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Simulation on Lighting Energy Consumption based on Building Information Modelling for Energy Efficiency at Highway Rest and Service Areas Malaysia

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Abstract. Building consumes 40% of global energy consumption which contributes for such a majority amount of carbon dioxide emission. Enhancing the energy efficiency strategies in buildings by retrofitting through different approaches is essential for reducing end user on the amount of energy consumption and carbon footprint emission. Previous research shows that only a few studies have been conducted on retrofitting the energy performance on Rest and Service Area yet the result shows that lack of technical feasibility practice was reviewed. Hence, this paper explores the energy efficiency strategy by improving the lighting performance based on 24 hours service building at Rest and Service Area Ayer Keroh Northbound Malaysia. The simulation that was performed in lighting energy consumption was EnergyPLUS software, Autodesk Revit and RELUX Plug in tool in Revit. Preliminary study was conducted to identity the problem on energy performance at Rest and Service Area Ayer Keroh by determine the total energy consumption by sources and Building Energy Intensity [BEI]. The result shows lighting contributes to the most total load consumption due to lack of energy conservation management and energy efficiency strategy practices. The lighting simulation scenarios was created to enhance the energy consumption performance and reduced the irrelevant carbon footprint emission. The simulation in Revit and EnergyPLUS showed 17% and 49% reduction respectively on the end load of lighting energy consumption by reducing the overall time operation and daylight control dimming system.

1. Introduction

Situated in a tropical region, Malaysia experience a hot and humid weather which results in a huge amount of energy consumption. From the year of 2000 to 2018, the total energy consumption in Malaysia gradually increased from 53 billion (kWh) to 132 billion (kWh) [1] with the electrical power generation mainly relies on fossil fuel and it is expected to grow from 48% in 2015 to 66% of the overall consumption by 2023 [2]. Thus, energy-efficient and low-carbon energy strategies for buildings is play an important role to achieve a major reduction of carbon dioxide emission toward a sustainable nation [3].

To cope with such weather, many studied has been focusing on the energy refurbishment in existing buildings such as retrofitting on the envelopes which can compromise thermal comfort and reduce the energy load [4]. Other studies are focused on retrofitting the building mechanism system such as heating, cooling and lightings to achieve significant energy reductions by study on the pattern of occupant behavior or optimize the equipment design its self [5]. Artificial lighting is one the most energy consumer is many non-residential buildings in which energy efficient measure such as dynamic simulation should be promoted to reduce the load of consumption [6]. A recent study by [7] analyze the behavior of indoor lighting environment in a cigarette factory and energy consumption through simulation in Ecotect software. By adjusting on the size of skylight and change material on the roof material, the indoor lighting environment is enhanced with adequate illuminance and efficient lighting energy consumption is performed. [8] conducted an artificial lighting controls simulation integrates with daylight harvesting in reducing the heat energy consumption in EnergyPlus simulation program. The effect from dimming control with daylighting can save about 40% of the total energy consumption and enhance the visual comfort in indoor environment [9].

This paper simulates the artificial lighting energy consumption on a 24hours service building by implement the effect of ON/OFF control dimming integrate with natural daylighting for potential energy saving. There are a few studies has conducted at Rest and Service Areas Malaysia regarding potential energy retrofitting yet there is lack of study which consider on energy simulation for estimating the real energy consumption and saving from the energy efficiency measure [10]. The building model of Rest and Service Area is built up in Autodesk Revit before it was exported to EnergyPLUS for energy consumption simulation. The lighting profile is simulated in Autodesk Revit 2018 by using the RELUX plugin tool for analyze on the exiting lighting performance of the building.

