ANALYSING PARAMETERS FOR ENERGY EFFICIENCY RETROFITTING INITIATIVES FOR HIGH-RISE BUILDINGS THROUGH AN INTEGRATED APPROACH

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INSTITUTE FOR ADVANCED STUDIES
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ABSTRACT

One of the biggest consumers of energy and producers of greenhouse gases (GHGs) is the building industry. Due to this, many countries have established acts, standards, and guidelines to ensure the new building development is in line with the main objectives of being energy-efficient and lowering GHG emissions. However, sole dependency on the new building development is inadequate. With the high number of existing buildings in Malaysia, which mainly are non-energy efficient, analysing a building's load profile is the first step in allowing the implementation of load factor improvement initiatives that improve load balancing while also lowering utility costs and emissions. The execution of load factor improvement initiatives could come from numerous strategies, which focused on either the non-design factor or passive design factor of a building, or even both. Essentially, the retrofitting initiatives are decided based on the most practical and cost-effective solution. In this research, Wisma R&D, Universiti Malaya was selected as the reference building and two approaches have been selected for analysing the effect of different building parameters. The outcome later could assist in effective retrofitting decision-making. Prior to the walk-through energy audit (EA) and simulation-based approaches, the load factor (LF) performance analysis was carried out based on the four conservative years (2015 to 2018) of the building's utility bills. Based on the analysis, the need for urgent retrofit is validated as the building's LF performance is measured between 0.3 to 0.4. The succeeding analysis focuses on identifying the most impacted non-design and passive design factors that contributed to the trio effect i.e. energy consumption, energy cost, and carbon emission from building operations. The outcome of the walk-through EA concluded that air-conditioning, server racks, lighting, and PC/laptops are the highest contributors to the total energy consumption in Wisma R&D with 34%, 18%, 18%, and 10% respectively. Nevertheless, it is not practical to work on saving initiatives for the server rack. Hence, an analysis of the potential saving from the utilisation of air-conditioning, lighting, and PC/laptops are presented in this research. In addition, the passive-design factors like the window glazing, opaque, and shading materials were analysed thoroughly using ArchiCAD. The simulation-based approach concluded that an *Argon-filled double-glazed* window with the combination of the aluminum ultimate metal frame provided the optimal thermal resistance (R-value) and infiltration rate (in ACH) for Wisma R&D. The effective match for both parameters was found to be 0.98 m^2K/W and 0.31 ACH respectively which resulted in 18,133.9 kWh, RM 6618.88 and 1265.16 kg saving of annual energy consumption, energy cost, and carbon emission reduction. Apart from the window design performances, the horizontal shading effect is too discussed. The findings of this research were summarised in a useful retrofitting suggestion for high-rise buildings in Malaysia.

Keywords: Effective Retrofitting, EA, Building Information Modelling (BIM), Energy Performance Evaluation, ArchiCAD

ANALISIS PARAMETER UNTUK INITIATIF PENGHASILAN SEMULA KECEKAPAN TENAGA UNTUK BANGUNAN TINGGI MELALUI PENDEKATAN BERSEPADU

ABSTRAK

Salah satu pengguna terbesar tenaga dan pengeluar gas rumah hijau ialah industri pembinaan. Disebabkan ini, banyak negara telah menetapkan akta, piawaian dan garis panduan untuk memastikan pembangunan bangunan baharu selaras dengan objektif utama untuk menjadi cekap tenaga dan mengurangkan pelepasan gas rumah hijau. Walau bagaimanapun, pergantungan semata-mata pada pembangunan bangunan baharu adalah tidak mencukupi. Dengan bilangan jumlah bangunan sedia ada yang tinggi di Malaysia, yang kebanyakannya tidak cekap tenaga, menganalisa prestasi faktor beban bangunan adalah langkah pertama dalam melihat keperluan pelaksanaan inisiatif penambahbaikannya di samping mengurangkan kos utiliti dan pelepasan gas rumah hijau. Pelaksanaan inisiatif penambahbaikan faktor beban boleh direalisasikan melalui pelbagai strategi, yang memfokuskan sama ada pada faktor bukan reka bentuk atau faktor reka bentuk pasif sesebuah bangunan, atau kedua-duanya. Pada asasnya, inisiatif pengubahsuaian diputuskan berdasarkan penyelesaian yang paling praktikal dan kos efektif. Dalam penyelidikan ini, Wisma R&D, Universiti Malaya telah dipilih sebagai bangunan rujukan dan dua pendekatan telah dipilih untuk menganalisa kesan dari parameter bangunan yang berbeza terhadap penggunaan tenaga. Hasilnya kemudiannya boleh membantu dalam membuat keputusan pengubahsuaian yang berkesan. Sebelum audit tenaga (EA) dan simulasi dijalankan, analisis prestasi faktor beban (LF) telah dijalankan berdasarkan bil elektrik Wisma R&D selama empat tahun (2015 hingga 2018). Berdasarkan analisa yang dijalankan, ia mengesahkan keperluan untuk pengubahsuaian segera kerana prestasi LF bangunan didapati berada antara 0.3 hingga 0.4. Analisa seterusnya memberi tumpuan kepada mengenal pasti faktor bukan reka bentuk dan reka bentuk pasif yang paling berkesan yang akan menyumbang kepada kesan trio iaitu penggunaan tenaga, kos tenaga dan pelepasan karbon daripada operasi bangunan. Hasil dari audit tenaga yang dijalankan, ia menyimpulkan bahawa penyaman udara, *server rack*, pencahayaan, dan PC/komputer riba adalah penyumbang tertinggi kepada jumlah penggunaan tenaga dalam Wisma R&D dengan masing-masing menyumbang sebanyak 34%, 18%, 18% dan 10% dari keseluruhan penggunaan elektrik. Walau bagaimanapun, adalah tidak praktikal untuk mengusahakan inisiatif penjimatan untuk *server rack*. Oleh itu, analisa potensi penjimatan daripada penggunaan penghawa dingin, pencahayaan, dan PC/komputer riba dibentangkan dalam penyelidikan ini. Selain itu, faktor reka bentuk pasif seperti kaca tingkap, bahan legap dan teduhan dianalisa dengan teliti menggunakan ArchiCAD. Pendekatan berasaskan simulasi telah menyimpulkan bahawa tetingkap *Argon-filled double-glazed* dengan gabungan *aluminum ultimate metal frame* telah memberikan rintangan haba optimum (nilai R) dan kadar penyusupan (dalam ACH) untuk Wisma R&D. Padanan berkesan bagi kedua-dua parameter didapati masing-masing 0.98 m^2K/W dan 0.31 ACH yang menghasilkan 18,133.9 kWj, RM 6618.88 dan 1265.16 kg penjimatan penggunaan tenaga tahunan, kos tenaga dan pengurangan pelepasan karbon. Selain daripada persembahan reka bentuk tingkap, kesan teduhan mendatar juga dianalisa. Penemuan penyelidikan ini diringkaskan dalam cadangan pengubahsuaian yang berguna untuk bangunan bertingkat tinggi di Malaysia.

Kata Kunci: *Effective Retrofitting, EA, Building Information Modelling (BIM), Energy Performance Evaluation, ArchiCAD*

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	:	Air conditioning
ACH	:	Air-Change per Hour
AEC	:	Architecture, Engineering, and Construction
AL	:	Average Load
ANN	:	Artificial Neural Network
BEI	:	Building Energy Index
BEM	:	Building Energy Modelling
BIM	:	Building Information Modelling
BL	:	Base Load
BREEM	:	Building Research Establishment Environment Assessment Method
BTU	:	British Thermal Unit
CAD	:	Computer-Aided Design
CIDB	:	Construction Industry Development Board
CO_2	:	Carbon Dioxide
CPU	:	Central Processing Unit
EA	:	Energy Audit
ECO	:	Energy Conservation Opportunities
EE	:	Energy Efficiency
EJ	:	Exajoules
EPU	:	Economic Planning Unit
EU	:	European Union
G	:	Ground
GBI	:	Green Building Index
GDP	:	Gross Domestic Product

GFA : Gross Floor Area

GHGs : Greenhouse Gasses

GR : Glazing Ratio

GW : Gigawatt

GWh : Gigawatt hour

HHG : Human Heat Gain

HP : Horse Power

HS : Horizontal Shading

HVAC : Heating, Ventilation, and Air Conditioning

IEA : International Energy Agency

IEM : Institute of Engineer Malaysia

IES : Integrated Environment Solution

IEQ : Indoor Environment Quality

IPCC : Intergovernmental Panel on Climate Change

ISO : International Standard Organization

JPPHB : *Department of Development and Estate Maintenance*

ktoe : Kilo-tonne of oil equivalent

LED : Light Emitting Diode

LEED : Leadership in Energy and Environment Design

LEO : Low Energy Office

LF : Load Factor

LG : Lower Ground

LNG : Liquefied Natural Gas

M : Mezzanine

MD : Maximum Demand

M&E : Mechanical and Electrical

MW	:	Megawatt
MS	:	Malaysia Standard
NASA	:	National Aeronautics and Space Administration
NEB	:	National Energy Balance
NG	:	Natural Gas
NGTP	:	National Green Technology Policy
NOAA	:	National Oceanic and Atmospheric Administration
NPCC	:	National Policy on Climate Change
nZE	:	Net Zero Emission
nZEB	:	Nearly Zero Energy Building
PC	:	Personal Computer
PL	:	Peak Load
PV	:	Photovoltaic
PWD	:	Public Works Department
RE	:	Renewable Energy
RH	:	Relative Humidity
ROI	:	Return of Investment
SDG	:	Sustainable Development Goal
SPSS	:	Statistical Package for Social Science
TNB	:	Tenaga Nasional Berhad
TP	:	Trip per Minute/Trip Time
TPES	:	Total Primary Energy Supply
UM	:	Universiti Malaya
U.S.A	:	United State of America
VRF	:	Variable Refrigerant Flow
VRV	:	Variable Refrigerant Volume

WWR : Window-to-Wall Ratio

ZEO : Zero Energy Office

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

Energy is one of the key inputs for urbanization, industrialization, development, and modernization which has become the push factor for fast-developing countries in becoming more energy-intensive. According to statistics published by International Energy Agency (IEA), a 30% rise in global energy demand towards 2040 (IEA, 2016, 2018c) should be a significant percentage for the government worldwide to seriously initiate and embark on energy-saving initiatives in all sectors. Furthermore, as a country moves towards a developed nation, it is a norm that the trend of business and its economy will as well shift from industrial-based to service-based. Due to this, energy consumption is expected to show a shift in trend too.

Malaysia, one of the countries which are currently facing rapid development, has recorded a paradigm shift in its energy consumption. This is shown in the statistics recorded in the Malaysia Energy Statistic Handbook 2016 (EC, 2016a), where the final energy consumption by sectors shows an increment of energy consumption in the transportation as well as the residential and commercial sectors. The industrial sector, on the other hand, had recorded a continuous reduction in energy consumption which reduced from 44% of the total country's consumption in the year 1978 to 38% at the end of the twentieth century. The decrement trend continues for the next decade, during which the industrial sector's final energy consumption was recorded to be only 31% of the total final energy consumption of the country. The latest result published in Malaysia Energy Statistic Handbook had shown that the industrial sector had only consumed 25% of the total country's energy consumption. Hence, this trend supports the earlier statement. However, through the years, the service sector has shown a higher growth percentage in energy consumption (EC, 2015). Among the top consumers in this sector are hotels, shopping complexes, offices, hospitals, and universities. However, the office building was the only one that showed a consistent increment from year to year in terms of its energy consumption. The increase of 24% and 32% subsequently between 2013 to 2015 (EC, 2015) has become an eye-opener and motivation for the government, developers, and building professionals to look into the aspect of making office buildings more energy-efficient as well as environmentally friendly.

Based on the current trend, the country's energy conservation initiatives have gone beyond the industrial and transportation sectors. Focus now includes the residential and commercial sectors. There are numerous initiatives taken by the Malaysian government and some were clearly outlined in the Eleventh Malaysia Plan (EPU, 2016b). Furthermore, the Malaysian government is encouraging detailed research in supporting the short and long-term energy conservation strategies for the countries. Due to this, detailed research is carried out which aims to analyse the impact of several building parameters on building energy consumption, specifically for a high-rise building in Malaysia. In parallel, the economic and environmental impacts are reviewed. In this research, these three elements are referred to as 'The trio effect'. In achieving this aim, several approaches need to be inculcated. Hence, different methods of analysing a building's energy performance are introduced in this research.

As mentioned earlier, the type of building within the commercial sectors includes schools, hospitals, shopping complexes, offices, and many more. Each type of this building has a different internal and external design, material, appliances, number of occupants, operating hours, and orientation. These parameters will either directly or indirectly contribute to the energy consumption of one building which later directly links to greenhouse gasses (GHGs) emissions mainly the CO_2 (Abanda & Byers, 2016; Jagarajan et al., 2017; Levesque et al., 2018). Together with the effect of drastic climate change, one prospective solution towards less carbonization from the commercial sector is to make a building greener. A building needs to be designed or retrofitted toward environmental sustainability in terms of its design, construction, and maintenance (Jagarajan et al., 2017). This was supported by (Schlueter & Geyer, 2018) who through their study summarized the importance of inculcating the methods of Building Performance Optimization to identify the best-performing designs of a building that lead to less energy, efficient energy consumption, comfort and be capable to harness the local energy sources mainly the solar. Unfortunately, only 2% of the total building in Malaysia are energy-efficient (Buletin IEM). Hence, it is very challenging for the country to achieve a significant result in reducing greenhouse gasses (GHGs) if the action towards making a building greener is not enforced on the existing building. Retrofitting the non-energy-efficient building should be one of the country's agenda as it could assist in reducing GHG emissions as well as fulfilling the Paris Agreement's commitment. It is no doubt that the Malaysian government has come out with various guidelines and initiatives for new building development, however, a practical guideline on retrofitting is not made available. As the research is targeting to analyse the building energy performance within a commercial sector, hence Wisma R&D Universiti Malaya has been selected as the reference building. A comprehensive analysis of the building energy performances is carried out through several methods which aim to acknowledge the effective retrofitting initiative for a high-rise commercial building in Malaysia.

Changes in office requirements took place as the country develops. An article written in the latest *The Edge* newspaper, (Khoo, 2019) highlighted several basic requirements which are important and included as the selection criteria of office spaces according to the property experts. Some of the factors highlighted on the list are the office location, type of office spaces, connectivity and accessibility to the road and highway as well as the availability to access to public transport. On a different aspect, as awareness among employers in enhancing their employee's productivity has emerged, the demand for a workspace that is flexible, conducive, and comfortable has increased. In other words, an office space that is 'healthy' is one of their utmost priorities. In general, employers believed that a green office creates a healthy work environment as well as allows them to enjoy tax incentives. Hence, developing a green building or retrofitting towards one has become one of the hot topics around the globe mainly in the construction sector.

There are several ways in achieving this aim. Methods like conducting the walk-through EA or detailed EA which include installing power meters for various floors or applications, load factor improvement, and the most effective and popular way which is through thorough building simulation (Ascione et al., 2017b; Gao, Koch, & Wu, 2019; M. Krarti, 2016) are recommended. Despite the outcome obtained from each of the above methods, each has its limitation. Walk-through EA limits the study of a building's energy performance up to the energy consumption which is based on the appliances' power rating and operating time. Even though a walk-through EA is one of the basic methods for identifying how a building is performing in the aspect of energy utilization, it is a time-consuming process especially when it involves a high-rise building. In parallel, it requires high involvement and commitment from both the building owner and the occupants in the building. Interview over interview is deemed necessary to ensure that the assessment and analysis are valid and align with the EA objectives. Detailed EA, on the other hand, is more accurate and practicable. It involves the installation of power meters within the building and the energy consumption is monitored accordingly. The significance of detailed EA is much depending on the installation plan. This is much related to the building layout, activities within the building as well as the financial capacity of the building owners. Even though a detailed EA is far more significant than a walk-through EA, it requires strong financial and technical support from the building management. Despite the added advantages compared to the walk-through EA, the building energy performance study is limited especially when it comes to the need for refurbishment. Both walk-through EA and detailed EA are only capable to analyse the effect of the appliances based on the power rating, quantity, and operations time information. Suitable and affordable control measures are commonly implemented in improving building energy performances. On top of the above two, load factor assessment and improvement is another significant method in assessing building energy performances. Unfortunately, all these methods are incapable to identify the other building parameters that are indirectly affecting a building's energy performance. Hence, thorough building simulation is found to be one of the comprehensive methods for identifying the effect of various building parameters on building energy performances. According to (De Boeck, Verbeke, Audenaert, & De Mesmaeker, 2015), building simulations play an important role in determining the optimal design variable, which influences the building energy consumption. In general, a thorough analysis of building energy performance can only be achieved through a combination of a few methods. Both the direct and indirect parameters of a building that contributes to a building's energy consumption could be identified which later helps in assisting in improving the new building development as well as the retrofitting process.

1.1 Research Background

Malaysia is among the countries that had committed to reducing the percentage of GHGs by up to 40% by the year 2030 (EC, 2016b; EPU, 2016a; Nations, 2016). Hence, the government needs to set very comprehensive strategies for achieving this target without jeopardizing the importance of securing and supplying the country's energy needs. Moving towards becoming one of the developed countries, Malaysia is facing a very intense energy requirement which will directly lead to the sharp depletion of energy resources mainly the non-renewable type. This scenario has caused the Malaysian government to work hand-in-hand with all sectors in taking effective approaches toward energy security for the country. Apart from increasing the number of power plants and working efficiently on setting up renewable energy power plants such as solar and hydro; it is crucial to look at other perspectives which involve the efficient utilization of energy (utilization initiative is one of the principles of the National Energy Policy) as this will prolong the amount of the reserves in parallel with the need to reduce the GHGs emission. Efficient utilization of energy covers vast aspects such as the installation of high technology devices in the power plant, proper planning, the introduction of the energy management system, EA exercises, efficient energy conservation in the building (including retrofit), and many others.

The National Energy Policy outlined by the Malaysian Government has predicated three main principles as part of the energy efficiency initiatives in Malaysia. These are supply objectives, utilization objectives, and environmental objectives (Sustainable Energy Division Ministry of Energy, Green Technology & Water Malaysia). Apart from the supply objectives, the remaining two principles can be achieved easier in; the short term via continuous effort and support by all the relevant parties such as the government, non-government organizations, industrial players, and others. In addition, public awareness needs to be elevated in meeting these objectives. Efficient utilization of energy and the elimination of wasteful and non-productive patterns of energy consumption are some of the key actions that are outlined in the National Energy Policy (EC, 2016b). In parallel, the third principle which links to the environmental objectives will come into play.

In general, global final energy demand from buildings has increased tremendously every year (Levesque et al., 2018; IEA, 2018c). Even though the demand for energy in buildings varies strongly across countries and climatic zone (Levesque et al., 2018), the commercial sector which mainly consists of various types of buildings is the most highly consumed worldwide. Initially, this trend was clearly shown in the developed countries where they are urged to find a way in solving this issue due to the high GHG emission (Martínez-Zarzoso & Maruotti, 2011), however, they have been recent calls for developing countries to play an active role in global emission reduction. A study reported that the level of GHGs emissions from developing countries, mainly CO_2 has been rapidly exceeding that of the developed countries and in 2003 accounted for almost 50% of the world's CO_2 emission. One of the main contributors to CO_2 emission is due to urbanization and approximately 64% of developing countries' population will be urbanized by 2050 (Bekhet & Othman, 2017). In short, urbanization leads to more buildings being built and higher energy is consumed due to increasingly demanding comfort standards from the occupants(Martínez-Zarzoso & Maruotti, 2011; Pacheco-Torres, Roldán, Gago, & Ordóñez, 2017). Hence, it is very important to focus on the development of sustainable buildings, which includes making building more energy-efficient. Aside from new buildings, it is paramount to pivot the same aim on retrofitting the existing non-energy efficient's buildings.

