COST-BENEFIT ANALYSIS AND EMISSION REDUCTION OF ENERGY EFFICIENT LIGHTING

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KUALA LUMPUR

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COST-BENEFIT ANALYSIS AND EMISSION REDUCTION OF ENERGY EFFICIENT LIGHTING

ABSTRACT

With the development of society and the growth of population, the usage of global power is increasing day by day. Of all power consumers, lighting accounts for the largest share of power consumption in the commercial and residential sectors. Lighting accounts for about 20% to 30% of global electricity consumption. As a result, lighting systems have great potential for energy savings. Thus, the main objective of this research project is to design the proper retrofit scenario and analyses the potential power savings, payback periods and potential environmental benefits. In this study, new energy-efficient LED lamps were used to retrofit existing lighting systems. At the beginning of 2018, all lighting systems were replaced, and the power consumption, payback period, life cycle cost and emissions were calculated. The 100% retrofit of existing lighting systems with LED lamps can save about 44.7% of energy consumption per year. The results of the life cycle analysis suggest that about two years later, the selected buildings will generate net saving and feasible for the investment. Using data access and calculations to predict the percentage of electricity consumption and fuel generation fuels in Malaysia, after 100% modifications, total emissions can be reduced by approximately 2,622 ton of CO_2, 11,197 kg of SO_2, 6,336.4 kg of NO_x and 1,904 kg of CO. Hence, the use of energy-efficient lighting systems will save a lot of energy and costs, while also reducing emissions.

Keywords: lighting retrofit; energy saving; emission reduction; life cycle cost.

[TAJUK LAPORAN PENYELIDIKAN/DISERTASI/TESIS]

ABSTRAK

Dengan pembangunan komuniti dan pertumbuhan penduduk, penggunaan tenaga global meningkat setiap hari. Dari semua pengguna tenaga, pencahayaan menyumbang kepada bahagian terbesar bagi penggunaan tenaga elektrik dalam sektor komersil dan kediaman. Pencahayaan menyumbang kira-kira 20% hingga 30% penggunaan elektrik global. Akibatnya, sistem pencahayaan mempunyai potensi besar untuk menjimatkan tenaga. Oleh itu, objektif utama projek penyelidikan ini adalah untuk merancang senario retrofit yang betul dan menganalisis potensi penjimatan tenaga, tempoh pembayaran balik dan faedah yang berkaitan dengan alam sekitar. Dalam kajian ini, lampu LED yang cekap tenaga telah digunakan untuk mengubah sistem lampu yang sedia ada. Pada awal tahun 2018, semua sistem pencahayaan telah digantikan, dan penggunaan tenaga elektrik, tempoh pembayaran balik, kos kitaran hayat dan pelepasan akan dikira. Peralihan 100% sistem pencahayaan sedia ada dengan lampu LED dapat menjimatkan sekira 44.7% daripada penggunaan tenaga setahun. Hasil analisis daripada kitaran hayat menunjukkan bahawa selepas dua tahun kemudian, bangunan terpilih akan menghasilkan penjimatan bersih dan berbaloi untuk melabur. Dengan menggunakan akses dan pengiraan untuk meramalkan peratusan penggunaan elektrik dan bahan api di Malaysia, jumlah pelepasan dapat dikurangkan sebanyak 2,622 tan CO_2, 11,197 kg SO_2, 6,336.4 kg NOx dan 1,904 kg CO selepas 100% retrofit. Oleh itu, penggunakan sistem lampu cekap tenaga akan menjimatkan banyak tenaga dan kos, di samping mengurangkan pelepasan.

Kata kunci: pencahayaan retrofit, penjimatan tenaga, pengurangan pelepasan, kos kitaran hayat.

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LIST OF SYMBOLS AND ABBREVIATIONS

CO_2	:	Carbon dioxide
SO_2	:	Sulphur dioxide
NOx	:	Oxynitride
CO	:	Carbon monoxide
EC	:	Energy Consumption
N	:	Number of Lights
W	:	Power consumed by the lamp
OH	:	Operating Hours
ES	:	Energy Savings
BS	:	Bill Savings
ET	:	Electricity Tariff
OC	:	Operating Cost
PWF	:	Present Worth Factor
r	:	Discount Rate
PC	:	Purchase Cost
LCC	:	Life Cycle Cost
EM_p^n	:	Emission for a unit electricity generation of fuel type n
EF_f^p	:	Emission Factors
FC_{nf}	:	Fuel Consumption
p	:	Emission per unit
f	:	Fuel usage per unit
n	:	Year
IEA	:	International Energy Agency

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background

In recent years, most countries in the world have continued to experience rapid urbanization of population growth. As a result, energy use in countries has increased significantly over the past decade. Among them, the power industry plays an increasingly important role in energy consumption (Di Stefano, 2000). In the 2017, 40% of the world's primary energy consumption was used to generate electricity, making it the largest consumer-use industry (Ge et al., 2018). At the same time, large amounts of emissions, such as CO_2, can be generated, potentially leading to serious environmental problems.

According to past research, buildings are the main contributors to energy consumption. Of these, it accounts for about 40% of the world's total net energy (Bujang et al., 2016). It is worth mentioning that lighting accounts for about 20% of global electricity consumption. As a result, lighting has great potential to reduce the use of non-renewable energy sources. In order to promote energy conservation in lighting systems, many Governments have issued directives prohibiting the use of energy-efficient incandescent bulbs and replacing them with other technologies, such as the replacement of lamps with LEDs (Caicedo et al., 2011), the re-planning of power lines (Uddin et al., 2013), etc. This increases the utilization of clean energy, while meeting the growing demand for energy while minimizing environmental pollution.

1.2 Problem Statement

In this modern era, light sources can produce the same light while consuming only half of the energy input compared to the traditional lighting system used 20 years ago. With the development of the country, new energy efficiency technologies must be developed due to the increasing cost of building new power plants, the continuous shortage of power supply and demand, and the competitive demand of investment capital. Of all the electricity consumers, lighting accounts for the highest share in the commercial and residential sectors. Lighting occupies about 20% to 30% of global electricity consumption. By transforming the use of more energy-efficient lighting technology, you can save a lot of energy. Trifunovic et al.'s study showed that residential potential energy savings of up to 27%, the business sector energy savings of up to 30% (Trifunovic et al., 2009). And, it can save money to reduce industrial cost.

Taking Malaysia as an example, with the rapid population growth, it is estimated that Malaysia's electricity demand will grow at an average annual rate of 3.1% by 2020 (Khorasanizadeh et al., 2015). Action is therefore necessary to reduce Malaysia's energy consumption. In terms of energy consumption, about 53% of Malaysia's electricity is used in the commercial and residential sectors, mainly for construction; This may consist of some relatively small non-buildings, such as street outdoor lighting, water and sewage treatment and loss (Sin et al., 2011). About 30% of Malaysia's electricity is used for building lighting (Al-Mofleh et al., 2009). Lighting therefore has great potential to reduce the use of non-renewable energy sources in Malaysia. This can reduce exhaust emissions and improve the energy structure (Shaikh et al., 2017). Rising electricity prices and growing concerns about climate change and energy independence are driving the lighting market in Malaysia towards energy-efficient light sources (Khorasanizadeh et al., 2016).

1.3 Research Objective

The purpose of this research project is to optimize the campus building lighting energy consumption while meeting ideal lighting demand in the building. It will be done by using lighting energy efficiency approach and evaluate it through calculation. The research aims to achieve the following objectives:

(a) To analyse the power consumption and emission reduction by replacing energy-saving lamps.

(b) To analyse the life cycle cost and payback period of energy efficiency lighting system.

1.4 Research Scope

The scope of this research project is to achieve the above objectives. On this basis, a great deal of research has been done on optimizing the energy consumption of interior lighting in buildings. This research project will use the method of application calculation to optimize the energy consumption analysis of building lighting.

The research takes a building in Faculty of Engineering, University of Malaya, namely Block L as the target building in the project which will under gone lighting energy consumption using data and calculations. The result obtained from calculation will be compared with actual data to validate its accuracy.

Analysis will be carried out to optimize the use of building lighting energy while meeting the lighting brightness required for the lecture classes. As a result of the retrofit of more efficient lighting systems, cost-effectiveness has been identified as a function of energy savings. The results of this study will bring significant benefits to energy conservation, cost-effectiveness of building lighting and emission reduction.

1.5 Research Project Report Outline

This research project report is divided into five chapters. Project layout shows the overall view on the lighting energy consumption of the structure of the study.

Chapter one shows the background of the project's overview and will determine a clear issue statement based on the current issues facing the industry. The goal of the study is to solve the problem of the target. Design suitable retrofit solutions for building lighting systems and analyze potential power savings, payback periods and potential environmental benefits. The scope of the project will facilitate the direction of the project. The results of this study will bring significant benefits to energy conservation, emission reduction and cost-effectiveness of building lighting.

In addition, chapter two has carried on the detailed literature review to the previous research. The literature review provides a clear understanding of the field of research, which will be based on journals, books, articles, etc. This chapter will discuss many different optimization scenarios for other studies, such as replacing the old system electromagnetic ballast, reducing wattage by lighting retrofit, changing old system adapters to new adapters etc.

Chapter three will discuss the details about the research methodology that being applied in this project. This chapter will illustrate how to calculate the lighting energy consumption and emission of target building. Furthermore, the method of how to verify the optimization strategies of lighting energy and emission is also discussed.

Chapter four gives the research results of this subject. The comparison between the calculation results of energy consumption of target building and the actual data is discussed.

Chapter five of the thesis will summarize the whole research, draw the conclusion of this research project and the future work to meet the objectives stated above.

CHAPTER 2: LITERATURE REVIEW

2.1 Global Energy Consumption

2.1.1 World Energy Mix

Energy is the foundation of economic progress and social development (Wu & Chen, 2017). Over the past 35 years, energy used in the world has increased twice times, greatly contributing to great economic growth and the improvement of living standards (Arto et al., 2016). Energy is defined as the ability to do work, which can exist in different forms, such as thermal, chemical, gravitational, electricity, mechanical, sound, nuclear, radiant, and motion (Bilgen, 2014). Energy can be stored, converted and/or expanded depending on the various applications. Energy sources can be fossil (petroleum, coal, shale oil, natural gas, etc.), renewable (alternative) (biomass, wind, hydro, solar, marine, geothermal, hydrogen, etc.)and fissile (thorium, uranium, etc) (Ferreira, 2013).

In 2017, the global energy consumption was strongly increased by around 2.2%, mainly by natural gas and renewable energy, the proportion of coal in the structure continued to decline. Structural forces in the energy market will continue to drive the world's transition to a low-carbon economy (de Lima et al., 2018). Nowadays, energy use has become the most critical challenge in the world today, as a key link among the three pillars of economic, social and environmental sustainability (Jones & Warner, 2016).

2.1.2 Lighting Energy Consumption

The power industry plays a more and more important part in energy consumption (Di Stefano, 2000). In 2017, 40% of the world's primary energy consumption is used for power generation, making electricity the largest consumer-use industry of energy consumption (Ge et al., 2018). With the rapid increase in wind energy (17%, 163 terawatt) and solar power generation (35%, 114 terawatt), renewable energy leads to global electricity generation (Ellabban et al., 2014). Global power generation grew by 2.8% in 2017, close to 10 average growth. Almost all of the growth is from developing countries.

It is worth mentioning that lighting occupies a large proportion of about 20% of global electricity consumption. In order to promote energy conservation, many governments have issued directives to ban energy-efficient incandescent bulbs and replacing them with other technologies, such as changing lamps into LEDs (Caicedo et al., 2011), replanning the wires and so on (Uddin et al., 2013). With the increase of population and the change of life style, mankind is in severe energy consumption and heavy environmental pressure. The trend of human economic activity has almost irrevocably undermined the environment, causing harmful climate change and culminated in recent global warming (Rossi et al., 2016). Thus, energy saving and emission reduction become more and more urgent demand (Dodoo et al., 2018).

2.2 Malaysia Lighting Energy Consumption

Demographic and economic changes over the past few decades have increased Malaysia’s electricity demand (Vithayasrichareon et al., 2012). As shown in Figure 2.1, population of Malaysia grew from 23.9 million in 2000 to 32.2 million in 2018, an increase of 38.9 percent (Group, 2013). It is estimated that Malaysia's population will reach 32.49 million by 2020. This growth increases the challenge of generating electricity and providing enough power to meet the country's growing electricity demand (Oh et al., 2010). Most of these population growth takes place in Malaysian cities , where the proportion of the population living in urban areas increased from 61.9 per cent to 73.3 percent over the same period (Khorasanizadeh et al., 2015). With the development of urbanization and population growth, the demand for electricity is increasing (Birol, 2010).

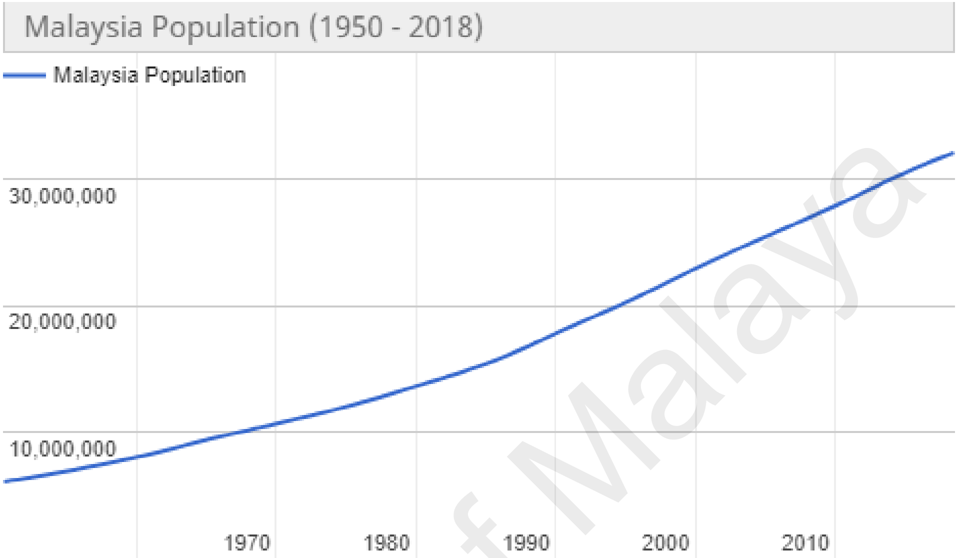


Figure 2.1: Population of Malaysia since year 1950 (Ahmad, 2018)

In Malaysia, there has been a substantial increase on electricity consumption from 2005 (Group, 2013). Malaysia’s share of electricity consumption in total energy consumption rose from 17.4% in 2007 to 21.7% in 2012 (Tan et al., 2013). It is estimated that Malaysia’s electricity demand will increase at an average annual rate of 3.1 percent by 2020 (Bujang et al., 2016). Therefore, it is essential to take action to reduce Malaysian energy consumption. In energy consumption, about 53% of electricity used in Malaysia is used in commercial and residential sectors, mainly in buildings. This may include some relatively small non-building, such as water and sewage treatment, street outdoor lighting and loss (Sin et al., 2011). About 30% of Malaysia's electricity is used for architectural lighting (Al-Mofleh et al., 2009). Therefore, lighting has a great potential to reduce the use of non-renewable energy in Malaysia. This can reduce exhaust emissions and improve energy structure (Shaikh et al., 2017). Rising electricity tariffs and growing concern about climate change and energy independence are driving the Malaysian lighting market towards the use of energy-efficient light sources (Khorasanizadeh et al., 2016).