2. Literature Review

2.1. Net-ZEB and sustainable Rest and Service Areas

The concept of Net-ZEB in buildings is the use of energy efficiency and the capability to generate electricity from renewable sources to fulfil the energy demand [11]. Various studies have conducted on the energy refurbishment of existing buildings due to a great attention has been paid on such matter in the recent EU directives [3]. [3] proposed an optimum approach for selecting the retrofitting measure and the outcome showed that modernization of energy systems is the most beneficial measure for reaching target of achieving net zero-energy. The study evaluated the energy efficiency measure in a historical building by analyse on the thermal comfort in EnergyPLUS software for potential energy saving. Cost-optimal is one of the most concerned factors for the practice of energy efficiency in order to archive the nearly zero energy building (nZEB) for energy performance [12] [13].

Rest and service areas are function as a part of highway services and facilities to provide passenger a more enjoyable journey. This type of facility offers a 24 hours service which refurbishment is essential to ensure the standard of services when the lifetime of building get to the highest productivity life. [14] explored the retrofitting measure by analysis on the variables effecting energy consumption in a non-residential building. The result from factor loading prioritized the level of significant of each variable effecting energy consumption which can provide a clear roadmap for energy retrofitting. There are numerous green building assessment tools such as BREAM, LEED, CASBEE, Green Star and GBI established for the purpose of promote the application of renewable energy sources and introduced to the passive design for reduce the operational energy use in building. On-site renewable energy sources combined with hi-tech energy efficiency application is the fundamental concept in green building toward nearly zero energy building or low carbon buildings [15]. [16] conducted a case study on rest areas at United States which adapted various energy efficiency strategies such as installing lighting sensors, enhance HVAC and window system, minimise toilet ventilation and improve the insulation enable to save the operational costs by $15,000 per year and reduce the electricity load by 500 million UK thermal Units. Another study conducted at 32 Colorado rest areas for optimize the cost saving from energy efficiency in order to consider a best decision for retrofitting options. The assessment on these rest areas is performed to determine the sustainability design and the quality of operation and maintenance activities by referred to LEED assessment criteria. The rest areas were categorized into four different types according to their function provided and each group was tested by adapted various type of energy retrofitting measure and implement the renewable energy sources. The assessment outcome showed that renewable energy sources such as solar power (PV) and wind turbines are highly potential to adapted at rest areas for generate on-site energy sources due to the potential alternative energy harvesting offered by each area. Heating and lighting load are the main dominated to electricity consumption and lighting is a primary energy consumer for some specific areas such as toilet, parking and walkway [17].

2.2. Lighting control methods

Artificial lighting contributes such a significant amount of global energy consumption. In non-residential buildings, the consumption of artificial lighting accounts about 40% of total load of consumption [18]. Therefore, control of artificial lighting and keeping the visual comfort is essential way to decrease the lighting load and reduce the building operational costs. Adapting the change of occupancy and integrated with daylight are the main methods for energy efficiency lighting control [19]. At 24 hours service building, the small change in occupancy behaviour can creates a significant effect to the energy consumption. Dimming control of luminaires and occupancy sensor used to adapt the amount of localized illuminance according to daylighting enable to provide a deep energy saving and flexible luminaires [20]. [19] categorized lighting control system into 2 primary designs namely centralized control and distributed control which is based on luminaire sensing as shown in figure 1.

