Research Article

An Enhancement of Lighting System Energy Efficiency Using an Automatic Light Dimming Control

Athisamai Sophan* and Chaiyapon Thongchaisuratkrul
Department of Teacher Training in Electrical Engineering, Faculty of Technical Education, King Monkut's University of Technology North Bangkok, Bangkok, Thailand

* Corresponding author. E-mail: athisamai.so@ssru.ac.th DOI: 10.14416/j.ijast.2018.04.001
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Abstract
Concerning about country's energy situation which depends on the import mainly and Global Warming the world's problem is also concern as well. So, this paper mentions a way to decrease the effect of those problems enhancing the energy efficiency in lighting system with an innovation using simple technology. After doing the energy conservation potential analysis of the original system, an automatic light dimming control using PI controller is the one in set of innovations will be developed. This control was designed using operational amplifier circuit and set PI gain using Ziegler-Nichols open-loop technique. This control has been installed and is being used in a classroom. With this control, the energy can be saved 6.36 kWh per month and the energy efficiency has been enhanced with the energy efficiency indicator 2.45 W/100 lx/m^2 decreased from 2.61 the former level.

Keywords: Lighting system, Energy efficiency, Energy saving, Daylight, PI controller

1 Introduction

1.1 *Research Background*

The important reason which this research was established is concern about Global Warming, the world's problem caused by greenhouse gases. 72% of the totally emitted greenhouse gases is Carbon dioxide (CO_2) [1]. In year 2011, Thailand released CO_2 by 230 million tonnes [2], [3]. It shows that Thailand is a cause of Global Warming and being effected at the same time. To deal this problem, using renewable energy and enhance the energy efficiency will lead the country to be the low carbon society [4].

How can people help their own world and country to deal with the problem? For the status of a teacher, performing the projects on issue enhancing the energy efficiency in lighting system is a solution. These reasons mentioned are the background of this research.

1.2 *Introduction to the energy conservation in lighting system*

1.2.1. The meaning of energy efficiency in lighting system

Generally, energy efficiency has the same meaning as energy conservation but, in technical term, when we need the indicator of energy efficiency, we find the number to be the representative that called "energy efficiency indicator". The indicator is calculated from total lamp wattage (watt, W), illuminance of light (lx) and working area (m^2) with the unit of W/m^2/100 lx [5]. If lighting system consumes less power, it will make less indicator which means that it has more energy efficiency. So, it can be said that, saving the energy makes more energy efficiency.

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1.2.2. Energy conservation in lighting system principle

The energy in lighting system can be varied controlling many variables which according to the formula as follow:

Power consumed and time of use can be expressed as [Equation (1)],

$$E_T = P_T \cdot t \tag{1}$$

In lighting system, the used power is [Equation (2)],

$$P_T = \frac{E \cdot A}{LPW \cdot CU \cdot MF} \tag{2}$$

Therefore, we will get the energy used in lighting system as,

$$E_T = \frac{E \cdot A \cdot t}{LPW \cdot CU \cdot MF} \tag{3}$$

Where, E_T is energy used, E is illuminance, A is working area, t is time of use, LPW is luminous efficacy of lamp or lumen per watt, CU is coefficient of utilization of luminaires, MF is maintenance factor. Equation (3) shows E_T direct variation to level of E, A and t, but reverse variation to LPW, CU and MF. Therefore, if we decrease E, A and t, the energy used can be saved but, on the contrary, if LPW, CU and MF are increased, the energy used will be saved also.

This research will mention the integrating process of electrical technologies, efficient equipment and some measures to make the apparatus which were approached to enhance the energy efficiency in lighting system for a classroom at a building in Suan Sunandha Rajabhat University, Thailand. This apparatus were assigned to some students under the supervision of their teacher (author). Therefore, this research would show that the apparatus were developed using simple technologies which can be created by a small group of students. The research is also hope that these projects will be inspired for any sector who has the energy saving potential and ability in control technology.

2 Method

The process began from proving the energy conservation potentiality after that, design and development the innovations on the problem solving ways have chosen then, test the system for data collection and finally, leaving all stuffs made on the real system.