2.3 Emission for Electricity Production

2.3.1 World Electricity Emission

The rapid growth in global energy use has increased concerns about energy exhaustion, supply problems and severe environmental impacts (such as ozone depletion, climate change, global warming, etc) (Saidur, 2009). After low or zero growth from 2014 to 2016, the amount of carbon emissions from energy consumption increased by 1.6%. Energy consumption, which is the biggest source of carbon emissions in the 2017, more than one-third of carbon emissions come from the power industry (Almeida & Ferreira, 2017). The reason for this high emissions share is that the industry relies heavily on fossil fuels. Around two-thirds of the world's electricity comes from fossil fuels that uses coal as the main fuel (Pei-dong et al., 2007). The global power supply sector released into the atmosphere accounted for more than 7.7 billion tonnes of CO_2 per year ; 37.5% of total CO_2 emissions under normal circumstances, the annual carbon emissions associated with electricity generation, including cogeneration, are expected to exceed 4000 tonnes C (Sims et al., 2003). Technically, there is a huge potential to reduce CO_2 emissions in the electricity production sector (Ang & Su, 2016). The shift from fossil to non-fossil fuels, such as renewable or nuclear energy, will meaningfully reduce emissions levels. Emissions can also be reduced by converting fuel from coal in a fossil fuel mixture. Improving the thermal efficiency of fossil fuel power plants is another way to reduce emissions (Franco & Diaz, 2009).

2.3.2 Malaysia Electricity Emission

Electricity demand in many developing countries is growing at a high rate. As a kind of high quality energy, electric power plays an important role in various major energy consumption fields. (Dai et al., 2016). A fundamental challenge for public managers in achieving carbon emissions targets is how to effectively allocate emission reduction incentives to minimize pollutant emissions and to have a positive impact on innovation (Mahdiloo et al., 2018).

Malaysia locates in the Southeast Asian region and is a fast-growing tropical country. Malaysia's power-to-GDP elasticity is around 1.5, which means that every 1% of GDP is growing, and electricity will grow by 1.5% (Shekarchian et al., 2011). Under the supervision of the Energy Commission, commercial and residential electricity consumption reached 7559 kilovolt in 2015, accounting for 53.6% of the country's total electricity consumption and 14.6% of the final energy demand (Mohamed & Lee, 2006). Meanwhile, the use of electricity produces a lot of exhaust emission (Kadir et al., 2013).

As the Figure 2.2 shows below, in the past decade, there has been a steady increase in emission rates, with CO_2 emissions reaching about 160 million tonnes in 2020. It is expected that by 2035, the largest source of CO_2 emissions will be the power generation industry, accounting for around 33% (Demand & Outlook, 2013). Therefore, it is essential to take action to reduce Malaysia’s electricity consumption. At the same time, reducing power consumption has a significant effect on the total energy reduction (Khorasanizadeh et al., 2015).

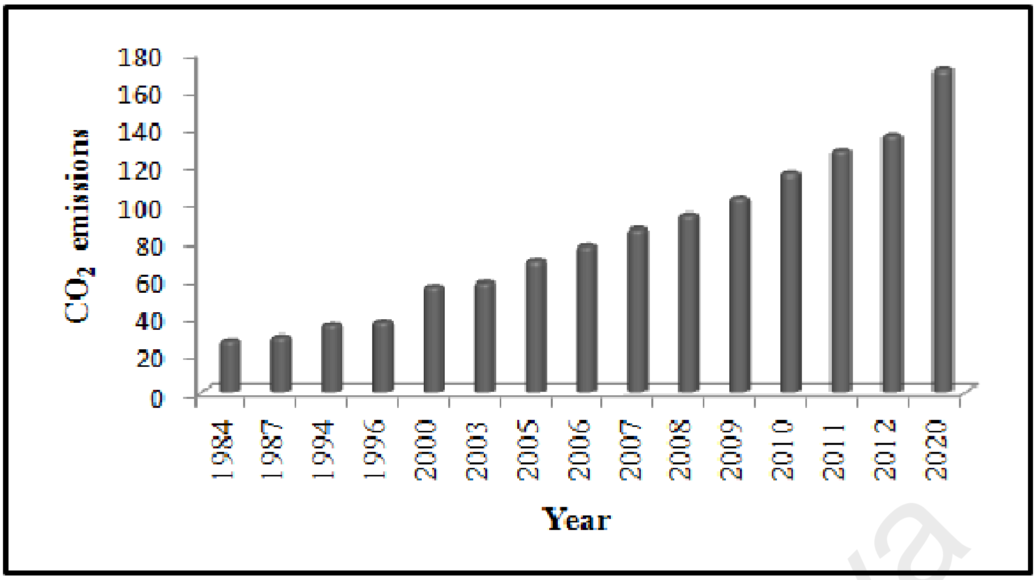


Figure 2.2: Total CO_2 emissions from thermal and electricity production (megaton) (Shekarchian et al., 2012)

2.4 Building Energy Consumption and Emission Production

2.4.1 Building Lighting Energy Consumption

Building energy consumption accounted for around one-third of the world's primary energy (Baloch et al., 2018). Figure 2.3 shows the EIA analyses and forecasts the future trend of building energy consumption in its International Energy Outlook (EIA, 2013).

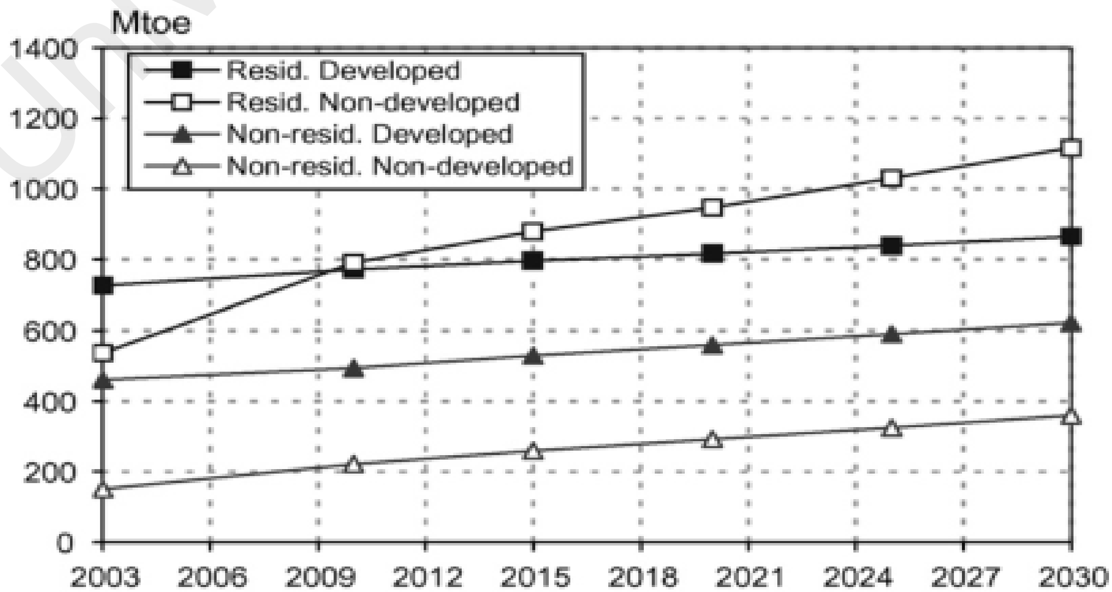


Figure 2.3: Buildings energy consumption outlook (EIA, 2013).

According to Figure 2.3, in the next 10 years, the energy use of the building environment will increase by 34%, with an average growth rate of 1.5%. By 2030, non-residential consumption and housing consumption will reach about 33% and 67% respectively (Pérez-Lombard et al., 2008). As a result, the growth of the construction industry will increase energy demand in the region.

Research by Tetri E, Halonen L shows that the potential energy savings in residential and commercial areas are 27% and 30%, respectively (Tetri & Halonen, 2007). Of all power consumers, lighting has the highest share of commercial and residential sectors. Lighting takes up about 20% to 30% (Uddin et al., 2013) (Soori & Vishwas, 2013) of global electricity consumption (T. M. I. Mahlia et al., 2005). As shown in Figure 2.4, taking the power consumption of a education building as an example, lighting system accounts for around 42% of energy consumption, only about 3% less energy consumption than HVAC. Another instance shows that, lighting systems had consumed of about 30% of the electricity in a fully air-conditioned building and up to 50% in a non-air-conditioned building. By turning to more energy-efficient lighting technology, a large amount of energy can be replaced. Therefore, lighting energy systems have great potential for energy savings.

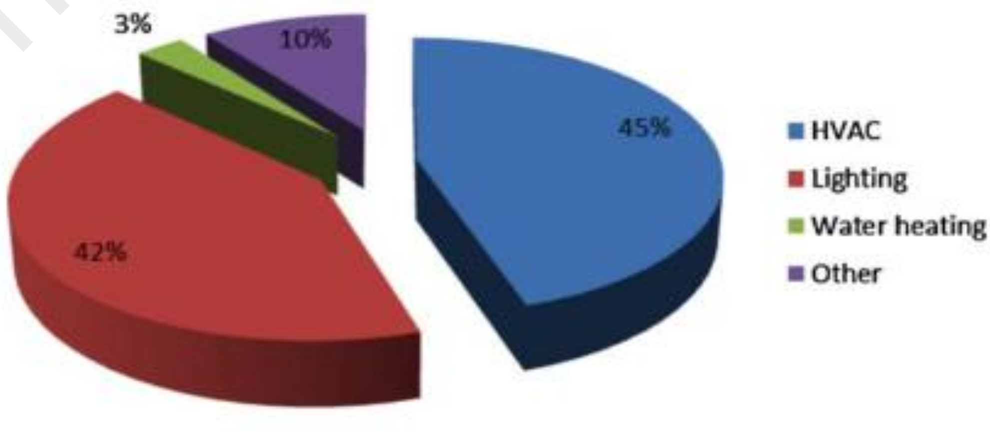


Figure 2.4: Percentage of energy consumption in educational building (T. Mahlia et

al., 2011a)

2.4.2 Building Lighting Electricity Emission

Energy consumption increasing has a negative influence on the environment, so policies for effective use of energy should be developed (T. Mahlia et al., 2011a). In the commercial sector, office buildings are the biggest emitters of energy consumption and CO_2 emissions (Pérez-Lombard et al., 2008). Of these, lighting occupies one-third of the electricity consumed in office buildings. Thus, the reasonable use of electricity in buildings is an important subject, especially when the energy is increasingly expensive and excessive use of electricity can lead to climate change through high greenhouse gas emissions (Linhart & Scartezzini, 2010).

Lighting systems are key to ensuring the comfort, safety and productivity of people in buildings. The power savings from the heavy use of energy-saving lamps will reduce mercury and greenhouse gas emissions (Trifunovic et al., 2009). Therefore, lighting systems need to be properly designed to achieve the required level of illumination while producing the least amount of emission.

2.5 Building Lighting Energy Optimization Method

Lighting is an important part of building energy use, it accounts for about one-third of commercial building power consumption (Xu et al., 2017). Thus, the optimization method of energy saving, cost-benefit analysis and reformation of building lighting is of great significance on lighting energy saving.

2.5.1 Changing Lighting Control Strategies in Commercial Buildings

The National Association of Electrical Manufacturers (NEMA) believes that control has greater potential to save energy in critical applications than to improve source efficiency (Doe 2011b). However, lighting controls are not included in federal energy efficiency standards and are only partially incorporated through state and local building codes. Although the energy savings of some system components, such as replacing T12 with T8, can be fairly easily quantified and guaranteed, but cost savings can be achieved when the lights are not turned off or turned off. The need depends on many factors, including application, site positioning and occupancy, architectural design, internal reflection, occupant behaviour, and adjustment and configuration during installation and commissioning, making the cost savings easier to predict.

For more than more than 30 years, researchers have been quantifying the energy-saving effects of lighting controls in commercial buildings, but there has been no comprehensive research assessment of control studies. This makes it difficult to understand the overall situation of control opportunities, because the objectives, methods, coverage and results of individual studies are very diverse. Some studies, such as those on the U.S. Environmental Protection Agency program, monitor existing data on the actual devices in multiple buildings in a paper (e.g., Vonneida, etc. 2000). Other studies, such as research by the National Research Council of Canada and the Florida Solar Center, have resulted in only one or two laboratory tests or experiments of controlled space and experimental space. Some studies separate the effects of controls from other lighting efficiency measures, while others do not. Some studies have been designed to determine the effects of other factors, such as window glass or direction, from controlled energy savings. Some studies focus on specific spatial types, while others report savings between buildings or buildings, without recording or reporting savings on space types within buildings (Williams et al., 2011).

B. Roisin and others attempted to determine the energy saving potential of different lighting control systems in the office (Roisin et al., 2008). They conclude that dimming the lamp according to external lighting conditions can save 45-61%, while the use of sensors can further increase savings. L.L Fernandes (Fernandes et al., 2014) monitors the actual performance of lighting systems at the New York Times headquarters building. They found that dimming control saved 20% compared to the prescribed code. It is recommended that the atrium corridor use dimming control of the monthly lighting energy saving range of 14-65% (D. H. Li et al., 2014). Lei Xu and others (Xu et al., 2017) have studied the energy performance and control strategy of various lighting systems in open office. Includes daylight dimming control and occupancy detection on/off control. Automatic monitoring, display and recording of the control data and power of the online data acquisition system. The different lighting control strategies were tested on-line for some time, and comparing the energy usage with the lighting system of the benchmark office. The energy saving potential of various illumination control strategies is simulated and analyzed. In the experiment, the illumination control strategy combining background dimming illumination and task illumination is studied.

According to Alison Williams et's study (Williams et al., 2011), primary data organization can be based on the four major control strategies defined in Table 2.1.

