UNIVERSITY OF ZIELONA GÓRA

CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2025; 35 (2): 0149-0169
DOI: 10.59440/ceer/202380
Original Research Article

LIGHTING CONFIGURATION FOR IMPROVING LIGHTING ENERGY EFFICIENCY OF REST AND SERVICE AREA IN MALAYSIA

Neardey MONH[1], Faridahanim AHMAD[1*], Eeydzah AMINUDIN[2], Anees Ahmad VIGHIO[3], Mariah Binti AWANG[4]

[1]Faculty of Civil Engineering, Universiti Teknologi Malaysia
[2]Faculty of Civil Engineering, Universiti Teknologi MARA
[3]Department of Civil Engineering, Mehran University of Engineering and Technology, Pakistan
[4]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), Malaysia

Abstract

Lighting configuration plays a major role in controlling visual comfort and lighting consumption in building. Many studies have focused on the lighting energy consumption of office buildings and institutions but there is still a lack of studies that have focused on open structure buildings such as Rest and Service Areas for Highway (RSAs). RSAs are highway facility which lighting layout of the building tends to adapt conventional lighting design approaches, resulting in energy wastage. Knowing the scorching and humid climate in Malaysia throughout the year, there is a high opportunity to harvest natural daylight and reduce artificial lighting consumption. The existing lighting performance of the building showed a very high luminance levels, for which the optimum lighting illuminance should be proposed. Hence, this study aims to analyse the optimum lighting configuration of RSAs Ayer Keroh Northbound Malaysia by modify on the existing lighting's layout of the building. The illuminance performance and lighting energy consumption is identified by using RELUX desktop and DesignBuilder software respectively. Next, the study proposed a new lighting layout for reduce energy consumption and provide an optimum visual comfort for users. The building geometry is modelled by Autodesk Revit and Building Energy Index was determined by Insight 360. The result from proposed lighting layout demonstrated significant energy saving potential, achieving a 24% reduction in total annual lighting load and RM 48,432 annually was saved from electricity cost.

Keywords: lighting configuration, lighting simulation, energy saving, rest and service area

1. INTRODUCTION

Minimizing energy consumption and carbon dioxide emissions has become a crucial focus in the development of sustainable policies and industries globally [1] .This emphasis is driven by the need to

[1] Corresponding author: Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), 81310 UTM Johor Bahru, Johor Darul Takzim, faridahanim@utm.my

tackle significant societal challenges associated with sustainability, climate change and energy security [2], [3]. Rest and service area refers to facility located along the roadside of highway which offer amenities such as fuel stations, restroom, dining area and other services for travellers [4]. Innovation on highway infrastructure is a part of Malaysia Green Highway Index (MyGHI) development. Green highway defined by MyGHI as a project life cycle which design and constructed with sustainable concept and carefully address economic, social and environmental aspects. MyGHI evaluates highway based on criteria such as sustainable design, material and technology use, energy efficiency and environmental management [5].

To tackle with the sustainable highway development, there are seven rating systems of Green Highway assessment were developed by various countries including Greenroads, WISE, GreenLITES, I-LAST, BE2ST, Greenroads and MyGHI [6]. Each Green Highway assessment composes on their own assessment criteria which take into consideration of reducing environmental impacts. Furthermore, most of highway assessment tools address energy efficiency generally without emphasize the specific requirement, while MyGHI designed energy efficiency criteria with a focus on area-based considerations [5]. Those area-based energy efficiency practice including Rest and Service Area (RSA), toll plaza, compound park and carpark and interchange [7]. Energy efficiency is one of the most crucial criteria in highway development due to the significant energy demands throughout the whole highway life cycle particularly on operation phase [5]. Table 1 compares the energy efficiency criteria which focus on area-based from seven green highway assessment tools.

Table 1. Energy efficiency criteria with a focus om area-based benchmarking from various assessment frameworks [6]

Criteria	**Sub-criteria**	[8]	[9]	[10]	[11]	[12]	[13]	[14]
Rest & service area	Reduced electrical consumption	x	x	√	√	x	x	√
	Sustainable Infrastructure	x	x	x	x	x	x	√
Toll plaza	Toll booth	x	x	x	x	x	x	√
	Lighting zone	x	x	x	x	x	x	√
	Administration and supervision	x	x	x	x	x	x	√
Compound and carpark	Energy efficiency performance	x	x	x	x	x	x	√
Interchange	Reduce energy consumption	x	x	x	x	x	x	√
	Stray light/light pollution reduction	x	x	√	√	x	x	√
General	Energy control	x	x	x	x	√	x	x
	Energy use	x	√	x	x	x	x	x
	Material & resources	x	x	x	x	x	√	x

Artificial lighting represents a significant portion of electricity consumption in many non-residential buildings, enhancing energy efficiency often begins with retrofitting lighting system. Moreover, lighting systems offer greater accessibility than other building systems such as heating and their shorter lifespans in relation to the building underscores the importance of retrofitting potential [15]. Building performance simulation (BPS), supported by building energy modelling (BEM) technology, has emerged as a pivotal and cutting-edge tool for enhancing energy efficiency in building design, operations and renovations, making it a vital factor in carbon mitigation efforts with the construction industry [16]. In the last decades, researchers has shifted their attention to lighting technology to improve indoor environmental quality and visual comfort by using numerous software namely Relux, Ecotect, EnergyPLUS and Designbuilder [17], [18].

A Rest and Service Area (RSA) on a highway serves as a designated stopping point facility for travellers. A study by [19] pointed out that these facilities consume significant amount of energy daily, primary through artificial lighting and HVAC systems. Achieving a depletion in fossil fuel consumption and operation carbon in RSAs can be realized through energy-efficient measures like refurbishment and the utilization of renewable energy sources [20]. Notably, RSA Ayer Keroh Northbound in Malaysia stands out for its continuous 24/7 service, making lighting the highest electricity consumer among its operation. This end-use energy consumption is substantial and contributed significantly to carbon emission. The conventional lighting design approach yields excessively high illuminance levels at each luminaire's location, resulting in poor lighting performance within the space. To tackle this problem, a modification of existing lighting layout has been introduced in this study to scaling down the end-use energy and also to adjust the artificial illuminance by harvest with the natural lighting.

RSA Ayer Keroh can be considered an open space building due to its building envelope characteristics, which make daylight harvesting a potential energy retrofit for this type of highway facility. A study by [21] has proved that lighting retrofitting by using lighting control technology offer significant energy saving with 43% average reduction. Many studies which focusing lighting efficiency in enclosed buildings such as office building or institution buildings [21]–[24] by upgrading advanced lighting control system and user behavioural control but a very few studies focus on lighting efficiency for open space building such as RSA.

Modernize lighting system of open space building for energy saving opportunities is crucial for enhancing building performance and improving indoor visual comfort for travellers along Malaysia highway. Therefore, this study proposed a new lighting configuration for RSA Ayer Keroh by analyse on lighting performance for seeking energy reduction. This research contributes to a new combined method of lighting energy simulation for energy saving and operational carbon emission reduction on Malaysia’s highway.

2. METHODOLOGY

2.1. Case study simulation for energy performance analysis

Rest and service area Ayer Keroh is located along north-south expressway Malaysia and the total area of the rest area is approximately 34,000 square meter. The facility of the rest area is explain in table 2 below. The dinning building of Ayer Keroh north bound’s RSA was chosen as case study in this research, this building situated on the west side of Peninsular Malaysia with longitude and latitude 2.397, 102.220 respectively.

Table 2. RSA Ayer Keroh facilities and characteristics

RSA Ayer Keroh	Facility	Total area
	Toilet & Prayer room	
	Parking	34,400 square meter (approximately)
	Restaurant	
	Café shop	
	Gas station	
	Electric charging station	
	ATM	

Preliminary study revealed that the primary contributor to the energy consumption was lighting, which account for approximately 50% of the total end use energy with the Building Energy Index (BEI) 287.88 kWh/m^2 per year. Figure 1 presents electrical consumption by appliances at RSA Ayer Keroh. The breakdown of energy usage shows that lighting is the primary load consumption driven by the extensive number of lighting fixtures and continuous 24/7 operation.