In achieving these, numerous initiatives need to be executed. Decision-makers have been expressing mounting concerns and awareness regarding Low Energy Office (LEO), Zero Energy Office (ZEO), EA, and other methods that could assist in energy conservation within the commercial sector. A lot of studies have identified the key building parameters that have contributed to the intense use of energy within a building (Moghimi et al., 2014; Tahir, Nawi, & Rajemi, 2015; Yuan, Ruan, Yang, Feng, & Li, 2016; Tahir, Nawi, & Zulhumadi, 2021; Leong, Yeap, & Ang, 2021). From Malaysia's perspective, looking specifically at the efficient energy conservation in buildings which has become one of the national strategies that were clearly outlined in the Eleventh Malaysia Plan (EPU, 2016a), it is vital to conduct an in-depth study to identify the key building parameters and their effect on a sustainable building. In meeting the objectives of this focus area, the Malaysian government has encouraged greater coordination and collaboration in the energy sector through greater institutional collaboration on energy planning and engaging the end-users on efficient energy consumption. In other words, great support from various parties is deemed necessary in meeting the national objective. Currently, the Malaysian government is not only focusing on the new sustainable building development but putting a high effort into retrofitting the existing building towards a sustainable one (Nazri et al., 2013; Carvalho, 2018). One of the key targets is on retrofitting all the main government buildings in Malaysia, especially in Putrajaya. Hence, this research is vital in supporting the need to identify and analyse the key building parameters and their effect on building energy performances, particularly for a high-rise building in Malaysia.

From the above strategies, it is seen that an energy-efficient building is of paramount importance in ensuring higher energy savings across all buildings in the country. A performance metric and a practical Malaysia Standard (MS) need to be continuously reviewed. Due to this, the focus of this research is to carry out an interactive analysis of the effect of different parameters on the energy consumption of an office building in Malaysia.

A guideline or reference is one of the crucial elements in the effort of designing future buildings or retrofitting existing non-energy-efficient ones. Historically, assessment tools like Building Research Establishment Environment Assessment Method (BREEAM) had been introduced and used back in 1990. It has been the world's longest-rating tool that rates and certifies the level of building sustainability. Followed by Leadership in Energy and Environmental Design (LEED), Green Star, Green Mark, and many others (De Boeck et al., 2015; Tam, Le, Tran, & Wang, 2018). The objectives of each tool are generally to promote the development of sustainable buildings across the globe. In-country like Malaysia, the evolvement of sustainable or green building assessment tools only kicked off in the twenty-first (21^{st}) century. In specific, it was reckoned with the introduction of the Green Building Index (GBI) in 2001. Table 1.1 demonstrates the development of the GBI tool in Malaysia which has become the reference for sustainable building development in Malaysia.

Table 1.1: Development of the GBI tool

Date	Agenda
August 2008	PAM invited the Association of Consulting Engineers of Malaysia (ACEM) to cooperate in developing and setting up the Green Building Index (GBI) in Malaysia.
September-October 2008	Set up a committee to perform comparative studies on the existing green building tools such as BREEAM, LEED, Green Mark, and Green Star to set up the criteria for GBI.
October - November 2008	Performed a study visit to the green building council of Australia's GREENSTAR, Singapore Building Construction Authority (BCA), and a few others.
December 2008	The final draft of both the Residential and Non-residential rating tools.
3^{rd} January 2009	GBI was first introduced at the Green Design Forum.
16^{th} January 2009	Fine-tune the GBI tool and launch the GBI assessment and accreditation framework including the terms of reference for the GBI Accreditation Panel (GBP), GBI Certifiers, and GBI Facilitators.

The existence of numerous sustainable building tools worldwide has yet to trigger the respective parties, mainly in the construction field to initiate aggressive development of a sustainable building, widely known as a green building. This was caused by several factors such as policy readiness, financial support, and level of awareness by the construction players as well as the client. Due to this, a concrete solution considering the effective short and long-term impact of sustainable building needs to be disclosed. In a nutshell, four main elements; i.e. energy consumption, energy cost, environmental impact, and occupant's comfort are expected to be optimized in sustainable building development. Finding the balance of these four elements has become the most challenging part of the construction field as well as the research arena. Even though the available references such as BREEAM, LEED, Green Star, Green Mark, and GBI act as basic guidelines for the building professional to meet the objectives of developing a sustainable building or retrofitting an existing one, there is a lot of other information that needs to be first understood, especially for a retrofitting initiative. Thus, it is important to analyse various factors in building design and operation before any decision is made. Furthermore, an in-depth analysis needs to be carried out to arrive at the best decision for developing or retrofitting a building.

In general, from the various available green building assessment guidelines, higher weightage is allocated to the energy efficiency-based element. A comparison was made between those three tools which were mentioned earlier. Table 1.2 describes the percentage allocated to the energy-based point in the respective building assessment tools. From the observation, it is concluded that the energy performance criteria have become one of the most impacted criteria in the development of sustainable buildings. Thus, a thorough analysis of which aspects of a building contribute to building energy performances is highly in need.

Table 1.2: Energy-based scores in various assessment tools

Tool	Country	Total point	Energy-based point score	%
GBI	Malaysia	100	35	35
Green Mark	Singapore	190	116	61
Green Star	Australia	100	22	22

In Malaysia's building and construction sector, Malaysia's green development policies can be traced in the 3rd Malaysian Plan (1976-1980) when the relationship between environment and development started receiving consideration in development planning (Onuoha et al., 2017). However, green building policies in Malaysia effectively were detailed out with the launch of the National Green Technology Policy (NGTP) and GBI somewhere in 2009. Even though the implementation of sustainable building is a bit behind compared to countries like Singapore and Thailand, the awareness has got deeper attention among the respected parties.

As mentioned earlier, GBI had been launched by the government on 21st May 2009. It is a green rating index developed as a guideline for developing environmentally friendly buildings. This initiative was part of the Ninth Malaysia Plan whose main aims were to promote green technology and reduce the GHGs released within the sector. In addition to the GBI, MS 1525 is a blueprint that contains a code of practices for the non-residential building including the office building. It was first released in the year 2007 and the improved version was published in 2014. In general, these policies and guidelines promote the element of energy efficiency (EE) and renewable energy (RE) in various aspects of the country including the building development aspects.

There are various aspects of building construction that requires detailed observation or otherwise lead to various problems. Such aspects as the design, use, and disposal of building materials, orientation, and many others are the key parameters associated with global concerns and issues; mainly climate change and GHG emissions. In specific, (Shafii & Othman, 2007) highlighted that on top of the generic concerns, areas of main concern include building energy use, waste generation, construction material consumption, water consumption and their discharge, integration of buildings with other infrastructure, and the social systems. In recent years, the building is also linked with social impact, behavior, and health. By this means, the building and construction sectors are in crucial need of inculcating the concept of sustainable development.

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) on *Climate Change Impacts, Adaptation, and Vulnerabilities for Asia* reports with high confidence that warming trends and increasing temperature extremes have been observed across most of Asia in the past century. Increasing numbers of warm days and decreasing numbers of cold days have been observed, with the warming trend continuing into the new millennium. The report states that "there is evidence that climate has changed in Asia and future changes can be expected which will increasingly challenge the resilience and undermine the development that has been achieved in the region. As this is a world issue in which Malaysia is not excluded, hence the Malaysian government has embarked on an economic transformation plan that emphasizes green technology and low-carbon development along with other national agendas.

Furthermore, the issue related to climate change increases proportionally with the increment of the population, and according to (Puppim de Oliveira, 2019), the world population is expected to reach 8.5 billion by 2030 with more than 60% will live in cities. Specifically for Malaysia, with around thirty million population recorded in 2017; an increase of 14% from 2007 has become one of the pushing factors that stimulate the need for various development projects in sectors like commercial, residential, and transportation. Moreover, the amount of a country's energy requirement is much related to the population. Hence, to reduce the side effects of the rapid development of the building and construction sector, comprehensive, systematic, and effective strategies are essentially required. The baseline of the strategies may require one country to outline suitable initiatives, policies, standards, and enforcement to support the development of the economy and society while ensuring environmental sustainability. International Standard Organization or ISO (Naden, 2019) states that as populations and economies grow so does the need for housing and infrastructure. In specific, as the demand grows for construction, means a greater requirement for efficient ways of working needs to be critically adopted within the construction industry to materialize sustainable building objectives.

Looking from a different perspective, the main source of GHGs emissions is due to the increasing trend of worldwide energy consumption. This has led to various environmental issues such as air pollution, ozone depletion, sea-level rise, adverse effects on biodiversity, and ultimately global warming. For this reason, it is critical to accelerate low-carbon development to ensure inclusive and sustainable development while building resilience to climate change and disaster risk reduction (Pereira, 2016). These means are the basic principles of the Kyoto Protocol and Paris Agreement which are known as international treaties to combat the issue of climate change. The protocol's major feature is that it has mandatory targets on greenhouse-gas emissions for the world's leading economic countries to reduce their overall emissions of such gases to ensure significant reductions in gas emissions. All the countries that had agreed on the Kyoto Protocol had mandatory targets after 2012 in committing to a certain percentage of carbon emission reduction (United Nations: Framework Convention on Climate Change). Malaysia in specific, along with other countries had agreed to commit to a 40% reduction of greenhouse gas emissions by the year 2020 (Anastaselos et al. 2015).

1.2 Problem Statements

Earth's 2015 surface temperatures were the warmest since modern record-keeping began in 1880, according to independent analyses by the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA). At the Paris Climate Change Conference which took place in 2016, the first equitable global agreement to deal with global warming was adopted and the target of limiting the increase in temperatures to 2 °C by the year 2100 was agreed to (Ascione et al., 2017a; Pacheco-Torres et al., 2017). As the main course of global warming is GHGs emissions which are indirectly related to global energy consumption, it is crucial to take into serious consideration all the main contributors. A comprehensive plan and action need to be taken by all the countries including Malaysia, in conjunction with the need to slow down the pace of global warming. This required strong collaboration and cooperation between the government and various relevant parties.

Given a closer look, (Jagarajan et al., 2017; Levesque et al., 2018) claimed that buildings consumed approximately one-third of global final energy consumption and have been the largest source of greenhouse gas production. According to the International Energy Agency (IEA), buildings globally were responsible for about 19%, 55%, and 32% of energy-related GHGs emissions, global electricity demand, and final energy consumption respectively (IEA, 2018b, 2018c). In addition, (Xu, Wang, & Tao, 2019; Zhou et al., 2016) added that as the construction industry becomes the major contributor to economic growth, the by-products of energy consumption and environmental burdens; such as air pollution, noise pollution, and solid waste generation had consistently increased. (Wong & Fan, 2013; Yin, Laing, Leon, & Mabon, 2018; Xu et al., 2019) added that the building development and construction sector is showing an increasing trend in many countries, mainly due to urbanization, economic growth, and modernization. Since the building sector emerges rapidly, this has become the largest threat to sustainable future development. It is a norm that the rapid development of one country mainly will associate with the world's environmental degradation issues. According to (Mohamad Bohari et al., 2015), Malaysia is also suffering from deforestation with major causes attributed to large-scale land development among others including construction activities. Hence, with the existing method of undertaking and managing construction projects, it is foreseen to create a more negative impact on the environmental issue in Malaysia. The inefficient management of construction projects will cause problems such as inefficient waste management and energy usage. Due to this, sustainable development through green construction is found to be the way out of this dilemma which has proven to impart numerous benefits like reducing GHGs emissions, conserving resources through efficient material design, and reducing waste throughout the construction phases. In making these practices a success, the government as the main stakeholder should send a signal to the whole industry to adopt green practices throughout the construction process which inculcates the standards, policies, guidelines, building codes as well as technology.

Besides the effect of GHGs emissions and climate change, comfortable living demands and health consciousness are among the principle set by people worldwide in enhancing the life quality (Ascione, Bianco, De Masi, de' Rossi, & Vanoli, 2014; Fasi & Budaiwi, 2015; Evola, Gullo, & Marletta, 2017; Hoisington et al., 2019). One prospective solution to these problems is to embark on 'green' or sustainable building. This can be achieved by promoting sustainable living and improving energy consumption in building stocks. However, a sustainable building could not assist in reducing the crucial need of cutting down GHG emissions and climate change if all countries are focusing only on new building development. According to (Jagarajan et al., 2017), the recent growth of new green building constructions is inadequate to overcome the negative impact of existing buildings. This applies to many countries (Zhou et al., 2016) including Malaysia where only 2% of the total building stocks are energy efficient (Yiing, Yaacob, & Hussein, 2013; EPU, 2016a).

Based on all the facts, retrofitting the existing building stocks has to be aggressively embarked upon as it is the main driver in reducing energy consumption which provides a comfortable living to the occupants as a whole (Husin, Zaki, & Husain, 2019). In supporting this initiative, (Hong, Li, & Yan, 2015) found that the energy savings potential in public buildings is estimated to be about 50% by combining energy conservation measures with improved operations. Hence, it is a big waste if the 50% potential saving is ignored. Subsequently, this will help to reduce the amount of the country's energy needs, which directly contributes to the reduction of GHG emissions. This applies to most developing countries including Malaysia (Nazri et al., 2013; Yin et al., 2018; Xu et al., 2019). Therefore, besides focusing on renewable energy power generation such as hydro and solar which are greener, and emission-free, it is wise to look at the energy conservation within the building.

In particular, retrofitting the existing building stocks, other concerns that arise are the methods and tools that are used in finding the best and most sensible solution. Retrofitting needs to be carried out in the most effective ways, hence it is crucial to identify the effective parameters within the building that will provide a significant impact toward the reduction of energy consumption and later GHGs emissions particularly, CO_2. In general, retrofit could involve modification or conversion of the existing building such as additions, deletions, rearrangements, or replacements of one or more building parts or facilities (Jagarajan et al., 2017). Ultimately, the final result of this retrofitting should turn the buildings more sustainable in terms of their design, operation, and maintenance. One of the well-known methods of analysing the existing building's energy performance is through an EA. The majority of energy performance assessments employ a well-known technique called a walk-through EA to assess chances for energy savings through an examination of the current equipment, operations, and overall energy utilized (Ascione et al., 2017a) (M Krarti, 2016; Thumann & Younger, 2008). However, a walk-through EA could only identify the active elements such as the number of equipment, the power rating of the existing equipment and appliances, total hours of operation, the number of occupants, and a few other non-design parameters.

1.3 Scope of Research

Based on the statistical report published in the Malaysia Energy Statistic Handbook (EC, 2016a), 14.3% of the final energy consumption is conserved by the residential (5.8%) and commercial (8.5%) sectors. Hence, through the Eleventh Malaysia Plan (EPU, 2016a), the government has announced the need to build environmentally friendly homes and workplaces which are not only water and energy-efficient but are resilient to climate change as well. An integrated design approach that takes into account all of the factors from technical measures to occupant behavior will offer the greatest potential for delivering a building whose actual performance is energy efficient (Hong et al., 2015). This integrated design approach is applied for both the new building construction and the existing building (retrofit). As mentioned earlier, numerous factors contribute to the energy consumption in the building. These factors lay under two categories; they are non-design factors and passive design factors (Huat et al., 2011). However, an integrated design approach is much more practical and affordable when it comes to new building development compared to retrofitting the existing one. This is due to limitations that arise in a retrofitting initiative compared to designing an energy-efficient building from scratch. However, a strategic retrofitting plan will allow building owners to identify the best and most practical solutions in achieving the end need which is to improve the building performance towards a sustainable one. Numerous methods are introduced for this purpose. Most building management starts their retrofitting plan by conducting an EA. As EA permits the identification of the sources of energy consumption, it has become one of the renowned methods applied by building management or building owners. Nevertheless, EA has its limitation too. It could not assist in identifying the passive design factors of a building that contribute to energy consumption as a whole. Based on the above limitation, it is important to identify several combination approaches to allow strategic retrofitting exercise which later promotes the best retrofitting process and solution.

Hence, this research focused on analysing both the non-design and passive design factors that could directly or indirectly contribute to better building energy performances. All the factors included in this research are only the potential solutions that could be considered in a retrofitting process. In short, factors like wind and weather effects; wall, floor, and roof material were not included as the factors. Nonetheless, factors that were included are the appliances/equipment such as air-conditioning systems and lighting as well as several passive design factors such as the window's glazing, opaque materials, and shading elements, as well as the external shading, were focused on in this research. As pointed out earlier, these are some of the building parameters that could potentially be included in retrofitting initiatives. As other approaches are deemed necessary to overcome the limitation of EA, the combination of real data (from the utility bill) and simulation-based approaches are included in this research. In a nutshell, three different approaches are selected in this research to analyse the significant building parameters that contribute towards enhancing building energy performances through retrofitting exercises. This combination of approaches will result in identifying numerous building parameters that could be considered in retrofitting process of the existing building, mainly the non-energy-efficient.

As electricity is one of the highest contributors to building performance, especially in the context of making it more sustainable, hence this research has focused on how the non-design and the passive design factors outlined earlier could enhance the building performance in the aspect of electricity consumption, electricity cost as well as carbon emission amount. The final research outcomes are presented to show the amount of reduction on these trio parameters, which significantly contribute toward greener building energy performances. In other words, other forms of resources like gas and water which contribute to building performances were excluded from this research. Hence, only

TNB's electricity bills (2015 – 2018) of the selected building were referred to in this research to ensure the outcomes from the other approaches are reliable.

1.4 The Research Questions

The dynamic research questions for this research are listed as follows to assist the whole research process and act as a guideline for the research aims to answer.

i. What are the capacity and effectiveness of conducting an EA for a building?
ii. Why it is important to analyse the LF performances of a building?
iii. What could the latest technology that is available in the market offer in assisting energy-efficient and sustainable building development of new and retrofitting processes?
iv. How does the BIM process assist in detailing the effectiveness of other building parameters beyond the capability of an EA and LF performance analysis?
v. Could BIM processes offer detailed information on the economic and environmental impact of its energy performance evaluation report for both new building design as well as for retrofitting purposes?

1.5 Research Objectives

In analysing the significant building parameters that contribute to building energy performances in Malaysia's environment, an existing building has to be selected. Thus, Wisma R&D Universiti Malaya has been chosen for the research. In particular, the objectives of the research are:

1. To analyse the non-design factors that contribute to the building's electrical energy consumption in Wisma R&D through a walk-through energy audit.
2. To model a high-rise building and analyse the passive design factors that contribute to the building energy consumption in Wisma R&D using ArchiCAD.
3. To estimate the economic and environmental impacts of potential retrofitting initiatives proposed for Wisma R&D.
4. To propose a practical retrofitting plan for a high-rise building in Malaysia.

1.1 Significant of the Research

Studying the impact of different building parameters will provide different implications for the energy consumption of a building. Based on (Hong et al., 2015), it was claimed that integrated design approaches should be gradually adopted into the design process of new buildings. This will require considering not only the technical aspects but involved the economic and environmental impact as well. However, integrated design approaches for the existing buildings, especially the non-energy-efficient ones, are not as simple as for the new buildings. Therefore, this research adopted three different approaches to analyse building energy performances. The combination approaches comprise the walk-through EA, real data from the utility bills, and the virtual building model design. These approaches have enabled an inclusive analysis to be carried out for Wisma R&D in establishing a practical and sensible retrofitting exercise that aims to directly reduce the trio effect of building performances; i.e. the energy consumption, cost, and carbon emission. The outcomes will indirectly lead to the occupant's comfort too. In detail, the inclusive analysis encompasses both the non-design factor and the passive design factor of building parameters. This research intends to analyse the significant building parameters that could provide the best outcome from the retrofitting exercises, particularly for the high-rise building in Malaysia. The outcomes could as well assist the other building owners in those countries that have similar weather like Malaysia.