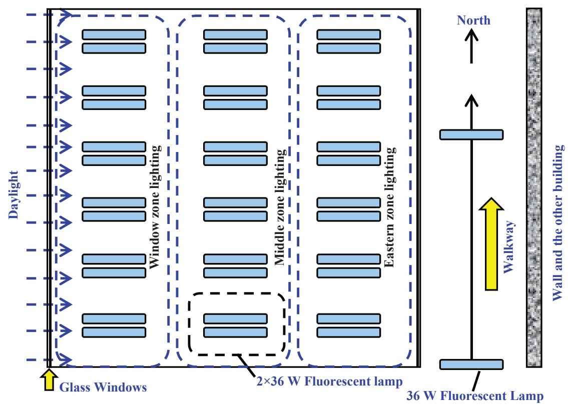


Figure 1: The diagram of original lighting system and room structure.

2.1 *The energy conservation potential of former system*

The original lighting system that will be developed was 2 parts as shown in Figure 1, classroom and walkway outside. The room was illuminated by 36 of 36 W fluorescent lamps with about 300 lx of illuminance. Walkway has 5 of 36 W fluorescent lamps with about 100 lx of illuminance. This part is used only at nighttime for building security lighting.

The system was analyzed and given some data for making decision to choose the development ways for the energy conservation or enhancing the energy efficiency. All choices in list are the energy conservation potentials as shown in Table 1.

2.2 *The development plan*

After the analysis, the case using LED lamps instead of fluorescent lamps was an unchosen choice. Because at that time and even now, they were too expensive about 5 times of conventional fluorescent. Even now LED type has the excited luminous efficacy up to 120 lm/W but it is now has only 2,200–2,400 lm per lamp which not enough to replace the 2,600–3,200 lm of conventional type to provide the same illuminace level. So, LED choice is appropriate for a new design system that the number of lamp should be sufficient for an activity being designed. Then the plan were made with 3 sub projects as shown in Figure 2.

Table 1: The energy conservation potential analysis

The Original System, Building Status and some Problems	Alternatives to be Developed	Energy Saving Estimation
Classroom Lighting		
18 luminaires of 2×36 W fluorescent lamp	Use high efficiency luminaire which can use 1×36 W luminaire instead of 1×36 W under the same 18 luminaires	50% of 18–2×36 W
	Use 2×22 W LED lamps instead of 2×36 W fluorescent lamps under the same 18 luminaires	39% of 18–2×36 W
Sunlight shines through the western windows onto interior	Let daylight shines through the room and dim the light inside	5–10% 6×36 W
Students sometimes use the room over time before and after their classes	Set measures or control about time of use	10–15% of 18×36 W
Building		
Security lighting with 5 of 1×36 W fluorescent lamp	Produced an electric power from solar energy using photovoltaic and used for security lighting	100% of 5×36 W
Terrace touched by sunlight from 8.30 am to 5 pm		

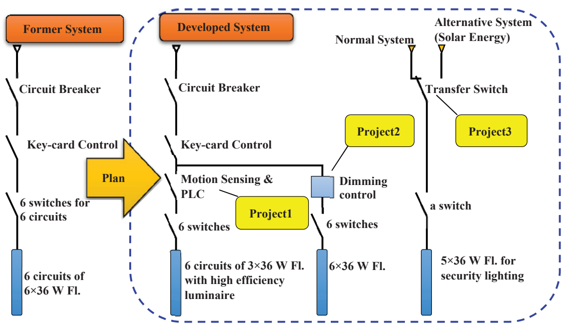


Figure 2: The development plan for enhancing the energy efficiency.

Figure 2 shows the former and the developed system which is the system that must be created aiming to save the energy. The developed system is not all new construction but adapted from the former system by 3 projects are as follows:

1. Lighting with efficient luminaires and to be a smarter lighting using Programmable Logic Controller (PLC)

2. Automatic dimming control using Proportional Integral (PI) controller

3. Security lighting with solar energy

Project 1 and 2 have been developed for a classroom while another one has been created for walkway outside at a building in Suan Sunandha Rajabhat University, Thailand. This paper will mention the process of one project from set of projects in the development plan. An automatic light dimming control using PI controller will be mentioned with the following details:

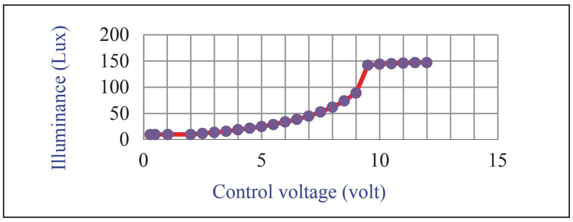
2.3 *Automatic light dimming control*

This control follows to the principle that using daylight through transparent parts of building such as windows or roofs compensation lighting from electric lamps. This technic is a simple way to save the energy from normal lighting [6], [7]. When the sunlight shines through the windows and makes the room brighter, to maintain the sufficient level of the illuminance, the light from the electric lamps can be dimmed by the control. With this dimming technique, the energy consumed by the lamps can be conserved. Base on the principle that too high level of the illuminace takes more energy but too low level makes inconvenient and unsafe work so, the sufficient level of light will be the goal of controller design.

