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Lighting Control System for Energy Management System and Energy Efficiency Analysis

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Lighting Control System for Energy Management System and Energy Efficiency Analysis

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Abstract. Most of the students are not aware of electrical energy consumption and it will lead to the waste of energy. Additionally, energy expenditure for a university on electrical energy consumption is extremely high and its burden the institution to pay the cost. One of the proposals to solve this problem is by implementing an energy management system. The main purpose of this research is to develop an energy management system for the lighting system and to analyze energy efficiency based on energy consumption. In this research, an energy audit and lighting audit has been performed to analyze the performance of the lighting system. Then, energy efficiency measures for the lighting system has been implemented. This implementation involving the replacement of the LED lamp, installation of a motion sensor and the development of smartphone applications. The energy usage has been measured and recorded in the IoT platform for analysis purposes. Based on MS ISO 8995:2005, the lighting system in the campus is in a good performance and followed the standard. By implementing the energy management system, the cost of energy usage can be saved up to 22.82% and the time taken for the payback is 40.589 months.

1. Introduction

Theoretically, the increase in energy consumption is proportional to the growth of the population. The population of Malaysia has been increasing as recorded by the Malaysian Statistical Department with an annual population growth rate of 1.1 percent, where the population in 2018 is 32.4 million compared to 2017 is 32.0 million [1]. In 2016, Malaysia's total final energy consumption recorded a growth of 10.5 percent to settle at 57,218 ktoe, compared to the previous year at 51,806 ktoe [2].

The energy management system (EMS) is introduced as a new type of energy management in order to minimize the usage of energy, hence, reducing the operation cost and carbon emission to the atmosphere. An energy management system is a useful tool for energy saving and efficiency by managing the energy usage of sites or facilities through the advanced software and hardware, internet, and wireless sensor network [3]. Smart energy management is one of the aspects of energy sustainability. Nowadays, many industries and institutions are attempted to make their building sustainable [4].

One of the most important technology aspects that are required in order to develop a smart management system successfully is the Internet of Things (IoT). IoT is the connection between the internet and the machine to make work easier, cheaper, and more effective. IoT is a technology revolution that represents the future of computing and communications. It has the ability to track the countless factors, trace the object, speed up the processes, and reducing the errors. It is also a new effective way of communication to promote a variety of concepts and advertisements [3].

In this study, an energy management system to monitor and control lighting systems for students' campus in Universiti Kuala Lumpur British Malaysian Institute (UniKL BMI) is developed, where the system is applied to the IoT concept. The purpose of the development of the system is because most of the students are not aware of the electrical energy consumption, and it will lead to the waste of energy. Energy expenditure for a university on electrical energy consumption is extremely high and expensive. It was a big concern for the university to reduce electricity bills on energy consumption. The system is the improvement from the traditional energy to counter the problems of energy waste and cost spending [5]. Although this system is developed to reduce energy consumption in the students' campus, the students' comfort and indoor air quality will remain the same as energy efficiency is applied in this study as well. Improving the energy management system in UniKL BMI is one of the techniques to increase students' awareness and involvement in smart energy management by using the engineering tools [4]

Before the system is developed, an analysis of energy efficiency is performed in order to optimize energy consumption. All the details on this method will be further explained in section 3 after the literature review in the next section. Finally, all the results and findings obtained from an energy audit, energy efficiency, and energy management systems will be included in the second last section before this research is concluded at the end of this paper.

2. Literature review

A building needs an effective system to manage and control electricity. The demand for the energy management system making it essential in every building. There are a few types of equipment that use a tremendous amount of power, such as air conditioning, fan, and lighting. This study only focuses on lighting, although the main contributors to energy consumption are chiller and air-conditioning, considering the case study's building is the students' campus, which has no air-conditioning and chiller. Hence, all the works of literature discussed here are related to the energy management system (EMS) involving lighting.

The EMS will facilitate energy saving for a building and also promoting sustainability for the whole building [4]. The EMS is the improvement of old energy management to assist energy saving and efficiency [6]. The EMS consists of computer-aided tools and a group of applications used by operators to monitor, control, and optimize the performance of the electrical network. Generally, various kinds of operations are performed by an EMS such as state monitoring, tie-line bias control, and economic dispatch. The implementation of the EMS is to ensure all the activities that used electricity can be measured.