Most research which was conducted on building energy consumption for the existing buildings in Malaysia thus far enfolded through either EA or simulation-based methods. Hence, the building parameters that were analysed include either the non-design factor or the passive design factor. As mentioned earlier, the effect on the trio parameters (energy consumption, cost, and CO_2 emission) from the non-design factors such as the equipment/appliances installed, the building's operation time, and internal and external temperatures could be analysed from the EA. However, the effect of the passive design factor such as the opening's glazing and opaque materials, shading elements, and external shading on building energy performance could not be analysed through EA. It needs to be carried out through other approaches such as simulation-based analysis. As the first step, a virtual building needs to be modeled to represent the real building. Therefore, this research intends to identify and analyse both the non-design and passive design factors of the existing Wisma R&D building which could contribute to the reduction of the trio effects. The virtual building is modeled using ArchiCAD software, one of the established tools in Building Information Modeling (BIM). ArchiCAD is well-known in countries like the United States of America (U.S.A), European countries, and Singapore, however, it is not a well-known tool and is widely used by building professionals in Malaysia compared to some other popular tools like Revit and EnergyPlus software. Therefore, this research tends to examine the effectiveness of ArchiCAD in analysing the building energy performances as a whole. The outcome will display the trio parameters effects of the building for a practical and sensible retrofitting initiative.

Later on, the research finding could contribute to the improvement and development strategies in establishing respective building design and construction guidelines like the GBI, MS 1525, and many more. In addition, the findings could probably act as a benchmark for the current practice in Malaysia's building design. For instance, it is found that the latest MS 1525 which is currently used as a reference for the building design is emphasizing more on the technical aspects factors instead of the non-design factors. Hence, the model proposed at the end of this research is proposing the best practices for building development in Malaysia. Ultimately, this research will assist the future and existing building design to achieve the ideal and recommended BEI as stated in the MS 1525 which is 135 $kWh/m^2/yr$ (Noranai & Kammalluden, 2012; Gunasegaran, Hasanuzzaman, Tan, Bakar, & Ponniah, 2022) through new design and retrofitting initiatives. Finally, the research aims to propose an efficient and practical retrofitting plan for a high-rise building in Malaysia which is based on the optimization of all the parameters selected.

1.2 Brief Methodology

The research employed three key approaches: LF performance analysis, walk-through EA, and simulation-based analysis. These methods were combined to identify and analyse the passive and non-design factors that affected the energy usage of the building, as relying on only one or two methods was insufficiently comprehensive. Wisma R&D, UM, was selected as the reference building for the analysis; hence, the parameters and assumptions used were based on the nature, geography, and functionality of this building.

1.3 Organization of the Thesis

This research focused on analysing possible parameters for EE retrofitting initiatives mainly for high-rise buildings. This thesis provides a thorough presentation of the overall research processes. It is broken down into five chapters: introduction, literature review, methodology, results and discussion, and conclusion. The current chapter contains the research background, problem statements, the scope of research, objectives, and significance of the research.

An extensive review of the prior research studies is found in **Chapter 2** of the thesis. In this chapter, a detailed review of world energy concerns, global and Malaysia primary energy supply, and final energy consumption are included. The review has since been focused on how much energy is used in buildings, the factors that impact how much electricity is used in buildings, and the methods and tools that may be used to improve a building's energy efficiency. Building Information Modelling (BIM), a well-known process that is currently used in the construction industry is introduced in the later section of Chapter 2.

The collaborative approach is thoroughly explained in **Chapter 3**. The entire factors inculcated in the measurement are thoroughly tabulated and discussed. In addition, this chapter includes the majority of the formulas that were employed in this research.

The findings and assessments of the three approaches are presented in **Chapter 4**, and the potential energy-saving measures that could come from them are analysed in accordance. The trio effect and the impact of different building factors on building energy consumption are both discussed. At the end of this chapter, a practical retrofitting strategy for a high-rise structure in Malaysia is suggested.

Chapter 5 contains general broad conclusions on the analyses presented in the research. The shortcoming of the research and recommendations for future research are highlighted in this final chapter.

In addition to the foregoing, this thesis contains three appendices (Appendix A, B, and C). They consist of the audit form, building layout plan, and ArchiCAD simulation results.

CHAPTER 2: LITERATURE REVIEW

2.1 World Energy Concerns

In today's world, energy sources have performed necessary functions, such as creating heat, supplying drinking water, generating power for certain appliances, and electrical products, and so on (Lotfabadi, 2015; Mughal et al., 2022). As reported by (IEA, 2022a), the change in global energy consumption was contributed by various sectors like the industry, buildings, and transport from the 2000s until 2021. In addition, the energy consumed in 2021 had shown that the demand from each sector had tremendously increased and this was due to several contributing factors. Some on the list include the country's annual population growth rate, urbanization, improving standards of living (Lotfabadi, 2015), and a few others. Despite the increasing energy demand, all the frequent practices have been intensified to utilize the earth and its environment as a source of energy. This has influenced the demand for fossil fuels (Tanveer Ahmad & Zhang, 2020). This is considered an imbalanced practice as it will directly contribute to the faster depletion of the earth's resources and contribute to the devastating impact of global warming unless an effective approach and green-based policies are carried through. This entails making an effort to balance a system's power input and output such that the system's operation consumes no more energy than is required to carry out its intended purpose with little to no leftover waste as well as (Lotfabadi, 2015). In addition, effective energy management through energy performance and cost-effective approaches (Tanveer Ahmad & Zhang, 2020; Tahir et al., 2021) has to be established within the government and other sectors.

In trying to fulfill the world's energy requirements, more environmental considerations should be taken from the public and industry sections, both in developed and developing countries. Currently, it is shown that human activities especially during the burning of oil and coal have made the planet warmer (Lotfabadi,2014). Hence, one of the fundamental challenges in today's world is substituting fossil fuels with renewable energies and at the same time finding various other greener approaches that can reduce energy consumption within numerous sectors and their activities.

Referring to the statistics, the world power demand is predicted to rise from 145 billion MW in 2007 to 218 billion MW in 2035 (Habib, Hasanuzzaman, Hosenuzzaman, Salman, & Mehadi, 2016). In fact, the amount of energy used globally has increased rapidly in recent decades, from 8,588.9 million tonnes (Mtoe) in 1995 to 13,147.3 Mtoe in 2015 (Dong, Dong, & Jiang, 2020). This is a huge amount needed within less than 30 years, hence if there are no intensive actions taken into consideration, many countries will be facing energy insecurity and interruption in their main activities.

On a different aspect, many countries worldwide are still depending on fossil fuels for their power generation. According to (IEA, 2018c), the production growth of fossil fuel has increased tremendously driven by a surge in coal and natural gas (NG) production at a higher pace. Subsequently, the latest energy supply by fuel report released by the IEA in the World Energy Outlook 2022 report (IEA, 2022b) shows as of 2021 statistics, the dependencies on fossil fuels have contributed to 35 gigatonnes of CO_2 production. If this trend continues, it is one of the biggest challenges in meeting the aim of cutting down GHGs and climate change. Because of that, alternative power generation such as solar, hydro, wind, and many others is a way of tackling this aforementioned issue. IEA has targeted curbing CO_2 emissions down to 25 gigatonnes and ultimately zero by 2030 and 2050 through Net Zero Emission (NZE) policies (IEA, 2022b). In parallel, efficient energy utilization is another solution to this matter. In short, energy efficiency improvement is one of the most important functions to reduce energy consumption (Habib et al., 2016). Due to this, tremendous efforts and initiatives are crucially in need to ensure that energy conservation could be carried out effectively.

2.2 Global Primary Energy Supply

In any energy analysis activity in a country, it is important to have a closer look at the primary energy supplies that are available versus the current and potential demand. An effective measure that includes best practices, efficient energy management, and carbon emission monitoring will assist one country to ensure its energy security at the highest point which could assist in minimizing or eliminating the interruption to the daily activities for all its end-use sectors including residential, commercial, industrial, transportation and others. Nowadays, instead of depending only on conventional sources like coal, gas, petroleum, and others, alternative energy sources like solar, hydro, nuclear, and wind have started to become reliable energy supply in many developing and developed countries around the world including Malaysia. Figure 2.1 shows the latest predicted trend of global primary energy supply within ten years; from 2021 to 2030 (IEA, 2022b). Currently, the main primary energy is highly dependent on fossil fuel resources like oil, coal, and NG. Their percentage is far higher compared to renewables-based resources. However, it is predicted that the RE will start to monopoly the global primary energy supply in 2025 onwards. Hence, it is crucial to ensure that the effort of promoting RE is constantly made. Despite the resource depletion issue, the dependency on fossil fuel-based resources has caused environmental degradation. Due to this, continuous effort and support from all countries are deemed necessary to ensure the aims outlined in the Paris Agreement are met.

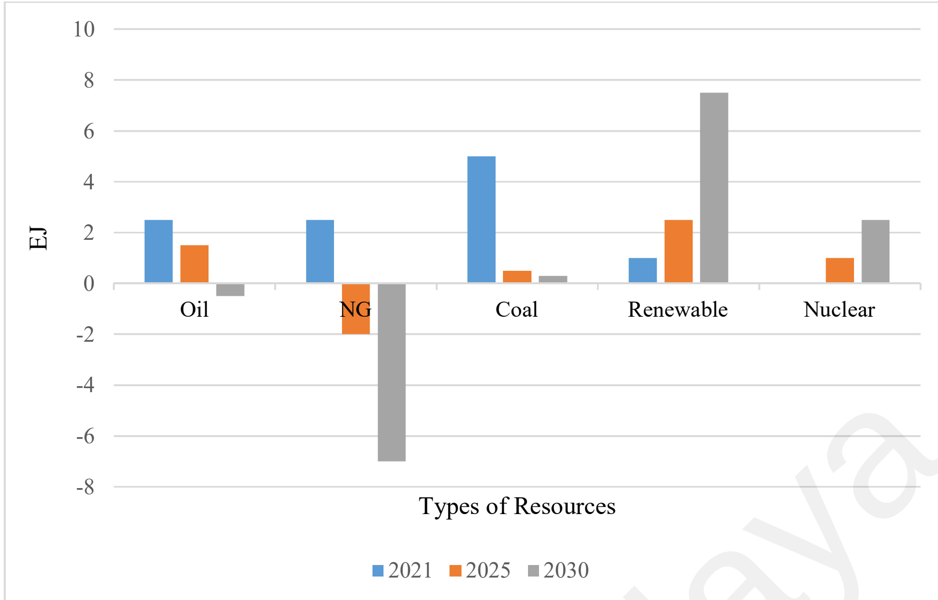

Figure 2.1: Global primary energy supply

(IEA, 2022b)

2.2.1 Primary Energy Supply in Malaysia

Malaysia is a developing country that has significantly transformed itself from a predominantly agriculture-based country to a manufacturing and now, toward modern services and modernization. During the transformation process, Malaysia's Gross Domestic Product (GDP) has grown by 3.4% for the 1971-2015 period (Bekhet & Othman, 2017). Furthermore, in 2016, the Malaysian economy recorded a growth of 4.2% despite considerable external and domestic headwinds. Looking at these statistics, it is predicted that in line with the population increase as well as the economic and socio activities, the country will productively move towards a developed country in the near future. This will trigger both the energy supply and demand in the country.

Statistically, the Total Primary Energy Supply (TPES) posted an increment of 3.6% over the past twenty years. The increment was contributed by an overall 2.4% higher production of crude oil, especially a 15.6% higher production from Sabah oil fields. In total, the primary supply of crude oil increased by 11.2%, coal, and coke recorded a growth of 8.5%, and hydropower and renewables registered a growth of 22.3%. On the other hand, the total primary supply of petroleum products and others recorded a decrease of 14.9 % due to higher export value. The same goes for natural gas (NG) as the total primary supply recorded a slight decline of 3.5%. Concerning NG, the downward trend was due to higher export recorded for Liquefied Natural Gas (LNG) (EC, 2016b). The latest data released through National Energy Balance 2018 (EC, 2018b) state that the primary energy supply had marked an increment of 1.6% from the preceding years. The final register recorded at 99,873 ktoe with coal and coke remained the biggest growth with 7.3%. This increment was influenced by the higher demand from the power sector. Even though the RE registered an increase of 4.0%, the amount is far too small compared to the fossil-fuel-based resources. The above trends continue to emerge. Figure 2.2 illustrates the latest statistics on the TPES released in the Malaysia Energy Statistics Report 2020 (EC, 2020). It can be seen that the TPES is dominated by fossil-fuel-based as it was recorded to cover more than 70% of the total primary energy supply in the country and the trend was similar since the year 2000.

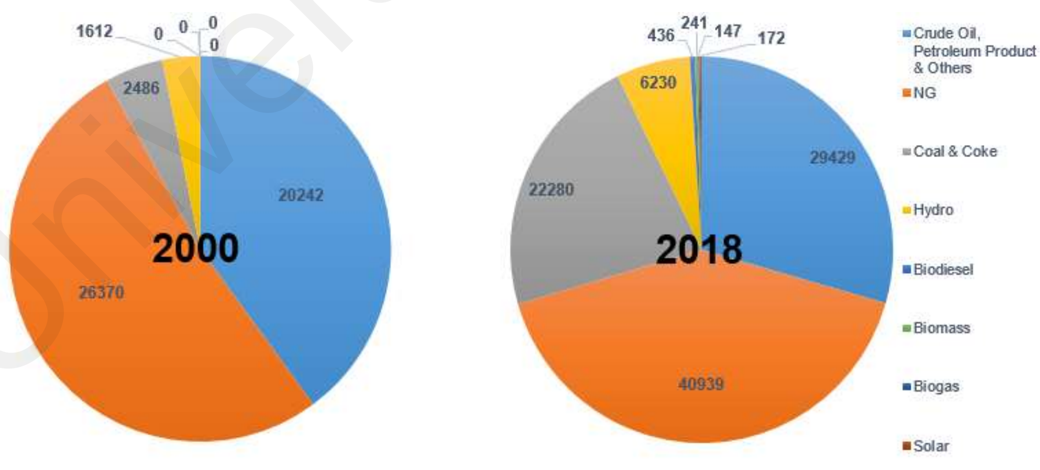

Figure 2.2: Total primary energy supply (ktoe) by fuel type

(EC, 2020)

Figure 2.3 shows the energy trends in Malaysia (EC, 2020). In summary, it is concluded that the total primary energy supply had continuously inclined since the year 2000. The only decrement in the energy supply was shown in 2009 before it continued to increase between 0.5% to 4% every year. Generally, the increase described the increment of fossil-fuel resources utilized as Malaysia is still highly dependent on non-renewables and this is inconsistent with the global sustainable goal. Due to this, the Malaysian government has established numerous policies, guidelines, and initiatives in solving this matter.

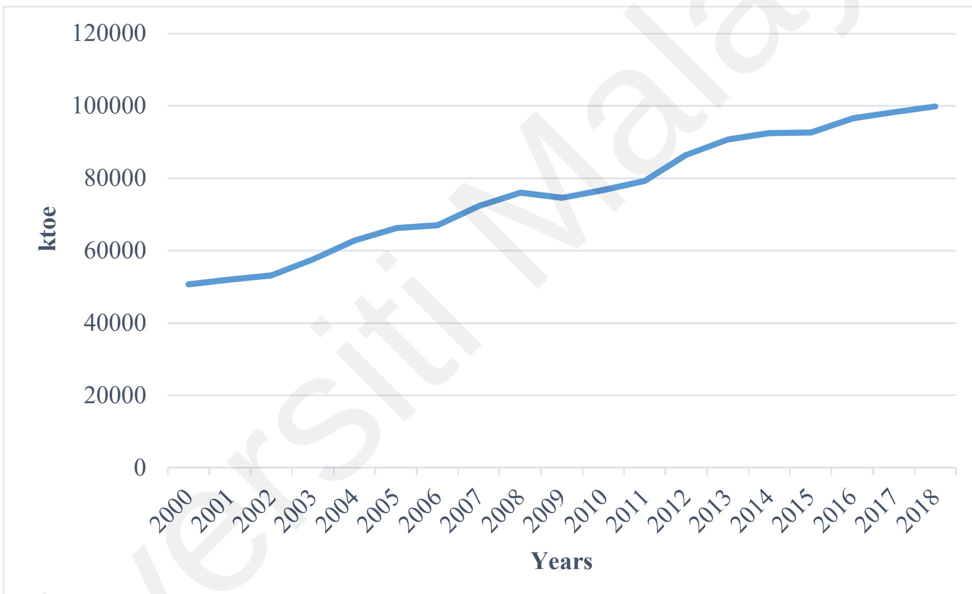

Figure 2.3: The total primary energy supply from the year 2000 to 2018

(EC, 2020)

Despite the challenges of superseding the non-renewable resources with RE, it is important to look into the aspect of efficient energy utilization from the end-user perspective. This excessively will assist in balancing the trio effect. Therefore, a details analysis is conducted in this research to analyse the effective retrofitting approach for the existing high-rise building towards efficient energy consumption. This is one of the utmost initiatives established within the building sectors.

2.3 Final Energy Consumption in Malaysia

As the earlier section highlighted the importance of energy efficiency as one of the essential approaches in lowering the resource depletion issue and balancing the trio energy effect, hence, it is wise to analyse the final energy consumption in one country. Due to this, it is wise to identify the end-users of energy in Malaysia. It needs to be reviewed and duly analyse to ensure that the ways of tackling this issue can be carried out effectively. Figure 2.4 represents the latest statistic published by the Malaysian Energy Commission (EC, 2020) on the final energy consumption. The data shows that 20.3% of the final energy consumption in 2018 was consumed for electricity generation. In particular, a total fuel input of 38,724 ktoe was utilized for this purpose with the highest consumption coming from coal & coke and followed by natural gas resources. Furthermore, the thermal-based station produced the highest electricity in the year 2018 with 80.2% of the country's electricity generation coming from this source. Therefore, it is crucial to embark on efficient energy utilization from the perspective of the end-user while the country is establishing the RE primary and electricity production. In parallel, this will cut down the GHGs emission, especially the CO_2 emitted from the thermal-based station. From the record, Malaysia is ranked 72nd among 163 countries, 11th in Asia Pacific, and 2nd in Asia with regards to environmental sustainability and global sustainable development goal (SDG) (Jeffrey D. Sachs, Guillaume Lafortune, Christian Kroll, Grayson Fuller, & Woelm, 2022). Earlier, Malaysia was ranked 38th among 146 countries worldwide (Nazri et al., 2013), hence lots of efforts need to be initiated in strengthening the SDG within the country. These efforts must be continuously led by the government and supported by all the relevant parties.

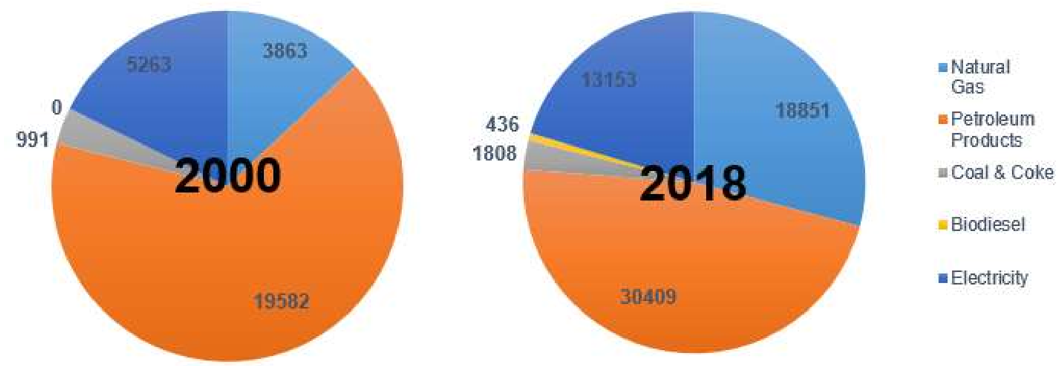

Figure 2.4: Final energy consumption (ktoe) by fuel type

(EC, 2020)

2.3.1 Electricity

As mentioned earlier, electricity consumption shows continuous growth for many years. A sudden peak was shown in 2016 and continued to grow in 2018. Even though the overall energy sector in 2018 had shown lower growth rates compared to 2017, in tandem with lower GDP (EC, 2018b). This was believed to be due to a switch in political power which has impacted related policies. Despite all that, electricity consumption had continuously shown an uptrend. On the aspect of electricity generation, a total of 153,415 GWh was recorded in the year 2018 compared to 155,456 GWh in the preceding year. In detail, coal power plants remained the highest fuel consumption with 47.3%, followed by NG, hydropower, renewables, and oil with 35.7%, 16.1%, 0.6%, and 0.3% respectively. From the total generation of 153,415 GWh in 2018, 152,866 GWh was consumed, left with only 549 GWh (less than 0.5%). It is concluded that the total electricity consumption in 2018 has increased by 4.3% compared to 2017. In addition, the statistics recorded that 78.9% of the total electricity consumption was consumed in Peninsular Malaysia compared to Sarawak and Sabah. Of the total consumption in 2018, almost half of it was consumed by the industrial sector, followed by the commercial and residential sectors which were recorded at 29% and 20.5% respectively. At a closer look, these two sectors had slowly picked up and are believed to precede the industrial sector in the near future. With the upwards consumption trends from these two sectors, the Malaysian government has been promoting sustainable living where green infrastructure (Husin et al., 2019), mainly buildings are designed to be energy-efficient which alleviates GHGs emissions, is comfortable, and has higher investment rates.