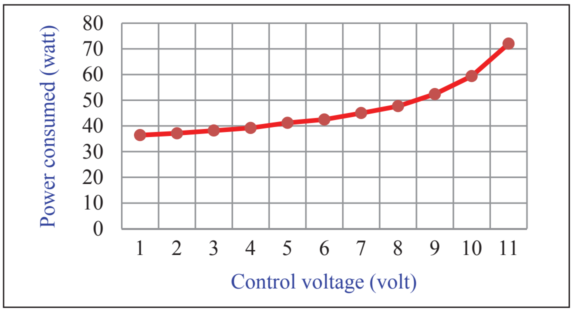
2.3.1 Energy saving potential proving

The test has placed a measuring of light in a classroom to prove that the room has more illuminance over the normal level for learning activity which can be dimmed in order to save the energy.

One day at twelve, in June, a monsoon month, the light was measured at 9 positions all over the room. The test found that the illuminance trend at window zone was higher than other zones for 32 lx as shown in Table 2. It means that the window zone light can be dimmed to be equal to the other zones level at 274 lx.



(a)



(b)

Figure 3: Trend of the power consumed and illuminance depend on control voltage.

This level was approximately 300 lx illuminance for classrooms according to EN 12464-1 standard [8].

Table 2: Illuminance level at each lighting zone

Illuminance (lx)		
Left (east)	**Middle**	**Window Zone (west)**
274	275	309
273	275	305
272	274	304
Average 273.8		Average 306
Difference 306–273.8 = 32.2		

For this control, some dimming ballasts (dimmers) for fluorescent lamps were needed. The illuminance can be controlled by DC voltage which input to dimmers. While power consumed for all lamps and ballasts is up to this voltage as well. The graphs as shown in Figure 3 are the result of the test as mentioned.

2.3.2 System development

This control using Feedback Control with Proportional (P) and Integral (I) Controller using the Operational amplifier (Op-amp) circuit. The control voltage or Control Variable (CV) is output of controller to drive dimmers and lamps. Feed-back part senses the light

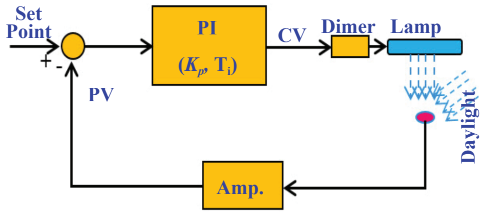


Figure 4: System of automatic dimming control.

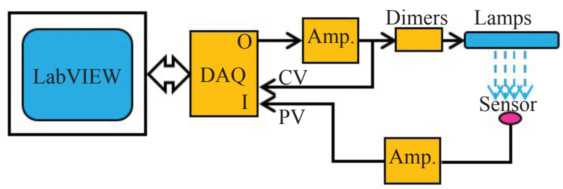


Figure 5: The experiment for controller gain tuning.

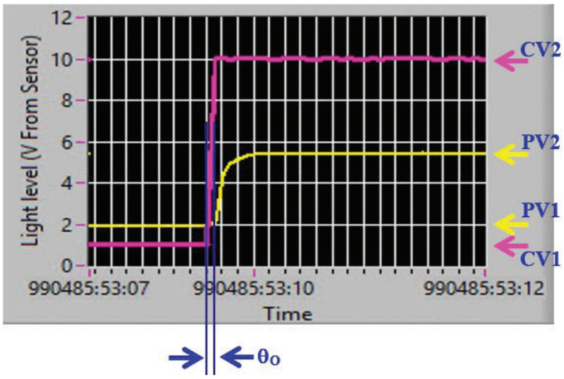
nearby a window and converses to voltage or Process Variable (PV) sent back to summing part. Sensor is a circuit which consists of main equipment Light Dependent Resistor (LDR) and an amplifier as shown in Figure 4.

Controller features were designed using Ziegler-Nichols open-loop simple tuning technique [9], [10] to find the proportional gain (K_p) and integral time (T_i). This technique just uses some data from an experiment which representative of the plant behavior.

