ESTIMATION OF BUILDING ENERGY MANAGEMENT TOWARD MINIMIZING ENERGY CONSUMPTION AND CARBON EMISSION

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ABSTRACT: Up to 20% of the world's total energy is used for lighting. Thus, one of the available solutions for minimizing energy consumption is by using a smart lighting system. In the smart lighting system, the lights are calibrated according to space occupation and the surrounding natural lighting condition. Accordingly, this paper estimates the impact of using smart lighting systems on the amount of energy consumption and carbon emission reduction. Seven days' electricity consumption in the building of the College of Engineering (COE) at the Universiti Tenaga Nasional (UNITEN) was collected from Facility Development & Management known as FDM; these data were then used for the estimation in this paper. Based on the calculated results, up to 85% energy saving, carbon emission reduction, and bill saving can be obtained using LED-based smart lighting system.

KEYWORDS: *Building Energy Management; Carbon Emission Reduction; Minimum Energy Consumption; Smart Lighting; Light Emitting Diode (LED)*

1.0 INTRODUCTION

The rise in energy consumption is associated with a rise in carbon dioxide emissions, which is the primary cause of global warming and climate change. Climate change has become one of the most critical environmental challenges in recent years in all continents and all countries around the world [1]. This is due to increased atmospheric temperature caused by burning fossil fuels and releasing greenhouse gases [2]. Various studies have been conducted toward improving energy efficiency and reducing overall energy consumption through either using energy efficient appliances or applying energy management strategies [3]. Another growing interest to achieve high energy efficiency is by employing renewable energy resources for covering part of nowadays growing energy demand [4]. In comparison to other energy-using sectors, buildings in their different types (including light commercial, commercial, residential, and institutional) are responsible for approximately one-third of the worldwide energy consumption [2]. It has been reported that buildings in the United States, for example, consume about 41% of the total energy consumed and are responsible for 39% of carbon emissions; vast majority of consumption and emissions result from aging buildings, which represent about 70% of United States existing buildings [5]. According to [5], it is possible to significantly reduce the carbon emissions and energy consumption of aging building through implementing various sustainability measures such as renewable energy systems efficient HVAC systems, and energy-efficient lighting. To implement these measures, many countries and educational institutions are working together with researchers and policymakers to develop new methods for achieving zero energy buildings [6]. A zero-energy building is defined as a building that roughly meets its own annual energy consumption requirements from renewable energy created on the. It is an emerging technology, which can contribute positively toward energy utilization, cost-saving, and carbon dioxide emissions reduction, as well as encountering the hazard facing our environment.

Many researchers have worked on building energy management systems (EMS) toward minimizing energy consumption and carbon emission reduction. In [7], a consumer-based EMS was developed for managing energy in the smart building that satisfies the energy needs while ensuring minimum cost and CO_2 emissions. Abdallah et al. [5] developed an optimization model capable of simultaneously reducing energy consumption and carbon emissions through identifying the optimal alternatives of existing building equipment and fixtures and also installing on-site alternative energy systems. Stadler et al. [8] presented a control method for greenhouse gas emissions reduction based on energy management and an optimal DER technology investment. Their aim was reducing the weighted average of the building’s energy consumption, annual energy costs, and CO_2

emissions. Kneifel [9] used an integrated design approach for estimating life cycle carbon emission reduction, cost analysis, and energy savings of energy efficiency measures in new commercial buildings. Lee et al. [10] presented a method to save energy and reduce CO_2 emission in the transportation sector by broadcasting traffic information to vehicles. Based on their study, with such information the drivers will be able to save fuel and reduce carbon emissions through reducing the unnecessary decelerating, accelerating or stop. Another study was conducted by Ahmad et al. [11] to investigate the relationships among energy consumption, carbon emissions, and economic growth of India in the interval 1971–2014. According to the study, energy consumption and carbon emission are related, and combination of energy sources is needed to improve environmental quality without affecting economic growth. In [12], the authors developed a model for the period of 2005 - 2030 to reduce the energy consumption and CO_2 emission using the STELLA platform for Beijing.