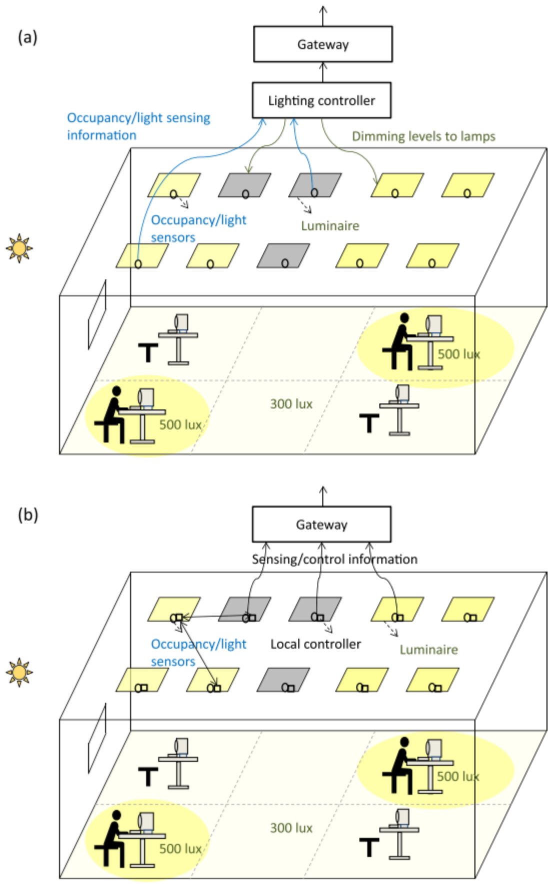

Figure 1. Smart indoor lighting system (a) centralized control and (b) distributed control [19].

3. Methodology

In this paper, a case study was conducted at Rest and Service Areas Ayer Keroh Northbound dining area building which located at west bound of Peninsular Malaysia. The aim of this study is to adapt the lighting energy efficiency to the building which is overload by the lighting energy consumption due to the lack of energy conservation and energy management measures [14]. Preliminary study revealed that the building energy consumption occupied majority by lighting load which account about half of the total energy consumption with the Building Energy Intensity [BEI] 287.88kWh/m^2/year according to the calculation. Equation 1 indicates the Building Energy Intensity based on Tahir [20] which most like being used for building.

Calculation Building Energy Intensity (BEI):

$$BEI = \frac{Total\ Energy\ Used\ per\ year}{Gross\ Floor\ Area} \left(\frac{\frac{kWh}{m^2}}{year}\right)$$ (Eq1) (Tahir *et al.*, 2015) [20]

Lighting energy efficiency was proposed with the use of dimming effect combine with natural daylight and turn off the light when there is adequate daylighting inside the building. 3 scenarios analysis was created for the simulation in Autodesk Revit and EnergyPLUS. In addition, RELUX desktop is use for testing the lighting performance of the existing scenario. The building architecture and electrical model was created in Autodesk Revit 2018 before import into EnergyPLUS simulation tool. There are total 29 light bulbs consist in the dining area of Ayer Keroh Rest and Service Area which does not include the light bulbs from the stall area or shop lot since the consumption for stall owner is separate from the building owner. The light bulbs type is high pressure sodium High bay NIKKON brand (Malaysia) with the power consumption of each bulb is 70W.

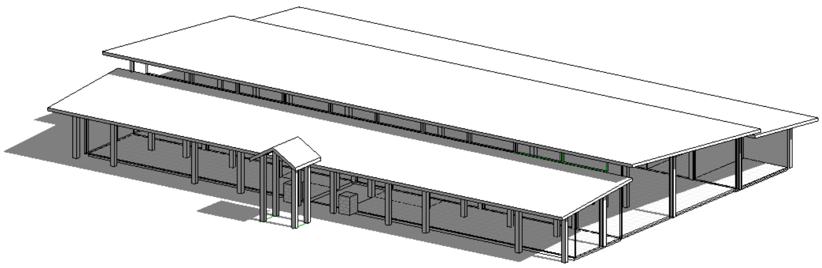

Figure 2. Ayer Keroh dining area Building Architecture model in Autodesk Revit 2018.