Previously, there are some studies conducted on EMS by using IoT. One of the researches was done by Wen-Jye Shyr, Chia-Ming Lin, and Hung-Yun Feng on the development of an energy management system based on the IoT technique. This study showed the energy usage using the IoT for lighting. The purpose of the system is to turn on and off in accordance with the timetable and the occupancy area. The timetable was set by the university. The system will turn off the light with two conditions, firstly the light will turn off based on the timetable, but if the sensor detects the motion in the area, the light will remain turn on. [7].

Another research about the EMS using the IoT was done by Li-Wen Zeng, Chen-Kun Lin, Wen-Jyer Shyr, Chia-Ming Lin, and Wen-Ying Hsieh. The main objective of this study is to monitor and control the operation of the lighting system. The authors implemented the sensor-based system with the combination of Web Access to control the process of turning on and off the lighting for the purposes of optimizing energy usage. Then, the web page was developed in order to show the status of every wireless gateway of the electrical equipment. The website was controlled by three users: administrator, instructor, and security. Also, the start time, end time, and date may be adjusted by the administrators through the web page [3].

The lighting system is a primary visible source of energy consumption in any buildings or industries. In order to minimize the energy usage, energy-efficient for the lighting system is required by a building [8]. Lighting audit is a process of initial survey or investigating the existing lighting system, the illumination levels for different areas, and their functionalities [8]. Also, the lighting audit carried out to determine the dimensions of the areas, the power usage by the lamps, and the number of lights used in the area [9]. Thus, the lighting audit may be used to propose a new energy-saving method for more effective lighting system and improve the energy saving for the building [10]. Many studies have shown that proper lighting controls can significantly reduce annual energy consumption. However, this depends on many factors, such as the climatic conditions of the country and its surroundings, such as the shade from the trees or reflections from neighboring buildings [11].

Previously, there was a study on lighting system audit and energy efficiency analysis, which was made by Basil Paul, Vedavyasa Kamath, and Mobi Mathew from Manipal University. This study was analyzing and surveying process for the lighting system in the pharmaceutical industry in Chennai, India. The lighting system for the pharmaceutical industry was simulated using Dialux software. Also, this study followed the standard IS 3446 to defining the required illumination level for the pharmaceutical industry. Thus, the study proposed the replacement of luminaires to LED fixtures for more energy saving in the pharmaceutical industry [8].

Another research on energy efficiency analysis was made by David Moreno, Carmen Munoz, Paula Esquivias, Ignicio Acosta, and Jaime Navarro, which took place in Spain. This study illustrated the comparison of energy efficiency for different lighting system control implemented in the office space. This study also analyzed the potential energy saving using a fluorescent lamp and various types of lighting control. The results showed that energy saving could be achieved by up to 27% by using the suspended lighting source and decreasing the range between the work plane and the lighting source [12].

There are many other studies in the EMS and energy efficiency analysis that was done by the previous studies that had not been cited since this paper only focuses on developing an energy management system for lighting control and energy efficiency analysis.

3. Research methodology

In this research, lighting control for the energy management system in one of the UniKL BMI buildings has been developed. Apart from that, this research also performed an analysis of energy efficiency in order to optimize energy consumption. The development of the lighting control for energy management systems and energy efficiency analysis is divided into 3 stages. The first stage is the audit stages, which involving energy audit and lux audit. An audit on the energy usage in the UniKL BMI has been conducted. Since it is impossible to develop an energy management system for the whole building, student lounge counter and study room level 1 are chosen as a pilot study. Figure 1 and Figure 2 illustrated the floor-ceiling plan for student lounge counter and study room level 1, respectively.