Lighting accounts for around 20% of the world's total energy usage [13]. Thus, one of the available solutions for minimizing energy consumption in buildings is by using a smart lighting system. A smart lighting system is essential because the conventional lighting systems operate in only two modes (on and off) and there is no intermediate level that can be calibrated according to the lighting status in the surrounding environment. The two options ON and OFF mean operating lamps continuously at maximum voltage and maximum intensity regardless of environment lighting conditions, which in turn causes significant energy loss. In addition, in the conventional lighting systems, everything needs to be controlled manually. Thus, these conventional systems lead to wastage of electricity, and at the same time a manual control is not effective in the modern era [13]. Contrarily, in a smart lighting system, the lights are calibrated according to space occupation and based on the status of surrounding lighting condition [14-15]. Smart systems operate automatically, making it possible to save time and cost-efficiently. Referring to [16], the target of attaining cost-effective and more comprehensive range application of the proposed system could be achieved through integrating the sensors that offer a better way to incorporate the related information. Accordingly, this paper will investigate the impact of using smart lighting systems on the amount of energy saving, CO_2 emission reduction, electricity bill reduction. In the following sections, the paper presents the methodology followed and the results obtained from this estimation study.

2.0 METHODOLOGY

In order to investigate the possibility of reducing energy consumption through management of lighting system, this paper has used measured data of the consumption of electricity for the building of the College of Engineering (COE) at the Universiti Tenaga Nasional (UNITEN), in the cases of using conventional fluorescent lamps and with the new technology LED lamps. These data were measured by the Facility Development & Management known as FDM of University Tenaga Nasional (UNITEN), and are used for estimation analysis in this paper. These measurements were taken for seven days, an average of eight hours per day. The measurements were then compared to quantify the amount of energy saving. Subsequently, a number of scenarios were assumed for a lighting management system operates the LED lamps during the time of building occupation only. Four cases with different working hours were assumed. In each case, energy-saving, carbon emission, and electricity cost were calculated and compared. Details of the studied cases are as follows:

i. Case 1: 2 hours ON, 6 hours OFF;
ii. Case 2: 4 hours ON, 4 hours OFF;
iii. Case 3: 6 hours ON, 2 hours OFF;
iv. Case 4: 8 hours ON, 0 hours OFF.

These cases were considered assuming that:

i. Working hours at the COE building is usually during the day time (8:30 am to 5:30 pm), and few rooms may be used in the early morning or night. Thus, the maximum working hours of the lighting system was assumed to be 8 hours.
ii. The surrounding light increases gradually from early morning to evening and decreases gradually from evening to late at night. Thus, the smart lighting system was assumed to calibrate the light intensity to decrease gradually while surrounding light increases and increases gradually while surrounding light decreases.
iii. The COE building has a number of rooms that are either used as offices or classrooms, in addition to a number of public spaces such as toilets and corridors. These rooms and places are often lit throughout the working hours even though they have varying occupancy duration. Thus, the smart lighting system was assumed to automatically turn off lights in offices, classrooms, and public spaces when it is not in use, based on information from vision and motion sensors.

iv. Depending on the above assumptions (2 and 3), the minimum operating hours for lighting in a working day can be reduced to only two hours.

The flow chart of the methodology used is shown in Figure 1. The characteristics of the fluorescent and its equivalent LED used are shown in Table 1.