2.4 Final Energy Consumption by Sector

Despite the need to reduce the dependency on fossil fuel resources in power generation, it is important to combat the aforementioned issues related to GHGs emissions and climate change through energy-efficient initiatives within all sectors. In order to prioritize and specify effective actions, it is important to review the final energy consumption of each sector. Based on the statistical report published in the Malaysia Energy Statistics Handbook 2016 (EC, 2016a), it was recorded that the transportation sector is the largest consumer with 46.6%, follows by industrial, non-energy, commercial, residential, fishery, and agriculture. Similar trends are seen in the Malaysia Energy Statistics Handbook 2020 (EC, 2020). Specific to the transportation sector, the final energy consumption has increased from 34,327 ktoe in 2014 to 23,555 ktoe in 2018. Similar to 2014, the highest energy consumption was followed by the industry, non-energy use, residential and commercial, and finally the agricultural sectors. Particularly for the commercial and residential sectors, their final energy consumption had increased by 4% within four years. However, the overall percentage of consumption by this sector had reduced by 2.3% due to the total country's final energy consumption that increased to 64,658 ktoe in 2018 compared to only 52,209 ktoe in 2014. Therefore, there is a need to address the issue of the 4% increment within this sector. Figure 2.5 and Table 2.1 have the details.

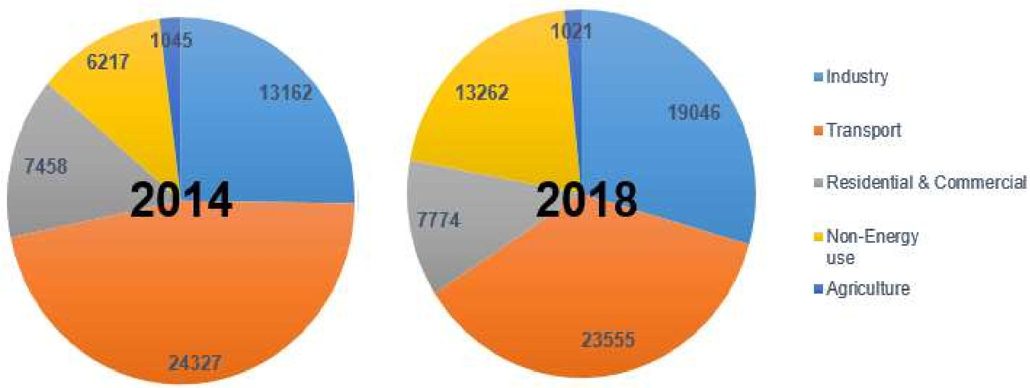

Figure 2.5: Final energy consumption (ktoe) by sectors

(EC, 2020)

Table 2.1: Summary of the final energy consumption by sectors in Malaysia (EC,2020)

Details	Malaysia Energy Statistics Handbook 2016		Malaysia Energy Statistics Handbook 2020	
Year	2014		2018	
Total energy consumption	52209 ktoe		64658 ktoe	
Sectors	**% consumption**	**ktoe**	**% consumption**	**ktoe**
Transport	46.6	24329.39	36.4	23535.51
Industrial	25.2	13156.67	29.5	19074.11
Non-energy use	11.9	6212.87	20.5	13254.89
Commercial	8.6	4489.97	6.9	4461.40
Residential	5.7	2975.91	5.2	3362.22
Fishery	1.9	991.97	1	646.58
Agriculture	0.1	52.21	0.5	323.29

In many situations, when a country moves from a developing to a developed country, the economic activities will switch to service-based dominants compared to manufacturing/industrial-based dominants. According to (Levesque et al., 2018), the buildings' energy consumption in developed countries amounts to 42 GJ/cap/year while it was recorded to be around 11 GJ/cap/year earlier. This shows that when a country moves from a developing to a developed country, the amount of energy consumption will increase, especially in space heating and cooling demand (Levesque et al., 2018). Due to this, it is worth focusing on energy-efficient initiatives specifically in the sectors that probably going to be the largest contributor to the final energy consumption. On one aspect, green building is known to be the sensible solution to this aforementioned issue due to their well-known performance. On the other hand, the ratio of the new building to existing buildings is way too small. This has forced the government and building professionals to emphasize the need to retrofit the existing building in the country (Nazri et al., 2013; Jagarajan et al., 2017; Husin et al., 2019). Therefore, it is important to conduct a comparative analysis in identifying the building parameters that are contributing to the energy consumption to achieve the ultimate outcome from the retrofitting initiative. An effective retrofitting is achieved upon the reduction of the trio effect which aids to occupant's comfort and health.

2.5 Energy Consumption in Buildings

The world statistical report released on global warming and environmental issues drives the crucial need of designing and establishing sustainable buildings across the globe. IEA states that buildings were responsible for about 32% of final energy consumption and 55% of global electricity demand (IEA, 2018c). On top of those, buildings globally had contributed around 19% to environmental issues mainly GHG emissions (Abanda & Byers, 2016), and this amount is rising every year. In summary, buildings are recorded as the major electricity consumers in many countries. For instance, Brazil recorded 45% of its electricity consumption from the building, 90% from Hong Kong, and around 40% from the U.S.A. (Jing, Wang, Zhang, Li, & Zhao, 2017; Alves, Machado, de Souza, & de Wilde, 2018; Nikdel, Janoyan, Bird, & Powers, 2018). In Europe, buildings account for 40% of total energy use and 36% of total CO_2 (Zhao & Magoulès, 2012) with office buildings recorded to be the second-largest category of non-residential building (Jung, Paiho, Shemeikka, Lahdelma, & Airaksinen, 2018). Based on (IEA, 2019), all countries had shown upwards trends in energy consumption, particularly in electricity consumption. Electricity consumption is one of the highest energy types which were consumed in the building sectors, especially in China, the Middle East as well as in ASEAN countries (IEA, 2018c, 2019).

Detailed statistics released by IEA proved that electricity has been recorded to be the highest energy source in the commercial and residential sectors (IEA, 2018c). The amount consumed is gradually increasing worldwide. In Europe, the electricity consumed by non-residential buildings has increased by 74% (Jung et al., 2018). In general, the electricity consumed is mainly used for heating and cooling, lighting, computer, printer, and many others (Santamouris & Dascalaki, 2002; Ihara, Gustavsen, & Jelle, 2015; DeForest, Shehabi, Selkowitz, & Milliron, 2017). Among these building loads, more than 40% is normally consumed by the Heating, Ventilation, and Air Conditioning (HVAC) system (Hassan, Zin, Abd Majid, Balubaid, & Hainin, 2014; Nikdel et al., 2018; Jazaeri, Gordon, & Alpcan, 2019), followed by lighting and other appliances (Pérez-Lombard, Ortiz, & Pout, 2008; Ihara et al., 2015; Tahir et al., 2015; Habib et al., 2016). These consumption patterns are exactly as the statistic shared in (IEA, 2019). In summary, space heating and cooling are the biggest electricity consumers in both residential and non-residential buildings (IEA, 2019). The percentages are 32% and 49% respectively, which is equivalent to 28.8 exajoules (EJ) and 17.15 EJ from the total of 90 EJ and 35 EJ consumption for residential and non-residential as a whole. In non-residential buildings, lighting and other appliances are the next superior electricity supplicants.

Similar trends were recorded in Malaysian buildings (Hassan et al., 2014; Husin et al., 2019). The data obtained from the Malaysia Energy Statistics (EC, 2016a) recorded that in the year 2008, the electricity used in the buildings sector was about 72,164 GWh and is predicted to grow rapidly (Ghazali, Salleh, Haw, Mat, & Sopian, 2017). Twenty years later, it has risen to 90,399 GWh (EC, 2018b), an estimated around 20% increment. This proved that the electricity consumption by the building sectors has increased consistently within twenty years times. As the population growth in Malaysia has steadily recorded an uptrend to 32.6 million in 2020 compared to 28.3 million and 23.3 million in 2010 and 2000 respectively, this has created more demand for building and infrastructure development (Mohamad Bohari et al., 2015). Thus, in response to the world's agenda for sustainable development, Malaysia's development needs to be on a green path. Hence, the overall construction industry which includes three main sectors i.e. buildings, infrastructures, and industrial needs to move towards a 'greener' process. According to (Mohamad Bohari et al., 2015), the term 'green' is associated with different concepts such as "energy-efficient" and "sustainable" which share the aim of creating environmentally-friendly products and services. Nevertheless, the transition from the existing building to sustainable will be meaningless if the energy consumption in the existing building stock is overlooked (Husin et al., 2019). The main reason behind this was due to the large number of the existing building in Malaysia which were built and designed without incorporating good energy standards. A study found that retrofitting at least 80% of the existing building stocks in Malaysia will then provide enormous potential in achieving the country's emission target (Husin et al., 2019). Therefore, continuous efforts and studies need to be carried out in finding the best practices for retrofitting existing buildings in Malaysia. Due to this, the prediction of energy use in buildings is, therefore, significant to improve their energy performance. However, as the energy system in buildings is quite complex (Zhao & Magoulès, 2012), comparative analysis through several approaches is deemed necessary.

2.6 Development of Sustainable Building in Malaysia

The construction industry is an important economic sector in every country, providing physical facilities and infrastructure. Malaysia, as an "upper-middle-income economy" and is currently on the track to achieving a high-income economy status has caused a great demand for physical developments to provide infrastructure for both social and business purposes. This includes a rapid development in various services such as education and retails, in infrastructure such as highways and transportation, and not to forget the fast development of buildings mainly in both the commercial and residential sectors. According to (Darko, Zhang, & Chan, 2017), the construction industry has a very profound impact on the environment, public health, economy, and productivity. In general, the experts believed that the building sector can potentially decrease energy usage, particularly electricity consumption as well as reduce CO_2 emissions by utilizing more renewable energy sources and establishing the requirement in building standards (Tayyab Ahmad, Aibinu, & Stephan, 2019; Husin et al., 2019). Specifically referring to the building standards, Malaysia has outlined various guidelines to encourage sustainable and greener building for future development. In addition, the concern about green building initiatives has received greater attention from government agencies, private organizations, and the public as a whole (Nazri et al., 2013). Numerous policies link to sustainable development frameworks such as the National Green Technology Policy (NGTP) and National Policy on Climate Change (NPCC) (Nazri et al., 2013; Onuoha et al., 2017) are proof of the country's commitment to this arena. NGTP and NPCC are two of the many policies which drive the current market in green buildings (Nazri et al., 2013). The sustainable development plan started in Third Malaysia Plan (Onuoha et al., 2017) and was continuously outlined in the latest Eleventh Malaysia Plan (EPU, 2016a). Specifically in the Eleventh Malaysia Plan, the need of implementing "Efficient Energy Conservation in Building" is clearly outlined as one of the important strategies to resolve the problem of sharp depletion of energy resources as well as ensure energy security in Malaysia. Earlier, Tenth Malaysia Plan includes a RM 230 billion development fund and RM 20 billion facilitation fund, of which 60% of it was spent on physical building development.

In conclusion, this shows that the construction sector will take up a great portion of activities to meet the economic and social demands of the country. On the other aspects, as the country's population continues to increase, from 25.4 million in 2009 to 32.7 million in 2021, it is expected that more than 75% of the population will be staying in the urban area (Hassan et al., 2014). This signifies that rate of the energy consumption will increase due to the usage of numerous home appliances, particularly air-conditioning (Hassan et al., 2014; Raihan & Tuspekova, 2022). Hence, focusing on the sustainable development initiative in this sector is a sensible solution to meet the country's comprehensive development plan. The GBI, the MS 1525, and a few other energy-efficient references are made available to assist the involved parties.

However, the sole dependency on sustainable building based on the new building development is insufficient. (Husin et al., 2019) claimed that the existing building stocks are the ones that could make a significant contribution to Malaysia's transition towards sustainable development as these buildings are the main drivers for excessive and increasing energy consumption in Malaysia. In the research conducted by (Tahir et al., 2015), there is only one out of three government buildings have achieved the BEI set in the MS 1525 which is 136 kWh/m^2/year. Therefore, there is a need for short and long-term solutions to establishing a sustainable movement in Malaysia. Despite the establishment of the new building development through its design, technology, and facility management; the focus on enhancing energy conservation in the existing building stock is found to be vital.

2.6.1 New Building Development in Malaysia

Between 36% to 40 % of a nation's energy output is used in construction (Lotfabadi, 2015), and finally 100% of the energy which is consumed in buildings is lost in the environment. According to (Schlueter & Geyer, 2018), to reach the aggressive emission objectives established by many countries, future buildings will need to use less energy, use energy more efficiently, and tap local renewable energy sources. Therefore, to have more control over the energy consumption in buildings, the role of architects, engineers, and other relevant parties is paramountly important for the improvement of the environment and ecological future (Lotfabadi, 2015). In other words, there should not be a single party within the construction industry that works in a silo in the building development process.

In the Malaysian context, the value of construction work recorded in June 2021 grew 42.6% amounting to RM28.2 billion. In particular, three main subsectors namely civil engineering, non-residential buildings, and residential building showed a growth of 59.5%, 37.0%, and 18% respectively in terms of construction works. In terms of the value of construction, the work done was dominated by civil engineering, followed by non-residential buildings, residential buildings, and lastly special trades activities. Particularly in building aspects, the non-residential building dominated around 28.2% of the total work done and the private sector continued to impel the construction activity compared to the public sector (Malaysia, 2021).

Based on the statistic released by (Malaysia, 2021), it is clear that Malaysia is going through rapid development in the construction industry. Hence, this is one of the opportunities to establish the development of green or so-called sustainable buildings. The new buildings have to obey the standards outlined by the Malaysian government mainly through Construction Industry Development Board (CIDB). However, solely dependency on the new building development is not capable of achieving the objectives of cutting down the GHGs emission and slowing down the impact of climate change in Malaysia. This is because, even though the new buildings are claimed to be net-zero energy, the significant impact on overall sustainability will take years to be felt (Husin et al., 2019; Jackson, 2005). Due to this, close attention needs to be given to retrofitting initiatives of the existing building stocks in Malaysia. Numerous researchers are in the same agreement (Zakaria, Foo, Zin, Yang, & Zolfagharian, 2012; Nazri et al., 2013; Husin et al., 2019).

2.6.2 Need of Retrofitting for the Existing Building Stocks in Malaysia

Malaysia's transition towards sustainable development will be pushed behind other developing countries like Thailand, and China if the dependency relies only on the new building development. Hence, sustainable development within this sector needs to include the existing building most of them were built without considering the 'green' components. The existing building stocks in Malaysia consumed around 33% to 48% of the total electricity (Hassan et al., 2014; Masrom, Rahim, Ann, Mohamed, & Goh, 2017) and contributed over 40% of the carbon emission to the environment (Zakaria et al., 2012) and these are expected to increase every year due to high expectation in the building comfort and increase of home appliances. Due to this, it is an effective move for the country to establish the need for retrofitting the existing buildings in Malaysia to forge a better-built environment. According to (Jagarajan et al., 2017), the majority of the building stocks in the country were built without inculcating the element of energy efficiency and the transition towards sustainable living cannot be achieved if the causal factors of excessive building energy consumption are not understood by the owner or tenants (Husin et al., 2019). In addition, it was recorded that the majority of the office building in Malaysia had BEI in the range of 200 – 250 $kWh/m^2/year$ even though the minimum requirement for BEI under Malaysia Standard MS1525 is 136 $kWh/m^2/year$ (Ghazali et al., 2017). However, (Masrom et al., 2017) found that the key barriers to sustainable retrofitting embarkment are due to high cost and lack of sustainable awareness among Malaysians. As a result, the number of green-restored buildings registered in the GBI is still significantly fewer than planned. The statistic recorded by the Economic

Planning Unit (EPU), one of the Malaysian government agencies has proved that only 2% of the total building in Malaysia are energy efficient or LEO. This is supported by the studies by (Walter & Sohn, 2016) and (Yiing et al., 2013). Hence, it is pivotal to ensure that a sustainable and inexpensive retrofit can be assessed ahead of time to increase building owners' confidence in undertaking retrofitting projects.

According to (Husin et al., 2019), many countries, including China, Singapore, Australia, Japan, and Korea, have retrofitted their old buildings, even though some countries have shown a low rate of retrofitting exercises (Schlueter & Geyer, 2018). On one hand, this proves that the developed countries have embarked on retrofitting initiatives to ensure sustainable energy growth, especially in the electricity consumption in the commercial sector. On the other hand, studies claim the poor retrofitting rate in numerous nations is attributable to a lack of information, low cost-effectiveness of measures, and legislative constraints that make finding the right solution difficult (Schlueter & Geyer, 2018). Due to this, several approaches; mainly the simulation-based approaches are deemed necessary in identifying effective retrofit measures.

In general, most governments and construction players know that green building is a green solution in the life cycle of buildings which involve examines of the interaction between design, construction, operations, and demolition to optimize the energy and environmental performance of the project, hence retrofitting of existing buildings presents by far the largest potential for the incorporation of renewable energy technologies and energy efficiency measures into buildings. For instance, in the case of retrofitting a university teaching room, research has shown that there is a good correlation and relationship between Indoor Environment Quality (IEQ) and learning performance

(Zakaria et al., 2012). This is just an example to emphasize the benefits of retrofitting an existing building to a green building or at least a better energy-efficient building.

In general, retrofitting a building involves modification or conversion of the existing building. Depending on the needs and financial capability of the existing owner, retrofitting may involve the rearrangement, addition, deletion, or replacement of one or more parts of the building stock (Jagarajan et al., 2017). Therefore, retrofitting initiatives could be carried out on any part of a building (S., 2012). It can be done either on a small part of the building area, for instance, one level or two or more levels of multilevel buildings, or even the whole building. A few other changes were inclusive of retrofitting the building envelope and heating meters (Zhou et al., 2016), replacing the existing appliances with the 'Energy Star' appliances (Lester, 2013), solar PV installation (Chowdhury, Sumita, Islam, & Bedja, 2014), HVAC system improvement (Mathews, Botha, Arndt, & Malan, 2001; Vakiloroaya, Samali, Fakhar, & Pishghadam, 2014) and many more. In addition, retrofitting could be carried out for the whole block of the facility as well.