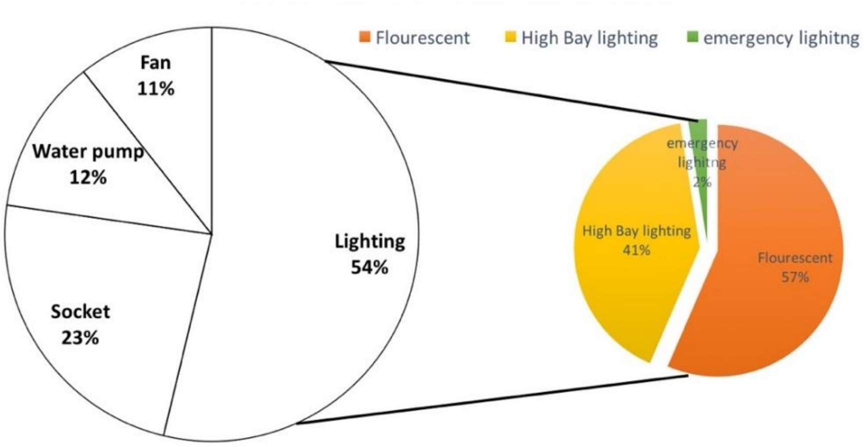


Fig. 1.Electrical distribution in average at RSA Ayer Keroh

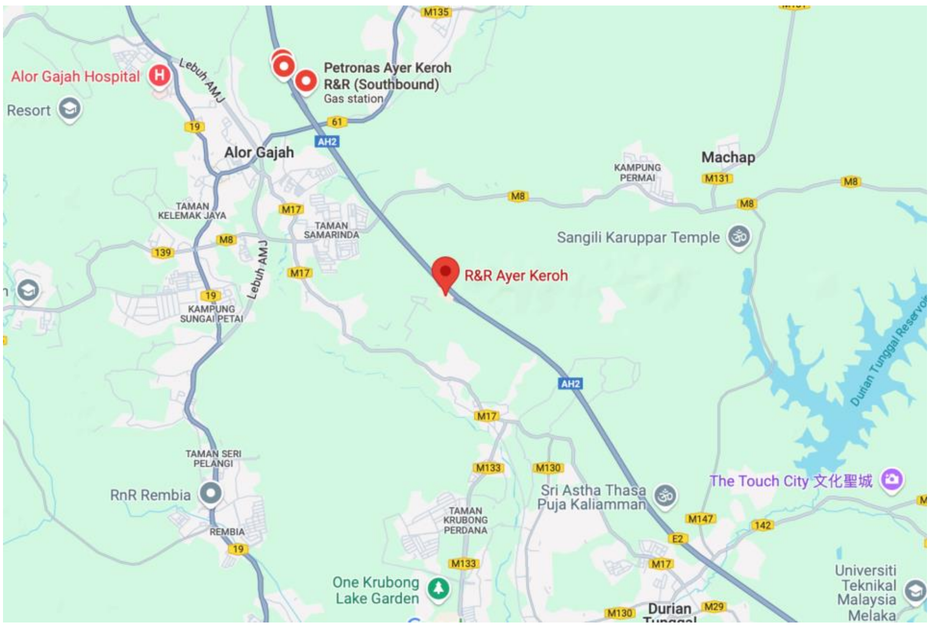


Fig. 2. Map showing location of RSA Ayer Keroh North-bound

As per guidelines outlined in MS1525, Malaysian code of practice for energy efficiency in non-residential buildings emphasizes that building with energy efficient practice could achieved BEI of 128kWh/m^2 per year [25]. Therefore, it is crucial to implement energy efficient practices for operational stage of this building. This study was conducted in 2018 which is part of project carbon footprint calculator for Malaysian highway. Figure 3 presents the BEI of case study building for 3 continues years from 2015 to 2017.

Calculation of Building Energy Index (BEI):

$$Building\ Energy\ Index\ (BEI) = \frac{Total\ energy\ consumption\ a\ year\ [\frac{Kwh}{year}]}{Total\ Occupied\ or\ Net\ floor\ area\ [m2]}\ [26] \quad (2.1)$$

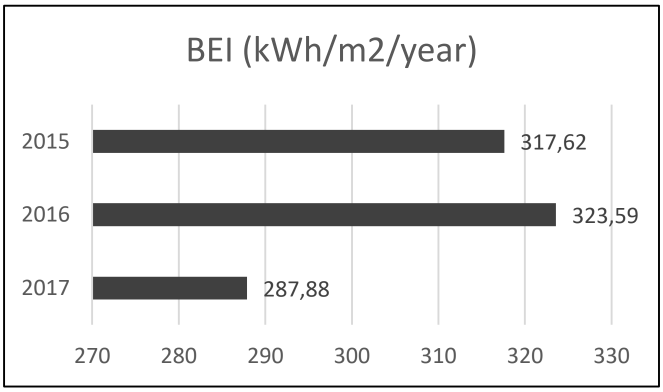


Fig. 3. Report of Building Energy Index for 3 years in Ayer Keroh RSA

In this study, energy performance analysis is conducted to determine the lighting energy consumption per meter square and Building Energy Index (BEI) of the case study building. Autodesk Insight 360 is a simulation engine for analysing building performance, seamlessly incorporating data within Revit software. This technology assists architects and engineers in designing energy-efficient buildings that align with green building principles [27]. The building's physical property and Energy Analytical Model (EAM) were created using Autodesk Revit. Then, the electrical components such as lighting device, socket, lighting switch were modelled in Autodesk Revit electrical template prior to Insight 360 simulation. Subsequently, Insight 360 was employed to simulation the building indoor performance analysis. The detailed process of the simulation is shown below in Figure 5.

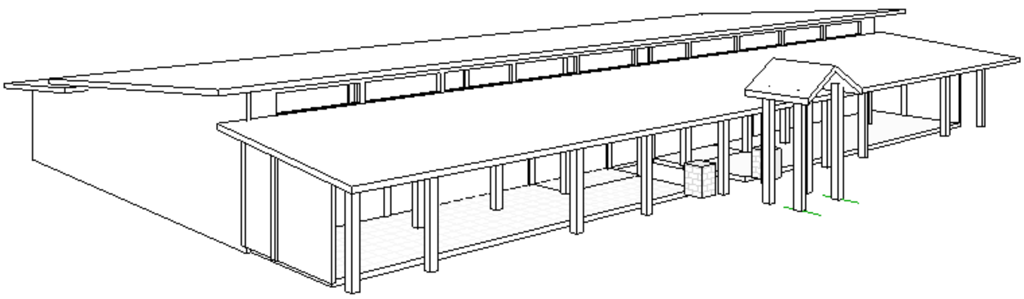


Fig. 4. Case study building architecture model in Autodesk Revit

In this process, Energy Analytical Model (EAM) is the most important character to define the accuracy of the simulation result which reflects the design intent. EAM also require to input inclusion details within the Revit model, including material characteristics, thermal space attributes, project phase, function of building and operation type. This information is an important element in controlling the behaviour of energy model creation.

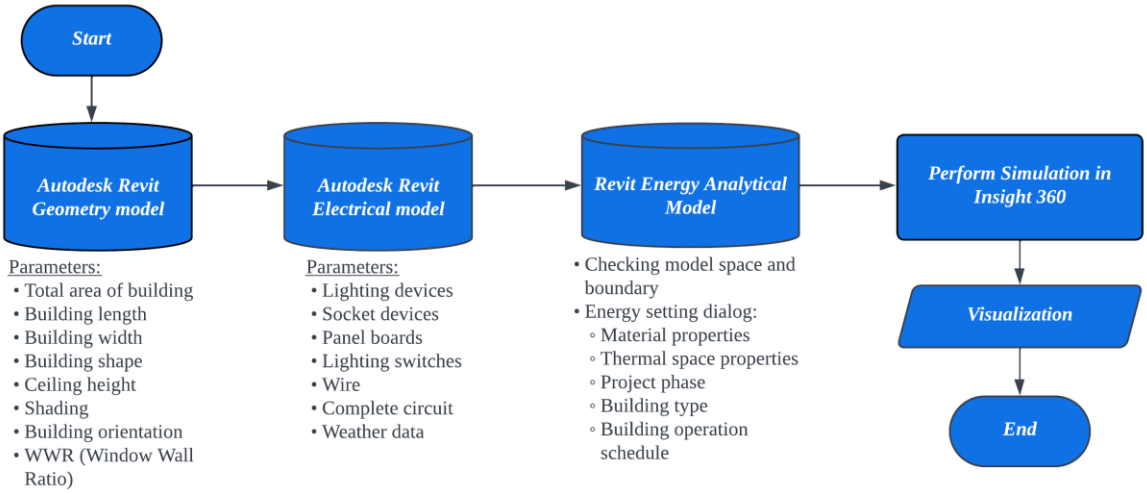


Fig. 5. Energy performance analysis workflow for the case study RSA

2.2. RELUX simulation for lighting performance

In this paper, artificial light and daylighting are simulated to seek the energy retrofitting opportunity. RELUX desktop is used to visualize the lighting performance which the software is a produce from RELUX Informatik AG. It is supported by a range of manufacturers of luminaire, sensor and lamps [17]. The tool offers solution for lighting simulation that enables users to incorporate visual design aspects of materials, furnishings and color representation within buildings. This effective graphical tool facilitates the simulation of both artificial lighting and natural daylighting. It is one of the most precise lighting simulation tools, demonstrating good agreement with analytical estimation across a wide range of scenarios [17], [28].

Following energy analysis of case study, the findings reveal of high consumption of lighting load and high building energy index (BEI) in result and discussion section. Therefore, it is imperative to investigate lighting configuration in order to suggest optimal retrofitting scenarios. The existing luminaire's distribution of the case study was built in RELUX with a total of 29 light bulbs model in the layout. Easylux function in RELUX makes the lighting modelling much more convenient, the location and specification of the luminaire were modelled identically to the case study. The existing layout comes up with four (4) rows of the luminaire which the distance from one luminaire to another in the X direction is 3.25 meters and the distance in the Y direction is 4.5 meters. Figure 6 illustrates the lighting configuration of the case study RSA Ayer Keroh.