Table 2.1: Major lighting controls strategies

Strategy	Definition	Relevant Technologies
Occupancy	Adjusting light levels according to the presence of occupants	occupancy sensors, time clocks, energy management system
Daylighting	Adjusting light levels automatically in response to the presence of natural light	photosensors, time clocks[1]
Personal tuning	Adjusting individual light levels by occupants according to their personal preferences; applies, for example, to private offices, workstation-specific lighting in open-plan offices, and classrooms	dimmers, wireless on-off switches, bi-level switches, computer-based controls, pre-set scene selection
Institutional tuning	(1) Adjustment of light levels through commissioning and technology to meet location-specific needs or building policies; or (2) provision of switches or controls for areas or groups of occupants; examples of the former include high-end trim dimming (also known as ballast tuning or reduction of ballast factor), task tuning, and lumen maintenance	dimmable ballasts, on-off or dimmer switches for non-personal lighting

[1] Note: Time clocks are often used for daylighting control in exterior applications, and while they in theory could be used in interior spaces, they rarely are. None of the 88 studies reviewed included interior time clocks for daylighting control.

(Williams et al., 2011)

One of the most important areas in this study includes whether the control system uses a clock or a sensor; control is dimmed, switched, or both; control is automatic or manual. Any changes to these control strategies are identified as different control configurations, and the results are rendered on different lines. They also included a delay field for closing the response; some studies have changed this, and the results are averaged from the smallest and largest latency tests and presented in a single line.

The results are as Figure 2.5 shows below:

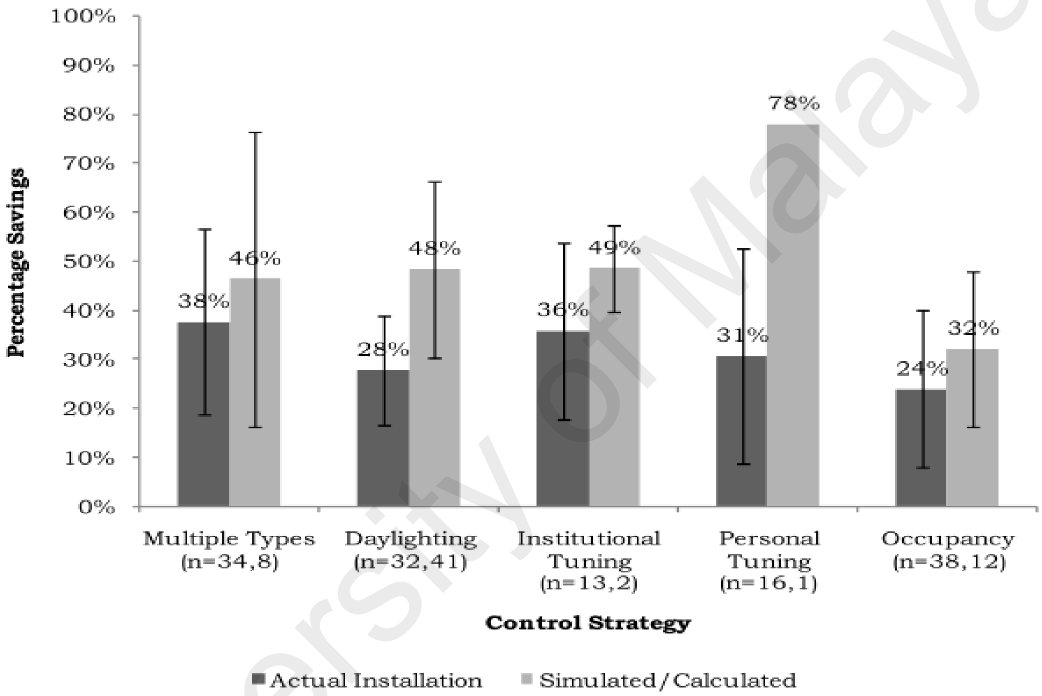


Figure 2.5: Comparison of energy savings between practical installations and analog or computational installations (Williams et al., 2011)

Based on meta-analysis, the best estimate of average energy saving potential is occupancy rate is 24%, day lighting is 28%, personal tuning is 31%, mechanism tuning is 36%, multi-method tuning is 38%. The results show that the simulation results significantly overestimate (at least 10%) the average cost of the actual building lighting can be saved.

Daylight-related dimming and switching controls have a significant influence on lighting energy savings. Combined with personal adjustable task lighting, these can achieve a 60% energy saving effect. However, energy efficiency optimization should not come at the expense of visual comfort. Thus, although the general lighting intensity reduction will reduce the lighting energy consumption, but the general lighting consumption should be limited. Otherwise, uncomfortable glare, high brightness contrast and other foreseeable comfort issues will be due to ultra-low general illumination levels. Experimental results also show that human behaviour can compensate for visual comfort by actively adjusting the task light. However, visual comfort is the result of a combination of factors, and the effect of activating task lighting to achieve a satisfactory lighting environment is limited.

2.5.2 Lighting Retrofit

Lighting retrofit is the replacement of inefficient lighting with efficient lighting (T. M. I. Mahlia et al., 2005). It is the process of the replacement of inefficient lighting systems with more advanced, more efficient systems. The success of the project depends on various parameters, such as regulations and policies, occupant expectations, human factors and building codes, which are most affected in other parameters (Ma et al., 2012). These parameters are highly interdependent and can have an important impact on the design (Ganandran et al., 2014). Over the time, the electricity saved is not only enough to pay for the new lighting, but also to generate returns. This can be achieved by reducing the input power or reducing the lighting work hours to reduce energy consumption (Di Stefano, 2000).

A large amount of data on the lighting system can be found in the lighting market reference (Vorsatz et al., 1997). The uncertainties, sensitivity analysis, payback period and life cycle cost of lighting system are shown in reference (Mcmahon, 2000).

Lighting components are usually measured in light output, colour temperature, colour rendering, efficacy and longevity. Colour temperature is a measure of how the eye perceives the colour of light. The colour rendering index (CRI) is a measure of the ability of a light source to reproduce various objects that are illuminated by a light source. Performance refers to the amount of light emitted per watt of power. This is usually discussed in Lumens/watt (LPW). In the normal environment, the service life is calculated by the hour (Powell, 2009).

There are several types of lighting systems on the market, but the choice of lamp depends on the type of task the lamp will accomplish and some characteristics of the lamp (T. Mahlia et al., 2011a). Then there is the introduction of the lamps commonly used in our lives, such as incandescent, fluorescent and energy-saving lamps.

(a) Incandescent Light Bulbs.

In the past 15 years, incandescent bulbs have been the most commonly used light source, also known as Edison bulbs. When the power is switched on, the current heats the wire and tungsten to 4,000 degrees Fahrenheit, and the tungsten begins to evaporate. Without inert gas (argon and nitrogen), tungsten particles will gather inside the glass to darken it. However, the gas collects tungsten particles and sends them back to the filament (Ganandran et al., 2014). Therefore, almost 90% of the energy produced by an incandescent bulb is released in the form of heat rather than light. This is the reason why incandescent bulbs are called inefficient sources of light. At the same time, the lifespan of an ordinary incandescent lamp usually burns out in about 750 hours (Ganandran et al., 2014).

At present, this type of lamp is gradually eliminated because of its inefficiency (T. Mahlia et al., 2011a).

(b) Compact Fluorescent Light (CFL).

The most common types of lamps currently used are fluorescent lamps (T. M. I. Mahlia et al., 2011b). A fluorescent or fluorescent tube is a gas discharge lamp that uses electricity to excite mercury vapour. The excited mercury atoms produce short-wave ultraviolet rays, which then emit fluorescence to produce visible light. Fluorescent lamps convert electrical energy into useful light more efficiently than incandescent lamps. Lower energy costs usually offset the higher initial cost of the lamp (Onaygıl & Güler, 2003).

Experience from around the world has shown that the large use of CFL in residential, commercial and public buildings has led to a significant reduction in power consumption and the peak daily power demand of national power systems (Trifunovic et al., 2009). In addition, energy losses in transmission and distribution networks are reduced, energy imports may be reduced (or exports are increased), new generation of investment, transmission and distribution capacity may be delayed and life expectancy extended (Al-Mofleh et al., 2009). As a result, most of the power companies and authorities around the world support the CFL promotion program. However, the cost-effectiveness of such plans must be calculated prior to action in order to provide a successful investment. It should also be emphasized that the use of CFL in energy and the environment has the following two drawbacks:

(1) The traditional CFL produces high-content high-current harmonics, resulting in voltage distortion (Radakovic et al., 2005) and higher losses in the distribution network.

(2) CFL contains mercury, which is why it is important to pay particular attention to the reasons for organized and safe disposal.

However, the CFL has a significantly lower light output and increased operating temperature, which translates into a general temperature loss caused by an inefficient method for wrapping a fluorescent tube into a smaller package. Smaller packages actually block the light. Most of these compact fluorescent lamps range in size from 8 to 12 watts, producing 400 to 600 lumens, and a common problem is that no two produce the same colour temperature. In contrast, a typical household incandescent bulb is 60 watts, producing 700 lumens (Powell, 2009).

(c) LED.

LEDs work in a completely different light than compact fluorescent lamps. In LED lighting technology, when electrons and holes are re-bonded, energy is released in the form of photons. Many high-brightness LED lights need to illuminate a large area, because all the light is generated in the PN junction (Ćuk et al., 2010). If all the world's traditional white light source is converted into energy-efficient LED light source, can reduce energy consumption by about 1000 watts per year, equivalent to 230 typical 500 MW coal power plants, reducing about 200 million tons of greenhouse gas emissions (Krames et al., 2007).

LEDs are called solid State lighting technology, or SSL. Basically, SSL does not glow from a vacuum or gas, but from a semiconductor consisting of a positive charge and a negative charge (Caicedo et al., 2011). When electrons move from a negative to a positive layer in a semiconductor structure, light is emitted. In the early LED models, the structure of the LEDs caused some of the light being trapped inside (Choi & Kim, 2012). As a result, older models are generally darker than incandescent bulbs. In order to optimize the LED bulbs performance and light quality while reducing prices, many studies are underway (Y.-C. Li & Chen, 2012).

There are basically two types of led: 5mm LED chips and onboard high-output chips (COB). The 5mm LEDs have low light output and lack the appropriate thermal path, which is essential to maintain the junction temperature of the LEDs. Typically, a 5-hour LED's glow is lowered to half of its original value after 6,000 hours. Cob is considered to be the current lighting option because it provides excellent light output and has the proper thermal path to adjust the junction temperature of the LEDs

(Ganandran et al., 2014).

Some research has been done on the benefits of using the new low-energy retrofit for traditional lighting systems (T. Mahlia et al., 2011a). Light-emitting diode (LED) lamps are more efficient and have a longer life than incandescent and CFL lamps, while providing similar luminescence. Uddin and other people found that (Uddin et al., 2011) LED lamps are found to be more convenient than traditional light bulbs and have improved in regard to environmental friendliness, but LEDs have higher initial costs in economic terms. Chen and Chung (Chen & Chung, 2011) studied the use of T8 fluorescent tubes to transform LEDs. They found that to replace 36W T8 fluorescent lamps with 20W LEDs would save about $288 in 5 years of operation.

Ryckaert and other people found that (Ryckaert et al., 2012) the use of T8 FL lamp to transform the fluctuation of LED lamp is studied. They analyzed 12 different LED tubes, and the results showed that a one-to-one luminare replacement could cause a lack of work plane quantity and quality. To solve this problem, additional LEDs are needed to reduce the potential for energy savings. In another study, Stefano (Di Stefano, 2000) identified three major barriers to energy-efficient installation of energy-saving lighting equipment in offices, such as low-lighting system uptime, low-cost power, and high initial costs for energy-efficient lighting components. Vahl and so on found that (Vahl et al., 2013) the long-term sustainability of the retrofit of low-efficiency bulbs with CFL and LEDs is analyzed. They found that CFL usually has the highest annual cost and toxic waste. FL tubes are the most economical alternative, but if their lifespan is shortened and led prices fall or achieve greater efficiency, LEDs become the most sustainable and economical alternative.

It is important to note that there are three options to do lighting retrofit:

1) Replacing the old system's electromagnetic ballast with electronic ballast.

2) Reducing the wattage by replacing the older bulbs with a new generation of bulbs. This transformation requires only a small investment to replace the bulb.

3) Transforming the old system into a new lamp adaptor, converting the power-hungry bulb into a new energy-saving bulb. It just simply clips in the existing fixture and takes out the starter. This adapter function is already built into the ballast. This adapter allows the end user to retrofit the system from the original bulb without the change of the fixture. By simply rewiring, it will produce better, more efficient lighting and meanwhile save money. While this solution requires a high installation cost, it can save more energy (T. Mahlia et al., 2011a).

This research project illustrates the investigation results of energy saving potential of building lighting system at the University of Malaya. Taking the lighting system of the administrative building as the main reference, the main objective is to design a suitable retrofit plan to calculate the potential energy saving, payback period and potential environmental benefits. Obviously, option 2 can help to save energy and get a return in the shortest possible time. Therefore, the old lighting system using a new type of energy-saving LED has been modified in this research project.

CHAPTER 3: METHODOLOGY

First of all, the selection of buildings as a case study will be the lighting energy consumption analysis. After that, some suggestions for improving the optimization of lighting energy consumption will be put forward. The method of energy optimization of illumination is evaluated by using the energy consumption calculation based on the watt number input of the bulb consumption. The results will show the results of these lighting energy optimization methods and determine the effectiveness of these methods. The overall methodology of the research containing is shown in Figure 3.1:

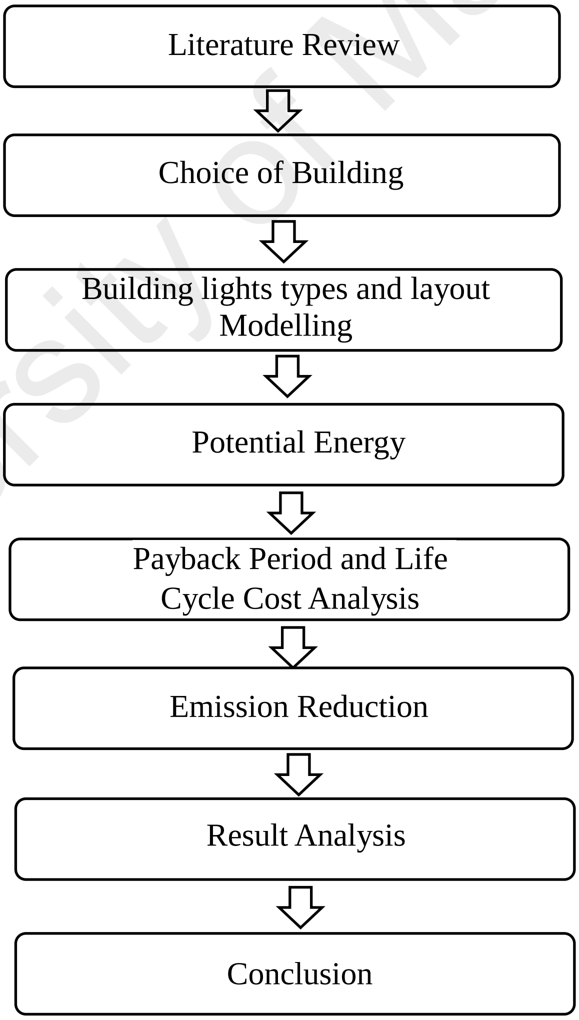


Figure 3.1: Workflow of Research Project

3.1 Choice of Building

Campus building is one type of building that is highly lighting energy consuming due to its activities likes machine, labs and research. Therefore, in this research, the focus will be on one of the building block in Faculty of Engineering, University of Malaya as shown in Figure 3.2. Then, the outcome of the research project can be further analysed.