In the current situation, where the need for sustainable building demands is high, retrofitting initiatives need to be executed effectively. This is important to ensure that the retrofitting projects that are carried out on the existing building are adding up to the number of sustainable retrofitting development in Malaysia. According to (Masrom et al., 2017), although Malaysia has a huge number of refurbishment projects each year, only a handful of them use sustainable methods to upgrade the existing structures. This aforementioned issue could be solved by measuring the retrofitting effectiveness outcome before the decision is made. In a situation where few alternatives are being outlined, the best and most practical approaches should be selected. In short, the selection should be among the approaches that are capable to provide the most significant effect toward the green building concept or sustainable retrofitting.

Several focused areas recommended by IEA as an effective path to lower the consumption of the existing buildings include retro-commission, lower electrical loads, improve building envelope, and the existing building systems (IEA, 2019). In specific, it is crucial to ensure that all the technologies are properly installed so that they assist in improving the building's performance. In addition, to reduce the electrical loads, lighting and other high-usage appliances need to be upgraded. In the aspect of the building envelope, the retrofitting initiative must improve the building insulation and air sealing. This can be done by improving the building's window system performance. Despite the listed actions, enhancing the existing system like the HVAC and heat pump system of one building put into main consideration.

Based on the above recommendations by IEA, this research aims of doing a comparative analysis of the building energy performances of Wisma R&D. The analysis aims to identify the most significant building parameters that should be inculcated in the retrofit initiative; both non-design and passive design factors which address the energy tri-dilemma (trio effect).

In achieving the above target, the initial step is to understand the pattern of the electricity consumption of the building. Analysing the historical data on the building's electricity consumption is hence vital. This can be done by observing the electricity bill for a few years back. In addition, any retrofitting process should typically entail EAing as one of the most important approaches. Due to this, the author utilized these two approaches as part of the research elements.

Regardless of how details of the EA and electricity billing analysis are being carried out, these approaches are limited in analysing the effect of the non-design factors such as specific appliances and equipment's electricity consumption, operating time as well as the existing system performances. The other building parameters, which are categorised as passive design factors, such as the building envelope, orientation, and weather effect could not be analysed through these approaches. Hence, a different approach to analyse their effect on building energy consumption has to be identified. Simulation is one of the renowned approaches in analysing these building parameter effects (Eskin & Türkmen, 2008; Asadi, da Silva, Antunes, & Dias, 2012; Han, Srebric, & Enache-Pommer, 2015; Jung et al., 2018; Schlueter & Geyer, 2018). Hence, a virtual building has to be modeled using specific software. Nowadays, there is numerous software that can be utilized for this purpose. Some of the well-known software that is used for this purpose are EnergyPlus, Revit, and a few others.

A combination of these three approaches is believed to provide a comprehensive outcome in assisting the retrofit initiatives for a specific building. The simulation approach is allowing various building parameters to be included in one process. Therefore, real-time data such as surrounding weather, soil type, and many others could be included based on the specific location of the building. Through these approaches, the retrofitting initiative can be accurately identified. (Schlueter & Geyer, 2018) supported this.

2.6.2.1 The economic impact of the retrofitting initiatives

In any retrofitting initiatives, the building owners or tenants are expecting a cost cut for the short and long term. The short-term saving is, particularly on utility bills. In the case of electricity consumption, the cost saving is seen from the reduction of the kWh. According to (Azis, Sipan, & Sapri, 2015), part of the economic benefits obtained from retrofitting include the reduction of electrical bills, long-term operating and maintenance costs, longer building life cycle, higher opportunity on tenancy, and higher future capital value of the building. Inarguable, there is tremendous economic impact as a result of the retrofitting initiatives. Due to this, (Hee et al., 2015) for instance, suggested that it is wise to perform a techno-economics evaluation to obtain suitable window material for a building, which could provide both occupant comfort as well as energy-saving. Particularly for this research, the economic benefit from the proposed retrofitting is focusing on the yearly electricity bill (in Ringgit Malaysia) and the ROI. The economic benefit is one of the most encouraging factors which positively convince the building owner to embark on retrofitting initiative.

2.6.2.2 The environmental impact of the retrofitting initiatives

As emissions from electricity generation make up the largest emission for the country (Mahlia, 2002; EC, 2020; Gunasegaran et al., 2022), intervention by the government to reduce emissions is urgently required. Despite the dependency on fossil fuel resources, retrofitting is one of the profound ways in achieving sustainable development for a country. In addition, it assists in the improvement of living standards and human health. Effective retrofitting emphasizes in enhancing the building's performance, especially its energy performance. As a consequence of the improvement made through an effective retrofitting process, the environmental impact will be reduced in tandem with the process. Although the issue of environmental protection was introduced in Malaysia in the 1960s, it is only after the Paris Agreement that the green concept has become the centre of attention among construction stakeholders and business entities in Malaysia (Mohamad Bohari et al., 2015; EPU, 2016a; Buyong, Marzuki, Junid, & Kadir, 2021). Figure 2.6 shows Malaysia's historical approaches toward environmental issues. Even though this issue was raised more than fifty years ago, the issue of imbalance between industrialised activities and nature protection has become crucial nowadays (Leong, 2009; Mohamad

Bohari et al., 2015; EPU, 2016a). Years back, Malaysia seems to treat the development and environmental issue as two different entities and they move in different directions. For example, the increase in the number of development projects has caused a higher impact on the environment which increases the level of GHGs released mainly through deforestation activity. Despite being removed through photosynthesis and photolysis; the gases are also broken down in the atmosphere in a reaction with oxygen and hydroxyl groups (Yaacob, Mat Yazid, Abdul Maulud, & Ahmad Basri, 2020). The remaining gases absorb infrared radiation and indirectly influence ozone concentration which ultimately contributes to world climate change. Furthermore, GHGs are as well released by the combustion of fossil fuels (EC, 2020) which made the need of reducing them more vital. Olivier and Peter (Olivier & Peters, 2020) through their recent report, stated that 73% of the emitted GHGs were CO_2, followed by methane, nitrous oxide, and fluorinated gases with 18, 6, and 3% respectively. Therefore, the calculation of the CO_2 reduction in tandem with the improvement of the building energy performances is a standard practice worldwide.

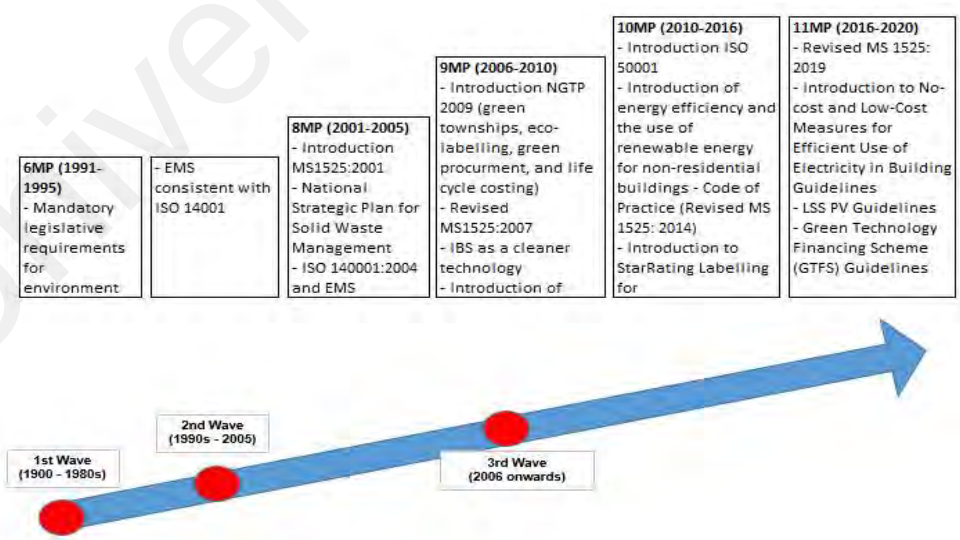

Figure 2.6: Policies and key practices related to environmental concerns in Malaysia

(EPU, 2016a; C. T. Leong, 2009; Mohamad Bohari et al., 2015)

In this research, the saving achieved from the lower electricity consumption upon the changes made (consideration as the retrofit initiative for Wisma R&D) will be used to calculate the amount of CO_2 reduction. The calculation of CO_2 reduction can be carried out in several ways. In this research, two methods are used in estimating the environmental impact of the retrofitting proposal. The *Greentech carbon calculator* is used in measuring and analysing the amount of carbon released from the building's electricity consumption. This is based on the existing electricity billings versus the proposed retrofitting initiatives. In other words, the proposed initiatives are based on the non-design factor such as appliance replacement and operation time. The online calculator is accessed at *http://www.greentechmalaysia.my/carboncalculator/*. Figure 2.7 shows *Greentech's carbon calculator*.

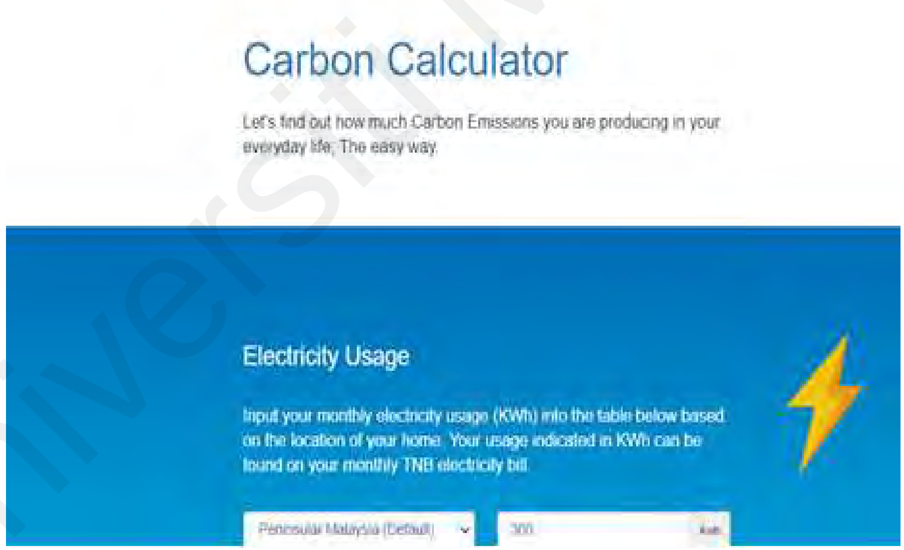

Figure 2.7: Greentech carbon calculator

http://www.greentechmalaysia.my/carboncalculator/

Later, the CO_2 reduction from a few passive design factors such as window glazing, opaque, and shading types are analysed from the simulation-based output. As this research is using ArchiCAD as the software for analysing the CO_2 impact on the different passive building parameters, hence the CO_2 measurement is based on the kWh reduction as well as the natural resources information that is inserted before the simulation is run. The detailed processes are explained in Chapter 3.

In overcoming the environmental degradation issue, several policies had been established. For instance, the NPCC and NGTP are among the framework for low carbon content in the country. In summary, most policies are made available to allow economic growth which in parallel keeps the impact on the environment to the minimum level. This includes the initiative which focuses on low carbon release, energy conservation, sustainable development, low carbon cities as well as enhancing public education and awareness of green technology. The policies are generally established under the Tenth Malaysia Plan (EPU, 2010).

Subsequently in the Eleventh Malaysia Plan, energy utilization has been outlined as one of the country's sustainable development plans (EPU, 2016a). This is because energy efficiency is well-known to be the potent and cost-effective way of meeting the demands of sustainable development and this fact has been mentioned in numerous articles (Sebitosi, 2008; Sadrzadehrafiei et al., 2012; Zhou et al., 2016). As the construction industry involved building entities, hence finding ways to enhance the green aspect of a building is paramountly important. Despite the focus on new building development, it is important to embark on effective retrofitting to as many building stocks in Malaysia, particularly in the urban area. As more populations are concentrated in the urban area, human activities emerged and this is the primary source of anthropogenic CO_2 emissions (Pacheco-Torres et al., 2017). As cities around the world were recorded to have produced more than 70% of global carbon emissions (Pacheco-Torres et al., 2017), hence retrofitting initiatives on the existing building blocks should be focused on the building in the cities.

2.7 Factors that Contribute to Building's Electricity Consumption

To achieve the goal of sustainable development, retrofitting the existing building stocks effectively is paramountly important. Concurrently, to ensure effective retrofitting for the existing building stocks, it is vital to conduct a comparative analysis before any decision is made. This will lead and assist building owners in identifying and selecting practical approaches on which factors and building parameters mostly contribute to a building's electricity consumption. According to (Zhou et al., 2016), these factors are broadly categorised as technology and management. (Zhao & Magoulès, 2012) on the other hand, simplifying the elements that influence the building energy performance is separated primarily into energy forms, building types, and building energy behaviour influences. In general, these parameters are categorized into two, i.e. the non-design and passive design factors. Each building parameter is categorised within these two main factors and has, directly and indirectly, contributed to building energy consumption, mainly electricity. The challenge lies in how much they had impacted one building's energy performance, hence a detailed analysis needs to be carried out to identify the most sensible and practical retrofitting initiative for one building. From the previous study, even though there are many research findings and guidelines available on which building parameters mostly impacted the building energy performances, they can only be used as a reference in the retrofitting process of another building as each building is unique.

As part of the energy-efficient retrofitting measures, parameters such as building orientation and the soil type on which the building is built, are impossible to change. On the other hand, environmental factors such as the external weather and wind effect are some of the factors that are beyond control, hence they need to be excluded from the retrofitting plan too. Nevertheless, these factors have to be included as part of the building energy performance analysis which is based on the location and the local meteorological department data. Moreover, building parameters such as the wall, roof, and floor materials are not practical to be part of the retrofitting plan even though the energy performance of the building envelope and its components (external walls, roofs, windows, and others are indeed critical parameters in determining how much energy is needed internally (Abanda & Byers, 2016). Due to that, retrofitting initiatives on the existing building stocks should be focused on the non-design factors such as the appliances and equipment installed within the building, the operating time as well as load factor performances. In addition, on the aspect of the passive design factors, parameters such as the glazing and opaque material, shading elements, external shading, and internal building temperature control are some of the suitable parameters to be included in the retrofitting initiatives.

Most of the surrounding factors and the other building parameters are interrelated. For instance, by replacing the glazing material from a single to double shade, it was found that the utilization of the air-conditioning is reduced throughout the building (Qahtan, 2019). This is due to the improvement of the building shell performance mainly the infiltration and thermal performance (Han et al., 2015; Hee et al., 2015; Jazaeri et al., 2019; Qahtan, 2019; Liu et al., 2021). Therefore, it is important to analyse the surrounding factors and other building parameters that impacted the overall building energy performances before any retrofitting initiatives are to be carried out. It can be done by analysing the individual impact as well as looking at various combinations of the surrounding factors and the building parameters. As this research is focusing on proposing a practical retrofitting plan for Malaysia's high-rise buildings, hence the selection of the several surrounding factors and building parameters are outlined and discussed in the following sub-sections. They are categorised into two main factors known as non-design and passive design factors. The details are discussed in the next sections.

2.8 Non-design Factors

As mentioned earlier, a group of building parameters that are impacting the building energy consumption is categorised as a non-design factor. According to (Huat & Akasah, 2011), non-design factors are the factors affected by occupancy and management, environmental standards, and climate. This includes the number of occupants, the type of activity and appliances installed, user attitude and behaviour, and finally the management and organization. Essentially, most of the non-design factors are either hard to control, impossible to control, or required continuous motivation and support from the management. For instance, the intensity of building occupancy is one of the non-design factors that could not be controlled. This applies to commercial buildings such as hospitals, universities, shopping complexes, and many others. On the other hand, replacing or upgrading the existing appliances or equipment to the more efficient is one well-known initiative taken by the majority of the building owners. Beforehand, a detailed analysis is deemed necessary to ensure the replacement could assist in the short and long-term benefits upon the retrofitting investment. Even though non-design factor such as building occupancy is usually excluded from building retrofitting initiatives, the effect from the intensity of building occupancy should be included as part of the overall analysing process as the number of occupants will contribute to the internal heat within a building.

Particularly in this research, the non-design factors that are selected to be analysed include the appliances and equipment used in the building, operating time, and load factor performances. These are categories under the non-design factors as they are related to the type of activity and building management. According to (Zhao & Magoulès, 2012), the operation of sub-level components like lighting and HVAC systems, occupancy, and behavior are among the non-design factors that tremendously impact the building energy performances. Hence, it is important to analyse the effect of each parameter. Particularly for the load factor performance analysis, it is pivotal in identifying the maximum load recorded throughout the building operation. The load factor performances are analysed through the monthly maximum demand recorded in the TNB's bill. Through it, effective retrofit initiatives can be put in place to shave down the maximum load of the building (Steiner, 2017; Association, 2018; Power, 2018). These three main impactful non-design factors are thoroughly explained in the following subsections.

2.8.1 Appliances and Equipment

Nowadays, buildings are equipped with numerous types of appliances and equipment. Depending on the type of building and the activity associated with the occupants of the building, appliances, and equipment are among the highest energy consumption in the building sectors (Levesque et al., 2018). In general, appliances like air-conditioning units, lighting, server equipment, and a few others are the major contributors to electricity consumption. However, the challenge is to identify the individual power consumption for each appliance or equipment. According to (Lam, Zheng, & Luo, 2019), knowing the power utilized by each appliance or equipment within the building will assist the building owner to monitor and work on energy conservation. Figure 2.8 and Figure 2.9 show the aggregated categories of appliances and equipment with their amount of consumption in both the residential and commercial sectors. The data published for the residential sector was referred to in the year 2016, whereas for the commercial sector, it was reported in the year 2014. In the residential sector, the final energy consumption was recorded at 2875 ktoe, and the highest consumption was nominated by home appliances (55%), followed by cooking (23%), space cooling (11%), lighting (8%), and water heating (3%). As home appliances were recorded as the highest energy consumer in the residential sector (EC, 2016b), it is worth looking into the type, power rating, and quantity of the appliances used in a more detailed manner. Huge potential for energy conservation could be achieved by installing or replacing the existing appliances with better and more energy-efficient ones.

The same applies to the other appliances and equipment used at home. For retrofitting purposes, it is wise to review the consumption of space cooling as well as lighting.

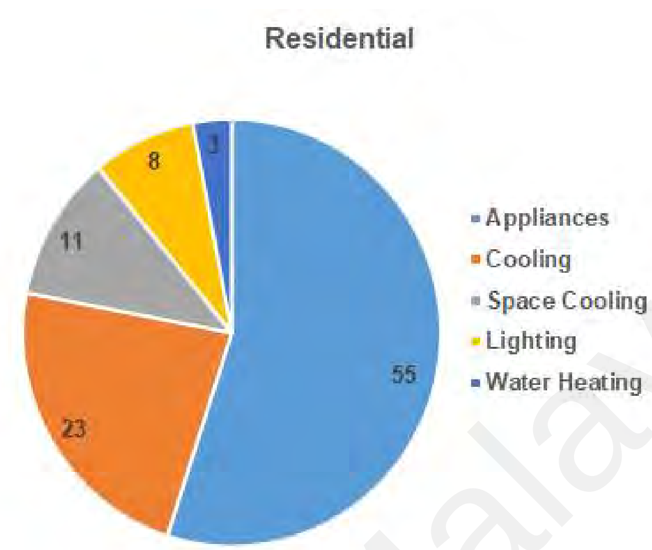

Figure 2.8: Final energy consumption by aggregated categories in residential buildings

(EC, 2016b)

Dissimilar trends were shown in the appliances and equipment in the commercial sector. As shown in Figure 2.9, space cooling recorded the highest electricity consumption in almost every commercial group in lieu of 'other' appliances. From the statistics, space cooling had recorded consumption of 42%, followed by 'other' appliances (33.5%), lighting (21.8%), and water heating (2.6%). Similar trends were shown in the prior year. These statistics were released by the Energy Commission of Malaysia in 2016 (EC, 2016b) and the consumption trends are consistent among all the selected groups in the commercial sectors. A similar trend was reported in commercial buildings in European Union (UN) countries (Aste & Del Pero, 2013). According to the IEA, worldwide energy demand from air conditions is anticipated to triple by 2050, making it one of the most important drivers of global electricity demand over the next three decades (IEA, 2018a). The IEA analysis is backed up by a study conducted in a Chinese government building, which found that air-conditioning systems should be given special consideration when evaluating energy retrofit incentives (L. Yuan et al., 2016). As this research is focusing on analysing the contributing factors to the electricity consumption of commercial buildings which later assist in the efficient retrofit initiative, hence, it is wise to focus on the space cooling, lighting, and 'other' appliances consumption of one building before any retrofitting initiative could be carried out. However, the 'other' appliances category consists of tremendously different appliances which are depending on the commercial building activities. Due to that, it is wise to focus on the effective retrofitting of the building's space cooling as well as the lighting as they will tremendously assist in the reduction of the trio effect, i.e. the energy, cost, and CO_2 emission in all commercial buildings. A detailed review of these appliances is discussed in the next subsections.