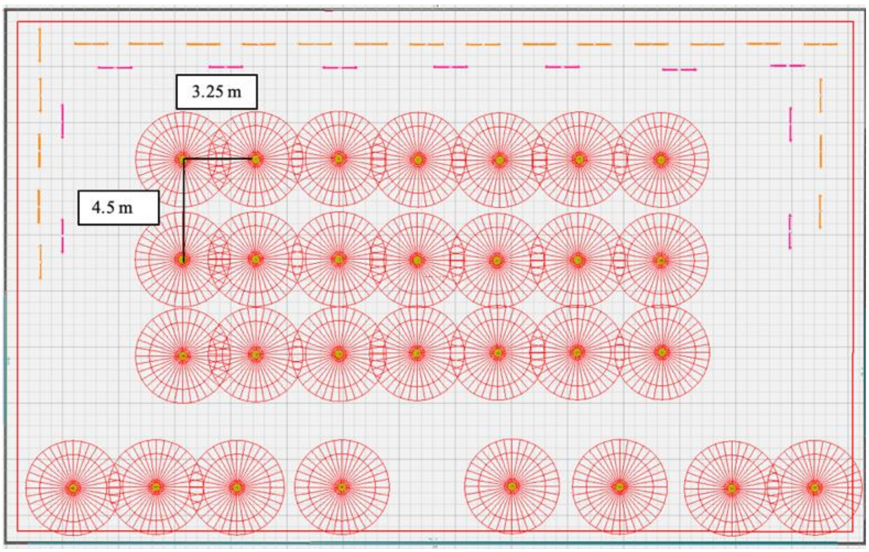


Fig 6. Existing luminaire layout configuration by RELUX desktop

Due to the overload of illuminance, ten (10) luminaires were removed from the base case layout and new arrangement was design to propose a better lighting distribution and more importantly reduce lighting consumption. In the new lighting configuration, the space between luminaire in X direction was expand about 2 meters compared to the previous configuration. This adjustment was made to lower the illuminance level compared to the existing set up. This set up is called proposed scenario TYPE (A) and this scenario is developed bases on RELUX desktop horizontal illuminance calculation, in which the minimum illuminance on the horizontal plane (Emin) and maximum illuminance on horizontal plane (Emax) are used to compare with Malaysia Standard 1525 (MS1525) in result and discussion section as a reference for building energy efficiency. Figure 7 presents the luminaire configuration TYPE (A) in this study.

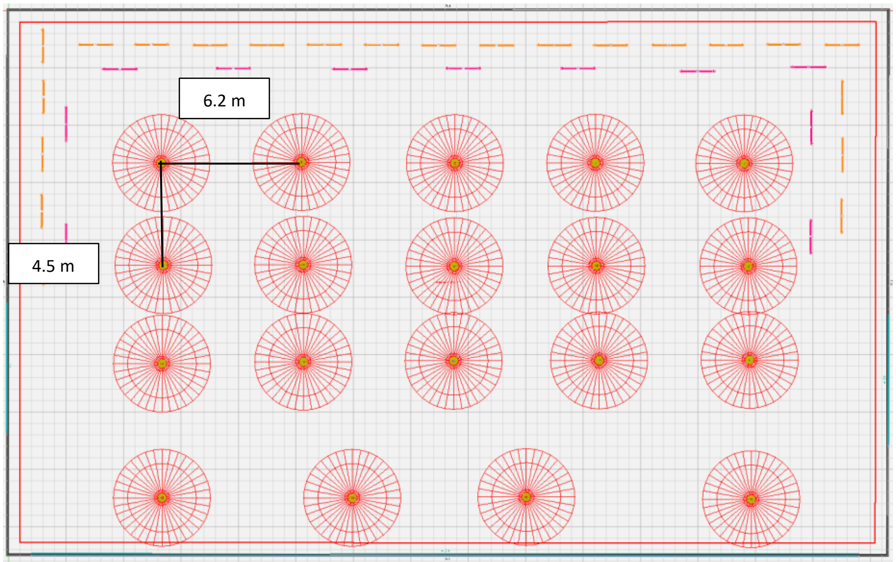


Fig. 7. Propose luminaire layout configuration TYPE (A) by RELUX desktop

To seek the optimum luminaire configuration for energy saving, another arrangement TYPE (B) was proposed to compare the horizontal illuminance. The total number of luminaire is this proposed TYPE (B) configuration is sixteen (16) bulbs with the distance from one luminaire in the X direction is 8.2 meter and distance in Y direction is 4.5 meter. The simulation on artificial illuminance at night time also be tested to see the sufficient luminaire without daylight. Figure 8 illustrates the propose lighting configuration TYPE (B) as shown below.

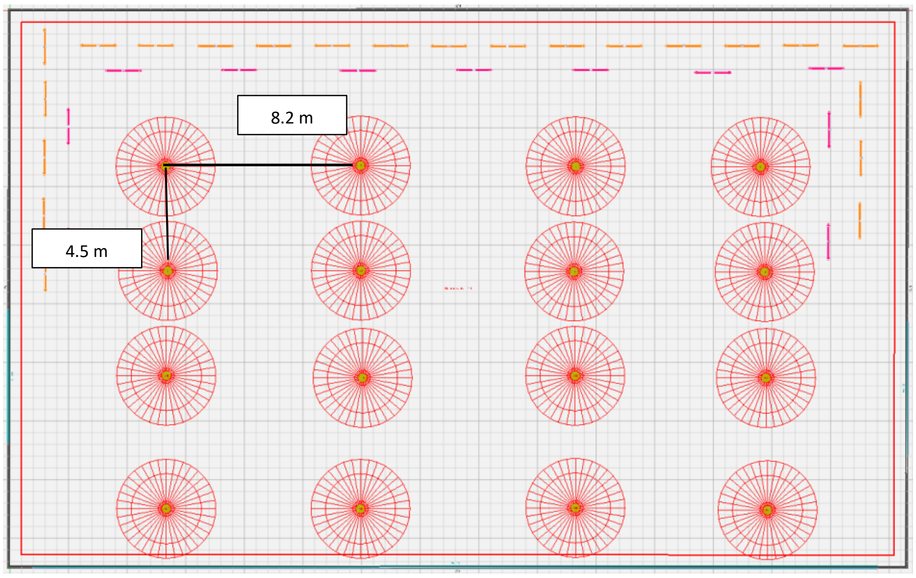


Fig. 8. Propose luminaire layout configuration TYPE (B) by RELUX desktop

Figure 9 explains the framework of RELUX simulation in this study. The procedure began by conduct preliminary study on energy consumption and identify the necessity of enhance lighting configuration in the case study the building. The initial phase involves with the modelling building geometry and lighting properties directly in RELUX following by simulation of the artificial and natural lighting of case study. Based on the lighting analysis result, the artificial illuminance is excessive which lead to proposal of two alternative lighting scenarios. The first scenario, the lighting layout was rearranged with the removal of 10 lighting bulbs, while the second scenario, 13 lighting bulbs were removed. Both lighting configurations undergo simulation in RELUX to test their lighting performance. A comparative evaluation is conducted to determine if there is scenarios fail to meets the standard illuminance requirement. This framework offers a systematic approach to optimize indoor lighting performance by integration simulation-based analysis.