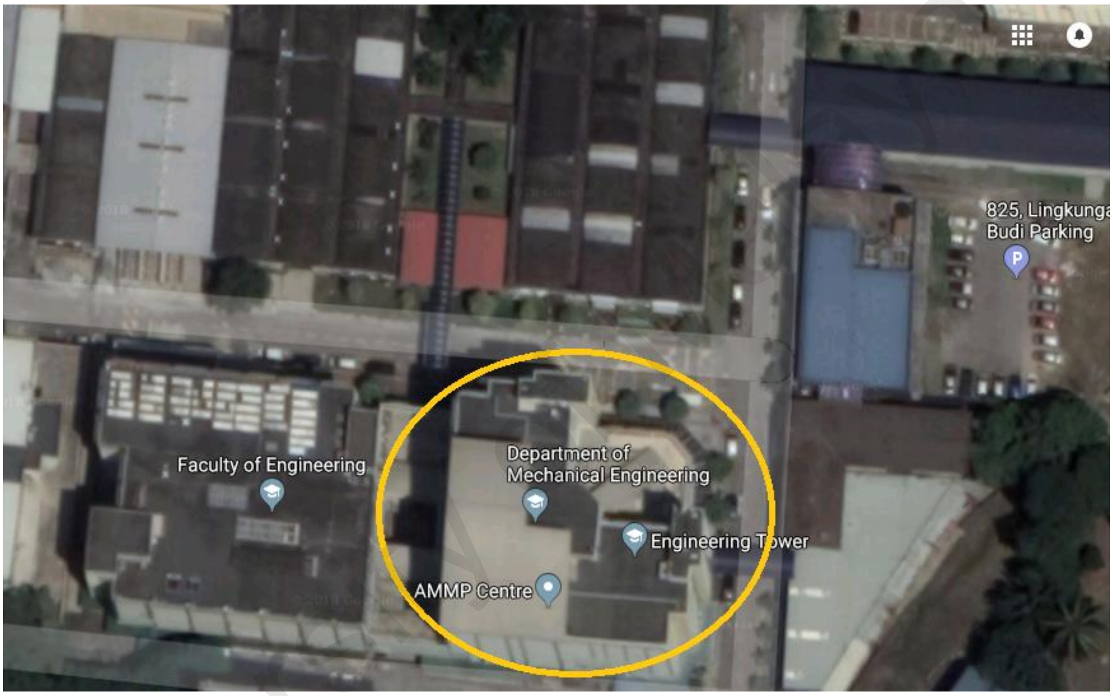


Figure 3.2: Location of Target Building

The campus buildings were simplified as office public buildings due to their activities and time of usage. Choice of building is vital to make sure the analysis of the research is appropriate. The prototype building was mainly used for lecture teaching, lecture working, administrative office and so on, including both weekdays and weekends.

3.2 Building Lights Types and Layout Modelling

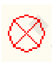
Manually calculate the type and number of lighting bulbs during the walking audit. Lighting layouts are also used to double-check the results to minimize data collection errors. The lighting layout, obtained from JPPHB of the University of Malaya, shows in detail the location and type of lights used in the building. It has been determined that the most commonly used light bulbs are: OSRAM DULUXSTAR 18W/654; Philips lifemax TLD 18W/54-765 2pin for 2 feet , and Philips lifemax TLD 36W/54-765 2pin for 4 feet. Some of light bulbs are shown in Table 3.1.

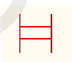
Table 3.1: Types of lights used in the building

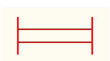
OSRAM DULUXSTAR 18W/654 fitting G24d-2	
Philips lifemax TLD 18W/54-765 2pin fitting G13 for 2 feet	
Philips lifemax TLD 36W/54-765 2pin fitting G13 for 4 feet	

The OSRAM DULUXSTAR 18W/654 CFL bulb comes with G24d-2 fitting. The bulb produces about 1,050 lumens and has a lifespan of 10,000 hours. The bulb is used as a down light source and the light is concentrated in the downward direction. The 18W Philips fluorescent tube has life time of 15,000 hours and produces 1,050 lumens. These bulbs can produce up to 1,500 lumens and have a lifespan up to 15,000 hours. The Philips liner fluorescent tubes consume 36W for the 4 feet long linear tube. They have a 15,000-hour service life and 2,600 lumens. Around the campus, this tube is usually used to illuminate buildings. Two pin design, easy to set up with just a plug-in.

The building used as prototype in the research is Block L, Faculty of Engineering, University of Malaya. The building model was created to serve as the criterion for determination of the average lighting energy consumption of teaching building. It is a 8-storey high building with all floors are utilized and fully equip with lighting system. Record the type and number of lights per floor, understand the distribution structure and measure the distribution distance, and use AutoCAD to map the distribution of each floor lamp, as shown in Figure 3.3-Figure 3.10:

 represents OSRAM DULUXSTAR 18W/654 CFL bulb ;

 on behalf of Philips lifemax TLD 18W;

 on behalf of Philips lifemax TLD 36W.

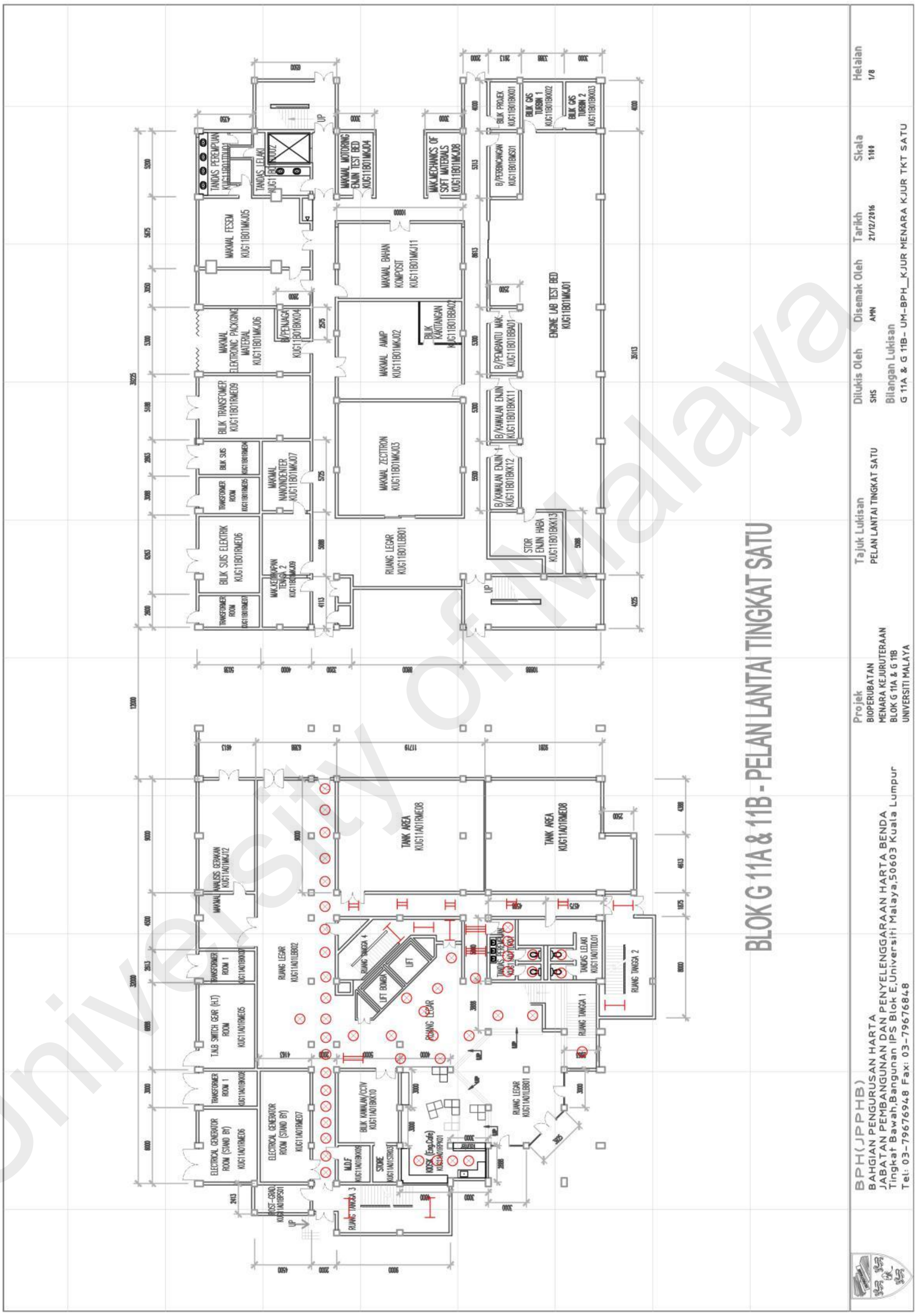


Figure 3.3: Block L Lighting Layout (First Floor)

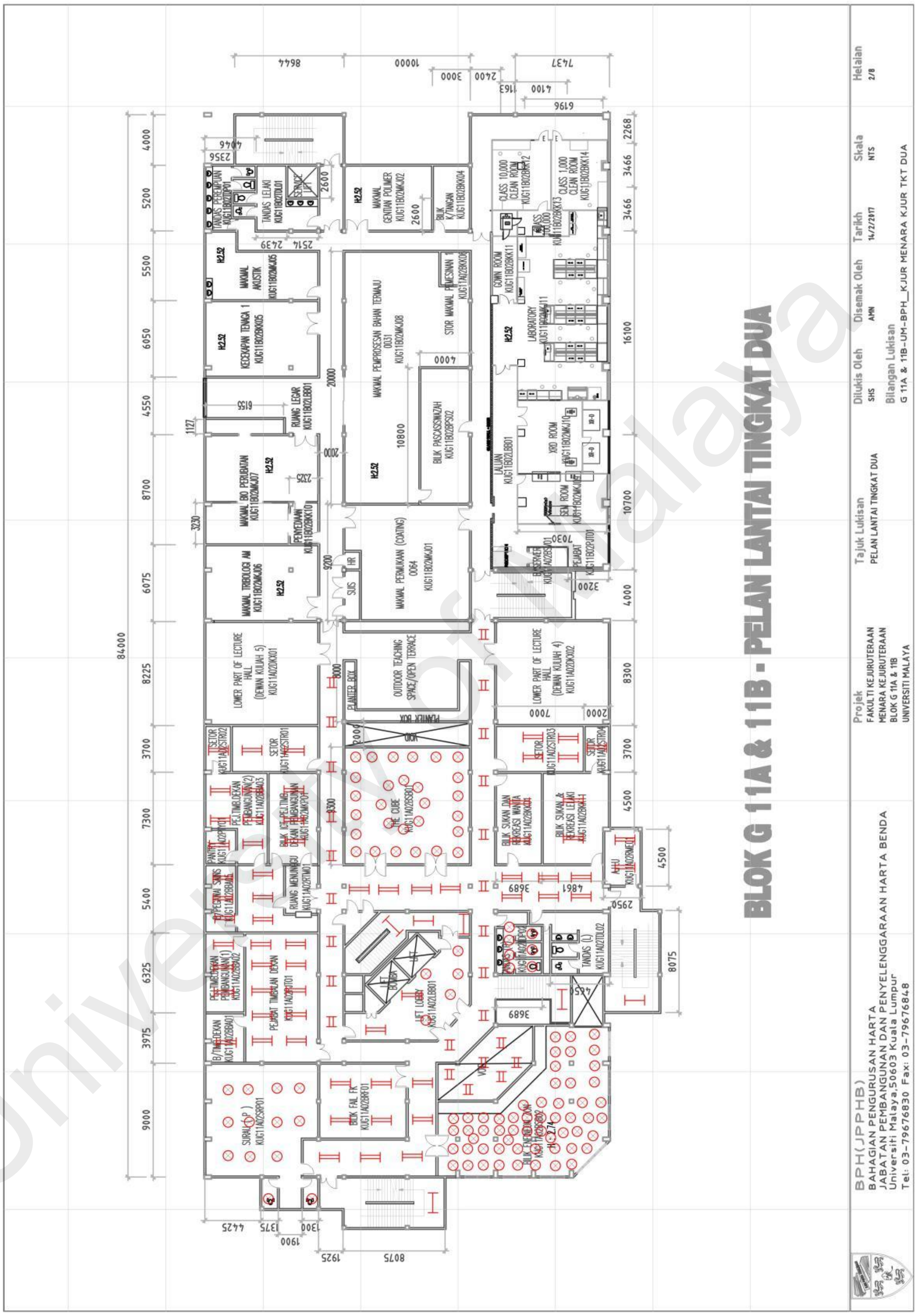


Figure 3.4: Block L Lighting Layout (Second Floor)