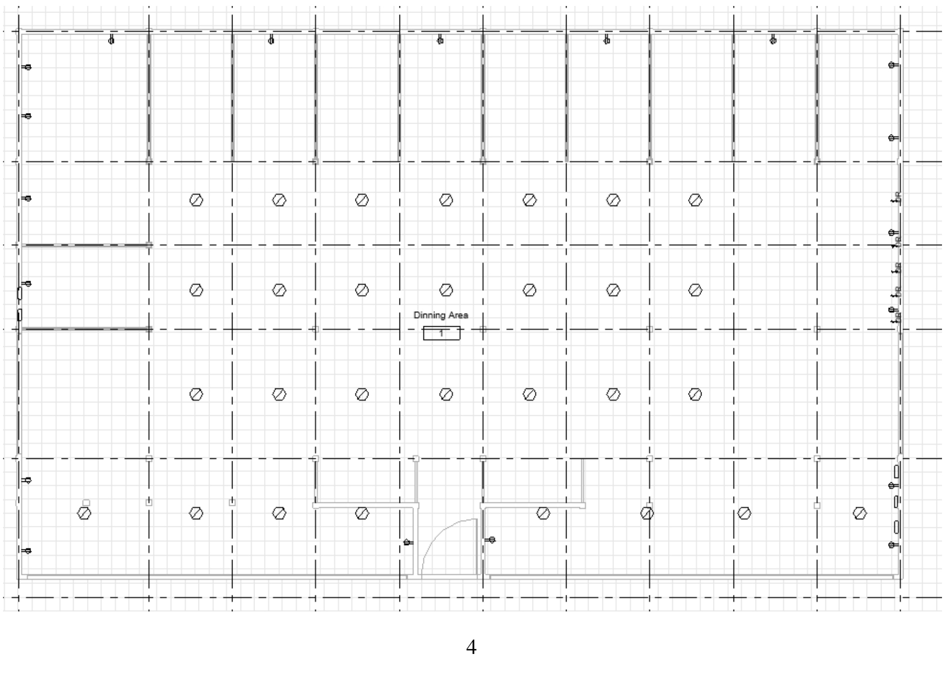

Figure 3. Ayer Keroh dining area layout model in Autodesk Revit 2018.

3.1. Scenario analysis

The lighting scenarios was made as control schemes to see the effect the lighting consumption of the building. Three scenarios with various lighting control measures are simulation and compare to the baseline scenario. The first scenario is considered as the baseline which the light is consumed to Turn ON for 24 hours as the practice of the existing condition of the building. The second scenario is the light turn ON when the area is dark or there is not adequate daylight in the dining area. The third scenario is the use of dimming lighting control technic by integrated daylight with artificial lighting. The artificial lighting responses to the affect from daylighting during the daytime by reducing its dimming which results in decreasing the load consumption. The illuminance will adjust accordingly to the area by the contributed from natural daylighting and it also adapt the same measure as scenario 2 which the light is turn ON when the area is dark.

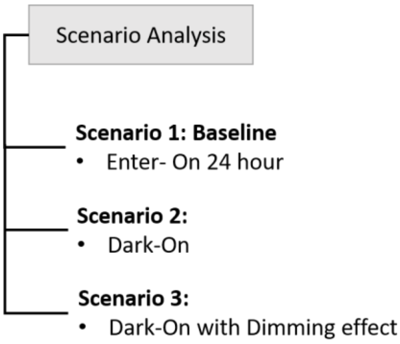

Figure 4. Scenario Analysis for Lighting simulation.

3.2. Simulation procedure

The architecture model electrical model was prepared inside BIM application software called Autodesk Revit 2018. The building components have to keep as simple as possible to avoid any error during the file export to EnergyPLUS simulation software. After the model is ready to export, the energy analytical model was necessarily needed before convert to gbXML format file. The gbXMLdata format was developed by Green Building Studio Inc. in 1999 for the purpose energy analysis. EnergyPLUS runs the simulation from the data transfer BIM model in the format of gbXML file [21]. In addition, RELUX plug in tool is also used to see the lighting performance of the existing scenario.

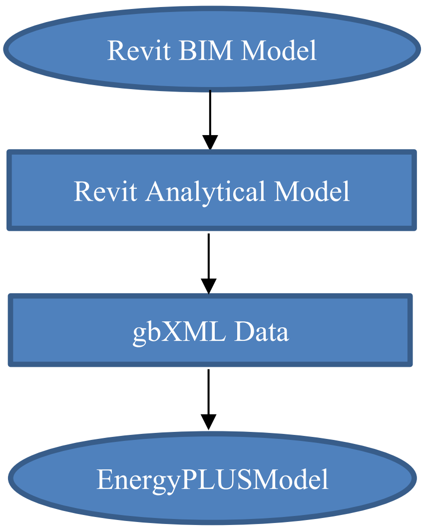

Figure 5. Data Diagram for Revit to EnergyPLUS transition.