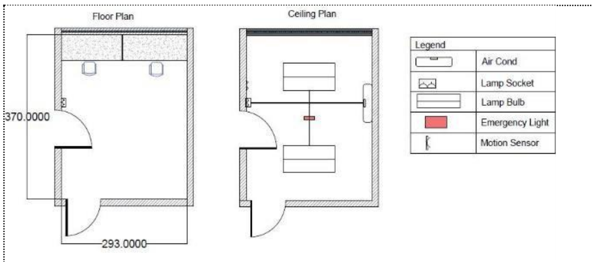

Figure 1. Floor plan student lounge counter

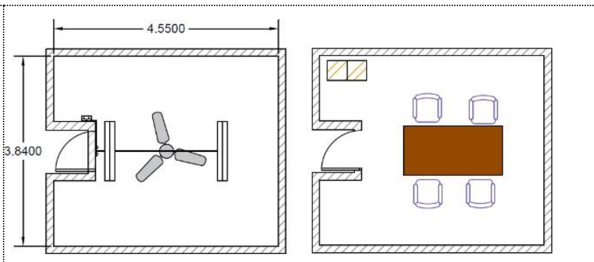

Figure 2. Floor plan study room level 1

3.1 Energy and lighting audit

The energy audit covered the current energy usage in the student lounge counter and study room level 1, the number of electrical appliances used in the building, and the area of the building. Another audit involved in this stage is the lux audit. The lux audit has identified the type and number of the luminaire used in the building. The lux calculation also involved in the lux audit. The lux calculation has to go through three phases, which are, firstly is to identify the standard lux for the specified building based on the MS ISO 8995:2005. Then, it undergoes the lux calculation to determine the number of luminaires required in the building. Secondly, the lux meter is used to measure the amount of luminous flux per unit area and the intensity if the light that hits or passes through the surface. To ensure all the calculations and the lux measurement are correct, the equations below are used for the calculation, while the simulation for the lux is run by using the Relux software.

$$Room\ Index, K = \frac{ab}{hk(a+b)} \tag{1}$$

$$Useful\ height, hk = h - hd - hv \tag{2}$$

$$Total\ number\ of\ luminaires\ (N) required, N = \frac{E \times A}{Lumen \times UF \times MF} \tag{3}$$

3.2 Implementation of the energy management system
The implementation of the energy management system is divided into three-part, where, in the first part, the type of lamp used in the study room level 1 has been changed from a fluorescent lamp to an LED lamp. Table 1 illustrates the comparison between the fluorescent lamp and LED lamp. It shows that the LED lamp is more energy saving compared to the fluorescent lamp, and it is proved by measuring the power consumption by the lamp. The second part is the development of a smartphone application to control the lighting system. The smartphone application also illustrated the current energy usage in the room and the status of the lamp.

Table 1. The comparison between the fluorescent lamp and LED lamp

Technology	**Osram 38-Watt T8 Fluorescent Tube**	**FSL 18-Watt T8 LED Glass Tube**
Operational Wattage	38 Watts	18 Watts
Average lumens (amount of light produced by the tube)	3300	1800
Light Efficiency	87 (3300 lumens/38 watt)	100 (1800 lumens/ 18 watt)
Colour Rendering Index (Ra)	≥80	≥70
Colour appearance	4000K	6500K

Besides using the smartphone application, the motion sensor has been applied in order to control the lighting system based on the movement in the area. When the motion sensor detected the movement of a human in the area, then the sensor will trigger the switch to turn on and off the light, depending on the existence. The last part is the measurement of energy usage in the room by using the energy sensor. This energy sensor measured the voltage, current, power, and energy for the usage in the respective room.

3.3 Data collection for monitoring
After all the data collected through the sensors, it has to be analyzed. The energy usage for the chosen room has been measured by using the energy sensor and has been recorded in the IoT platform. Figure 3 illustrates the block diagram for the data monitoring and controlling system. The microcontroller is the main component for this system to receive and transmit the data for the collection.

For control, a Raspberry Pi Zero is used as a microcontroller and 2 channel relays are used to control the turn on and off the light. The Raspberry Pi Zero connected to Blynk app through an internet connection to receive and transmit the command. The relay is used to connect with the 240V as the microcontroller only can receive 5~12 V.

For monitoring circuits, a NodeMcu as microcontroller and PZEM-004t as energy sensors are used to read the value of voltage, current, power, and energy. NodeMcu worked as the microcontroller to receive and translate the data from the energy sensor and transmit the data to the cloud. The NodeMcu required the internet connection to send the data to the cloud. The IoT platform recorded the real-time data in the cloud, and the user may download the data online.

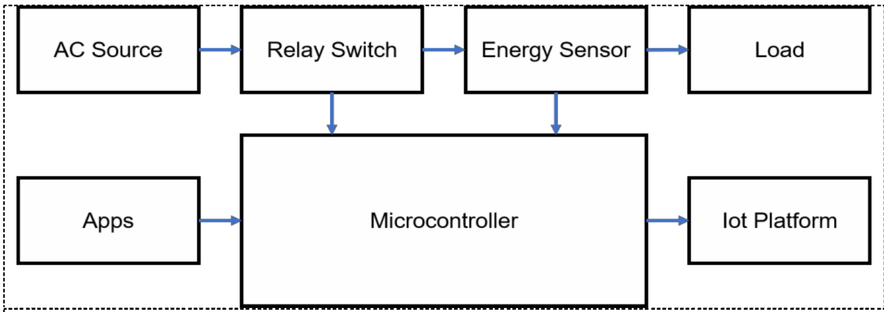

Figure 3. The block diagram for data monitoring and controlling system

3.4 Cost saving and return of investment

By using the data obtained, the calculation for energy efficiency, cost-saving analysis, and the return of investment (ROI) has been performed. Hence, a conclusion can be drawn either the energy management system can optimize energy usage or not. The equation below is used to calculate the ROI for this project:

$$\mathbf{ROI} = \frac{\mathbf{Annual\ retro\ fit\ saving - project\ cost}}{\mathbf{project\ cost}}$$