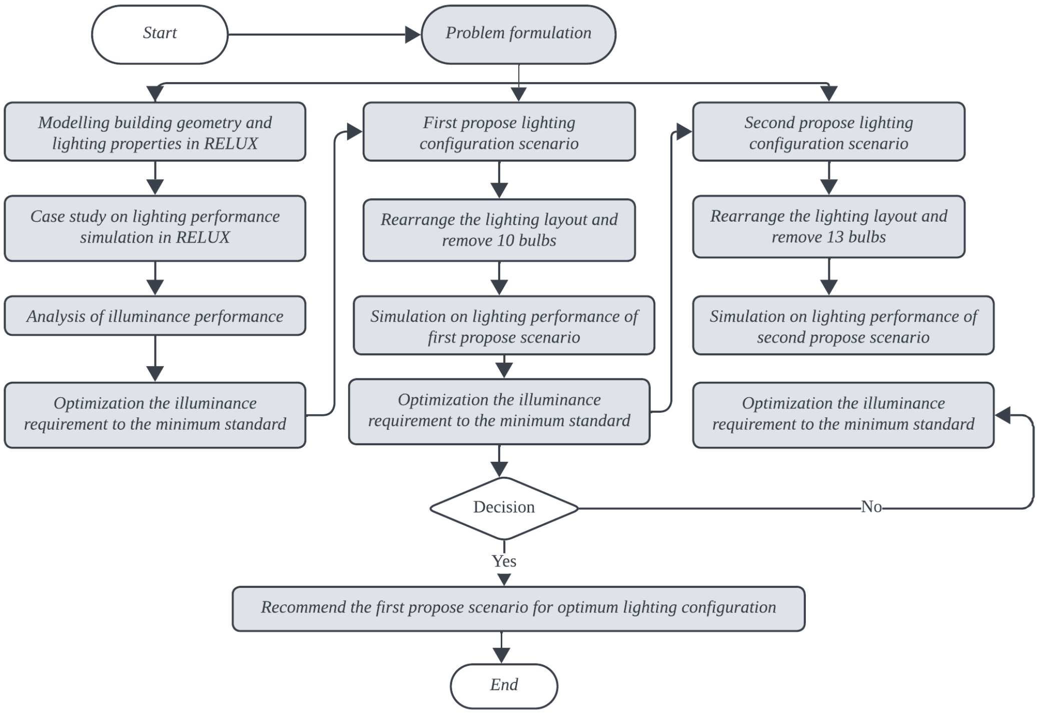


Fig. 9. Flow process explains RELUX simulation conducted in this study

2.3 Simulation on lighting energy consumption in DesignBuilder Software

Once the building model was successfully generated in Autodesk Revit, an EAM was created based building properties of case study building. Following by gbXML file (Green Building XML schema) was exported to DesignBuilder software for the purpose of conducting energy consumption simulation. The gbXML data format, established by Green Building Studio Inc. in 1999, was specifically designed for energy performance analysis [29]. Figure 10 explains the overall process of conducting energy simulation using DesignBuilder.

Fig. 10. Data exchange flow of energy simulation

The three (3) lighting retrofitting scenarios were proposed in this study, DesignBuilder software was running lighting load consumption simulation to compare which scenario consume lowest energy. For scenario 1, the Revit model was constructed as the base case of case study building located at RSA Ayer Keroh Northbound Malaysia. After importing the gbXML file into DesignBuilder, the lighting schedule was configured to operate 24 hours a day, reflecting the actual usage pattern of case study building. DesignBuilder offers a range of pre-existing schedule templates tailored to various occupancy and operation requirements. The simulation framework of this research is detailed in the figure 11 below which the gbXML file is required to export manually into DesignBuilder to transfer Revit energy models. gbXML is more based upon space such as thermal performance, solar radiation and energy demands. XML, which stands for Extensible Markup Language, is a computer programming language that enables software applications to exchange data with minimal or no human intervention. In the year 2000, an extension to XML known as "gbXML" was introduced for the purpose of constructing building-related XML schemas. This extension was initially proposed for inclusion in the XML standard. However, it wasn't until 2004 that gbXML gained the backing of prominent computer-aided design (CAD) software vendors, such as Bentley systems, Autodesk, and Graphisoft, within the software industry. This support led to the further development of gbXML, making it a facilitator for seamless interoperability and the transfer of building-related information from CAD models to various engineering analysis tools specially the 3D Building Information Model (BIM) and Building Energy Simulation (BES) [30]. The gbXML file was imported manually to DesignBuilder for energy consumption simulation of the two proposed scenarios. The three (3) lighting retrofitting scenarios were proposed in this study, DesignBuilder software was running lighting load consumption simulation to compare which scenario consume lowest energy. For scenario 1, the Revit model was constructed as the base case of case study building located at RSA Ayer Keroh Northbound Malaysia. After importing the gbXML file into DesignBuilder, the lighting schedule was configured to operate 24 hours a day, reflecting the actual usage pattern of case study building. DesignBuilder offers a range of pre-existing schedule templates tailored to various occupancy and operation requirements. While the scenario 2 and 3, the number luminaires was reduced to only 19 bulbs and 16 bulbs respectively in order to reduce excessive illuminance.

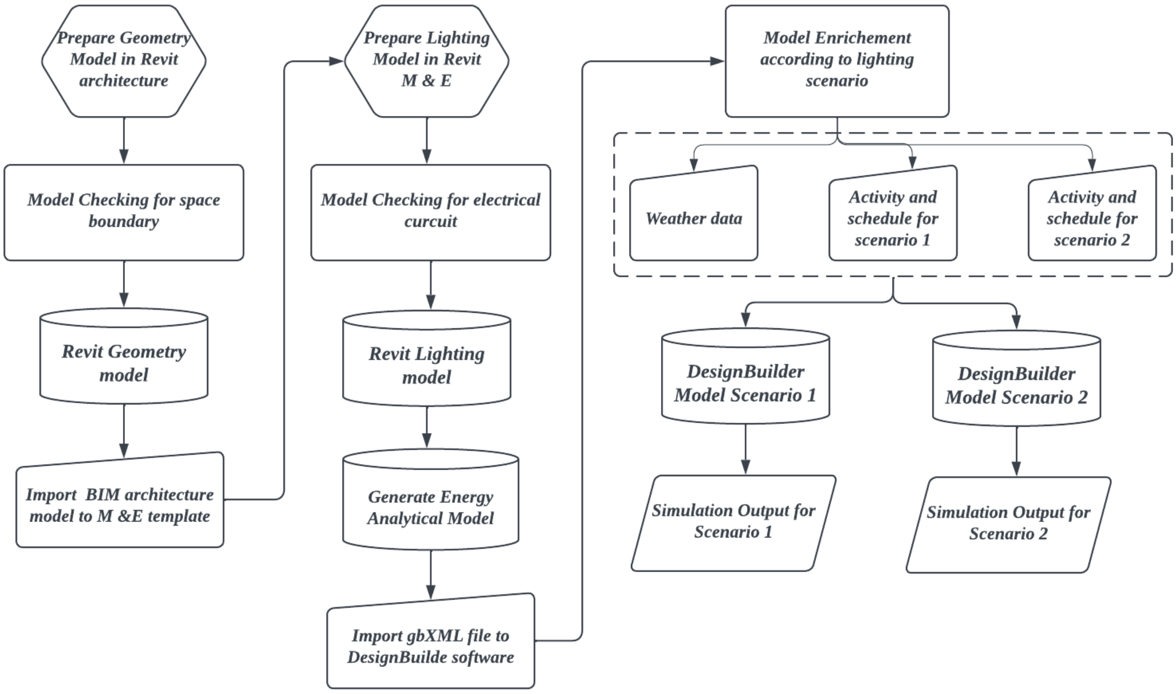


Fig. 11. Workflow diagram for information transfer and simulation process between Autodesk Revit and DesignBuilder

3. RESULT AND DISCUSSION

3.1 Energy performance analysis by Autodesk Insight360

The building geometry and electrical properties of the case study are modelled in Autodesk Revit prior conducting the energy analysis. Once the architectural template was completed, the electrical model was developed and imported into the Autodesk Revit M&E template. Electrical components, including lighting and sockets, were assigned to the circuit. For Ayer Keroh food court building, only lighting and sockets were included in the circuit modelling since the study focused solely on lighting load. In addition, the lighting fixture used in RSA Ayer Keroh food court is high bay lighting with 70 Watt power consumption and lighting fixtures were set the same elevation as the actual case study. The layout function of the food court building consists of dining area, kiosk and ATM machine. Figure 12 presents case study food court building layout model in Autodesk Revit.

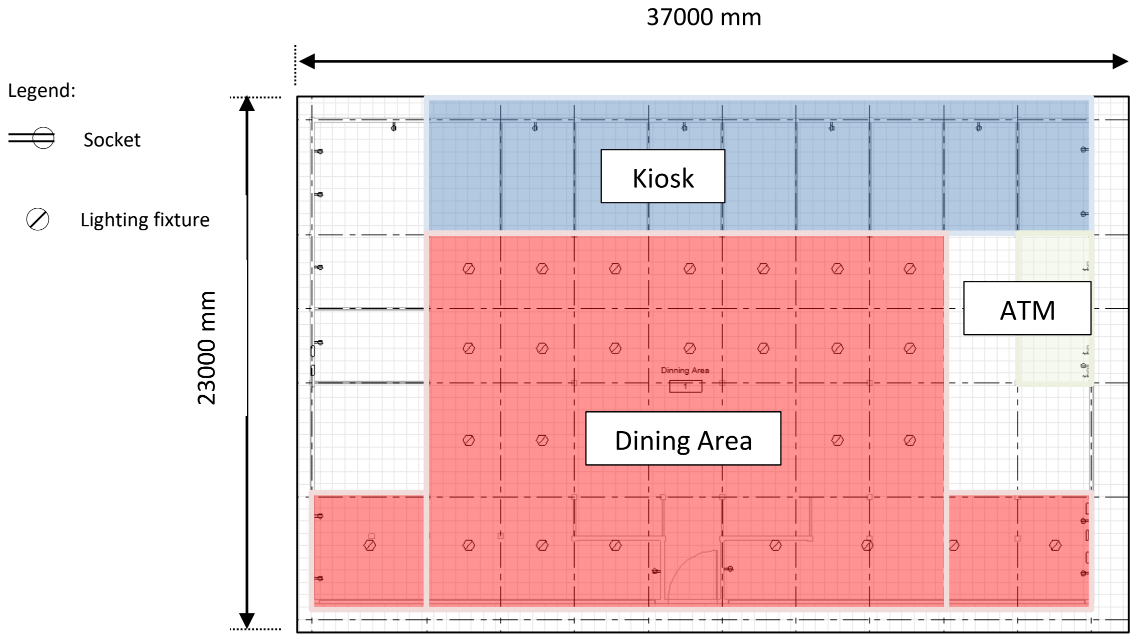


Fig. 12. Ayer Keroh food court lighting layout model in Autodesk Revit M&E template