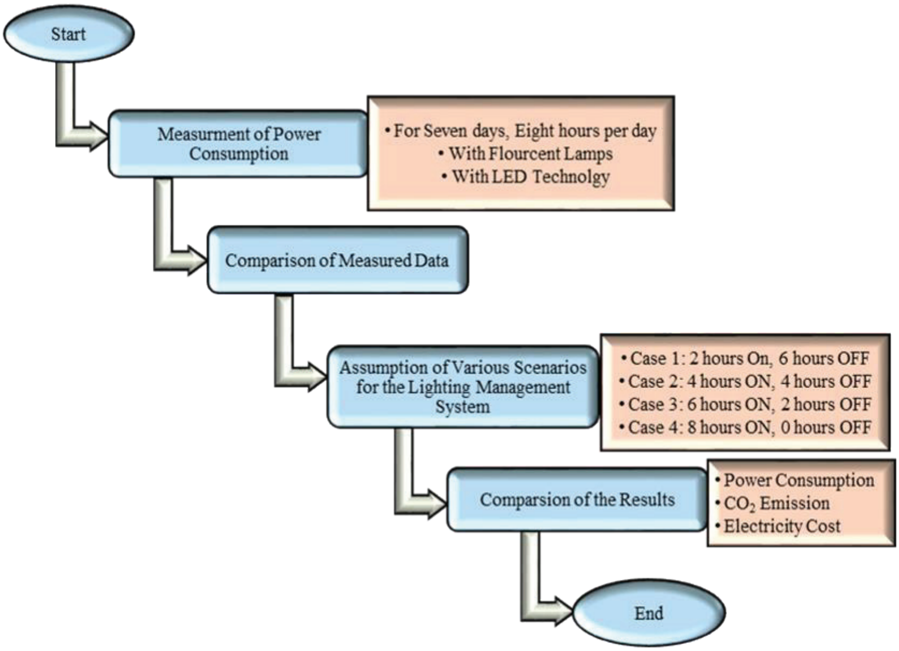

Figure 1: Flow chart of the methodology used

Table 1: Characteristics of fluorescent and equivalent LED tubes

Technology	Ballast Factor	Operational Wattage (W)
Fluorescent Tube	0.88	34
LED Tube	1	16

3.0 RESULTS AND DISCUSSION

The main aim of this paper is estimating the result of using smart lighting systems on the amount of energy saving, CO_2 emission reduction, electricity bill reduction. In this section, measured data are shown and analyzed for the purpose of quantifying this impact. The measured power consumption for seven days is shown in Table 2 and compared in Figure 2. In Table 2, the energy-saving was calculated based on the following equation:

$$\text{Energy Savings (\%)} = \frac{P_{Fluorescent} - P_{LED}}{P_{Fluorescent}} \times 100 \quad (1)$$

where $P_{Fluorescent}$ is the total power consumption of fluorescent lamps and P_{LED} is total power consumption of LED lamps. It is clear from the Table 2 that by replacing the fluorescent lamps with LED lamps, the total energy consumption can be reduced by 40%. This number can be translated into the fact that the amount of energy consumed in fluorescent lamps in one day can be sufficient to operate LED-based illumination system for two and half days. In addition, from this number it is possible to realize the importance of technological upgrades for improving energy efficiency, where continuous service is maintained but with consuming less energy. Replacing fluorescent lights with LEDs not only saves a significant amount of energy but also maximizes the usefulness of the emitted light. It was reported that light from fluorescent lamps scatters in the area around the lamp at angle 360 degree, while the light from LEDs radiates to more useful direction and orients to the meant area under the LEDs at angle 110 degrees [17]. Besides, LEDs are mercury-free and thus have become more environmentally friendly and have gained comparatively higher life expectancy than the other lamps [18].

Table 2: Comparison of energy consumption between fluorescent operation and LED operation

Day	Power Consumption (kWh)		Energy Saving (%)
	Fluorescent	LED	
1	8172.49	4903.50	40
2	9394.03	5636.42	40
3	8521.55	5112.93	40
4	9561.18	5736.71	40
5	7804.68	4682.81	40
6	9476.03	5685.62	40
7	9533.73	5720.24	40
Total (kWh)	62463.68	37478.21	-----
Average (kWh)	8923.38	5354.03	-----

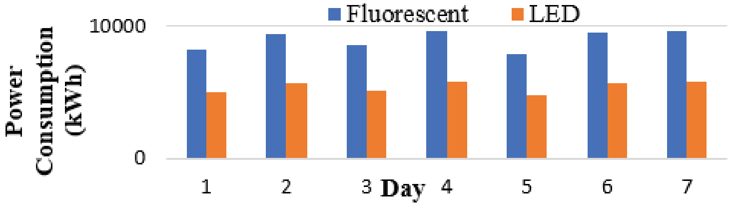

Figure 2: Comparison of energy consumption between fluorescent operation and LED operation in the COE building

For the different assumed scenarios of the smart lighting system, where LEDs turns ON only during the occupation and when there is no surrounding light available, Figure 3 and Figure 4 show the power consumption and energy-saving, respectively. As indicated in figures, by minimizing working hours of the LEDs, higher energy can be saved. The maximum energy saving can be obtained using this method is 85%, when operating time of LED-based lighting system are minimized to only 2 working hours, while the minimum energy saved (40%) obtained when there is no smart lighting system (lights operating time is 8 hours, which is same as total number of working hours).