4. Findings

4.1. Lighting profile

The lighting performance was simulation inside Autodesk Revit with the RELUX plug in tool. RELUX is software developed by RELUX Informatik AG in Switzerland with the collaboration from the various number of luminaire and lamp manufacturers provides an easy way to import the lighting manufacturers' database to the simulation [22]. This lighting simulation tool is simple and reliable for conducting lighting simulation and it is also simulated the visual building design elements such as materials, furnishing and colour [9]. [9] conducted a daylight simulation in RELUX for analysis of annual energy saving in an enclosed building in University of Nottingham, UK. With the help of RELUX, the illuminance distribution in the room is displayed.

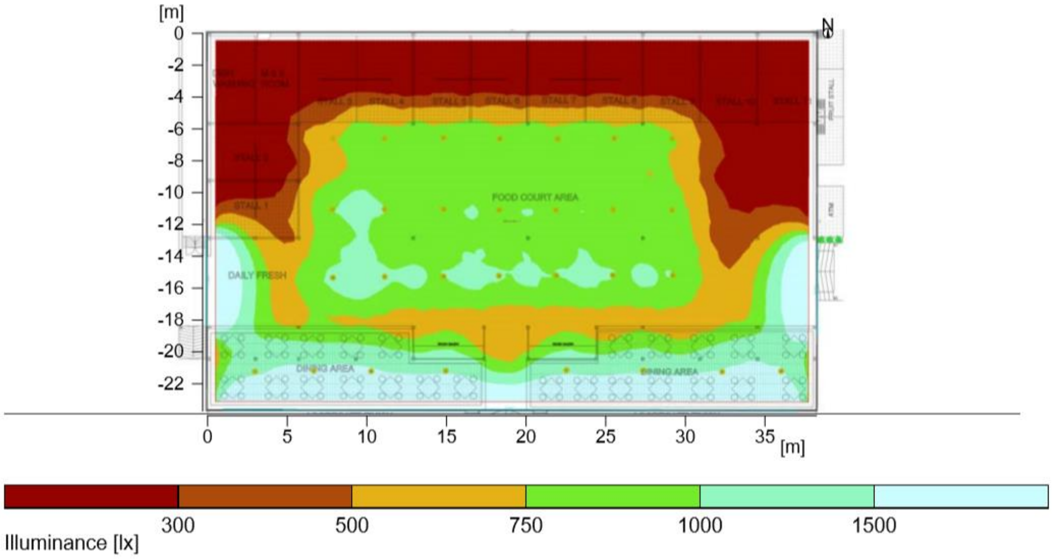

Figure 6. Artificial and daylight profile of the dining area of the Rest and Service Area.

The stall area was assumed there is no light install since there is a separate meter between the dining area and the shop lots. The electrical bill was assigned separately to the shop lots owner and the dining area lighting load was meant for PLUS Behad company which is one of the Malaysia highway concessionaires. The lighting bulb that use in the dining area is high bay lighting with the power consumption is 70W NIKKON Brand. As can be seen from the graph, some area in the dinning space is over illuminance which the colour is turn to light green. and the lighting distribution in the area is not uniform. According, Malaysia Standard MS 1525:2014 for non-residential building, the adequate illuminance for dining space is only 300 lux [23] . Due to the building is as open space building, harvesting the daylighting and decrease the demand for artificial lighting to illuminance the area is considered as an efficiency strategy for energy saving this building. Thus, replace the convention lighting bulb and the lighting control technology is compulsory to reduce the energy consumption for the area.