This is important to generate the energy analytical model before conducting energy simulation. Figure 13 illustrates the perspective view of the food court building, showcasing intensity of energy consumption in various zone. The building components such as shading device was removed to keep the building shape as simple as possible to avoid any error during the file export to DesignBuilder software. The area in blue colour represents the space boundaries or thermal zone of the energy model. Thermal zone also depicts the conditioned spaces where lighting , heating and cooling load are considered. While the light green colour on the model represents the building envelope perimeter including walls, windows, glasses or shading devices)

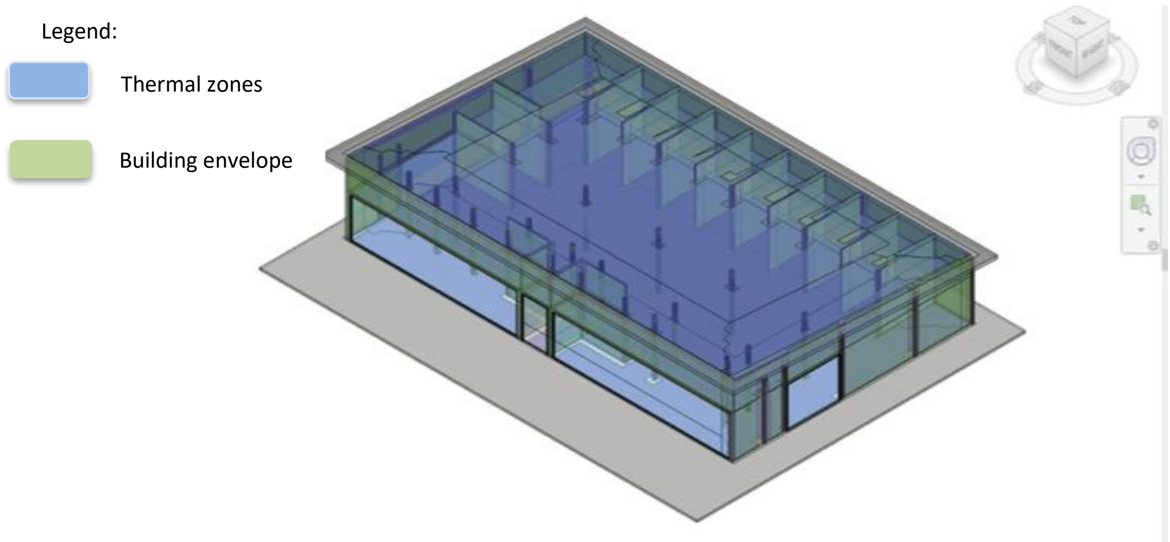


Fig. 13. Energy analytical model of the food court building

Insight 360 plugin tool in Autodesk Revit is a cloud simulation which enables designers to enhance energy efficiency in building designs by providing advanced building performance analysis directly integrated into Revit [27]. In this study, Insight 360 was used to benchmarking building energy index (BEI) and lighting consumption per meter square (m^2). The outcome of building energy index (BEI) from simulation shows an excessive amount of energy consume in this food court building by 379 kW/m^2/year as shown in figure 14 below. The benchmarking standard used in this simulation is based on ASHRAE 90.1, which represents the American Society of Heating, Refrigeration, and Air-Conditioning Engineers' guidelines for assessing energy efficiency and building performance. The MS1525 standard stipulates that the adoption of energy efficient practices in Malaysia buildings has the potential to attain a Building Energy Index (BEI) of 136 kWh/m^2/year [25]. Insight 360 is one of the popular software for benchmarking BEI for improving building energy performance. [31] also conducted the BEI benchmarking in Insight 360 and reduce the energy consumption in residential building from options provide by the simulation. As a result from simulated optimization, 50% of end use energy is reduced by modifying the heating and cooling systems. Thus, the case study excesses a high amount of building energy index which enhancement on energy performance is compulsory for improve building energy efficiency. The primary energy use or (PE) index [kWh/m^2/ year] is referred as energy efficiency reference which emphasize on the demand of total energy from non-renewable source [32]. However, a study conducted by [33] reports that the energy audit findings indicate that the majority of office buildings in Malaysia typically fall within BEI range of 200 to 250 kWh/m^2 per year.

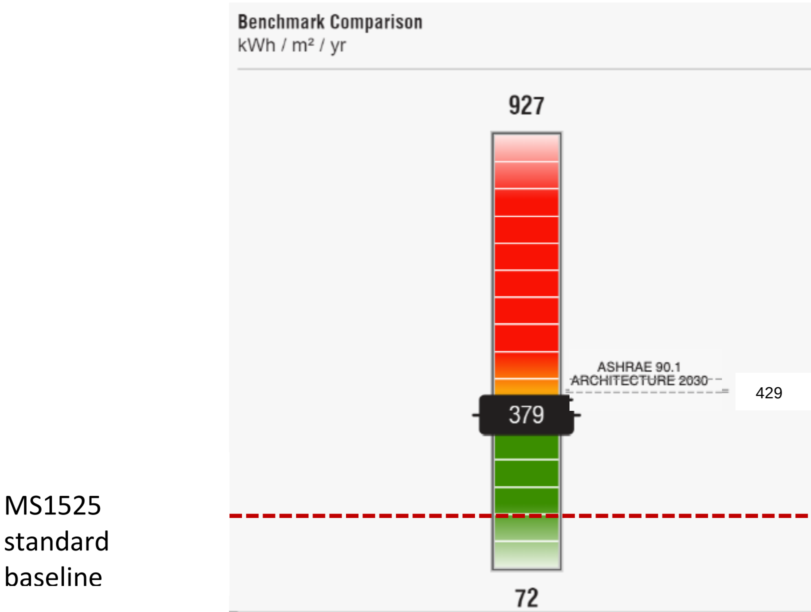


Fig. 14. Building Energy Index (BEI) benchmarking from Insight360

The findings from lighting energy consumption shows the average internal heat gain and power consumption of RSA food court building is 20.45 W/m^2 with the cost of 22.08 RM/m^2/year (4.94 USD/m^2/year) as shown in figure 15 (a) and figure 15 (b) respectively. However, this number can be lower if the energy efficient for lighting system is implemented. According to [34], the index W/m^2 is used to measure a lighting system's energy efficiency. This indication describes the amount of energy required to illuminate a square metre at 100 lux. The index value for W/m^2/100 lux decrease when the desire illumination level for the area is exceed to a considerable extent. The simulation from Insight 360 provide options for reduce the lighting consumption to only 3.23W/m^2 and that would also be reduce the BEI about 36 kWh/m^2/year from the case study.

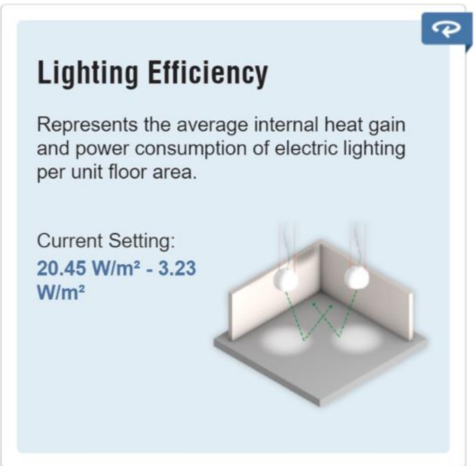


Fig. 15(a). Power consumption index of case study

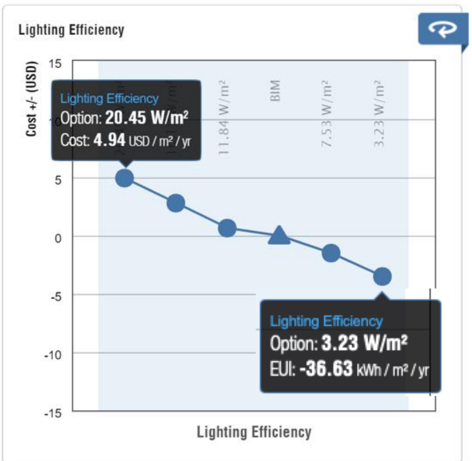


Fig. 15(b). Cost consumption index of case study

3.2 Proposed lighting retrofitting scenarios for energy saving

As RSA Ayer Keroh is an open-space structure that offers the opportunity to utilize natural daylighting effectively while decreasing the reliance on artificial lighting. According to section 2.2, three (3) lighting scenario were proposed in this study to seek energy reduction by removing several luminaire due to excessive amount of daylighting in the area. Table 3 explains the results of lighting configuration from RELUX simulation relevant to three scenario suggested. In order to seek lighting load reduction, power consumption and lighting power density were investigated. The layout TYPE (B) demonstrated the lowest energy consumption with only 3.91 W/m^2 and layout TYPE (A) with 19 lighting bulbs consumption 4.36 W/m^2.