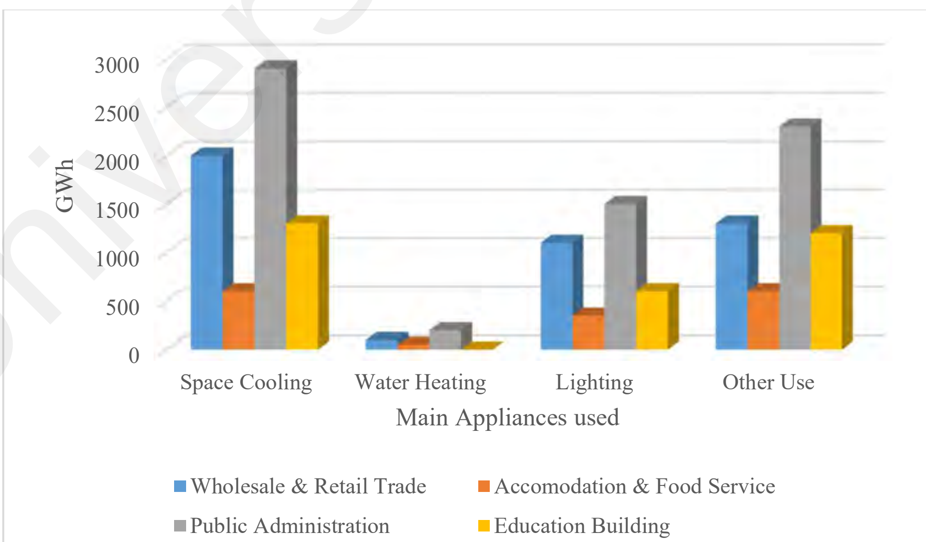

Figure 2.9: Final electricity consumption by aggregated categories in the commercial sector

(EC, 2016b)

2.8.1.1 Air-conditioning Unit

As the world is getting warmer due to climate change, it has been seen that the demand for air-conditioning units has grown tremendously. According to the IEA report (IEA, 2018a), the growing use of air conditioners in homes and offices is foreseen as one of the top drivers of global electricity demand in the next 30 years. The global stock of air conditioners in buildings is estimated to grow to 5.6 billion, an increase of more than 71% from the stock utilized in buildings today. As air-conditioners bring comfort to the occupants, hence it is expected to increase drastically, especially in the emerging country. With the current statistics, most buildings are recording an electricity consumption of around 35 to 40% (Ghazali et al., 2017; IEA, 2018a; Nikdel et al., 2018) of the total electricity consumption, hence the efficiency performance of AC units and the building cooling system as a whole must be prioritized. In addition, (Aste & Del Pero, 2013) reported that heating, cooling, and lighting are responsible for associated consumption in business buildings in EU countries. The improvement of AC efficiency could lead to higher energy savings and assist in reducing the electricity cost and environmental implications. As the rise in cooling demand is particularly seen in the hotter regions (IEA, 2018a), not to exclude Malaysia, hence it is important to have a clear policy, guideline, and awareness of the cooling efficiency across the involved parties. Particularly in building operations, the building owner needs to review the building AC's system and work on making it more efficient. Stringent energy performance standards, installation of high energy-efficient label equipment, and smart monitoring and control are some of the effective approaches to making a building sustainable. In short, setting higher efficiency standards for cooling is one of the significant steps for the government to reduce the need of accommodating new power plants and cut emissions effectively. For instance, guidelines such as the *Minimum Energy Performance Standard requirement for Air Conditioner with Cooling Capacity « of 7.1 kW* that was published by the Energy

Commission (EC, 2018a) are very important in assisting the whole intention to enhance building sustainability in the country. This too is very useful for the retrofitting initiatives for the existing building. Besides scheduled maintenance, temperature control and monitoring are some of the effective approaches to reducing the electricity consumption from AC units.

There are several types of AC units used in building applications. In specific, the most popular types used in commercial buildings are HVAC, VRV, and several other types like the Wall Hung Split and Ducted Air Conditioning. Each of these types has its operating system, configuration, and power rating. The building owner needs to select the most suitable AC based on the building space, building design, operating time, and many others. Selection of the energy-efficient AC unit/system is vital to assist the building owner to reduce the building's energy consumption for the building. On the other hand, improper selection of AC system can maximize the initial running costs of the building and decreases human comfort as well as the air quality levels (Elnaggar & Alnahhal, 2019). In addition, it is important to conduct EAs for a building within a certain timeframe. The reason behind this recommendation is based on the report which estimated that 39% of the energy spent in the commercial building was wasted because of heating or cooling unoccupied spaces, overheating or undercooling, air leakage, and inefficient appliances (Nikdel et al., 2018). Due to these, it is important to have policies and guidelines for new building development and effective ways of monitoring the AC unit/system for the betterment of the existing building's performance. Various best practices can be adopted by the building management as part of retrofitting initiatives for the AC unit/system of the existing building.

2.8.1.2 Lighting

Among all the electricity consumers, lighting is one of the highest shares in the residential and commercial sectors (Soori & Vishwas, 2013; Ganandran, Mahlia, Hwai Chyuan Ong, Rismanchi, & Chong, 2014) and is the second electric power consumption after the air conditioning in most Malaysia building (Leong, 2009; Rozana Zakaria, Amirazar, Mustaffar, Mohammad Zin, & Abd Majid, 2013). In general, it accounts for approximately 20% to 30% of the electricity consumption worldwide (Soori & Vishwas, 2013; Rozana Zakaria et al., 2013; Bohari et al., 2018). Lighting is considered one of the utmost important appliances in building operation as it supports not only comfort and a safe environment, but an effective lighting system has allowed the optimization of energy used. (Ganandran et al., 2014). As technology emerged, the existing lighting features are capable to produce the equal or desired luminaire compared to the traditional lighting system with half the energy input (Ganandran et al., 2014). Furthermore, (Kusumadewi & Limmeechokchai, 2015) affirmed that lighting is the most important end-use to reduce energy consumption in a building and offers many opportunities for energy-efficiency improvement (Soori & Vishwas, 2013). Due to this, enormous energy-efficient lighting is now available in the market which should be utilised through effective retrofitting initiatives by the existing building owners to improve the energy building performances. Besides the energy-efficient luminaires, natural lighting could assist in the electricity reduction of one building. On top of reducing the electricity and cost incurred, natural lighting is one of the significant solutions for a sustainable building as it improves the vision of the occupants too (Soori & Vishwas, 2013). According to (Bohari et al., 2018), there are three approaches to reducing energy consumption from the viewpoint of lighting; either replace the lighting bulb with Light Emitting Diode (LED) type, reduce the lighting hours, or install of switching timer.

2.8.1.3 Other Appliances in the Commercial Building

In Malaysia, the commercial sector is grouped into twelve main categories based on their economic activities. These include the *Wholesale and Retail Trade*, *Transportation and Storage*, *Accommodation and Food Services*, *Information and Communication*, *Selected Services*, *Professional, Scientific and Technical, Travel Agencies and Tour Operators*, *Public Administration, Education*, *Human Health and Social Work*, *Arts, Entertainment and Recreation*, and *Other Services* (EC, 2016b). Due to the different types of economic activities within the commercial sector, hence 'other' appliances consist of a variety of appliances such as printer and photocopy machines, server racks, kitchen appliances, lifts, laboratory equipment, and many others. Generally, 'other' appliances in a building can be categorised depending on the type of building and its economic activities. As this research is focusing on an institutional and high-rise building, it is important to analyse in-depth the 'other' appliances like personal computers and/or laptops, lifts, kitchen appliances, printers and photocopy machines, server racks, phone chargers, emergency lights, and many others. In this research, the energy consumption for each of the 'other' appliances was detailed. Particularly, the lift contribution towards building energy consumption which is rarely discussed was analysed and summarized in this research. Detailed analysis was carried out from the walk-through EA.

2.8.2 Operating Time

The operating time is one of the non-design factors that play a significant role in contributing to the total building energy consumption. Mainly for an office building, the standard operating time is based on the standard office hours; 8.00 am to 5.00 pm or 8.30 am to 5.30 pm. In this research, the operating time is set for EA and simulation-based analysis is from 8.00 am to 5.00 pm.

2.8.3 Load Factor (LF) Performance Analysis

The load factor is one of the indicators that describe how much energy is consumed in a building (Power, 2018). The eagerness to cut down the electricity consumption in the building has urged many building owners to launch numerous energy-efficient initiatives within the building. As the owners of commercial buildings are commonly charged for electric power based on energy consumption and peak load (Sun, Wang, Xiao, & Gao, 2013), the building owner needs to analyse not only the total building energy consumption but the amount of its peak load too. The load factor performance study is mainly focusing on cutting down the peak load or sometimes called the maximum demand. Furthermore, because the load factor is used to determine which buildings are more energy-efficient than others, learning about LF can help a building owner gain a better understanding of energy management and make decisions that save both energy and money (Association, 2018).

By definition, a peak load is the highest load recorded over a specified billing period, e.g. a month and the peak load in commercial buildings usually lasts for a relatively short period but its cost can contribute up to 50% of the overall bill (Sun et al., 2013). Therefore, it is pivotal for the building management to analyse the load factor performance of a building, which indicates the ratio of the average load and the peak load of a specified period. This will lead to effective energy-saving measures; specifically in shaving down the peak load which results in substantial savings on the total electricity bill too. In other words, building owners may be able to minimize their electricity bills by reducing the building's peak load.

The desire for peak shaving is driven by two factors. The high charges of the peak load specified for the building sector, mainly the commercial is one of the push factors of this need (Sun et al., 2013). In Peninsular Malaysia, based on the TNB's tariff, peak load prices are reported to be 80% higher than per-unit electricity charges (www.tnb.com.my/pricing-tariffs). In particular, the tariff of the peak load for the commercial building is RM 30.30/kW and RM 45.10/kW for C1 and C2 groups. Therefore, it is important to analyse the peak load of any building in operation. In addition, (Jin Sol, Ismi Rosyiana, Jung-Su, & Hwachang, 2020) state that the peak load of large buildings has been rising every year, and to meet the demand, the number of power plants must be increased, which is not only costly but also harmful to the global warming. The rise of energy demanded by the building sector in a country like Saudi Arabia, which accounts for almost 80% of their national power consumption is urging the government to implement various energy efficiency programs which probably could save 10,000 GWh/year of energy consumption, shave the peak load by 2,290 MW and reduce carbon emission by 7.6 million tons per year (Fardan, Gahtani, & Asif, 2017). The aforementioned issue could be tackled if the peak load is reduced.

There are various ways to be carried out on shaving the peak load of a building such as utilizing the renewables supply, Energy Storage System, utilization of Building Management System, smart metering, Demand Respond Program, load decomposition system, load shifting control, installation of the energy-efficient appliances (4-star and 5-star rating appliances) and many others (Sun et al., 2013; Fardan et al., 2017; Issi & Kaplan, 2018; Lam et al., 2019; Jin Sol et al., 2020). However, before any initiative or method could be implemented in minimizing the peak load, a thorough study of the load profile of the building needs to be executed. Through the building's load profile, a detailed analysis could be conducted to examine the building's energy performance. This is to say, the building load factor performance is one of the important non-design factors that contribute to building energy consumption. It is an indicator that portrays whether a building is utilizing the energy efficiently or vice versa. In the concept of electricity consumption, the load factor performance is an indicator that triggered the building management to review their electricity consumption within the building. A close look at the peak load amount, day, and time that occurred are necessary before any improvement could be effectively performed. According to (Issi & Kaplan, 2018), to execute correct load management in the building, information on power consumption and load profiles is required. Therefore, it is important to carry out a thorough EA of a building which later enables the building management to analyse the building load profile from the recorded data. It is a crucial step before embarking on an effective retrofit for the building. In this research, the load factor performance analysis is carried out based on the four conservative years of the building's electricity bill and it is one of the significant contributions to the building energy performance research for the non-energy efficient building in Malaysia.

2.9 Passive Design Factors

Another category of building parameter that could impact the building energy consumption is the passive design factors. Even though there are numerous passive design parameters within a building, the focus is being put on the opening characteristics such as the glazing, opaque material, and shading. The glazing and opaque materials are categorised under the building façade. In addition, the effect of a room/internal building temperature is analysed. On top of the above, the effect of the external shading surrounding the building is taken into consideration in the analysis. All the passive design factors selected are based on their possibility of being replaced, set, or added in through potential retrofitting initiatives. However, various passive design factors of a building are inculcated during the simulation such as the building location and orientation, type of building (in this case an office building), surrounding temperature, type of soil, and many others. The input to all these parameters is obtained from Google Maps as well as the online temperature data. It is important to include as many parameters as possible to be able to attain accuracy from the simulation-based analysis. In this research, the building location and weather are the real-time data input.

As mentioned earlier, the impact of these passive design factors could only be analysed through a detailed simulation-based approach. In other words, the effect of these passive design factors on building energy consumption could not be analysed either from the EA or the building utility bill information solely. For instance, studies had shown the effect of a room/internal building temperature on energy consumption. A case study conducted at the Putrajaya buildings for instance affirmed that the increase of the room temperature by only one degree has reduced the building's energy consumption by 10% (Roy et al., 2015). Therefore, it is very costly to have too low temperatures in the building, especially in a tropical climate country like Malaysia where its surrounding temperature lies between 24ºC to 35ºC. On top of the internal temperature, the demand for energy in buildings varies strongly across countries and climatic zones (Levesque et al., 2018). As each building is unique, hence the simulation-based approach is found to be another interactive approach in analysing the effect of the passive design factor on building energy consumption and later on be a reference for the retrofitting initiatives.

2.9.1 Building Facades

Building facades are one of the most technologically complex and interdisciplinary components of a structure. The facade is one of the most essential components of a building from the standpoint of architectural design since it showcases the building's aesthetic values and architectural expression. Furthermore, building envelopes, particularly the façade, play an important role in safeguarding (maintaining) indoor thermal conditions and energy balance, and increasing the long-term performance of buildings from an engineering standpoint (Halawa et al., 2018; Krstić-Furundžić, Vujošević, & Petrovski, 2019). The building envelope and its components (external walls, roofing, windows, and many others), according to the IEA (IEA, 2018b), can be essential in deciding how much energy is required internally and later affect overall building energy performance due to their effect on cooling and heating needs. In a simpler form, this part of the building separates the indoor from the outdoor environments and it plays a substantial role in determining the energy demand to maintain a comfortable indoor environment of a building (Fasi & Budaiwi, 2015; Lee, Kim, Song, Kim, & Jang, 2017; Halawa et al., 2018). As a result, it is critical to carefully plan and select the materials for a building's façade to ensure that it provides occupant comfort, is energy efficient, and has a low environmental impact. In particular, the selection of the building façade material could affect indoor natural ventilation, visual comfort, thermal comfort, the overall performance of building energy consumption and reduce environmental pollution (Halawa et al., 2018; Krstić-Furundžić et al., 2019). In addition, according to (Krstić-Furundžić et al., 2019), as the façade of a building loses the most energy, it is one of the most significant aspects to consider in the design and construction of a sustainable structure. The impact of heat loss from the building façade is segregated into three, which are the roof, window, and wall. (Feng et al., 2017). Among these three parameters, the window is the most practical element to be considered in the retrofitting initiative as compared to the wall and roof.

The parameters that must be considered while designing building facades have been identified through various research findings. Some of the important ones include the building physics, location, orientation, exterior and interior walls and materials, thermal insulation, windows, glazing, window-to-wall ratio (WWR), roof insulation, and external shading (Zhou et al., 2016; Halawa et al., 2018). Due to the correlation of the building façade related parameters, the design of a sustainable building that could optimize energy performance could be complex and challenging. For instance, increasing WWR to achieve optimum daylighting may be effective in decreasing the energy consumption derived from the use of artificial lighting; however, this approach may increase solar gain and increase the need for energy for cooling (Halawa et al., 2018). On a different aspect, increase reliance on natural ventilation may result in an unacceptable humidity level in occupied building spaces (Safarova, Halawa, Campbell, Law, & van Hoof, 2018). In short, the correlation of all the above façade elements is contributing to the main losses of the building envelope. Nevertheless, this can be resolved via a simulation-based approach using available state-of-the-art software and green construction processes. From the standpoint of new building development, multiple parameters of building façade should be incorporated to optimize the building energy performance. It is in line with the global need that encourages more energy-efficient building development. Oppositely, there are several limitations to enhancing the building performance for the existing building. It is recommended that the potential building façade that could be considered in retrofitting initiatives are the parameters that relate to building opening, mainly windows. The reason for this statement is due to several studies have found that the building opening has a significant impact on the building's energy performance when compared to other key features, including those listed as building façade (AmirHosein GhaffarianHoseini et al., 2013; De Boeck et al., 2015; You & Ding, 2015). The findings reinforced many retrofitting initiatives and studies to promote the energy-efficient in achieving the goals of green building (Santamouris & Dascalaki, 2002; Zakaria, Foo, Mohamad Zin, Yang, & Zolfagharian, 2012; Zhou et al., 2016; Alves et al., 2018; Streicher et al., 2019). After all, the retrofit initiative should avoid massive replacement or repair activities as it will involve a high amount of investment and is time-consuming. Hence, in this research, the building parameters which are analysed due to their potential retrofitting capability are limited to the window glazed and opaque materials as well as the shading device.

As mentioned, as this research is particularly analysing the effective retrofitting for the existing building, hence the main building parameters that are analysed are the glazed and opaque materials as well as the shading type. (Ihara et al., 2015) claimed that reduced solar heat gain coefficient and window u-value, as well as increased solar reflectance of opaque sections, were determined to be viable approaches for lowering energy consumption. This combination or somehow part of the combination could be thoroughly analysed through a simulation-based approach.

As a rule of thumb, the heat transfer coefficient (u/R-value) is used as one of the key references in analysing the effect of these building opening materials and devices. The better the heat transfer coefficient (u/R-value) of the building envelope, which is obtained from appropriate and high-quality building insulation, the lower the energy usage of one building (Singh & Garg, 2009; Sadrzadehrafiei et al., 2012; Lee et al., 2017; Zhang et al., 2023). Another aspect to be considered is the building's internal heat gain and by properly managing and controlling the internal heat gain, optimization of the energy performance within a building could be achieved along with desirable occupant comfort (Gasparella, Pernigotto, Cappelletti, Romagnoni, & Baggio, 2011; Hee et al., 2015). Apart from internal heat gain, (Han et al., 2015) claims that air infiltration rates have had a larger or smaller impact on building energy consumption, depending on the tightness of the building enclosure, heating ventilation, and air conditioning system. Even though some baseline value of the internal heat rate is set for commercial buildings (Lee et al., 2017), the reduction and control should be focused on the window material as it is the main source of the internal heat rate. This is due to the lighting system and the solar heat gain emanating from the selection of window design and material (Wan Mohd Nazi, Royapoor, Wang, & Roskilly, 2017). Therefore, this research is conducted to review the significant impact of the glazing and opaque material as well as the shading devices on the internal heat gain and infiltration rate. However, according to (Zhou et al., 2016), improvements to the building façade, particularly insulation will involve a huge capital cost. Therefore, the ROI is to be carried out to determine the affordable retrofitting scheme. In short, the lower the ROI, the more reasonable the retrofit scheme is and this is the economic measure that is analysed in this research. Several combinations of the selected building façade are analysed throughout this research. The outcome which is observed from the simulation results is presented and compared on their trio effect; i.e. the energy consumption (kWh), the energy cost (RM), and the carbon emission (kg).