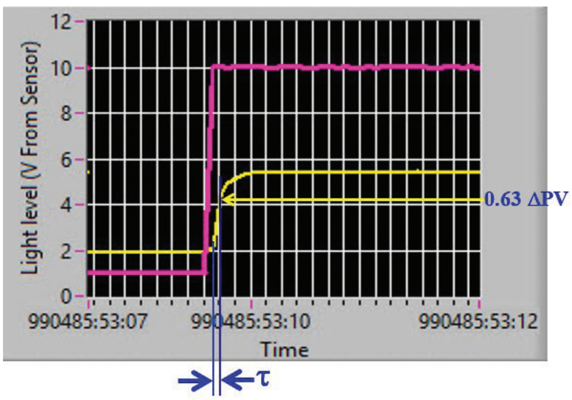
The experiment was placed to drive a lamp through a dimmer with Control Variable (CV) and sense the light to be a Process Variable (PV) back to the computer through a Data Acquisition card (DAQ). Both CV and PV were plotted on LabVIEW a kind of data and signal processing program. This experiment is shown in Figure 5.

On the experiment, CV_1 and CV_2 were set by 1 V and 10 V respectively then, PV_1 and PV_2 would respond and were plotted on the same scale of CV_1 and CV_2. The graphs plotted as shown in Figure 6.

Figure 6 (a) and (b) are from the same graph. Graph (a) shows the level of control variable (CV_1, CV_2), process variable (PV_1, PV_2) and phase displacement of them. Phase displacement between PV and CV at the origin of them will show the process dead time (θ_0). As graph (b) shows the level changing of the process variable. The difference between the time at 63% of maximum value and the time at the origin is the process time constant (τ) of process variable response. Both graphs would be analyzed for the controller features.



(a)



(b)

Figure 6: Control and process variable curves from the experiment of controller gain tuning using Ziegler-Nichols open-loop technique.

K_p and T_i can be calculated by equations as follows:

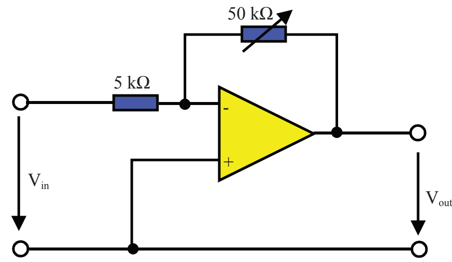
$$K_p = \frac{0.9}{K \cdot \alpha} \tag{4}$$

$$K = \frac{PV_2 - PV_1}{CV_2 - CV_1} \tag{5}$$

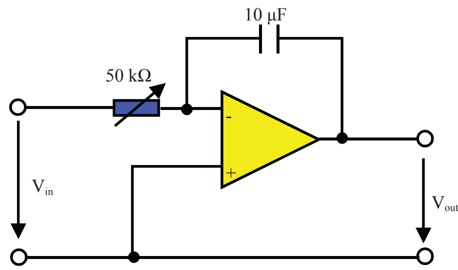
$$\alpha = \frac{\theta_o}{\tau} \tag{6}$$

$$T_i = \frac{1}{K_i} \tag{7}$$

$$K_i = \frac{1}{3.33 \cdot \theta_o} \tag{8}$$



(a) P controller circuit



(b) I controller circuit

Figure 7: P and I controller circuits using operational amplifier and passive devices.

Where, K is process gain, K_i is integral gain, α is process controllability, θ_0 is process dead time and τ is process time constant.

According to Figure 6, it shows that 30 scales in x-axis take 5 s so, each scale takes 2 s. Finally, we get $\theta_0 = 0.11$ s, $\tau = 0.1$ s and $\alpha = 1.1$ by Equation (6).

According to Figure 6 (b), it shows $CV_1 = 1$ V, $CV_2 = 10$ V, $PV_1 = 2$ V and $PV_2 = 5.5$ V therefore, with Equation (5), $K = 0.388$, with Equation (4), $K_p = 2.1$, with Equation (8), $K_i = 2.73$ and with Equation (7), $T_i = 0.36$ s.

Then, PI controller were built using operational amplifier and passive devices resistors and capacitors as shown in Figure 7.

It is a simple circuit but effective for this plant, K_p can be adjusted from zero to 10 (50 kΩ/5 kΩ) that extensively the gain from tuning technique 2.1, while T_i was set and can be adjusted from zero to 0.5 s (50 kΩ × 10 µF) which is sufficient for the time from tuning technique 0.36 s.