Table 3. Luminaire power consumption of three (3) propose scenarios

Type of luminaire configuration	Total Power Consumption	Lighting power density W/ m^2
Existing: 29 bulbs	5301 W	5.85 W/m^2
Proposed TYPE (A): 19 bulbs	3951 W	4.36 W/m^2
Proposed TYPE (B): 16 bulbs	3546 W	3.91 W/m^2

In addition, Table 4 presents the horizontal illuminance for the proposed three scenarios in this study. For proposed layout TYPE (A) enables to reduce the power density 5.85 W/m^2 from existing layout to only 4.36 W/m^2 and the minimum horizontal is adequately provided for the area at 211 lux. While the existing layout exhibited the highest power consumption due to the excessive horizontal illuminance projects in the area with the average horizontal illuminance is 815 lux. The proposed scenario TYPE (B) consumed the lowest power consumption, however the minimum horizontal illuminance fell short with only 18 lux which is not adequate for the standard requirement for dining area. According to MS1525 (Malaysia & Standard) code of practice for building energy efficiency, the requirement illuminance for a dining area need to be at least 200 lux to offer a comfort visual to the user [25]. Thus, it can be considered that the proposed layout TYPE (A) represents a promising retrofitting scenario for this study. The study also testing the artificial illuminance at night time of the propose scenario to see the sufficient luminaire. The result from the proposed layout TYPE (A) also shows a satisfactory illuminance distribution across all dining areas. [35] also adapted a lighting control system by using dimming sensor to fit with occupancy scenario. This method offers a smart lighting system which able to provides an optimum dimming levels of luminaire required. However, this approach faced a challenged in term of technical counterpart. The control system requires advanced sensor technology which can provide various occupancy information such as user location , activity and lighting information.

Table 4. Illuminance comparison to guideline MS1525

Type of luminaire configuration	Min/Max horizontal illuminance	Average horizontal illuminance	MS1525 Requirement
Existing: 29 bulbs	228 lx/ 1940 lx	815 lx	Pass
Proposed TYPE (A): 19 bulbs	211 lx/ 1810 lx	674 lx	Pass
Proposed TYPE (B): 16 bulbs	18 lx/ 670 lx	292 lx	Fail

3.2.1 Lighting profile analysis

Lighting profile analysis was carried out to evaluate the current illuminance performance in the case study and the proposed the retrofitting scenario for daylight harvesting within the building. Thus, the case study lighting profile was simulated in RELUX desktop, taking into account both natural daylight and artificial lighting. Figure 16 (a) illustrates the lighting profile of existing case study while figure 16(b) illustrates the lighting profile of the propose scenario. From figure 16(a), the illuminance profile of case study is excessive which some area is showing red color particularly in the corridor area, signifying uneven lighting distribution. The illuminance is depicted using three main colors: red, green and blue. Blue presents the lowest illuminance, approximately 200 Lux. Jungle Green color corresponds to 300 lux of illuminance, Green indicates 500 Lux of illuminance. Flaxen yellow highlights around 750 lux, and red signifies illuminance 1000 lux or higher. Malaysia Standard MS 1525:2019 for non-residential building recommended the illuminance level for dining space is 200 lux [25]. Therefore, due to the excessive illuminance level in the case study, reducing the reliance on artificial lighting by remove some bulbs are the effective strategies for energy saving in this building. Moreover, this strategy also cost effective and a enable to ensure the energy reduction in the future. Integrating lighting simulation to design process has proved to fulfil lighting efficiency and visual comfort [36]. [36] has conducted lighting simulation in RELUX to facilitate lighting designers with a visualization to enhance design process. This simulation-based lighting solution provides the comprehensive visualization of lighting configuration which able to enhance the readability of the results. Figure 16(b), the lighting profile for the propose configuration is RELUX is illustrated. The number of high bay lighting fixtures was reduced to just 19 bulbs and their placement was realigned with the current layout. As a result, the illuminance in the dining area has been lowered, indicated by a shift to the "Green" category. Meanwhile, the highest illuminance level (depicted in "Red") remains concentrated in the building's corridor.

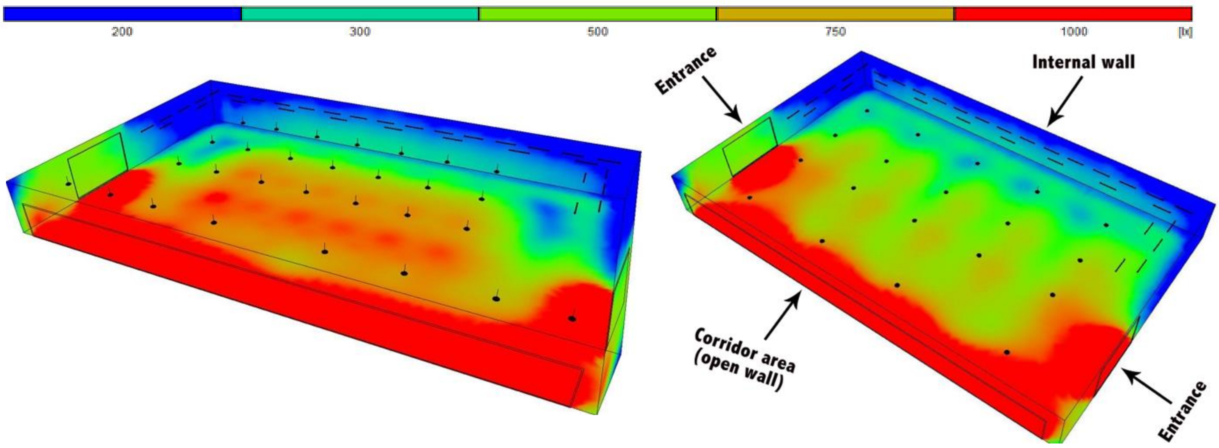


Fig. 16(a). Artificial & daylight profile of base case   Fig. 16(b). Artificial & daylighting profile of proposed case

RELUX desktop also offers a detailed breakdown of the lighting distribution at each luminaire spot, enhancing the comprehensive of the lighting simulation results. Figure 17(a) depicts the case study illuminance distribution at various points within the building. The region illuminated by the high bay lighting exhibited illuminance levels ranging from approximately 600 lux to almost 2000 lux. The highest illuminance reaching 1940 lux, is situated closest to the outside space, making it easily accessible for daylighting. In contrast, the lowest illuminance spot measure only 228 lux and is located near the food stall which is far from natural daylight sources.

However, figure 17(b) presents the illuminance distribution for the propose scenario. As mentioned before, the high bay lighting was reduced to 19 bulbs and their positions were reconfigured to fit the existing layout. The majority of the spots continue to attain an illuminance level exceeding 300 lux, with the exception of a few spots situated in the inner most parts of the building, distanced from natural lighting sources. The lowest illuminance level of the propose case is 211 lux meanwhile the highest is 1810 lux. Thus, this propose configuration is sufficient and valid for lighting saving strategy in RSA Ayer Keroh. Subsequently, the simulation for artificial lighting during night time also conducted to determine the illuminance capacity of the propose scenario without the reliance on natural daylighting.

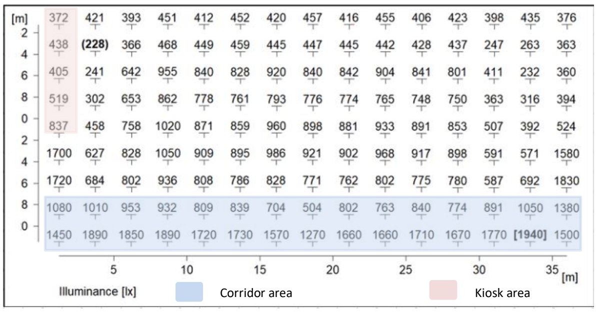


Fig. 17(a). Illuminance value for case study

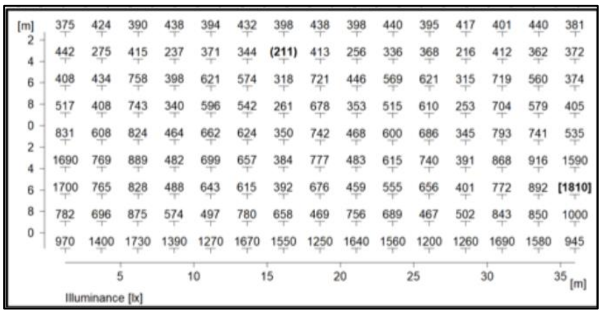
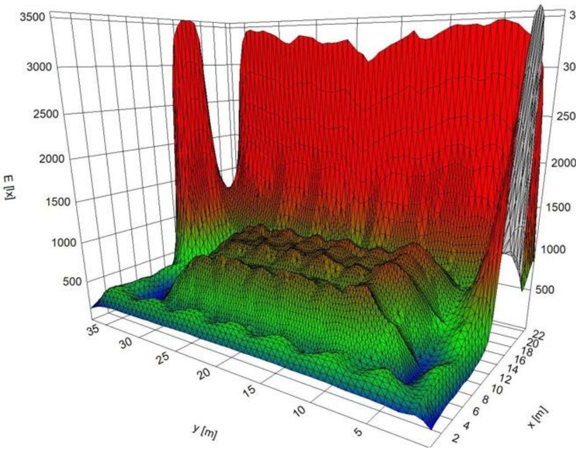