4.2. Lighting consumption from the Scenarios

The benchmark result of building energy performance from Autodesk Revit showed that BEI of the building is 379 kW/m^2/year which the cost for energy consumption per meter square per year is about 27.5 USD. The standard of the benchmark is followed ASHRAE 90.1 standard for energy efficiency index. ASHRAE 90.1 stands for American Society of Heating, Refrigeration and Air-Conditioning Engineers which is standard manual for rating building performance. Performance Cost Index (PCI) was modelled by ASHRAE to compare the prototype building regulated energy cost for a given building prototype, climate zone and edition [24]. This benchmark is use as future reference for the energy saving and energy efficiency measure.

$$BPF_{YearX} = \sum \frac{Prototype\ Building\ Regulated\ Energy\ Cost\ \ yearx}{Prototype\ Building\ Regulated\ Energy\ Cost\ 2004} / N_p \quad (2)\ [24]$$

Where:

Prototype Building Regulated Energy Cost year x = The portion of annual energy cost due to regulated energy use from PNNL prototype, climate zone and edition of Standard 90.1.

Prototype Building Regulated Energy Cost 2004 = The portion of annual energy cost due to regulated energy use from PNNL prototype buildings for a given building prototype, climate zone and the 2004 edition of Standard 90.1.

N_p = Number of prototype buildings of a particular building type

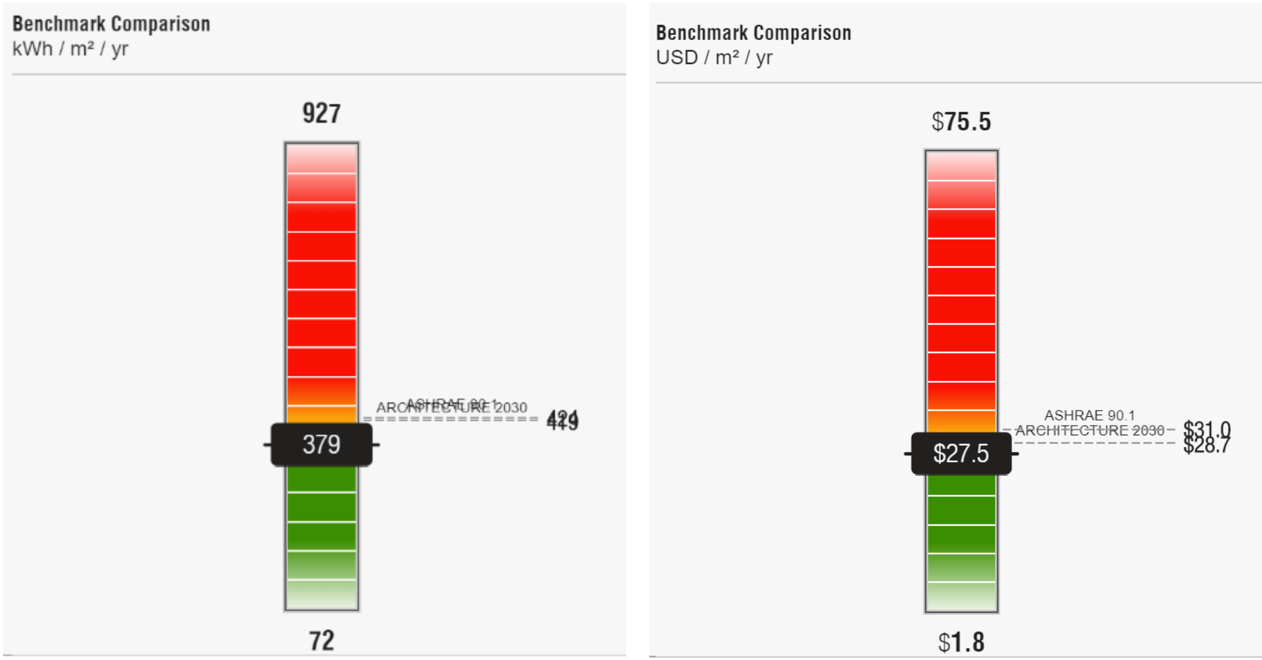

Figure 7. Building Energy Index Benchmark.