3 Results

The results of this research were expressed with data collected from 2 experiments are as follows:

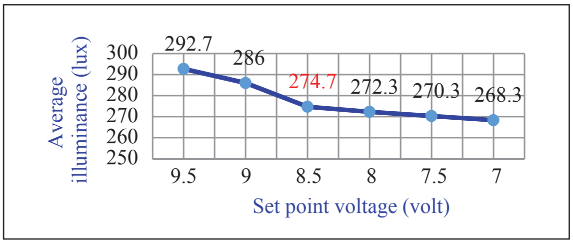


Figure 8: Window zone illuminance corresponds to level of set points.

3.1 *Experiment a: Find the proper set point voltage*

The set point voltage was adjusted from low to high level to find the 274 lx illuminance for window zone lighting which equal to 273.8 lx of the other zones (see Table 2) which were not dimmed. The result of this step is shown in Figure 8.

From the Experiment, at 274.7 lx, the controller set point voltage was about 8.5 V. So, the test found that the proper set point voltage level was around 8.5 V. This illuminance level makes sure that window zone lighting has the same illuminance level as the other zones which means that the room has enough light for learning activities as usual.

This research has a limitation which is the set point was got from a season. When the season changes, it has to be slightly adjusted up or down from this point. It has been developed using simple techniques which aims to be easily imitate or rebuild base on the concept that the energy conservation should be performed by simple ways. So, using simple technology is a strong point of this research that it can be developed by just a small group of students who were taking the course senior project.

3.2 *Experiment b: Power saving effected by daylight*

The experiment was made on the real system. It placed the set point voltage at 8.5 V for dimmers to make the desired illuminance with 6 lamps for window zone lighting while 12 lamps in other zones were driven by conventional electronic ballasts. To know the effect of daylight, it was measured using a lux meter at a glass window nearby controller sensor location. The illuminance level will be regulated via PI controller on changing of daylight strength. The data was collected on the next day after the first collection for Table 2 which has nearly the same weather. The experiment began from 10.50 am to 2.50 pm to take enough times for the data in table daylight effect. The experiment can find the power saved by comparing the power used as being dimmed to the former value which not dimmed yet. The data collected is shown in Table 3 and in Figure 9 graphically. Even though the trend of daylight effect would increase according to the time passing, but sometimes its strength was also up to the sky conditions cloudy or clear, such as the effect at 12.20 pm, daylight effect dipped from 755 lx at 11.50 am to 585 lx because it was cloudy at that time.

Table 3: The power saved influenced by daylight outside

Time	Daylight Effect (lx)	Window Zone Illuminance (lx)				Total Power Used (W)			Saving (%)	
		Front	Middle	Back	Average	Undimmed	Dimmed	Saved	A row	Total
10.50 am	603	273	274	274	273.67	669.6	619.06	50.54	21.39	7.55
11.20 am	667	274	275	274	274.33	669.6	600.56	69.04	29.219	10.31
11.50 am	755	275	276	276	275.67	669.6	596.56	73.04	30.91	10.91
12.20 pm	585	273	274	273	273.33	669.6	640.06	29.54	12.50	4.41
12.50 pm	750	275	276	274	275	669.6	589.56	80.04	33.87	11.95
1.20 pm	615	274	274	273	273.67	669.6	616.06	53.54	22.65	7.99
1.50 pm	672	274	274	274	274	669.6	600.06	69.54	29.43	10.39
2.20 pm	725	275	276	274	275	669.6	599.06	70.54	29.85	10.53
2.50 pm	789	275	276	275	275.33	669.6	581.06	88.54	37.46	13.22
Average					274.44	669.6	604.67	64.93	27.47	9.69

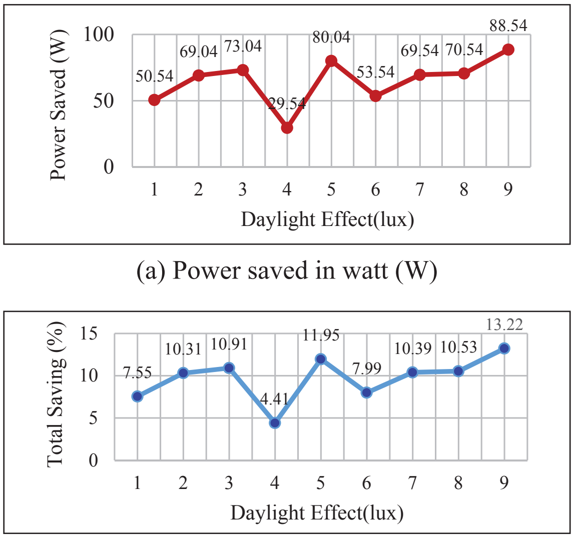


Figure 9: Power saved influenced by daylight through glass windows.