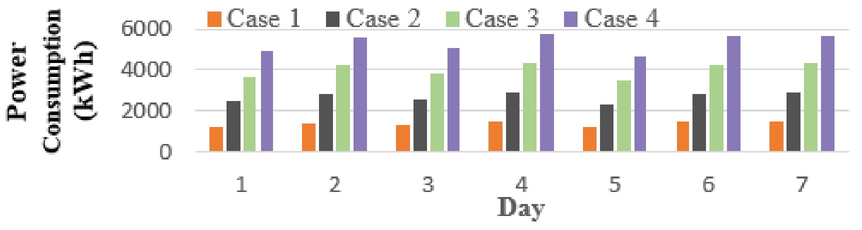

Figure 3: Comparison of power consumption for all conditions using the LED-based Smart lighting system

Similarly, it is worth mentioning that saving energy in the first three cases is achieved through minimizing service time as shown in Figure 4; however, it was assumed that this cut in energy usage does not affect people comfort. This is because switching OFF the LEDs is due to either availability of sufficient natural lighting or there are no people at that time. This energy-saving can also be achieved through many other ways, including changing people habits by adopting simple steps to switch light OFF when there is no need. As a result, the less we use, the less we need to generate and the less the bills.

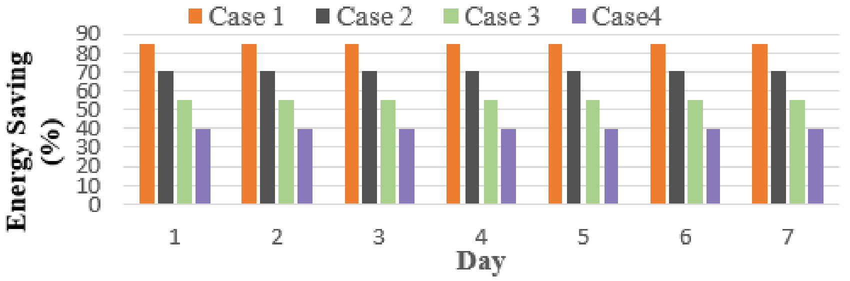

Figure 4: Comparison of energy-saving for all conditions using the LED-based smart lighting system

Similarly, CO_2 emission for all cases is calculated to investigate the effect of replacing fluorescent lamps with LEDs and using smart lighting system. The calculation results are summarized in Figure 5 and Figure 6. The emission is calculated based on Equation (2), and the CO_2 reduction is calculated based on Equation (3).

$$CO_2 \text{ Emission(Kg)} = \text{Energy Consumption(kWh)} \times 100 \quad (2)$$

$$CO_2 \text{ Reduction(\%)} = \frac{CO_{2Fluorescent} - CO_{2LED}}{CO_{2Fluorescent}} \times 100 \quad (3)$$

where $CO_{2\,Fluorescent}$ is the CO_2 emission of fluorescent lamps and $CO_{2\,LED}$ is the CO_2 emission of LED lamps. Similar results to those of energy-saving are achieved for CO_2 emission reduction. It is indicated in the Figure 5 and Figure 6 show the comparison of CO_2 reduction and CO_2 emission under all condition using the LED-based smart lighting system. Similar of energy saving, the obtained results show that the percentage reduction ranges from 40% to 85%, depending on the day and scenario of LEDs operation. Thus, climate change and environmental effect could be reduce using LEDs-based smart lighting system which will achieve the United Nations sustainable development goals as well as decarburization of the electric power grid.

Besides being kinder on the environment, the LED-based smart lighting system is also kinder to saving money and bringing more profits. In order to prove that, the cost of electricity bill for all studied cases was calculated based on Equation (3) and summarized in Table 3. The table demonstrates how an exact minimized cost of energy can be achieved with application of such a system. Considering the fluorescent lighting and Case 1 of the LED-based smart lighting system, as an example, the saved cost is RM 820,772.69 per year.

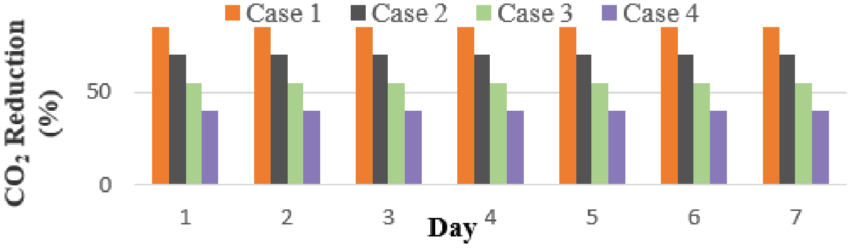

Figure 5: Comparison of CO_2 emission for all condition using the LED-based smart lighting system