The result from EnergyPLUS software showed that the lighting consumption performed a major reduction from the lighting control measured adapted. From the first scenario, the lighting consumption of the existing condition of the building is about 25000 MWh per year. After using the control measure by switch off the light during the daylight period, a reduction of 17% of total energy load per year is achieved. The last scenario showed a major reduction in electrical consumption by save 12121.65 MWh which is about 49% compare to the baseline scenario. The dimming lighting control combine with timing sensor technic adapts in scenario 3 is more energy saving efficient compare to scenario 2 which the load of energy consumption is 7982.55 MWh difference. Harvesting the sunlight during the daytime for open space building is beneficial and efficient for building lighting refurbishment. From the simulation result, the energy saved from scenario 2 and 3 is significant. It shows an opportunity to achieved lighting energy saving by switching from conventional lighting systems to light with daylight responsive dimming functions.

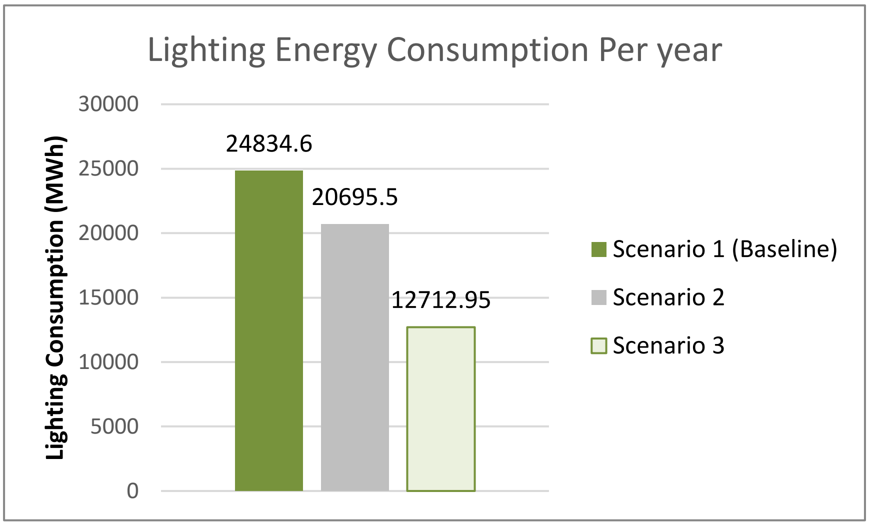

Figure 8. The lighting energy consumption from the simulation result.

As the reduction of the energy consumption is achieved, the carbon emission from fossil fuel combustion is also decreased. According to [25] the emission factor for electricity in Malaysia is 0.714 Kg per KWh based on the fuel mix input with coal and oil. Electricity consumption accounts in scope 2 (indirect emission sources) of Carbon Footprint emission which categorized under purchase energy is one of the most carbon emission from buildings (Sotos, 2014) . The reduction in the Carbon footprint emission play a major role to the climate change and sustainability. The graph shows a major reduction of 17% and 49% respectively for scenario 2 and scenario 3 compare to the baseline scenario.