From Table 3, the illuminace was rather constant even it has more changing of daylight effect. The data also shows the higher strength of daylight the more power will be saved. e.g. at 2.50 pm, when daylight effect was 789 lx, it made power saved maximum at 88.54 W which is more than 2 times higher than 36 W lamp. Saving rate for specific window zone and the whole room are 37.46% and 13.22% respectively. While the average total saving is 64.93 W to be representative of this control saving ability.

Based on use rate of 7 hour a day, 14 days a month and 8 month a year for this academy and 64.93 W power saved. This project saves electrical energy about 6.36 kWh per month and 50.9 kWh per year. However, this saving rate can be varied via other controller set points and sunlight effect depends on the weather in each day and season.

In case of the energy efficiency which is a result of the energy saving measures. The energy efficiency can be expressed by energy efficiency indicator calculated by Equation (9) below [5],

$$EEI = \frac{100 P_T}{E \cdot A} \quad (9)$$

Where, EEI is energy efficiency indicator, P_T is power consumed, E is average illuminance and A is area of working place. So, EEI calculation has to use illuminace level of lighting which both dimming and undimming cases are summarized in Table 4.

Table 4: Average illumination in case of dimmed and undimmed light

Lighting Zone	Illuminance (lx)	
	Undimmed	Dimmed
Other Zones	273, 274.7	273, 274.7
Window Zone	306	274.44
Average	284.56	274.05

A classroom which has been implemented for this project has $A = 9 \times 10$ m^2 and according to Equation (9), data in Table 3 and 4, we have got the results as follows:

Undimmed case, E = 284.56 lx, PT = 669.6 W therefore, EEI = 2.61 W/m^2/100 lx,

Dimmed case, E = 274.05 lx, PT = 604.67 W therefore, EEI = 2.45 W/m^2/100 lx

The result showed, on dimmed case has EEI lower than undimmed case. We know that, the lower number of EEI has the energy efficiency more than the higher number. So, we can summarize that, this automatic dimming control has made this lighting system more efficient. So, it can be said that, this lighting system is an efficient system according to EU GPP Criteria for Indoor Lighting which the energy efficiency indicator must not exceed 2.6 W/m^2/100 lx for school classroom [5].

4 Conclusions

This project is one from pack 3 project. It has been finished and now on the real system being used as the electrical energy saving apparatus. Sometimes it used as an instructional media for the energy saving technology study. According to the purpose of research, the energy which can be saved or the energy efficiency enhancement is the research success.

In issue the earth concern, with the saving rate 6.36 kWh per month, the energy can be saved up to 50.88 kWh per year, CO_2 emission can be reduced 27.78 kg based on 0.546 kg per 1 kWh the rate of Thailand's power production CO_2 release [11]. This is the reduction of global warming effect [12].

For the author's country, Thailand, if the energy saved 50.88 kWh per year is conversed to the primary energy for power generation, it would be 0.00437568 toe (8.6 E-5 toe = 1 kWh) and equal to 0.0299 barrels of oil equivalent (boe) based on 6.84 boe per 1 toe [13], [14]. That is the oil saving rate per year and it means that the country's energy import is reduced by this project and the energy security situation became slightly better also.

Finally, the energy saving rate 50.88 kWh per year can save the money 168 Thai Baht (3.3 THB per 1 kWh) or 4.8 USD (35 THB per 1 USD) electricity cost per year for my workplace Suan Sunandha Rajabhat University.

However the energy saved will depend on how strengthen of the irradiance in each season [15]. Generally summer in Bangkok Thailand, the strength of sunlight is usually higher than monsoon and cool season. So, more sunlight effect enter the room during summer months will make more energy saved. It means that the energy saved can be higher than the level mentioned that collected during monsoon months.

This research has already been proved that the energy efficiency in lighting system can be enhanced using simple technologies by just student who were taking course senior project. We are just a small group which can make a tiny effect at the time. If business and other academic sectors who have potential start to do as this trend, the conservation will be the larger scale and make more delighted.

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