Fig. 17(b). Illuminance value for propose scenario

Figure 18(a) depicts the mountain plot in 3D of daylight and artificial lighting profile of case study. Overall, it can observe that the highest illuminance are concentrated in the building’s corridor and the value gradually drop as you move further away from the corridor. In the deeper areas of the building, such as the kiosk area, the daylight factor remains relatively consistent. However, certain locations exhibit exceptionally high illuminance levels thus the indoor lighting fixtures can be reduced to lower the unnecessary high illuminance and also to enhance the visual comfort of occupants. On the other hand, after reduce the number of luminaire to 19 bulbs, the mountain plot still display Green and Red colours. Thus, it means that the illuminance at the area remains inadequate regardless some of lighting fixtures was removed. In addition, simulation of lighting profile in night-time of the propose scenario also conducted to validate the illuminance capacity. A study conducted by [37] emphasizes that RELUX demonstrated an accurate simulate indoor daylight illuminance under CIE sky condition and various room configurations. Moreover, the software enabling realistic representation of glazing surfaces and materials by supports a range of reflectance and transmittance values. The output from RELUX such as 3D mountain plot of illuminance offers a powerful features of the daylight behaviour mimic in the room.



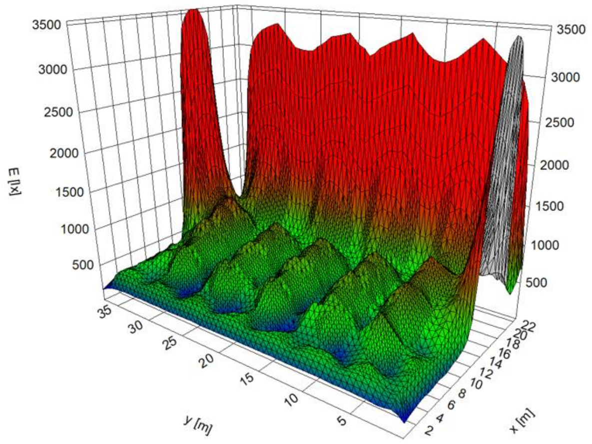


Fig. 18(a). Mountain plot of lighting for base case. Fig. 18(b). Mountain plot of lighting for propose case

Figure 19 presents the illuminance view of propose scenario TYPE (a) during the night time. The artificial lighting visualization depicts the sufficient illuminance during night-time despite nine (9) luminaires were removed from the layout. This result explained that the proposed layout type (a) is an appropriate lighting strategy for reduce energy load in this study.

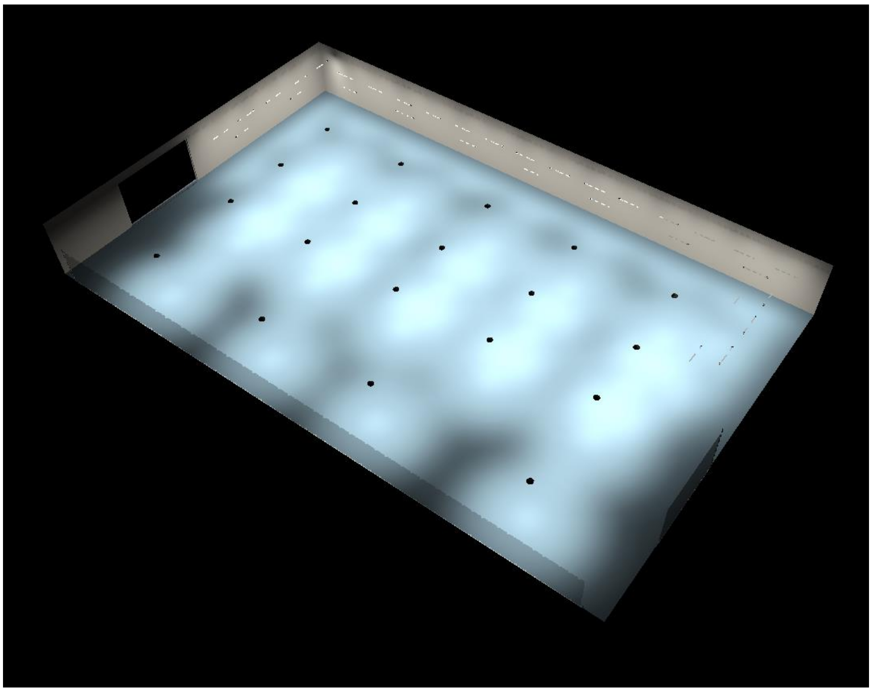


Fig. 19. Illuminance profile of propose scenario during night-time by RELUX desktop

3.2.2 Lighting energy consumption simulation in DesignBuilder

Lighting energy consumption simulation in this study was conducted by DesignBuilder to compare the monthly and annual energy of the propose scenarios. After the Energy Analytical Model (EAM) was generated in Revit, gbXML file (Green Building XML schema) was manually exported to facilitate energy consumption simulation in DesignBuilder. The gbXML format is specifically designed for energy analysis which developed by Green Building Studio Inc. To ensure a smooth export process and avoid errors in DesignBuilder, the building components must be simplified as much as possible. DesignBuilder simulates the building data from BIM model in the gbXML file format [29].

Figure 20(a) and figure 20(b) explain the result monthly lighting energy load of the case study and propose scenario. The lighting energy load appears to fluctuate throughout the entire year, with varying monthly consumption. On average, the lighting consumption is 110,590 kBtu, which is equivalent to 32,415 kWh per month. While for the propose scenario, the lighting load reduced significantly from 110,590 kBtu to 83,420 kBtu monthly.

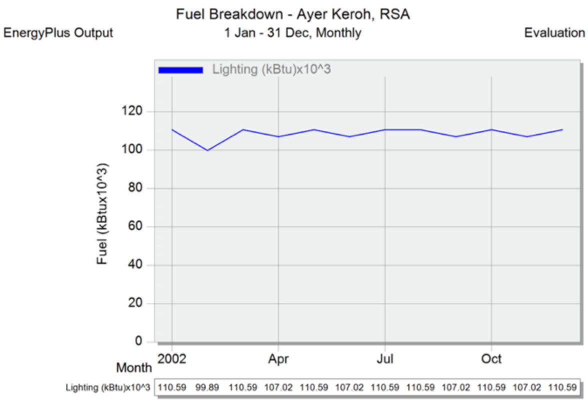


Fig. 20(a). Monthly lighting load of case study

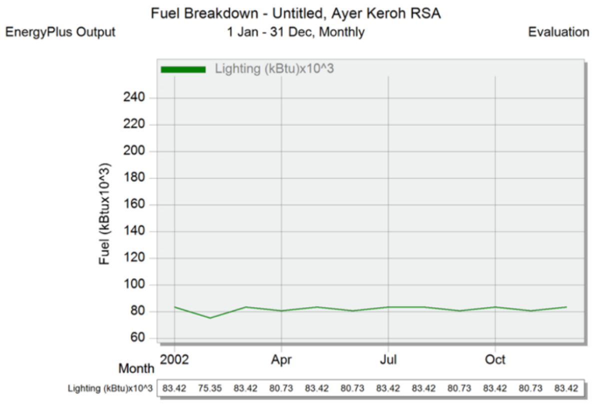


Fig. 20(b). Monthly lighting load of propose scenario

Figure 21(a) displays the difference between annual lighting consumption of case study and propose scenario express in kWh. By modify of the lighting configuration and remove ten (10) luminaires from the existing case study leads to an annual energy savings by 24.44% compared to the baseline scenario. What's more, lighting energy efficiency through natural daylight harvesting in the propose scenario enable to reduce the building operational cost about 48,400 Ringgit Malaysia (RM) every year. This propose lighting configuration holds promise for energy saving and facilitates daylight harvesting in public buildings with open-space structure such as RSA.