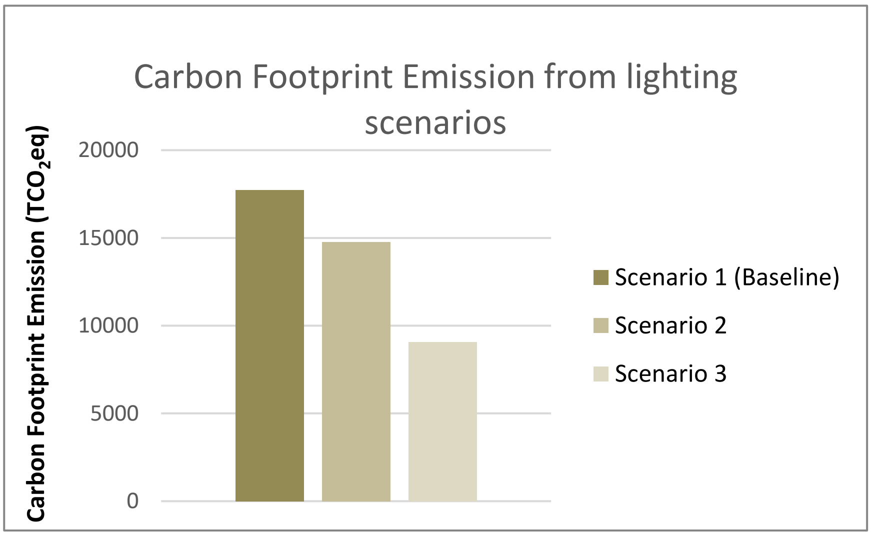

Figure 9. Carbon Emission reduction from the lighting consumption.

The cost of energy retrofitting is one of the most important factors in decision making for energy efficiency in building. Approximately 6 million Ringgit Malaysia was saved from the operational cost annually compare to the existing baseline scenario if the dimming lighting control measures is adapted at RSA Ayer Keroh Northbound Malaysia. The combine of two energy efficiency measures on lighting can save a massive amount of electrical bill annually. By only switch off the light during the daytime as adapt in scenario 2, about 2 million Ringgit Malaysia of operational cost is saved annually from the retrofitting measure.

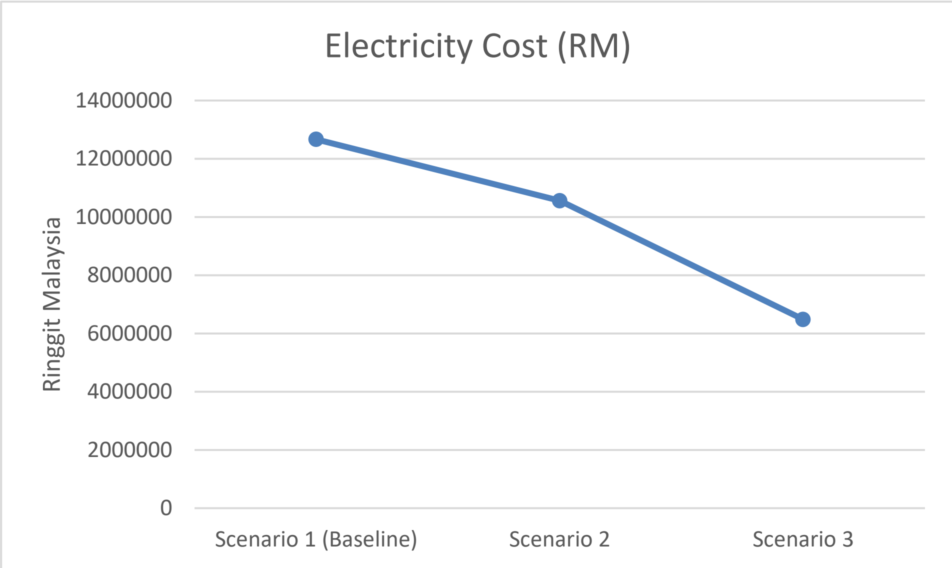

Figure 10. Electricity Cost from the lighting consumption.

5. Conclusion

Non-residential building such as Rest and Service Areas demand an efficiency refurbishment on the energy for enhance the performance of the building. Energy efficiency on the lighting control is a suitable measure for energy retrofitting in this building due to the overload of lighting consumption and high opportunity of energy saving from the simulation result. Natural lighting is one of the important sources of energy to harvest for open space building. It not only capable of improving the visual comfort but also can save the energy consumption. Deep energy retrofitting is can be achieved if there is a combine between more than two energy efficiency measures. From the results of this study, the opportunity to achieved lighting retrofitting is feasible and should be introduced for implement at Rest and Service Area Ayer Keroh Malaysia.

This study is beneficial to support the concept of nZEBs to promote the energy efficiency and Green building in Malaysia.

6. Acknowledgments

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