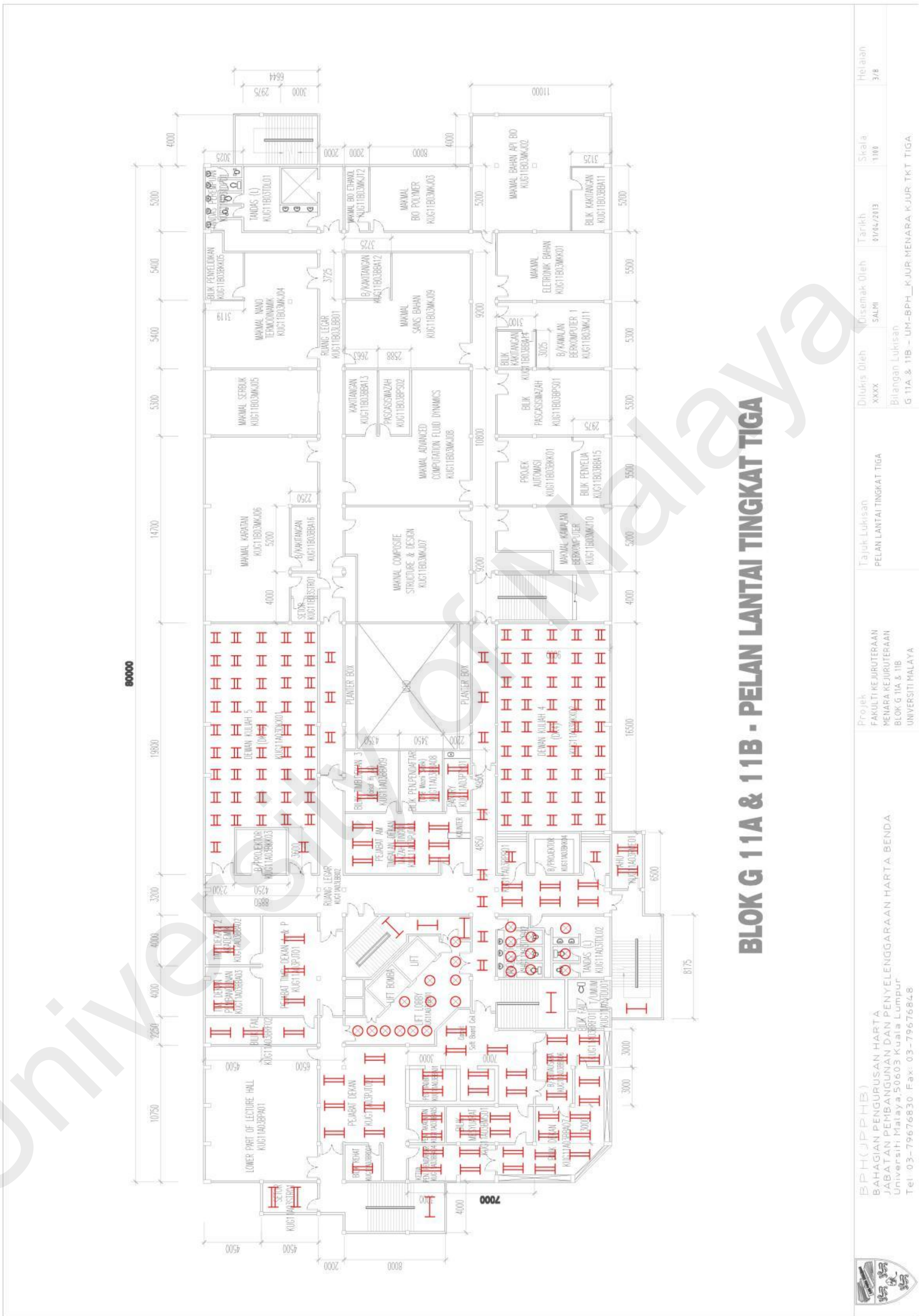


Figure 3.5: Block L Lighting Layout (Third Floor)

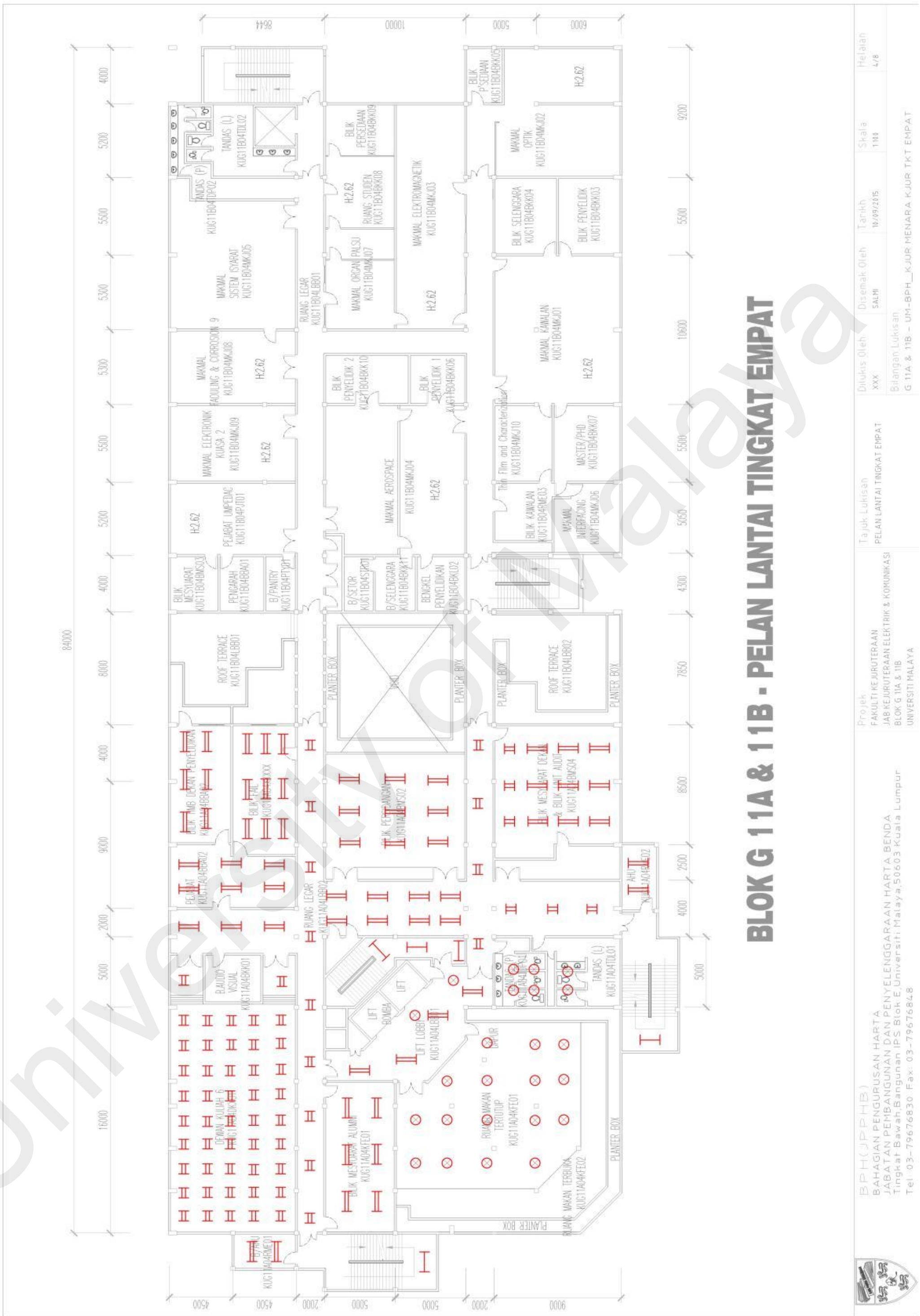


Figure 3.6: Block L Lighting Layout (Fourth Floor)

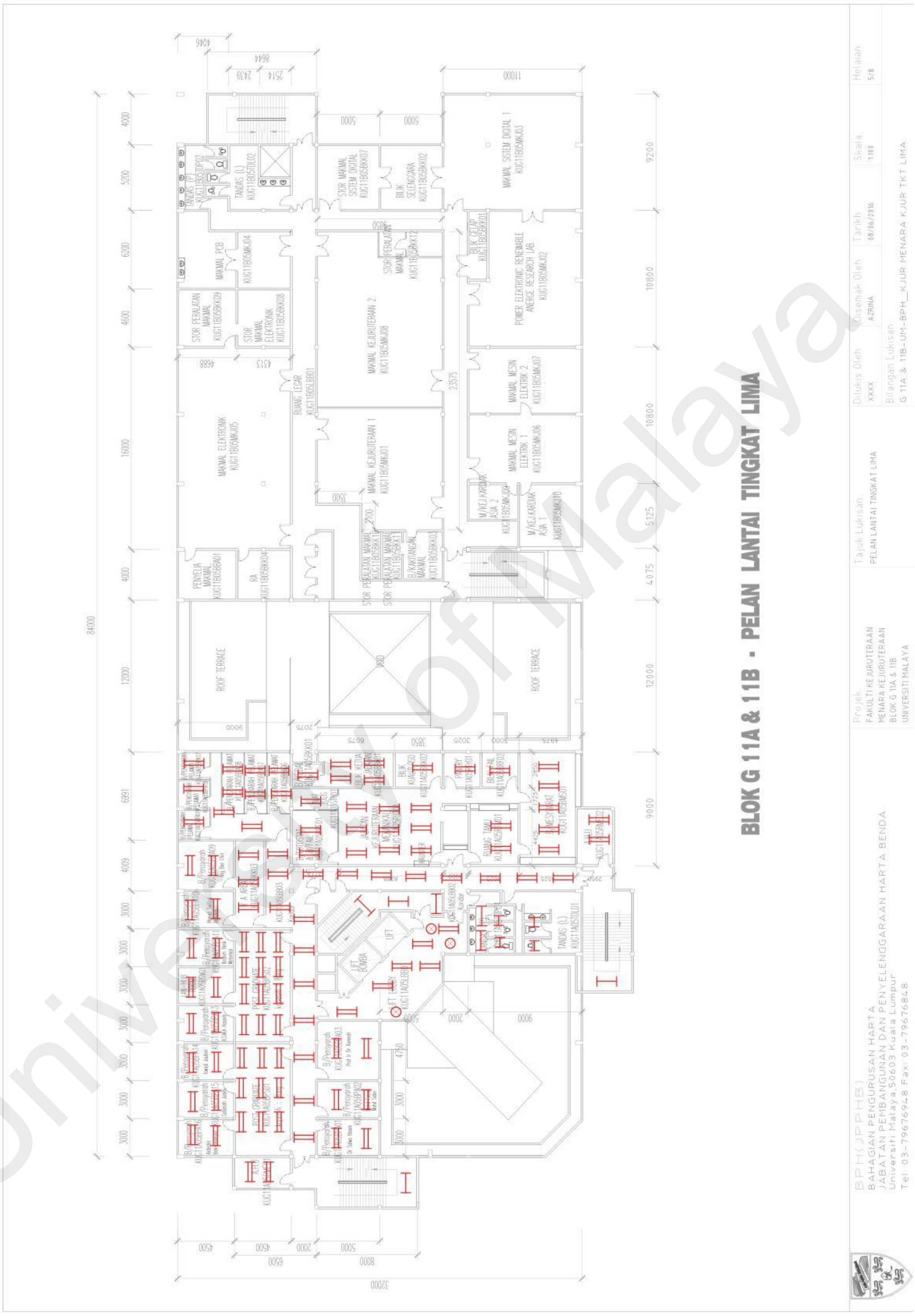


Figure 3.7: Block L Lighting Layout (Fifth Floor)

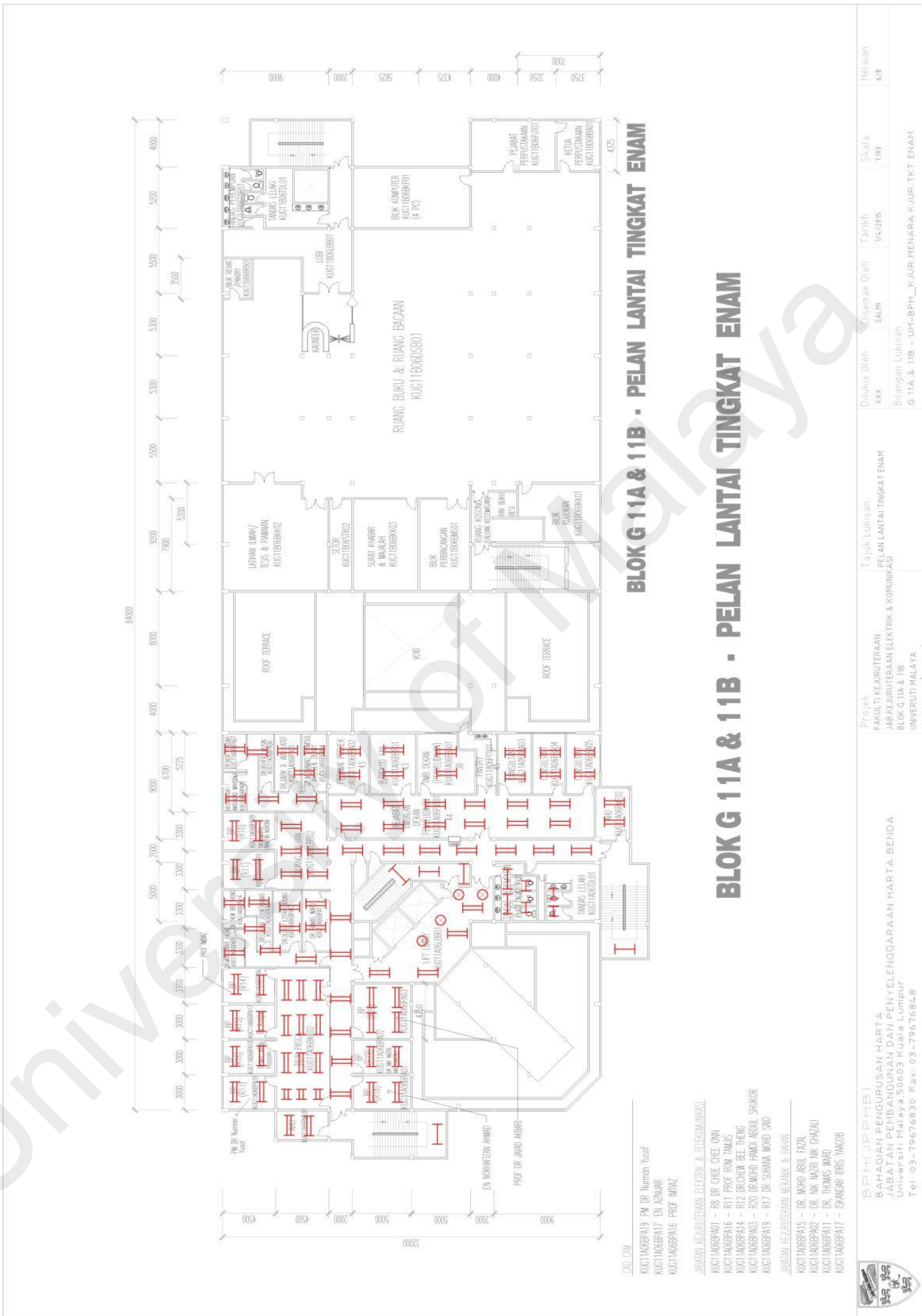


Figure 3.8: Block L Lighting Layout (Sixth Floor)