2.9.1.1 Glazing Material

As fundamental features of building facades, openings, particularly windows, provide for natural lighting and ventilation, visual connection to the outdoors, and heat penetration (Cuce, 2018; Halawa et al., 2018). Unfortunately, various research findings had found that a large quantity of heat gain or loss occurred most through the windows, affecting the thermal comfort of the building's occupants (Sadrzadehrafiei et al., 2012; Fasi & Budaiwi, 2015; Hee et al., 2015; Cuce, 2018). They play a dramatic role in the heating and cooling loads of buildings since they have notably high thermal transmittance or u-value (Cuce, 2018). (Wan Mohd Nazi et al., 2017) claimed that the lighting system and solar heat gain through windows were found to account for 71% of the building's heat gain, which caused a significant impact on the building's cooling load. However, it is impractical to have a building without windows due to the above-mentioned needs and these are essential contributors to the occupants' comfort. In addition, the benefits of the exterior view and the biological effect of natural lights on humans (Hee et al., 2015) should be considered. Due to this, window design is found to be an important element in achieving a sustainable built environment as it has a significant potential for reducing building energy usage and leading to improvement of the building energy performances, particularly for the existing building.

For warm climates countries like Malaysia, sustainable facade design strategies which mostly are space cooling dominated (Sadrzadehrafiei, Sopian, Mat, & Lim, 2011) is focusing on reducing external heat gains while at the same time allowing natural daylighting as well as enhancing window performance from a heat loss perspective (Sadrzadehrafiei et al., 2012; Halawa et al., 2018). Hence, energy-efficient glass material, which reduces the need for extreme heating and cooling by slowing the movement of heat through the building (Kim & Rigdon, 1998) is found to be the best criterion in glazing material selection. In short, to improve a building's energy efficiency, the aesthetics of the window system must be modified (Sadrzadehrafiei et al., 2011).

As this research focuses on analysing the best and most practical retrofitting initiative for the high-rise building in Malaysia, hence the physical aspect (design and area) of the window is not the main focus. The focus leans on the glazing material which could reduce the unnecessary cooling need within the building. Primarily, this performance is based on the thermal transmittance or u-value of the glaze material. It is due to the capability of better performance glazing that could help to cut down the solar gain and penetration into the building (Sadrzadehrafiei et al., 2011) as well as reduce the unnecessary need for extreme cooling during the building operation. As a result, this will enhance the overall energy building performance, occupant's comfort as well as CO_2 emission.

According to (Halawa et al., 2018), various types of glazing material can be used including multiple panes with different gases between them, tinting, low emissivity coatings, and several framing materials. (Sadrzadehrafiei et al., 2011) summarized a study in Hong Kong that found that the application of low-E glazing had led to a decrease in cooling electricity use by up to 4.2%. In another study, it was found that the embodied impacts of glazing solutions are increased by the tempered or laminated glass, as well as the glazing coating (low-E film) (Saadatian, Freire, & Simões, 2021). (Hee et al., 2015) conclude that both static and dynamic glazing have their contradictions in offering a balance between visual and energy aspects. Furthermore, climate background is also a very important key to determining the suitable glazing of buildings. As a whole, it is known that the impact from different glazing materials is enormous as it is interrelated with window area, the orientation of the window wall, size, climate, building wing's orientation, room type and location, and a few others (Yik & Bojić, 2006; Sadrzadehrafiei et al., 2011; Fasi & Budaiwi, 2015; Djoković et al., 2022; Faragallah, 2022). Therefore, detailed analysis is indeed very important in identifying the best and most practical glazing material for the building window system, mainly to retrofit the existing block.

As thermal insulation is one of the key criteria of the window system, the thermal transmittance, known as the u/R-value of the window glazed is an important step in evaluating the thermal insulation performance of the window material. A lower u-value is an indicator of good insulation which allows the window to block the external heat to penetrate the building and is sufficient to maintain the internal temperature. The typical u-values of building elements (Cuce, 2018) are shown in Figure 2.10. It can be seen that the u-value of the window is among the highest compared to other building façades, like the roof, ground/floor, and wall. Therefore, developing windows with low thermal transmission can significantly reduce building energy expenses and generate significant energy savings (Cuce, 2018; Djoković et al., 2022). From this perspective, some countries specified the window material with u-values of 1.6 W/m^2 K and below in their building code (Bjarløv & Vladykova, 2011; Stene, Alonso, Ronneseth, & Georgnes, 2018). However, countries like China had specified different values of recommended building envelopes due to weather and the surrounding environment (Yang, Lam, & Tsang, 2008). Referring to MS1525, there is no specific value of heat transfer coefficient recommended for the Malaysian building (DOSM, 2019b). However, (Mirrahimi et al., 2016) found that it is best to keep the thermal transmittance lower than 2.0 W/m^2K. Inversely to that, the thermal resistance needs to keep to higher than 0.5 Km^2/W.

Figure 2.10: Typical u-values of building elements

(Cuce, 2018)

In a different aspect, the interrelation of the thermal resistance (R-value) with building energy consumption was introduced by Spielvogel in 1974, which was now referred to by ASHRAE in their handbook (ASHRAE, 2001). Figure 2.11 illustrates the interrelationship. It is indicated that the best thermal resistance (R-value) is one with the least amount of overall heating and cooling energy. From the graph, the Y is estimated as 0.8 Km^2/W or 1.25 W/m^2K (u-value). Hence, this supports the recommendation made by (Cuce, 2018) and several other countries' building references which recommend that the optimum window u-value is best to be less than 1.6 W/m^2K.

On one hand, the lower u-value from the window is found to be related to the number of additional glazing layers (Sadrzadehrafiei et al., 2011; Abdelhafez et al., 2023). On the other hand, the cost of the glazing material increase with the number of layers as well as its quality and performance (Hee et al., 2015). However, a study by (Lee et al., 2017) illustrated a different perspective. It was concluded that the current u-value standard for the window in Korea which is 2.1 W/m^2K is ineffective for buildings with high internal heat gain. If the window u-value is not excessively low, less energy is required to heat and cool the structure when the internal heat gain is considerably high. Due to all these factors, it is important to conduct a thorough evaluation in determining the optimum glazing material (types and layers) before embarking on a retrofitting initiative. This research is intended to analyze the amount of electricity consumed that can be reduced by applying different glazing materials (types and layers) to the virtual Wisma R&D building.

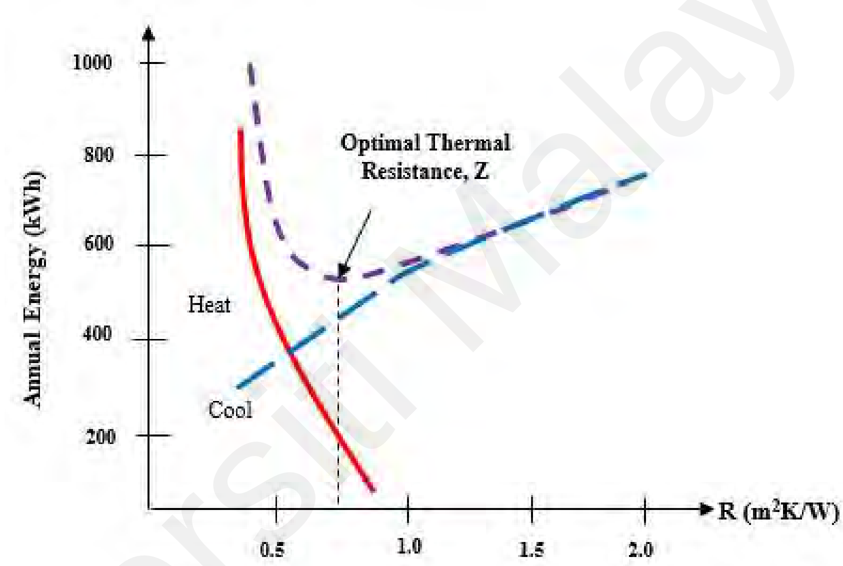

Figure 2.11: Optimal thermal resistance for building

(ASHRAE, 2001; Yuan, Farnham, & Emura, 2017)

2.9.1.2 Opaque Material

The majority of energy-saving construction rules and building codes focus on improving the insulation and airtightness of the building envelope. They are found to reduce heat loss during the heating season but lead to overheating in the cooling season (Lee et al., 2017). High thermal insulation in envelopes with high internal thermal loads demonstrates low heat dissipation through the envelope will increase the energy consumption needed to cool the building (Lee et al., 2017). In short, inappropriate envelope design standards could increase the energy consumption of a building rather than reduce it (Mohamed, Hamdy, Hasan, & Sirén, 2015). In different studies, (Gasparella et al., 2011) found that a window's energy efficiency is also affected by air leakage caused by the frame and installation airtightness. Due to this, it is pivotal to select a suitable opaque material that can lead towards the optimization of the building heat gain as well as the indoor thermal environment. The optimum envelope thermal insulation level has proved to contribute towards the efficient energy consumption of a building. The building's internal heat gain and the optimization of the envelope thermal insulation level are analysed through the u-value of the selective building envelope components, which normally combine several building parameters. According to (Halawa et al., 2018), opaque facades provide higher thermal insulation than just glazed ones. Hence, in this research, the combination of the glazing and the opaque selection are analysed. In specific, the window u-value is observed from the effect of both with and without the opaque material (through window frame) improvement. The final results will evaluate whether the combination of window glazing and opaque materials could effectively increase the thermal insulation of the building through their combined u-value). Furthermore, the investigation will analyse the effect of these combinations on the internal heat gain as well as the infiltration rate of Wisma R&D. In specific to the infiltration rate of the Malaysian building, a study conducted by Jabatan Kerja Raya (JKR) in 2007 had concluded that an average of 1.0 air changes per hour (ACH) was summarized from 50 government buildings, which was 144% higher than the infiltration rate stated by ASHRAE handbook (ASHRAE, 2001; Razad, 2007). Hence, this research is conducted to analyse the performance of an existing high-rise building in Malaysia based on these parameters.

2.9.1.3 Shading

To avoid excessive solar gains and glare discomfort for occupants, appropriate solutions that limit incoming solar radiation, such as highly reflecting coatings or adjustable shade devices, must be implemented (Evola et al., 2017). Alike glazing, shadings do have an impact on the amount of energy used in a building too. It contributes to the amount of lighting, heating, and cooling required for a building, as well as the occupants' visual and thermal comfort (Krstić-Furundžić et al., 2019). Several studies proved that the shading devices had assisted in reducing the total energy consumption of the building, especially buildings with large glazed surfaces (Eskin & Türkmen, 2008; Evola et al., 2017; WBDG, 2018; Sayed & Fikry, 2019). In specific, (Sayed & Fikry, 2019) concluded that the introduction of shading devices for double glass façade has the effect of decreasing the consumption of cooling energy by 2-5%. On different findings, (WBDG, 2018) stated that an estimate of 5% to 15% of annual cooling energy consumption was reported through well-designed sun control and shading devices, however, it is depending on the amount and location of fenestration. According to (Melo & Lamberts, 2009), increasing the shade factor by 75% can reduce the use of the air conditioning system by 8%.

Natural landscaping or architectural elements such as awnings, overhangs, shutters, and trellises can function as shading devices. A tree, as illustrated in Figure 2.12, act as a shading element for a building in both the summer and winter season. In addition, some shading systems can also act as reflectors and light shelves, bouncing natural light deep into building interiors for daylighting (WBDG, 2018).

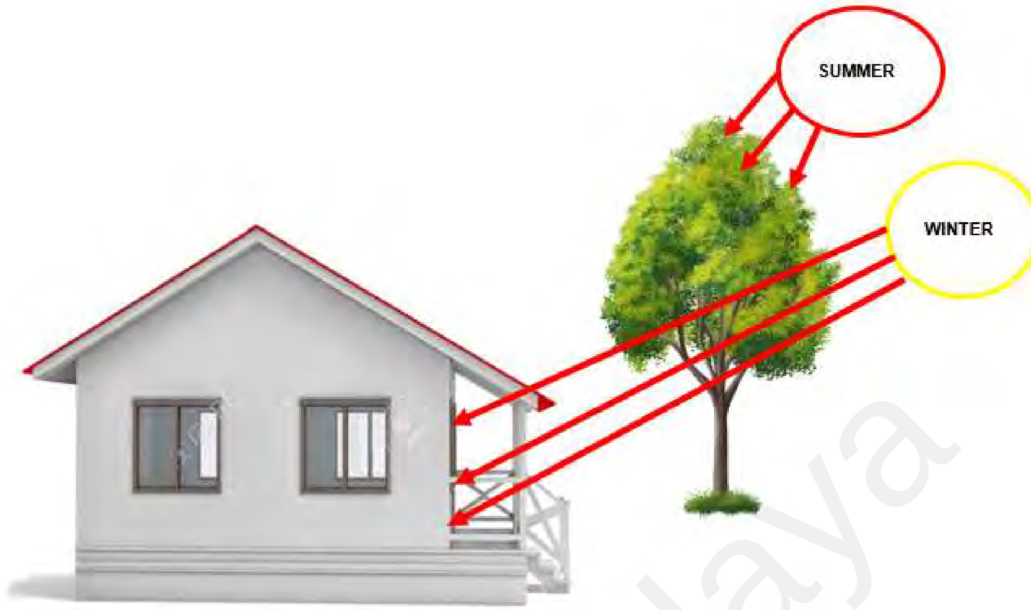

Figure 2.12: Trees as a shading element during winter and summer

(WBDG, 2018)

An understanding of sun angles is critical to various aspects of building design. A careful study, particularly of the weather aspect and the sun angles, is required when selecting the appropriate shade feature for a building too.

In general, the best and most effective design shading are depending on various building parameters as well as the climates in which they are situated. (Melo & Lamberts, 2009) stated that for commercial buildings with larger internal loads, increased insulation can prevent internal gains from being dissipated to the exterior, resulting in a higher cooling load demand. Due to this, it is tough to establish broad generalisations about shading device design. Despite the aforementioned varieties, a detailed analysis through the virtual building simulation is deemed necessary in identifying the suitable shading elements for a specific building design. The same applies to retrofitting exercises. Hence, in this research, several shading elements are evaluated.

2.9.2 Internal Room/Area Building Temperature

The internal room/area building temperature plays an important role in determining the total energy consumption of one building, especially in hot and humid climate countries like Malaysia. In addition, it is pivotal to set an appropriate temperature that could allow occupants comfort. If the building is too warm or too cold, it could affect the occupant's comfort and health. Referring to the MS 1525:2007, (Leong, 2009) summarized the recommended indoor temperature which suits Malaysia's external temperature. It was divided into three which are tolerable comfort temperature for a short duration, the comfort zone boundary, and the recommended design comfort zone for Malaysian buildings according to the relative humidity (DOSM, 2007; Leong, 2009). However, the latest MS1525:2019 stated that the temperature control should be kept between 23°C to 27°C (DOSM, 2019b). As one of the aims of air-conditioning system in the building design is to provide comfort for the occupants, hence all the building owners are highly recommended to sustain the internal room/area temperature from 23°C to 27°C.

As informed earlier, the difference between the external and internal temperatures will significantly contribute to the high cooling need for the countries like Malaysia. According to MS 1525-2007, the heat may be conducted both in and out of the building depending on the time of the day, especially for typical office buildings that are air-conditioned during the daytime only. (DOSM, 2007). Hence, weather conditions are one of the important factors in determining building energy usage. The weather is very much related in many forms and ways; such as temperature, humidity, solar radiation, wind speed, and many others (Zhao & Magoulès, 2012). Due to this, the impact of the internal room/area within the buildings is one of the parameters that is analysed through the simulation-based approaches in this research.

2.9.3 External Shading Surrounding the Building

As shown in Figure 2.12, trees are one of the elements that could provide sufficient shading to the building. Several studies (Gómez-Muñoz, Porta-Gándara, & Fernández, 2010; Rouhollahi, Whaley, Byrne, & Boland, 2022; Zhang et al., 2022) have shown that external shadings like trees and other infrastructure that surround the building could assist in providing shade to the building. This can be achieved through a proper landscaping plan by the city council or by the building management. A basic understanding of the sun path diagram is the key to identifying the need for suitable external shading. As this can be part of the retrofitting initiative for the existing building, hence this research has inculcated this element as part of the simulation-based approaches. The sun path diagram (DOSM, 2019a) shows a bigger glazed area on the south part of the building will provide a higher impact on the building temperature, hence the external shading will assist in the reduction of the sun penetration into the building. This theory is referred to and analysed in this research based on the position of the window of the Wisma R&D building. The total window areas at each cardinal location are measured through the virtual building model. The finding is discussed in Chapter 4.

2.10 Tool and Effective Approaches for Retrofitting

Due to the complexity of building energy behavior and the uncertainty of the influencing factors, many models were proposed for this purpose aiming at accurate, robust, and easy-to-use prediction (Zhao & Magoulès, 2012). There are numerous simulation tools, energy management processes as well as proposed modeling concepts that are recommended for the same purposes. Table 2.2 has the details of several methods and approaches available for building energy consumption and performance evaluation. As mentioned earlier, a single approach could not be able to identify the best and most practical retrofitting initiatives that suit a specific building, hence a combination of several approaches is deemed necessary. For instance, the engineering methods employ physical principles to calculate thermal dynamics and energy behaviour on a whole building or sub-level component level, and they may be divided into two categories: detailed comprehensive method and simplified method. Hundreds of software programs, such as DOE-2, EnergyPlus, BLAST, and ESP-r, have been developed to assess energy efficiency, renewable energy, and sustainability in buildings. On the other hand, in the field of building energy prediction, Artificial Neural Network (ANN) is the most extensively employed artificial intelligence model. This type of model is good at solving non-linear problems and is an effective approach to this complex application (Zhao & Magoulès, 2012). Numerous available methods and approaches in analysing the building energy performances have allowed a variety of choices for the building owner in deciding the most suitable way of improving the building life cycle. From the retrofitting point of view, it is a vital process to ensure the short and long-term benefits of the retrofit initiative are met.

Table 2.2: Comparative analysis of the commonly used methods for the prediction of building energy consumption (Zhao & Magoules, 2012; Mehdipoor, 2016)

Methods	Model complexity	Easy to use	Running speed	Inputs required	Accuracy
EA	Fair	Yes	N/A	Detailed	To some extend
LF Performance	Fair	Yes	N/A	Historical data	High
Elaborate Eng.	Fairly high	No	Low	Detailed	Fairly high
Simplified Eng.	High	Yes	High	Simplified	High
Statistical	Fair	Yes	Fairly High	Historical data	Fair
ANNs	High	No	High	Historical data	High
SVMs	Fairly high	No	Low	Historical data	Fairly high
BIM	High	No	Low	Detailed	High

In this research, three different approaches were utilised in analysing the building energy performances of Wisma R&D, and later, the recommendations for retrofitting the building towards energy-efficient are outlined. They are the LF performance through the TNB billing data, walk-through EA, and simulation-based analysis using ArchiCAD software. ArchiCAD is one of the available software that is used in BIM for overall building construction, energy performance analysis as well as facility management. Each of these approaches is discussed in detail in the next subsections.

