobudi, R. H., Widodo, W., Zahoor, M., Zekker, I., and Lomi, A. (2022). Technical Design of Aluminium Scrap Processing Machines by Utilizing Direct Exhaust Air Using Conveyor Drying System, *Proceedings of the Estonian Academy of Sciences*, Vol. 71, No. 2, 178–185. doi:10.3176/proc.2022.2.01.