4. Results and discussion

This section compromise results analysis of lighting system control for the energy management system and energy efficiency analysis. A lighting simulation has been performed using Relux Software for study room level 1 and student lounge counter. Figure 4 and 5 illustrate the simulation and concentration of light distribution in the study room level 1, while Figure 6 and 7 illustrate the simulation and concentration of light distribution in the student lounge counter. Based on these two simulations, it showed that the light concentrated in the middle of the room as the luminaire placed in the middle of the room. Also, the light is distributed around the room.

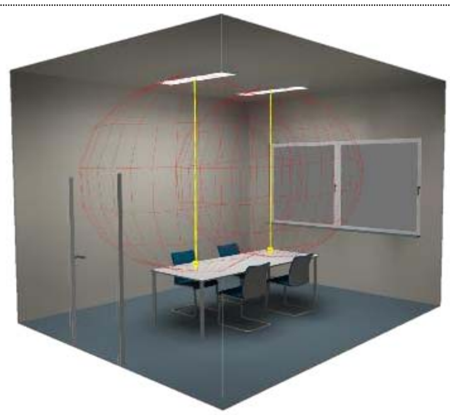

Figure 4. The simulation of the light system in the student lounge counter

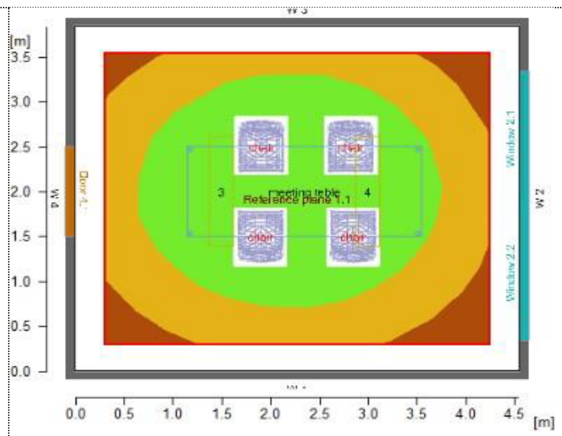

Figure 5. The concentration of light distribution in the student lounge counter

Figure 6. The simulation of the light system in the study room level 1

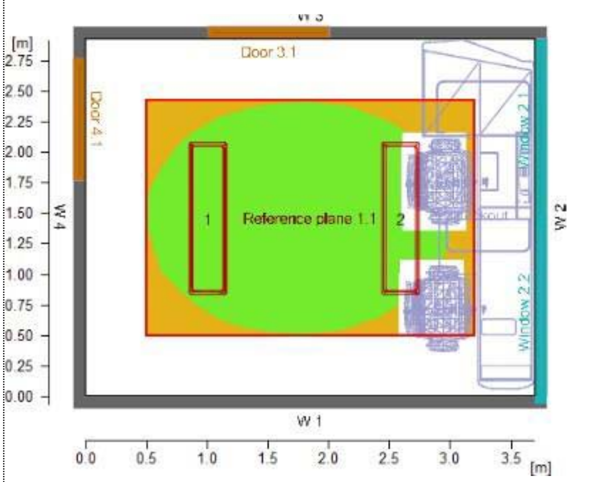

Figure 7. The concentration of light distribution in the study room level 1

Table 2 shows a comparison between simulation and lux meter for student lounge counter and study room level 1. It shows that both the simulation and lux measurement for the student lounge counter has followed the standard stated by MS ISO 8995:2005.

Table 2. Comparison between simulation and lux meter for the student lounge counter and study room

Student Lounge Counter		
Item	Simulation	Lux
Minimum Lux	395 lx	304 lx
Maximum Lux	614 lx	626 lx
Average Lux	562 lx	459 lx
Study Room Level 1		
Minimum Lux	124 lx	167 lx
Maximum Lux	255 lx	220 lx
Average Lux	184 lx	183.3 lx

An energy management system has been implemented in two locations, which are student lounge counter and study room level 1. The implementation of the energy management system involved the installation of the motion sensor, the changing of LED lamps from the fluorescent lamp, and the development of smartphone applications.