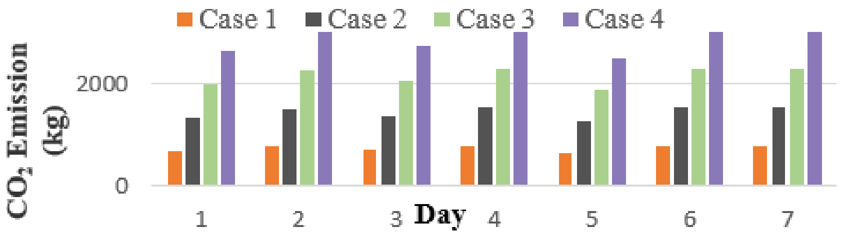

Figure 6: Comparison of CO_2 emission reduction for all condition using the LED-based smart lighting system

Table 3: Comparison of electricity bill cost and reduction for all conditions using the fluorescent and LED-based system

Time	Fluorescent	Cost (RM)				Bill Reduction (%)			
		Case				Case			
		1	2	3	4	1	2	3	4
Daily	3,257	488	977	1,465	1,954	85	70	55	40
Monthly	97,711	14,656	29,313	43,969	58,626	85	70	55	40
Annually	1,172,53	175,879	351,759	527,639	703,519	85	70	55	40

The cost of electricity was calculated using Equation (4). The number (0.365) in the equation is the tariff rate at which UNITEN pays its electricity bill to the utility during the peak period. It is based on the Tenaga Nasional Berhad pricing and tariff. This tariff category is defined as TARIFF C2, and it is used for medium voltage peak/off-peak commercial buildings. In this category, the tariff rates are different at different times of the day (as shown in Table 4).

$$\text{Cost of Electricity(RM)} = \text{Average Power Consumption(kWh)} \times 0.365\text{(RM/kWh)} \quad (4)$$

Table 4: Tariff rates for medium voltage peak/off-peak commercial tariff (Tariff C2)

Tariff Category	Unit	Rates (RM)	
Tariff C2 - Medium Voltage Peak/Off-Peak Commercial Tariff		Top-Up	Standby
For each kilowatt of maximum demand per month during the peak period	RM/kW	45.10	14.00
For all kWh during the peak period	sen/kWh	36.50	
For all kWh during the off-peak period	sen/kWh	22.40	
The minimum monthly charge is RM 600.00			

The daily electricity bill with the different lighting systems is drawn in Figure 7. Figure 7 shows that the money spent on electricity in the case of using the fluorescent lamps system within one day can cover the bill cost for more than six days in the case of using LED-based smart lighting system under the first scenario, more than three days in the second scenario, more than two days in the third scenario, and more than one day and half in the fourth case.

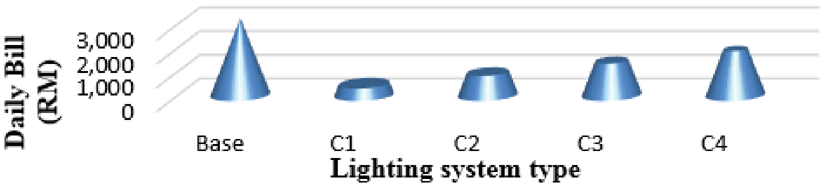

Figure 7: Daily electricity bill with different lighting systems

All these case studies data are obtained using fluorescent and LED-based lighting system in the building of the College of Engineering at the Universiti Tenaga Nasional. The obtained results demonstrated that the energy saving and carbon emission reduction under different case studies are 40% to 85%, respectively. Similar kind of study is conducted in University of Melbourne, Australia using energy efficient lighting technology to evaluate energy saving and carbon emission reduction. It has been seen that the University of Melbourne studies on four lighting system resulted in energy saving of 13.9%, 20.5%, 24.4%, and 64.9%, respectively [19]. Thus, based on the obtained results of the proposed study, the energy saving and carbon emission reduction strategies are suggested for building energy conservation to improve the usage and efficiency of the lighting systems.

4.0 CONCLUSION

Due to the buildings' lighting accounts for approximately 20% of global energy consumption, many researchers nowadays are seeking new methods to reduce this percentage. With the modern methods used, the use of smart lighting has become one of the most effective solutions available. This paper attempted to quantify the impact of using such systems on energy saving, carbon emissions reduction, and electricity bill. The calculated results showed that there was an apparent effect reached up to 85% in all studied variables. If the university management can implement LED-based smart lighting system, the energy consumption and the cost of energy will definitely reduce as seen in the analysis.

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