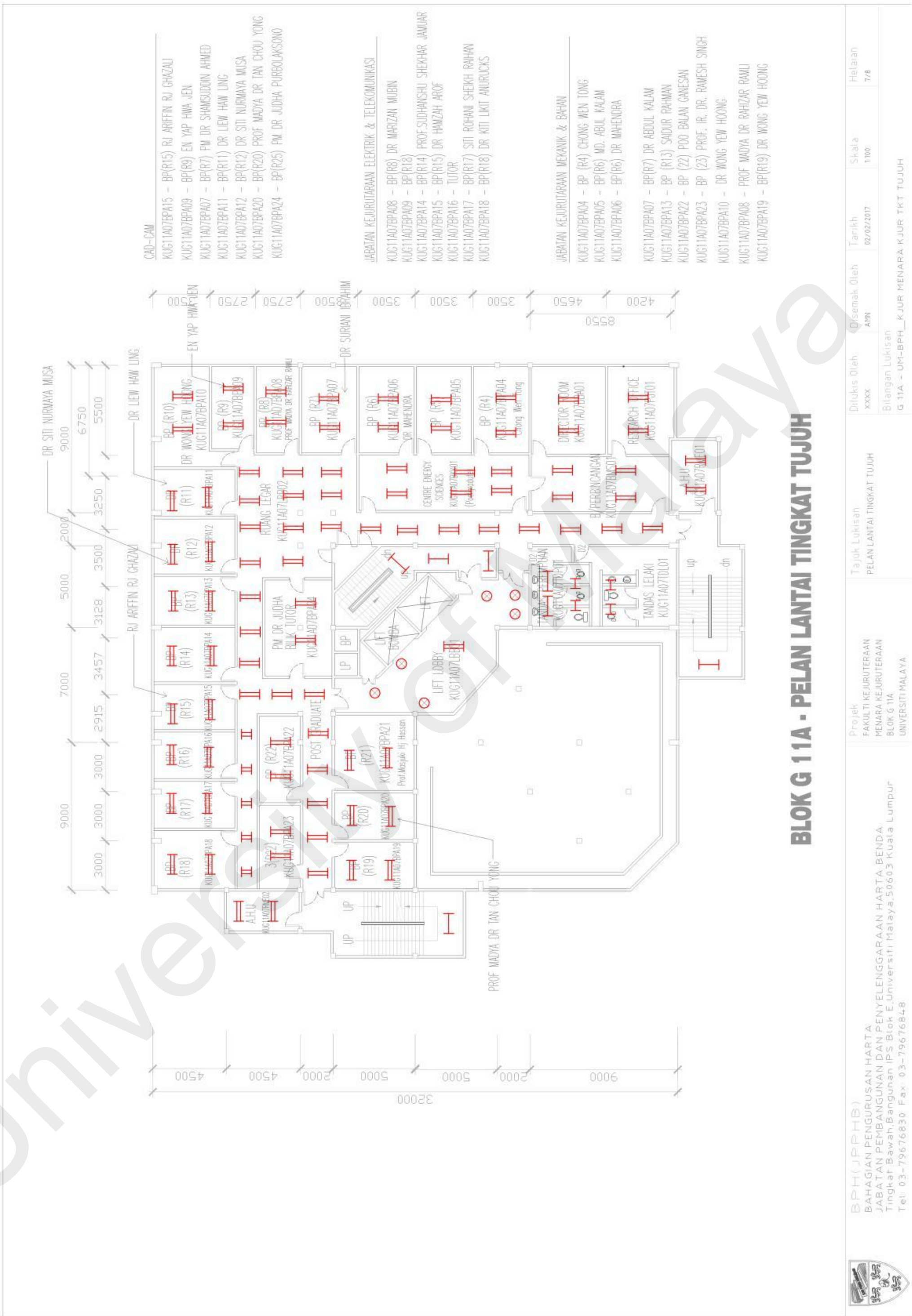


Figure 3.9: Block L Lighting Layout (Seventh Floor)

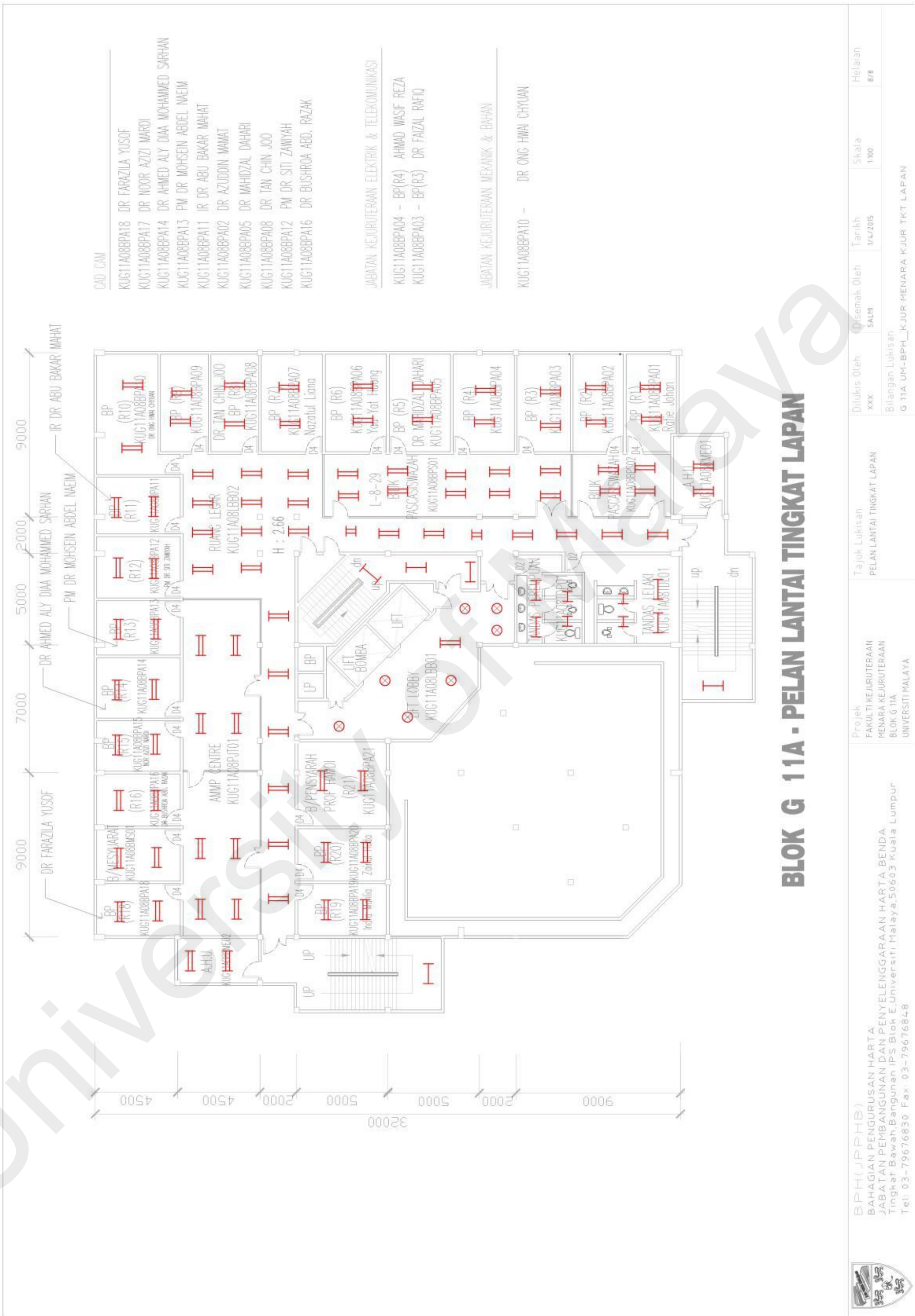


Figure 3.10: Block L Lighting Layout (Eighth Floor)

3.3 Ideal Lighting Technology.

CFL and Fluorescent tubes are the main lighting systems on campus. However, they are not considered energy efficient compared to new technologies. The appropriate lighting technology that can be achieved is the LEDs. LEDs save 80% more energy than incandescent lamps and save 30% to 40% more than most fluorescent lamps (Ganandran et al., 2014). LEDs are environmentally friendly and do not contain mercury, but fluorescence and CFL contain mercury and require special treatment or recycling methods, which contribute to the generation of hazardous waste. LED light sources have a longer life than traditional technology and can save replacement and maintenance costs. In addition, LEDs provide illumination without harmful infrared or ultraviolet radiation.

In the current market variable LED lamps can provide similar to the 36W fluorescent tube light output level. Replacing 36W T8 fluorescent tubes with 20W LED lamps can save up to 48%. The wattage and cost of LED lamps that replace 36W T8 vary by manufacturer. The advantage of replacing LED lamps is that they can be installed directly into the current fluorescent fittings simply by removing and replacing the starter. The cost of LEDs is higher than that of T8 to T5 converters, but the service life of LED lamps is almost five times that of quality. Lightweight retrofit has been recognized as one of the most effective ways to reduce overall energy consumption, such as the ISO 50001:2011 Standard and the management plan shown in the ASEAN Energy proposal (AEMAS). The light bulb selection in this study follows the above criteria to ensure that the required lighting is provided to the employees and students in the selected building.

The 4 feet LED tube which consists of 192 LED produces 2100 ± 100 lumens with 50,000 hours lifetime. Efficiency can reach up to 90 lm/W. LED tube has an easy installing method by just removing the current tube including the ballast and simple rewiring which is suggested to be done by qualified electrician. The 2 feet LED tube which is made of 108 LED creates 1150 ± 100 lumens with 50,000 hours life span. The installation method is same as the 4feet LED tube. Last but not least, the 9W LED bulb gives an equivalent output of a 18W CFL bulb. The lumens output is 650 ± 70 lumens and has 30,000 hours lifespan. Select the type of light used to replace the existing lighting system as shown in Figure 3.11.

(a) (b)

(c)

Figure 3.11: (a) 20W 4 feet LED tube replacing 36W fluorescent tube (b) 10W 2 feet LED tube replacing 18W fluorescent tube (e) 9W LED bulb light replacing Osram 18W (CFL) bulb.

3.4 Potential Energy Saving.

3.4.1 Electricity Consumption

The power consumption of existing fluorescent lamps throughout the building is estimated based on the data collected. The total energy consumption (EC) of the lighting system is determined by multiplying the number of lights (N), power of the light (W) used by each lighting unit with the operating hours (OH) of the illumination. The energy consumption of existing lighting systems per year is calculated based on the following equations (T. Mahlia et al., 2011a):

$$EC = \frac{N \times W \times OH}{1000} \qquad \text{(Equation 3.1)}$$

3.4.2 Energy Savings

Energy Saving (ES) is the difference between the energy consumption of existing (EC existing) and modified lighting (EC retrofitting) systems.

The following equations are used to calculate section energy:

$$ES = EC_{Existing} - EC_{\mathrm{Re}trofitting} \qquad \text{(Equation 3.2)}$$

3.4.3 Bill Savings

Cost savings (BS) are calculated by the product of energy saving (ES) and electricity (ET). In this study, it is assumed that electricity bills increase by around 2% a year (Mahlia, 2011). This can be calculated by the following equation:

$$BS = ES \times ET \qquad \text{(Equation 3.3)}$$

3.5 Payback Period and Life Cycle Cost Analysis.

3.5.1 Operating Cost

Operating costs (OC) are the cost of the newly revamped system, that is, the total number of lights (N), multiplied by the consumption of Watt (W), the number of running hours (OH) and electricity (ET), which can be achieved through the following equations:

$$OC = N \times W \times OH \times ET \quad \text{(Equation 3.4)}$$

3.5.2 Present Worth Factor

The present value factor (PWF) is the value of future cash flows received in order to obtain the current present value. The present value coefficient is calculated by the following equation:

$$PWF = \sum_{1}^{N} \frac{1}{(1+r)^t} = \frac{1}{r}\left[1 - \frac{1}{(1+r)^N}\right] \quad \text{(Equation 3.5)}$$

3.5.3 Payback Period

The payback period (PAY) measures the time required to increase incremental cost (ΔPC) required to improve efficiency by reducing operating costs. Find pay by solving the following equations:

$$\Delta PC + \sum_{1}^{PAY} \Delta OC_t = 0 \quad \text{(Equation 3.6)}$$

Typically, when the above expression changes the symbol, pay is found by interpolation between two years. If OC is a constant, the equation has the following solutions:

$$PAY = -\frac{\Delta PC}{\Delta OC} \quad \text{(Equation 3.7)}$$

PAY is the ratio of incremental costs (from baselines to more efficient products) to reduced operating costs per year. If PAY is larger than the lifespan of the product, it means that the increased purchase price will not be recycled at reduced operating costs.

3.5.4 Life Cycle Cost

Life cycle cost (LCC) analyzes the cost of a computing system or product over its entire life cycle. In this study, LCC was used to calculate the cost of energy efficiency improvement for retrofit-based lighting systems. LCC is the sum of the investment cost (PC) and the operating cost (OC) per year of discounts within the product life cycle. LCC can be calculated by the following equation (T. Mahlia et al., 2007):

$$LCC = PC + \sum_{1}^{N} \frac{OC_t}{(1-r)^t} \quad \text{(Equation 3.8)}$$

If the operating costs remain the same over time, the LCC is reduced to the following equation:

$$LCC = PC + (PWF)(OC) \quad \text{(Equation 3.9)}$$

3.6 Emission Reduction.

Carbon and hydrogen are considered to be the main components of most fuels, followed by a small fraction of sulphur. Combustion involves oxidation reactions, which usually provide necessary oxygen by a mixture of air, oxygen and nitrogen. Natural gas is used as the main fuel for electricity generation in Malaysia. The emission rate (EM) is equal to the emission factor (EF) multiplied by the fuel consumption (FC). Therefore, emissions (p) from the use of fuel (f) during the year (n) can be used in the following formula (Shekarchian et al., 2012):

$$EM_{nf}^{p} = EF_{f}^{p} \times FC_{nf} \quad \text{(Equation 3.10)}$$

Table 3.2 summarizes the potential emissions of each fuel based on Malaysian conditions.

Table3.2: Emission factors for estimating emissions from power plants (kg/kWh)

Fuel type	CO_2	NO_x	SO_2	CO
	Kg/kWh			
Coal	1.18	0.0052	0.0139	0.0002
Natural gas	0.53	0.0009	0.0005	0.0005
Fuel oil	0.85	0.0025	0.0164	0.0002
Diesel	0.85	0.0025	0.0164	0.0002

Projected emissions from the electricity generation process from 2017 to 2027 are derived from projected scenarios reported on the basis of local conditions. Scenarios are tools for sorting perceptions of future alternative environments, and the results may not be accurate for tomorrow's images, but may make better decisions for decision makers. Whatever the hell, analysts and policymakers will have scenarios similar to those of the future and will help researchers consider the consequences and possibilities of the future. The results are shown in Table 3.3.

Table 3.3: CO_2, SO_2, NO_x and CO emission production per kWh of electricity generation.

Fuels	Emission (kg/kWh)			
	CO_2	SO_2	NO_x	CO
Coal	1.18	0.0139	0.0052	0.0002
Petroleum	0.85	0.0164	0.0025	0.0002
Gas	0.53	0.0005	0.0009	0.0005
Hydro	0.00	0.0000	0.0000	0.0000
Other	0.00	0.0000	0.0000	0.0000

CHAPTER 4: RESULT AND DISCUSSION

Before any lighting system optimization strategies, overall lighting electricity consumed by the building was analyzed using both actual data and calculation results. The total lighting energy consumption was taken under consideration of the period of one year. The annual energy consumption of the building is the compared in terms of actual and calculation results.