Table 3 shows the results of data for LED lamp replacement and motion sensor implementation. LED lamp consumed only ±74 W for power. For the installation of the motion sensor, the motion has consumed 0.6W if the main switch is not off. The energy consumed is to maintain the connection between the main switch and the load and also to ensure the sensor always working to detect the movement in the area.

Table 3. The results of data for LED replacement and motion sensor implementation

Voltage (V)	Current (A)	Power (W)	Energy (E)
239.8	0.525	74.2	0.202
239.7	0.525	74.1	0.203
nan	nan	nan	nan
nan	nan	nan	nan
239.6	0.025	0.6	0.229
239.7	0.026	0.6	0.229

A smartphone application has been developed to switch on and of the lighting system. Figure 8 illustrates the smartphone application interface for controlling and data monitoring. This smartphone application worked as an alternative way to switch off and on the lighting system through online. Another feature in this smartphone application is data monitoring. The user may monitor the current usage in the room and also the value of voltage, current, and power consumed.

Figure 8. The smartphone application interface

After the implementation of the energy management system, a data monitoring has been developed. The purpose of this data monitoring is to monitor the energy usage for the system. For the data monitoring, an energy sensor was implemented together with the microcontroller as the IoT meter to read and send the data to the cloud. The energy sensor measured the current, voltage, power, and energy of the lighting system. The system measured the data for every 1 minute. The data obtained from the energy sensor was sent to the cloud as the data storage.

For the data monitoring system, the energy sensor used is PZEM-004t v3.0, and the microcontroller used is NodeMcu. The microcontroller is functioned to operate the PZEM-004t and to send data to the cloud. The microcontroller gave the command to the PZEM-004t to read the value of current in Ampere, voltage in Voltage, power in Watt, and energy in kWh.

After the implementation of the energy sensor as the IoT meter, a platform has been set up to store the data online. Thing Speak was set up as the IoT platform and storage medium. The data has been collected for a week in two locations, which are student lounge counter and study room level 1. Figure 9 illustrates the ThingSpeak dashboard for data monitoring. The graph shows on the dashboard are based on current usage. The data obtained has been downloaded in the form of CSV (comma-separated values).

Figure 9. The ThingSpeak dashboard for monitoring

A cost analysis for lamp replacement and the implementation of the energy management system in UniKL BMI has been performed. In this section, the cost analysis for lamp replacement focused on study room level 1, and the cost analysis for the implementation of the energy management system has focused on the student lounge counter. This cost analysis covered the energy usage for both locations based on the data collection. Then, the analysis has compared with the energy audit performed in the first stage of the research.

By replacing the LED lamp, the cost of energy usage can be saved up to 50% per year, and the time is taken for the payback is 3.27 months. By implementing the energy management system, the cost of energy usage can be saved up to 22.82%, and the time is taken for the payback is 40.589 months. Thus, the implementation of the energy management system can reduce the energy usage for the lighting system in the educational building.

5. Conclusion

In this research, an energy management system in UniKL BMI has been developed to optimize energy usage. Student lounge counter and study room level 1 have been chosen as a pilot study. An energy audit and lux audit have been performed to investigate the current performance of the lighting system and other electrical equipment in the selected rooms. Also, the energy audit and lux audit are important components to study the behavior of the building and environmental impact.

For this research, an energy management system involving monitoring and the controlling system has been developed for lighting control. In order to improve energy efficiency, LED replacement and motion sensor installation in the chosen locations have been proposed. The LED lamp is more energy-efficient compared to the fluorescent lamp. It is also low maintenance and lasts longer. The motion sensor is functioned to control on and off the lighting system if the sensor detected no movement in the area.

For the controlling system, a smartphone application has been developed. The smartphone application is functioned to turn on and off the lighting system through online. Also, through the smartphone, the user may observe the current energy usage in the room and the value of voltage, current, power, and the total cost of the usage for the month. For monitoring system, the data of energy usage that has been collected in the chosen locations were stored in the IoT platform. The administrator may view the data online. The data were collected every 1 minute, and the data collected based on the current usage of the room.

Based on the implementation of the energy management system in the educational building, there are few recommendations that can be applied and carried out for improvement. Firstly, the prediction of energy consumption using the statistical method or machine learning algorithm can be applied in order to improve the energy efficiency of the smart building. Second is design a warning system for the user through the notification to avoid excessive usage of energy, and lastly, this project can be implemented in any building to upgrade as the smart building also it can be applied in high voltage usage.

Acknowledgments
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