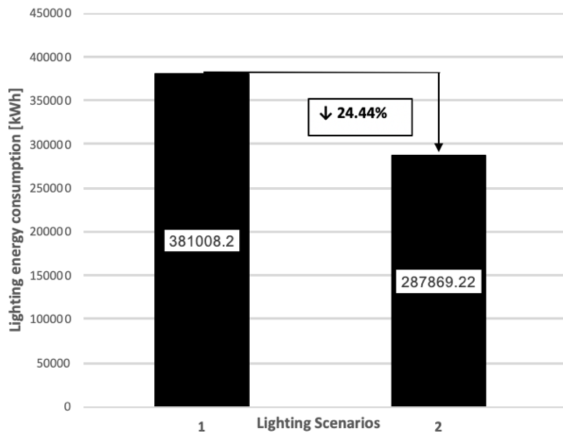


Fig. 21(a). Annual lighting load

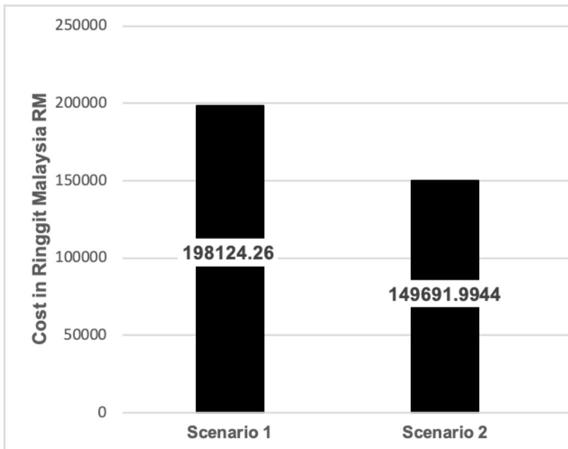


Fig. 21(b). Annual lighting consumption cost in RM

4. CONCLUSION

Rest and Service Area (RSA) is non-residential building type which requires energy-efficient retrofitting to enhance building's energy performance, primarily because of the aging facility and the absence of energy conservation or energy efficiency practices. Enhancing energy efficiency serves as a significant approach to simultaneously address energy security and environmental concerns. Retrofitting the facilities like RSA is essential to maintain modernized operational services and more importantly to lower operational energy and carbon footprint emission. Upgrading the energy efficiency through advanced lighting system is a potential retrofitting solution for energy efficiency measure in this type of building due to the excessive of lighting consumption. The energy-saving simulations presented in this study introduce innovation lighting configuration by predictive simulation which is a sustainable solution to improve energy performance and reducing operational costs for highway operations. This study plays a crucial role in supporting Malaysia's national policy toward low carbon buildings and Malaysia Low Carbon City Framework (LCCF) for achieving the United Nations Sustainable Development Goals (SDGs). By minimizing the reliance on artificial lighting, this strategy able to reduces end-use energy consumption and contributes to SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). In conclusion, natural lighting stands out as a crucial energy source to harness in open-space envelope buildings like RSA. Deep energy retrofitting is can be achieved through the synergistic combination of multiples energy-efficiency measures.

ACKNOWLEDGEMENT

I would like to thanks to Organization for Women in Science for the Development World (OWSD) a unit program by UNESCO and UTM International Doctoral Program (UTM IDF) for sponsoring this research.

REFERENCES

1. Szymczak-Graczyk, A, Kalka, J and Ksit, B 2024. Evolution of Energy Efficiency of Buildings Using the Guidelines of the European Green Deal Plan. *Civil and Environmental Engineering Reports* **34**, 16–30.
2. Bulbaai, R R and Halman, J IM 2023. Standby energy consumption and saving potentials in the residential sector in tropical areas: the Caribbean island Curaçao as a case study. *Energy Efficiency*, **16**, 34-35.
3. van Oorschot, JAW, Halman, JIM and Hofman, E 2021. The adoption of green modular innovations in the Dutch housebuilding sector. *Journal of Cleaner Production*, **319**, 128524.
4. Romo-Martín, A and Pérez-Acebo, H 2018 Analysis of the Location of Service and Rest Areas and their facilities in Spanish paying motorways. *Transportation Research Procedia*, **33**, 4–11.
5. Zakaria, R, Seng, FK, Muhd, MZ, Zin, RM, Hainin, MR, Puan, OC and Moayedi, F 2013. Energy efficiency criteria for green highways in Malaysia. *Jurnal Teknologi (Sciences and Engineering)*, **65,** 91–95.
6. Husin, NI, Julaihi, FA, Rais, SL, A Redzuan, AF, and Bidin, ZA 2024. an Integrated Analysis of Green Highway Assessment Criteria for Sustainable Infrastructure Development. *Planning Malaysia*, **22**, 397–411.
7. Balubaid, S, Bujang, M, Aifa, WN, Seng, FK, Rooshdi, RRR, M, Hamzah, N and Ismail, HH 2015. Assessment index tool for green highway in Malaysia. *Jurnal Teknologi*, **77**, 99–104.
8. Willoughby, K 2015. Green Roads : A Sustainability Rating System for Roadways, (May)
9. Bryce, J 2008. Developing Sustainable Transportation Infrastructure. Exploring the Development and Implementation of a Green Highway Rating System, 21
10. Outstanding, R, and In, L 2008. Certification Program, (September).
11. Douglas Knuth, J, Aquino, JF, Abdul, D, Rick, W, and Michelle, A 2012. *I-last*.
12. Transportation-Infrastructure-Highway, BE and ES 2012. *BE2ST-Manual*.
13. Transportation, D 2011. *Greenroads MANUAL v1.5 © 2011*.
14. Zakaria, MNA Bin A 2020. *MyGHI and PHJKR Comparison for Succeeding Criteria on Sustainable Road Design and Construction Activities of Road Green Tools*.
15. Gavioli, M, Tetri, E, Baniya, RR and Halonen, L 2015. Lighting Retrofitting : Improving Energy Efficiency and. *28th CIE Session*, **June 28 – July 4**, 1903–1911.
16. Pan, Y, Zhu, M, Lv, Y, Yang, Y, Liang, Y, Yin, R and Yuan, X 2023. Building energy simulation and its application for building performance optimization: A review of methods, tools, and case studies. *Advances in Applied Energy*, **10**, 100135.
17. Yu, X, Su, Y and Chen, X 2014. Application of RELUX simulation to investigate energy saving potential from daylighting in a new educational building in UK. *Energy and Buildings*, **74**, 191–202.
18. Zhu, P, Gilbride, M, Yan, D, Sun, H, and Meek, C 2017. Lighting energy consumption in ultra-low energy buildings: Using a simulation and measurement methodology to model occupant behavior and lighting controls. *Building Simulation*, **10**, 799–810.
19. Monh, N 2021. Lighting Simulation of Energy Saving for Rest and Service. Universiti Teknologi Malaysia.
20. Ferrari, S and Beccali, M 2017. Energy-environmental and cost assessment of a set of strategies for retrofitting a public building toward nearly zero-energy building target. *Sustainable Cities and Society*, **32**, 226–234.
21. Snyder, J 2020. Energy-saving strategies for luminaire-level lighting controls. *Building and Environment*, **169**.

22. Dabe, TJ and Adane, VS 2018. The impact of building profiles on the performance of daylight and indoor temperatures in low-rise residential building for the hot and dry climatic zones. *Building and Environment*, **140,** 173–183.
23. Gentile, N 2022. Improving lighting energy efficiency through user response. *Energy and Buildings*, **263,** 112022.
24. Dai, Q, Huang, Y, Hao, L, Lin, Y and Chen, K 2018. Spatial and spectral illumination design for energy-efficient circadian lighting. *Building and Environment*, **146(August)**, 216–225.
25. Malaysia and Standard 2019. *ev i*.
26. Tahir, MZ, Nawi, MNM and Ibrahim, A 2016. Low-cost and no-cost practice to achieve energy efficiency of government office buildings: A case study in federal territory of Malaysia. *AIP Conference Proceedings*, ***1761*.**
27. de Wilde, P 2018. Building Performance Analysis. *Building Performance Analysis*.
28. Maamari, F, Fontoynont, M and Adra, N 2006. Application of the CIE test cases to assess the accuracy of lighting computer programs. *Energy and Buildings*, **38**, 869–877.
29. Ivanova, I, Kiesel, K and Mahdavi, A 2015. BIM-generated data models for EnergyPlus: A comparison of gbXML and IFC formats. *Building Simulation Applications*, **2015-Febru**, 407–414.
30. gbXML 2023. About gbXML Board of Directors.
31. Sameer, M 2024. CONVERTING CONVENTIONAL BUILDINGS INTO GREEN, **8**.
32. Skiba, M and Rzeszowska, N 2017. Analysis of the Dependence between Energy Demand Indicators in Buildings Based on Variants for Improving Energy Efficiency in a School Building. *Civil and Environmental Engineering Reports*, **26**, 31–41
33. Aun, CS 2009. GREEN BUILDING INDEX – MS1525: Applying MS1525:2007 Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings. *GBI CPD Seminar*, 1–22.
34. Ensto 2023. Lighting ’s energy-efficiency.
35. Pandharipande, A and Caicedo, D 2015. Smart indoor lighting systems with luminaire-based sensing: A review of lighting control approaches. *Energy and Buildings*, **104**, 369–377.
36. Fernandez-Prieto, D and Hagen, H 2017. Visualization and Analysis of Lighting Design Alternatives in Simulation Software. *Applied Mechanics and Materials*, **869,** 212–225.
37. Bhavani, RG and Khan, MA 2011. Advanced Lighting Simulation Tools for Daylighting Purpose: Powerful Features and Related Issues. *Trends in Applied Sciences Research*, **6**, 345–363.