The data of total annual lighting electricity energy consumed by target building was obtained from the Electrical Department, Department of Development and Asset Maintenance, University of Malaya (JPPHB). Data showing that the total lighting electricity energy consumed by Faculty of Engineering is 6144567 kWh (RM 3,125,986.20) in terms of electricity bill for year 2017. As for Block L (Department of Mechanical Engineering), it consumed 1377417 kWh; its lighting system consumed 15760 kWh, which occupies around 1.15% of total energy consumed by Block L.

4.1 Ideal Lighting Technology.

Table 4.1 shows the results of the walk-through lighting audit in the selected buildings above. There are three common types of lighting systems for selected buildings, namely OSRAM DULUXSTAR 18W/654 fitting G24d-2; Philips lifemax TLD fluorescent tubes 18W/54-765 2 pin fitting G13 for 2 feet and Philips lifemax TLD fluorescent tubes 36W/54-765 2 pin fitting G13 for 4 feet. The most commonly used tube is the Philips 36W/2Pin with G13 fitting that makes the total number of 1168 tubes. There are 438 of 18W fluorescent 2feet tube. The quantities of OSRAM DULUXSTAR 18W/654 fitting G24d-2 CFL bulb are 225. The total number of various types of lamps used in the selected building is 1831.

Table 4.1: Types and quantities of lights per floor.

Floor	Osram	18W	36W
1	47	10	15
2	110	50	134
3	23	210	164
4	24	132	133
5	4	4	235
6	4	10	201
7	6	14	139
8	7	8	147
total	225	438	1168

In order to calculate energy consumption and potential energy savings using efficiency lighting retrofits, the average number of hours worked per day and the number of lights are required. Interviews with staff revealed that in selected buildings, the normal working hours of the lighting system were 8 hours a day, 7 days a week (Postgraduate students have classes on weekends).

4.2 Potential Energy Saving.

This section describes the calculation results for electricity energy consumption, potential energy savings, billing savings, and payback periods. According to the latest electricity prices of TNB, a national power supplier, the electricity price for low-voltage commercial buildings is RM 0.5 per kilowatt-hour. Because electricity bills will grow as prices grow, it is assumed that electricity prices will increase by about 2% a year (T. M. I. Mahlia et al., 2011b). In this study, the first year of using a new energy-saving led to retrofit the old lighting system, the process lasted about 2-3 days.

Based on the formula mentioned in the preceding chapter (Equation 3.1), the daily electricity consumption is calculated to show that the total power consumption of lighting applications for selected buildings is approximately 434 kWh per day. At the same time, the total daily power consumption of LED lamps is about 240 kWh, showing a possible 44.7% savings in electricity. Table 4.2 shows the total energy consumption results of the existing lighting system. Among them, the first two lines represent the daily power consumption of each type of luminaire in the existing lighting system, while the latter two lines indicate the daily power consumption for each lamp type after replacing the LED lamp.

Table 4.2: Daily energy consumption between current and alternative light.

Present Light	Osram bulb 18W	Philips TLD 18W 2feet	Philips TLD 36W 4feet	total(kWh)
kWh	33	64	337	434
Alternative light	9W LED bulb	10W-2ft LED tube	20W-4ft LED tube	
kWh	17	36	187	240

Therefore, if all existing lighting systems are replaced by energy-saving LEDs, the annual electricity consumption prior to replacement is $434 \times 365 = 158410 \quad kW \cdot h$; and the annual electricity consumption after replacement is $240 \times 365 = 87600 \quad kW \cdot h$, so can save about 70,810 kWh of energy and 35,405 ringgit bills per year (based on RM 0.5 per kilowatt-hour). When fully replaced, power consumption decreases. This is because the size and the wattage of the bulb has been reduced meanwhile it can produce the same amount of light as the standard lighting system. In 2017, the lighting energy consumption of existing lighting systems is 158,410 kWh while LED systems proposed in 9 years (from 2018 to 2027) consumes 87,600 kWh.

It can be seen that when the light bulb is completely replaced, it can save a lot of original electricity bills every year.

Table 4.3 shows the bill savings calculated by Equation 3.3.

Table 4.3: Summary of billing savings is modified as a percentage per year

Years	Present EC(kWh)	LED energy consumption (kWh)	Price	BS
2017	158,410	158,410	0.50	0
2018	158,410	87,600	0.51	36,113.10
2019	158,410	87,600	0.52	36,835.36
2020	158,410	87,600	0.53	37,571.79
2021	158,410	87,600	0.54	38,322.37
2022	158,410	87,600	0.55	39,087.12
2023	158,410	87,600	0.56	39,866.03
2024	158,410	87,600	0.57	40,666.18
2025	158,410	87,600	0.59	41,480.50
2026	158,410	87,600	0.60	42,308.98
2027	158,410	87,600	0.61	43,158.70

4.3 Payback Period and Life Cycle Cost Analysis.

The payback period is used to measure the time it takes to recover an investment. The payback period is an important basis for financial management personnel to judge whether the investment has an appropriate payback period. Cost refers to the total energy costs consumed by the retrofit system.

In order to analyze the life cycle cost of the lighting system, the total cost of the installation, maintenance and operation of its life has been taken into account. In this project, LCC is used to determine the cost of effective progress in the energy of the LED lighting system to be implemented. Table 4.4 shows the complete LCC analysis calculation of 20W LED lamps replaced with Philips 36W fluorescent tubes.

Table 4.4: LCC analysis 20W LED tube instead of Philips 36W fluorescent tube.

Variables	**Value**	**Unit**
Power of LED Lamps	20	Watts
Unit price of LED lamps	60	Ringgit
Power of existing lamps	36	Watts
Unit price of existing lamps	10	Ringgit
Number of lights	1,168	Lamp(s)
Operating hours (per day)	8	Hours
Number of days of operation (per year)	365	Days
Energy cost/kWh	0.5	Ringgit
Calculations	**Existing system**	**LED**
Electrical costs		
-Electrical load of lamp(s)	42,048	23,360
-Annual operating hours (hours)	2,920	2,920
-Annual energy consumption (kWh)	122,780.16	68,211.2
-Saving electricity (kWh)	0	54,568.96
-Energy total cost (per year)	RM61,390.08	RM34,105.6
-Save on Electricity bills (per year)	RM0.00	RM27,284.48
Capital requirements		
-Purchase requirements Cost	RM11,680.00	RM70,080
-Installation cost per unit	RM2.00	RM1.00
-Installation costs	RM2,336	RM1,168
-Total capital investment requirements	RM14,016	RM71,248
-Net investment requirement	RM0.00	RM57,232
Maintenance requirements		

-Lamp lifespan (operating hours)	15,000	50,000
-Need to be replaced (per year)	227.37	68.2112
-Replacement costs (per year)	RM2,273.7	RM4,092.67
-Installation cost per new unit	RM2.00	RM1.00
-Maintenance costs (per year)	RM454.74	RM68.21
-Total maintenance costs (per year)	RM2,728.44	RM4,160.88
-Maintenance saving (per year)	RM0.00	-RM1,432.48
Return on investment (ROI) results		
-Total operating cost (per year)	RM64,118.52	RM38,266.48
-First year total savings	RM0.00	RM25,852
-Payback period (year)	n/a	2.21
-More than 10 years LED (ROI)	RM0.00	RM83,084

Calculating the LCC for 20W LED tube can get Table 4.5 as following:

Table 4.5: LCC calculation for 20W LED tube

Year	Year No.	r	PWF	PC	Maintenance Cost	EC	LCC
2017	0	0.07	1	71,248	4,160.88	34,105.6	0
2018	1	0.07	1.08	0	4,474.06	36,672.69	112,394.75
2019	2	0.07	1.16	0	4,810.82	39,433.00	156,638.57
2020	3	0.07	1.24	0	5,172.93	42,401.07	204,212.57
2021	4	0.07	1.34	0	5,562.29	45,592.55	255,367.41
2022	5	0.07	1.44	0	5,980.95	49,024.25	310,372.61
2023	6	0.07	1.55	0	6,431.13	52,714.25	369,517.99
2024	7	0.07	1.66	0	6,915.20	56,681.99	433,115.18

2025	8	0.07	1.79	0	7,435.70	60,948.37	501,499.24
2026	9	0.07	1.92	0	7,995.37	65,535.88	575,030.50
2027	10	0.07	2.07	0	8,597.17	70,468.69	654,096.36

The same method is used to analyze the LCC of the 10W LED lamp, which is used instead of the Philips 18W fluorescent tube, and the 9W LED bulb is used instead of the Osram 18W CFL bulb. Can get Table 4.6-Table 4.9.

Table 4.6: LCC analysis 10W LED tube instead of Philips 18W fluorescent tube.

Variables	**Value**	**Unit**
Power of LED Lamps	10	Watts
Unit price of LED lamps	30	Ringgit
Power of existing lamps	18	Watts
Unit price of existing lamps	5	Ringgit
Number of lights	438	Lamp(s)
Operating hours (per day)	8	Hours
Number of days of operation (per year)	365	Days
Energy cost/kWh	0.5	Ringgit
Calculations	**Existing system**	**LED**
Electrical costs		
-Electrical load of lamp(s)	7,884	4,380
-Annual operating hours (hours)	2,920	2,920
-Annual energy consumption (kWh)	23,021.28	12,789.6
-Saving electricity (kWh)	0	10,231.68
-Energy total cost (per year)	RM11,510.64	RM6,394.8
-Save on Electricity bills (per year)	RM0.00	RM5,115.84
Capital requirements		

-Purchase requirements Cost	RM2,190	RM13,140
-Installation cost per unit	RM2.00	RM1.00
-Installation costs	RM876	RM438
-Total capital investment requirements	RM3,066	RM13,578
-Net investment requirement	RM0.00	RM10,512
Maintenance requirements		
-Lamp lifespan (operating hours)	15,000	50,000
-Need to be replaced (per year)	85.26	25.5792
-Replacement costs (per year)	RM426.3	RM767.376
-Installation cost per new unit	RM2.00	RM1.00
-Maintenance costs (per year)	RM170.52	RM25.58
-Total maintenance costs (per year)	RM596.82	RM792.95
-Maintenance saving (per year)	RM0.00	-RM196.13
Return on investment (ROI) results		
-Total operating cost (per year)	RM12,107.46	RM7,187.75
-First year total savings	RM0.00	RM4,919.71
-Payback period (year)	n/a	2.14
-More than 10 years LED (ROI)	RM0.00	RM15,431.71

Table 4.7: LCC calculation for 10W LED tube

Year	Year No.	r	PWF	PC	Maintenance Cost	EC	LCC
2017	0	0.07	1	13,578	792.95	6,394.80	0
2018	1	0.07	1.08	0	852.63	6,876.13	21,306.76
2019	2	0.07	1.16	0	916.81	7,393.69	29,617.26
2020	3	0.07	1.24	0	985.82	7,950.20	38,553.28
2021	4	0.07	1.34	0	1,060.02	8,548.60	48,161.908

2022	5	0.07	1.44	0	1,139.81	9,192.05	58,493.76
2023	6	0.07	1.55	0	1,225.60	9,883.92	69,603.28
2024	7	0.07	1.66	0	1,317.85	10,627.87	81,549.00
2025	8	0.07	1.79	0	1,417.04	11,427.82	94,393.86
2026	9	0.07	1.92	0	1,523.70	12,287.98	108,205.53
2027	10	0.07	2.07	0	1,638.39	13,212.88	123,056.80

Table 4.8: LCC analysis for the 9W LED bulb replacing Osram 18W fluorescent bulb.

Variables	**Value**	**Unit**
Power of LED Lamps	9	Watts
Unit price of LED lamps	20	Ringgit
Power of existing lamps	18	Watts
Unit price of existing lamps	5	Ringgit
Number of lights	225	Lamp(s)
Operating hours (per day)	8	Hours
Number of days of operation (per year)	365	Days
Energy cost/kWh	0.5	Ringgit

Calculations	**Existing system**	**LED**
Electrical costs		
-Electrical load of lamp(s)	4,050	2,025
-Annual operating hours (hours)	2,920	2,920
-Annual energy consumption (kWh)	11,826	5,913
-Saving electricity (kWh)	0	5,913
-Energy total cost (per year)	RM5,913	RM2,956.5
-Save on Electricity bills (per year)	RM0.00	RM2,956.5

Capital requirements		
-Purchase requirements Cost	RM1,125	RM4,500
-Installation cost per unit	RM2.00	RM1.00
-Installation costs	RM2,250	RM4,500
-Total capital investment requirements	RM3,375	RM9,000
-Net investment requirement	RM0.00	RM5,625
Maintenance requirements		
-Lamp lifespan (operating hours)	10,000	30,000
-Need to be replaced (per year)	65.70	21.9
-Replacement costs (per year)	RM328.5	RM438
-Installation cost per new unit	RM2.00	RM1.00
-Maintenance costs (per year)	RM131.4	RM21.9
-Total maintenance costs (per year)	RM459.9	RM459.9
-Maintenance saving (per year)	RM0.00	-RM0
Return on investment (ROI) results		
-Total operating cost (per year)	RM6,372.9	RM3,416.4
-First year total savings	RM0.00	RM2,956.5
-Payback period (year)	n/a	1.9
-More than 10 years LED (ROI)	RM0.00	RM8,581.5

Table 4.9: LCC calculation for 9W LED bulb

Year	Year No.	r	PWF	PC	Maintenance Cost	EC	LCC
2017	0	0.07	1	9,000	459.90	2,956.50	0
2018	1	0.07	1.08	0	494.52	3,179.03	12,673.55
2019	2	0.07	1.16	0	531.74	3,418.31	16,623.60
2020	3	0.07	1.24	0	571.76	3,675.61	20,870.97
2021	4	0.07	1.34	0	614.80	3,952.27	25,438.03
2022	5	0.07	1.44	0	661.07	4,249.75	30,348.85
2023	6	0.07	1.55	0	710.83	4,569.62	35,629.30
2024	7	0.07	1.67	0	764.33	4,913.57	41,307.21
2025	8	0.07	1.79	0	821.86	5,283.41	47,412.48
2026	9	0.07	1.92	0	883.72	5,681.09	53,977.29
2027	10	0.07	2.07	0	950.24	6,108.69	61,036.22

20W LED tube completed the transformation of the investment payback period of 2.21 years, 10W led tube for 2.14 years, 9W LED bulb for 1.9 years. Fundamentally, after two years, the target building will generate profits for the investment. The results of the investment payback period analysis are shown in Figure 4.1-Figure 4.3.

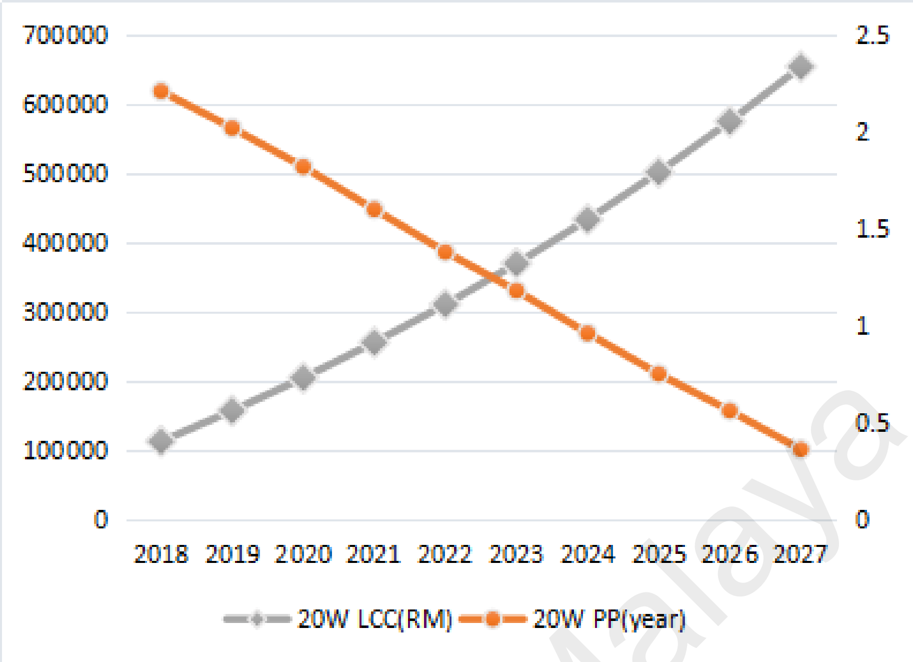


Figure 4.1: Life cycle cost and payback period of 20W LED tube

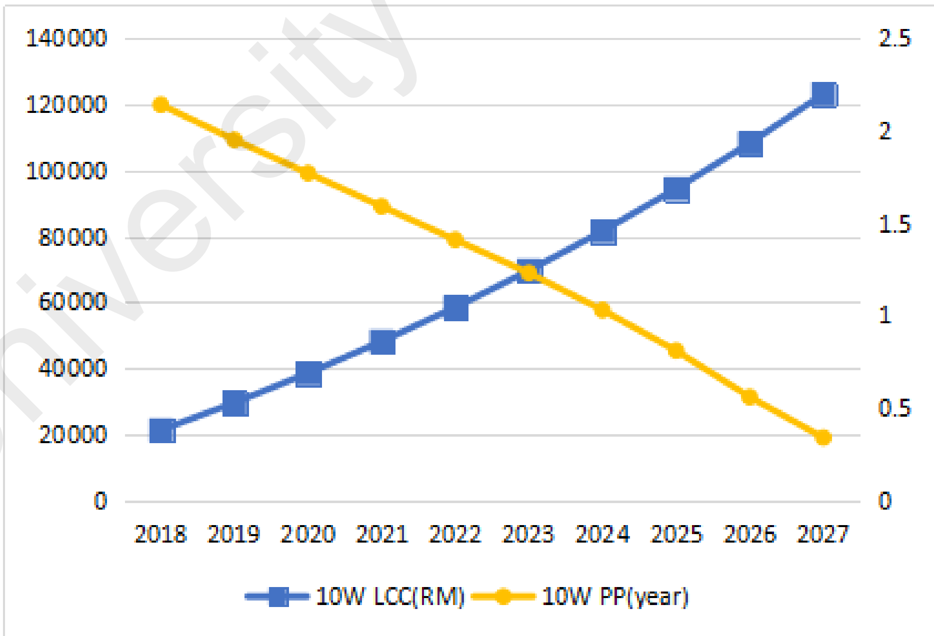


Figure 4.2: Life cycle cost and payback period of 10W LED tube

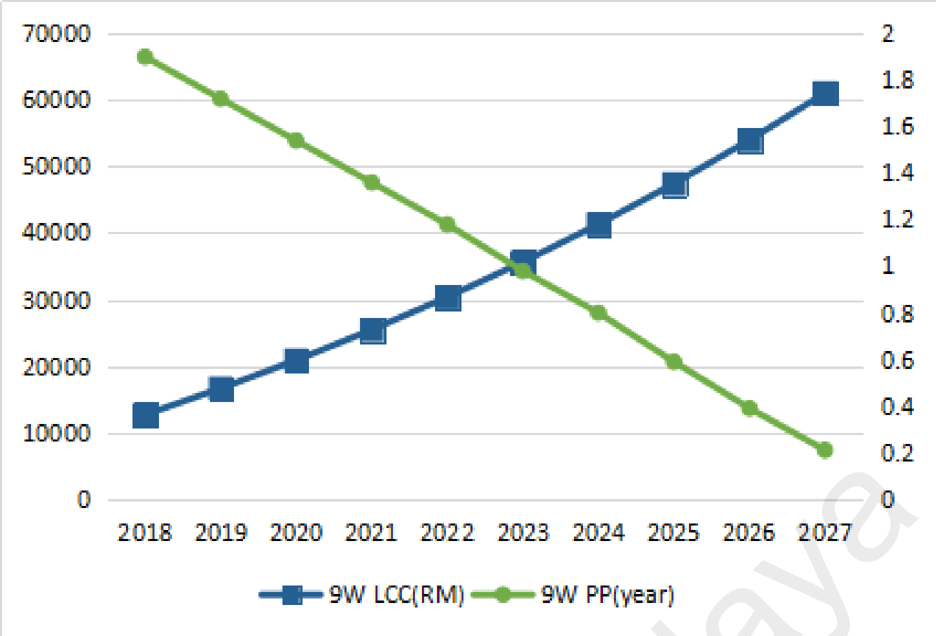


Figure 4.3: Life cycle cost and payback period of 9W LED bulb

4.4 Emission Reduction.

The emission reduction analysis of energy-saving LEDs is carried out by predicting future data of fuel hybrid power generation in Malaysia. However, due to unpredictability, the data used may differ from the actual situation and are beyond the scope of this study. The data shown in Table 4.10 are calculated and tabulated according to the data. Figure 4.4 shows the projected Malaysian power generation fuel portfolio used in the project. As shown in the figure, Malaysia is also beginning to invest in renewable energy.

Table 4.10: Forecast of electricity consumption and percentage of fuel generation fuels in Malaysia

Year	Total(kWh)	Coal(%)	Petroleum(%)	Gas(%)	Hydro(%)	CO2 (ton)	SO2 (kg)	NOx (kg)	CO (kg)
2017	158,410	24.86	1.09	41.95	32.10	8,316	60,893	26,890	4,144
2018	87,600	26.16	1.04	41.20	31.60	4,694	35,152	15,392	2,281
2019	87,600	27.54	1.01	40.55	30.90	4,805	36,760	15,963	2,276
2020	87,600	29.00	1.00	40.00	30.00	4,929	38,500	16,582	2,277
2021	87,600	30.34	0.96	39.30	29.40	5,032	40,043	17,129	2,269
2022	87,600	31.72	0.93	38.65	28.70	5,143	41,652	17,699	2,264
2023	87,600	33.10	0.90	38.00	28.00	5,253	43,261	18,270	2,260
2024	87,600	34.48	0.87	37.35	27.30	5,363	44,870	18,841	2,255
2025	87,600	35.86	0.84	36.70	26.60	5,473	46,478	19,412	2,250
2026	87,600	37.24	0.81	36.05	25.90	5,583	48,087	19,983	2,245
2027	87,600	38.62	0.78	35.40	25.20	5,694	49,696	20,553	2,240

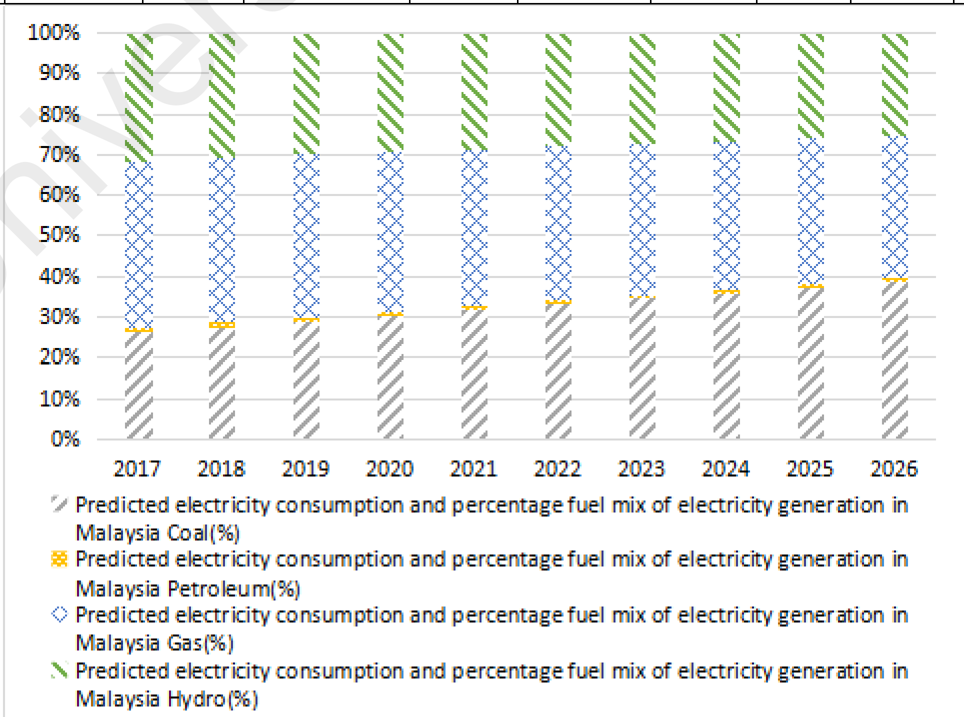


Figure 4.4: Percentage of electricity fuel portfolio projected

Reduced total electricity consumption as a result of transformation, thus helping to reduce the harmful effects of greenhouse gas emissions. The proposed model illustrates that the overall emission production reduction of around 2,622 ton of CO_2, 11,197 kg of SO_2, 6,336 kg of NO_x, and 1,904 kg of CO after 100% retrofit. The total reductions from 0% to 100% of CO_2, SO_2, NO_x and CO gases emissions during electricity generation retrofitting is presented in Figure 4.5 as an annual increase in emission reduction.

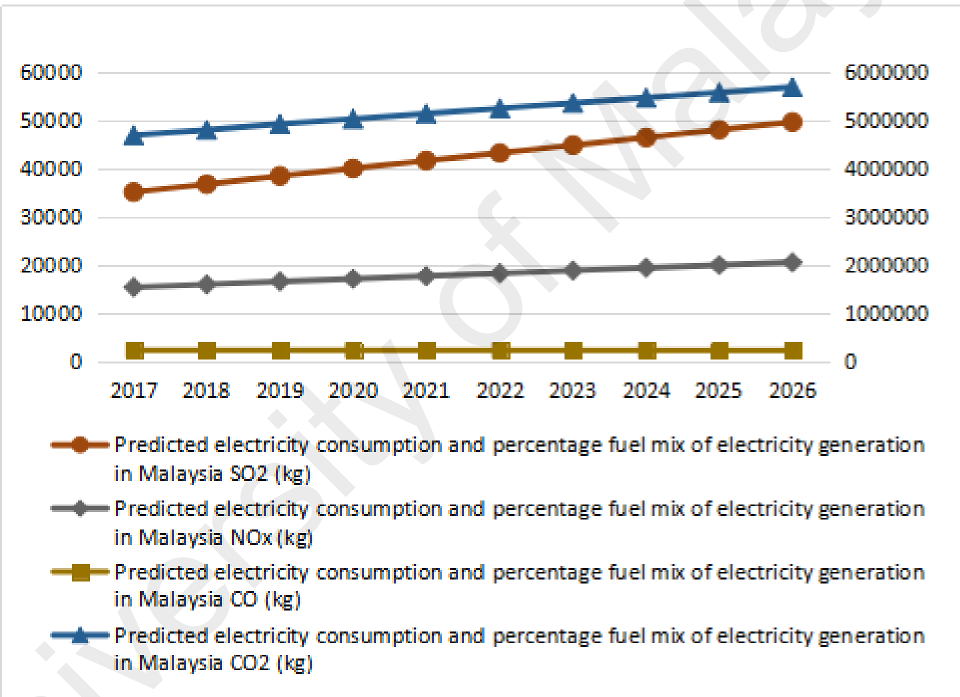


Figure 4.5: Patterns of electricity generation emissions in Malaysia.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The demand for electricity is increasing in both developed and developing countries as a result of increasing global electricity use. One of the quick options for energy saving is the use of energy-efficient appliances. The lighting system has great potential in energy saving among them. The present research project has focused on the selected buildings in Faculty of Engineering, University of Malaya, aiming to design appropriate lighting retrofit solutions and calculate the potential power-saving costs, payback periods and potential environmental benefits. In this project, based on the comparison between the existing lighting system and the proposed transformation with LED, the generation of energy saving and emission reduction is analyzed. Besides, the strategy of retrofitting old lighting systems with new energy-saving LEDs at the beginning of the first year is used to replace all lighting systems. The results of the life cycle analysis reveal that, around two years later, the selected buildings will bring investment profits.

In addition, compared with the existing CFL lighting system, the replacement of T5 electronic ballast and the replacement of LED lamps are more energy-efficient. By 100% retrofit of existing lighting systems using LED lamps, can save about 44.7% of energy consumption and have a payback period of about 2 years. However, by using the T5 lamp with electronic ballast, the power saving is less and the investment payback period is longer. The advantage of replacing LED luminaires is that they can be installed directly into the current fluorescent fittings by simply removing and replacing the starter. The cost of LEDs is higher than that of T8-T5 converters, but the service life of LED lamps is almost 5 times that of quality. Therefore, while the initial investment cost of

LEDs is higher than that of T5 electronic ballast lighting systems, LED lighting systems will still save more on electricity costs in the long run.

As a result, the proposed strategy could be applied to other buildings because, as evidenced by the Institute, it has significant potential savings in reducing electricity costs and reducing emissions. It can also meet the objectives of the research project stated before.

5.2 Recommendation

The following are some of the suggested steps that could be taken into account in future research work. Further extensions of the research that could be carried out include:

(a) On the premise of satisfying the lighting conditions, try to optimize the type of LEDs or appropriately reduce the number of LEDs.

(b) Partial or complete replacement of electronic ballasts while replacing LED lights.

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