2.10.1 Load Factor (LF) Measurement

The load factor (LF) is one of the measures that describe how much energy is utilised in a building (Association, 2018). Through LF value, it portrayed the consumption characteristic of electricity in buildings. The LF value is measured between zero (0) to one (1). It is a ratio of the average load (AL) and the peak load (PL) of the buildings. According to (Steiner, 2017) and (Association, 2018). The load factor is the ratio of average electricity use versus maximum electrical demand (also known as PL) for a given period. The closer the LF to 1, the better the consumption characteristic where the sudden PL is controlled effectively within the period measured. Oppositely, the lower the LF, the higher the electricity charges the building owner must pay. The most desirable load profile for most facilities is as close to a flat line as possible, with the least amount of PL (Power, 2018). Equation 2.1 shows the LF calculation.

$$LF = AL \div PL \quad LF = AL \div PL \qquad (2.1)$$

In particular, a facility with an LF of 0.6 or higher is considered to be reasonably efficient in its energy distribution, but facilities with an LF of less than 0.6 can analyse the opportunities for load shifting and peak shaving alternatives (Steiner, 2017). As higher LF indicates that the energy usage in the building is more evenly distributed, which indicates a good load balancing, hence it is one of the approaches selected in this research to improve the building energy performance through effective retrofitting. The existing LF of Wisma R&D is calculated using the four conservative years (2015 – 2018) of electricity data from TNB utility bills obtained from the Department of Development and Estate Maintenance (JPPHB) Universiti Malaya.

2.10.2 Energy Audit (EA)

An EA is a process to detect operating problems, improve occupants' comfort, and optimize the energy use of existing buildings. In addition, it identifies opportunities for energy conservation (Alajmi, 2012). From the standpoint of a building operational process, the EA process is one of the most important procedures to consider while conserving energy.

There are three (3) levels of EA. According to ASHRAE 100-2006 standard, the levels include the following: Level 1, “walk-through assessment”, level 2, “energy survey and analysis “, and level 3, “detailed analysis of capital intensive modifications”(Alajmi, 2012). (M Krarti, 2016) affirmed that a building EA can range from a quick walk-through to a detailed examination with hourly computer simulation. In summary, EA's decision is based on the amount of time, budget, construction complexity, and customer requirements (Alajmi, 2012). Even though the standards did not provide any detailed guidelines on how EA should be conducted, it somehow has to be able to produce a list of energy conservation opportunities (ECOs) for the respective parties to determine the significant actions which can improve the energy-efficient level of the building stock. This has been proved through several studies. (Singh, Singh, & Singh, 2012) conducted an EA and discovered that plant efficiency improves and energy waste decreases. Different findings, (Alajmi, 2012) prove that EAs and ongoing commissioning may improve operational efficiency and close the gap between expected and actual building performance in a variety of ways. Frequent EA and ongoing commissioning can improve operational efficiency and close the gap between expected and actual building performance (Gerrish et al., 2017).

As the first objective of this research is to identify and analyse the non-design factors that contribute to the building's electrical energy consumption, hence the total power consumption at each level of the building needs to be analysed. Through EA, the appliances installed and their power rating, hours of operation, type of rooms available, and the air conditioning and lift systems operating trends could be identified. The result from the walk-through EA is analysed and later compared with the average energy consumption of the whole building recorded in the TNB utility bills from January 2015 until December 2018 (4 conservative years). The idea behind this exercise is to identify potential appliance/area/level in the building that is suitable for short and long-term energy conservation initiatives. As this research aims to identify and evaluate any potential ECOs in Wisma R&D, a walk-through EA was conducted on the entire building zones. The type of room/area, appliances, and quantity were counted manually during the audit. Upon the analysis, practical and affordable ECOs or potential retrofitting initiatives are outlined.

2.10.3 Simulation-based Analysis

Understanding the current state of energy consumption is the first step toward reducing the amount of energy used in buildings (Al Qadi, Sodagar, & Elnokaly, 2018). However, a suitable implementation procedure, as well as post-retrofit measurement and verification, are deemed necessary to ensure a high success rate of the retrofitting project plan (Walter & Sohn, 2016). Hence, with the advancement of technology, a variety of energy modelling tools and approach methodologies can be used to validate the most effective retrofit strategy.

In terms of the importance of picking the appropriate building parameters throughout the retrofit process, there is currently enough energy simulation software accessible to assist in making that decision. The simulations vary in complexity, from simple static computations to complex dynamic simulations (Schlueter & Geyer, 2018). EnergyPlus, Ecotect, RhinoBIM, Design Builder, DEST, Revit, ArchiCAD, and Integrated Environmental Solution are only a few examples of well-known software used in building modeling and evaluating building energy use. These softwares are commonly used to determine the energy demand profile, analyse energy usage, calculate GHGs emissions, and do many other tasks related to a building.

From the standpoint of retrofitting, as the goals have gone beyond energy savings and GHGs emission reduction, the element of cost is one of the important features that is been looked up in the software selection. The main reason is to identify the most cost-effective techniques for retrofitting the existing buildings as it will aid in the prioritisation of interventions and the success of cost-cutting measures (Alves et al., 2018). In addition, a well-planned retrofit project can lessen the unpredictability in the relationship between the amount invested and the predicted energy savings (Walter & Sohn, 2016). Hence, by choosing the correct and appropriate software, the simulation-based analysis can be optimally carried out.

BIM is a relatively new process and the most effective way of managing construction work. Prior to the introduction of BIM, the construction industry operated in silos, with each project team member looking out primarily for his or her interests, and the project taking a backseat to other considerations (Hardin & McCool, 2015). Further compounding the isolation issue was the prevalence of the hard bid delivery method, which contractually and financially isolated team members from one another (Hardin & McCool, 2015). There was a lot of waste and expense overruns as a result of this culture and aloof delivery technique. As a result, the construction consumers have to bear for the mistake made during the process. Hence, BIM is seen as one of the latest recovery and solutions to all these problems.

Among the well-known BIM software used in Malaysian construction nowadays is Revit (A Ahmad Latiffi, Mohd, Kasim, & Fathi, 2013; Khoshdelnezamiha, Liew, Bong, & Ong, 2019). ArchiCAD on the other hand is not well-known among the building relevant parties in Malaysia. In summary, the finding by (Abanda, Vidalakis, Oti, & Tah, 2015) found that there are at least 150 BIM software systems available around the world. In this research, the simulation-based analysis which is carried out mainly to analyse the passive design factors that contribute to the building energy performance in Wisma R&D is done using ArchiCAD. The details of the software features are explained in Chapter 3.

2.11 Building Information Modeling (BIM)

In the current construction industry scenario, different involved parties; such as architects, engineers, contractor, facility managers, and others are utilizing their preferred tools in designing, analysing, simulating, and optimizing their respective tasks on a building. In parallel, the construction industry continues to benefit from tremendous technological advancements in terms of development and innovation (Ali Ghaffarianhoseini et al., 2017). The emergence of the technology offers the solution and the opportunity to reinvent contemporary construction practice which consists of numerous drawbacks such as misalignment, tedious model preparation, model inconsistency, and costly implementation (Hardin & McCool, 2015; Ali Ghaffarianhoseini et al., 2017; Gao et al., 2019) which occurred throughout the building design, construction, and maintenance.

The phases from manual drawing to two-dimensional (2-D) drawing and later a virtual three-dimensional (3-D) are taking place within the industry. BIM within the context of Architecture, Engineering, and Construction (AEC) has been developing since the early 2000s and is considered to be a key technology (Ali Ghaffarianhoseini et al., 2017). Unfortunately, it has yet to be widely implemented, and its clear benefits have yet to be fully realised by industry players. (Abanda et al., 2015; Ali Ghaffarianhoseini et al., 2017; Mehdipoor, 2017). Previous studies had shown that software systems, which are the editor of BIM have generally been limited in scope focusing predominantly on operational issues (Abanda et al., 2015) but the urgency of inculcating BIM is beyond this need.

In definition, BIM is a broad word that encompasses a wide range of activities in object-oriented Computer-Aided Design (CAD), which allows for the depiction of architectural elements in terms of their 3D geometric and non-geometric qualities, as well as their relationships (Ali Ghaffarianhoseini et al., 2017). Typically, international standards often define it as a common digital representation of physical and functional features of any created thing that serves as a dependable foundation for decisions (Volk, Stengel, & Schultmann, 2014). As the construction management industry as a whole is headed towards a results-focused toolset that is connected, collaborative in nature, and mobile-ready, construction firms around the world continue to realize the benefits of BIM as well as the ancillary features of better methods of sharing and coordination information (Hardin & McCool, 2015). Beyond the outline benefits, BIM permits the opportunity to analyse the building energy performances during the design or retrofitting process. In general, BIM offers lots of excitement and opportunities to improve the construction industry throughout the building lifecycle.

In the Malaysian construction industry, BIM has been introduced by the Director of the Public Works Department (PWD) in 2007 to reduce construction costs and avoid design problems. Since then, other projects, like the National Cancer Institute, have been built or are being built utilising BIM (Aryani Ahmad Latiffi, Mohd, & Brahim, 2015). Even though Malaysia introduced BIM back in 2007, the utilisation of BIM using the Revit software through two pilot projects started only in the year 2012. The projects were the Clinic KK5 Sri Jaya Maran, Pahang, and Administration Complex of Suruhanjaya Pencegah Rasuah Malaysia (SPRM), Shah Alam Selangor (A Ahmad Latiffi et al., 2013). Then, National Cancer Institute was built and is the pioneer building in Malaysia that was built through the BIM process. It has an interesting architectural interior design and landscaping to create an ideal environment for healing and recuperation (Aryani Ahmad Latiffi et al., 2015). It is also designed to provide a comfortable and functional ambience for the user.

Various BIM software programs that deal with various forms of construction information have saturated the market during the last three decades (Abanda et al., 2015). The greater options of BIM software also known as BIM editor in the market have amazed the construction players to review their benefits. In recent years, many governments including the Malaysian government have been promoting the use of BIM as a means of facilitation, collaboration, and improving delivery efficiency and project quality (Abanda et al., 2015).

As mentioned earlier, there are tremendous benefits of BIM which encompass its technical superiority, interoperability capabilities, early building information capture, integrated procurement, improved cost control mechanisms, reduced conflict, established team coordination, and improved energy conservation of one building (Aryani Ahmad Latiffi et al., 2015; Ali Ghaffarianhoseini et al., 2017; Gao et al., 2019). In particular, regarding the energy conservation of a building, (Gao et al., 2019) claimed that building energy conservation could be identified through the coordination of BIM and Building Energy Modelling (BEM). Nowadays, due to technological emergence, these can be done at the same time as most of the software or BIM editors are embedded with the energy performance measurement function. To put it another way, BIM-based BEM technology has piqued the interest of both academic and industry communities (Gao et al., 2019) as it saves a lot of time in transferring CAD drawings and information into a building energy model. An estimate of 75% time-saving was affirmed (Gao et al., 2019).

2.11.1 Challenges in Building Information Modelling (BIM) Implementation

According to (Abanda et al., 2015), the plethora of software packages, software interoperability challenges, and high implementation costs are among the causes of the unpopularity of BIM implementation among construction professionals. Ultimately, surveys conducted by National Building Specification have revealed that lack of knowledge on this available BIM software is one of the major barriers to their adoption among the construction players, especially the small and medium-sized enterprises (SMEs) (Aryani Ahmad Latiffi et al., 2015; Arif, Hasmori, Deraman, Yasin, & Yassin, 2021). (Mehdipoor, 2017) supported this. To overcome these problems, BIM benefits need to be well-versed across all parties in addition to the affordability (cost of the software), interoperability format, and clear application impact as well as user-friendliness. However, some of the BIM software or known as BIM editors are complicated, not cost-efficient, and required lots of information about a building (Abanda et al., 2015), hence suitable software needs to be properly selected to ensure the benefits could be optimised throughout the project.

On top of the knowledge barriers, low level of awareness, cost, and software complexity, the study of building energy performances through BIM usually ended up with an error (Jung et al., 2018) due to a lack of modeling detail. This applied mainly to the model of the existing building where BIM is utilised for retrofitting initiatives. Most dynamic simulation studies simply account for a few selected zones to simplify, reduce simulation run-time, and reduce the complexity of the model to be simulated (Jung et al., 2018) and this has neglected the opportunity to specify the exact zones within the building that contributed to the whole building energy consumption. In addition, according to

(Simson, Kurnitski, & Kuusk, 2017), as simplified approaches are unable to discern changes in power needs properly, the average inaccuracy increases as the level of modeling information decreases. Due to this, it is highly recommended that the virtual building model is representing the whole building instead of a few zones or floors. This will assist in more accurate simulation results that could improve the data flow on the demand side and assist in finding the most practical and effective retrofitting initiative. Hence, this research is carried out based on the full-scale virtual building model of Wisma R&D. The outcome from the initial simulation which is based on the existing building design is compared with the total electricity consumption from the TNB's utility bills. This outcome is used as the main reference in the research and remarked as A_0. A detailed explanation is discussed in Chapter 3.

2.11.2 Type of BIM Software

There is numerous software available in the market which allow the implementation of BIM. According to (Abanda et al., 2015), there are at least 150 BIM software systems available around the world. Due to this, it is prudent to select and use the most practical BIM software that benefits all parties involved. In parallel with the current requirement, building design and development is beyond the construction task. It includes the capability of the software to analyse the building performance, especially energy consumption. As mentioned earlier in Chapter 2, section 2.10.3, some of the BIM software are Ecotect, RhinoBIM, Design Builder, DEST, Revit, ArchiCAD, and IES. This software allows the correlation of BIM-based BEM analysis for both new and existing buildings which are very essential for the development and sustainable building. Yet, Revit and ArchiCAD are among the popular software in the USA and Europe (Breakwithanarchitect, 2021).

2.11.2.1 ArchiCAD

As aforesaid, among the BIM software that is available in the market, is ArchiCAD. ArchiCAD's comprehensive set of built-in capabilities and easy-to-use interface make it the most efficient and intuitive BIM software on the market for designing, visualising, documenting, and delivering projects of all sizes (Graphisoft, 2021). In addition, ArchiCAD boosts productivity while also providing a better-coordinated design and a computer model based on the construction process which is not available in the AutoCAD software. Revit on the other hand is Autodesk's BIM software which is designed to fulfill the aforementioned issue within the construction industry and ArchiCAD is developed for the same purposes. However, ArchiCAD is less popular among Malaysian building professionals and researchers if compared to Revit even though the software was first introduced by Graphisoft in 1982.

In this research, ArchiCAD has been selected and explored as the tool for conducting the simulation-based analysis of the energy performances of the Wisma R&D building. The main reason for selecting ArchiCAD is due to its simpleness in the modelling process and smaller file size compared to Revit software. In addition, due to its unpopularity in the Malaysian construction industry, the author decided to explore its capability in assisting the retrofitting initiative of the existing building.

As the main focus of this research is to analyse various building parameters that impacted the building energy performances, the passive design parameters of a building could only be analysed through simulation-based approaches. Hence, the outcome of this research has contributed to knowledge awareness; through publications and conferences. The passive design parameters are inserted as part of the modeling process based on the information obtained from the technical drawing layout, observation during the walk-through energy survey, and assistance from the building technical team.

The similarities and differences between ArchiCAD and Revit software are summarized in Table 2.3 (Breakwithanarchitect, 2021; Graphisoft, 2021).

Table 2.3: Comparison of ArchiCAD and Revit

Features	ArchiCAD	Revit	Similarity/Different
Required digital modelling	YES	YES	Similarity
Link to BEM	YES	YES	Similarity
Popularity in Malaysia	Unpopular	Very popular	Different
Level of complexity in design geometry	Medium	High	Different
Owner of software	Graphisoft	Autodesk	Different
Learning complexity	Functional and user friendly	Complex and time-consuming	Different
3D view	Axonometric and perspective views	Axonometric views only	Different
File size for complex design	Smaller in size compare to Revit	Larger size	Different
Resources and technical assistance	Less	High	Different
Cost of license software	High	Lesser than ArchiCAD	Different

2.12 Research Gap

Despite numerous research focusing on building energy performances which were carried out through energy audits (EA), there is a paucity of research that emphasizes the importance of the load factor (LF) performance analysis before the EA. This knowledge gap restricts our understanding of how LF performance analysis might improve the overall building energy performance study. As a result, the outcome of this research demonstrated the significance of LF performance analysis as an indicator that a building needed immediate EA and retrofitting actions.

In addition, when new technologies emerge, there has been little research on the applications and benefits of emerging BIM-BEM tools/software accessible in the market other than Revit. With the expanding need of exploring the best and most user-friendly tool for virtual building models among professionals, there is a need for more research on the advantages and disadvantages of each tool/software. This methodological gap has limited the building professional to explore the potential of other tools/software available in the market. Hence, the outcome of this research aims to show the significance of utilizing ArchiCAD as one of the BIM-BEM tools mainly in analysing the effect of passive design factors on overall building energy performances, including the economic (energy cost) and environmental impact (CO_2).

Despite substantial research on the impact of lift operation on building energy consumption, especially in a high-rise building, there may be a lack of recommendations on how savings could be obtained from efficient lift operation. Most of the time, lifts are categories as 'others', and specific retrofitting recommendations were not specified. As mentioned earlier, lift generally contributed about 7% to 10% of the total building energy consumption. Therefore, the outcome of this research has significantly proven the contribution of lift operation towards the total energy consumption for high-rise buildings and it should be part of the non-design factor that has to be paid attention during the EA.

Finally, due to the complexity of the modelling process, there may be limited research carried out on high-rise buildings. As modelling is a time-consuming process, much research was focusing on modelling a virtual building that is less than five floors. This research provide an interesting outcome when a 25-floor building was modeled and simulated.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The main focus of this research is to analyse the contributing factor of several non-design and passive design factors of a building that had been discussed in the prior chapter. In other words, this research focuses on identifying the impact of different building parameters on building energy consumption, cost, and carbon emission. A reference building was selected for this purpose. The non-design factors such as the appliances, air-conditioning load, and lighting type were identified through the walk-through EA process. However, the passive design factors like window's glazing, opaque, and shading material could not be analysed through the EA approaches. A virtual building was first modeled using ArchiCAD software to analyse the impact of the passive design of the reference building. To support the research obligation, the LF Performance analysis is added as part of the approaches. This is to ensure that the building selection is assuredly needed to be retrofitted.

Based on the intercorrelation between various building parameters on the building energy consumption, this research later concluded the overall effect and relationship of several building parameters towards its building energy consumption, which later impacted the cost and the carbon emission. This has later assisted in establishing a retrofit plan for the reference building. In parallel, the findings could assist building professionals and building owners, mainly in Malaysia, in designing and retrofitting related and similar buildings in the future.

3.2 Methods of Research

Generally, this research incorporates three different types of research methods. These include *descriptive research*, *experimental research,* and *correlational research*. The *descriptive research* focuses on data collection, hence a walk-through EA was carried out. During the audit, the type and quantity of the appliances installed and the operating time are noted. In addition, the type of room and the cooling load information was observed and recorded for each level of the building. Besides thorough observation, several interviewing sessions with the occupants, mainly the administrative office and maintenance personnel were taken place.

Even though the type of room information did not directly influence the outcome of the walk-through EA, it is required for the thermal block identification during the modeling process which was required in the simulation-based approach. *Experimental research* was carried out to investigate the cause-and-effect relationship of several building parameters towards energy consumption, electricity cost, and carbon emission. The final part of the research involved the *correlational-based* approach to determine to what percentage the combination of two or more building parameters could affect the building energy consumption, cost, and carbon emission of one building. Ultimately, as highlighted in the objectives, one of the aims of this research is to propose a practical retrofitting plan for a high-rise building in Malaysia. This was based on the outcome obtained from the combination of three main approaches; i.e. LF performance analysis, walk-through EA, and simulation-based approaches which were carried out in this research.

3.3 Selection of the Reference Building

Figure 3.1 shows the Wisma R&D, University of Malaya building. It is situated in Jalan Pantai Baharu, Kuala Lumpur, and has been under the Deputy Vice-Chancellor (Research & Innovation) administration since 2010. Originally this building was owned by Telekom Malaysia and was built around thirty years ago. Located at 3°7'0.69"N, 101°40'0.98"E in the province of Wilayah Persekutuan Kuala Lumpur, Wisma R&D consists of 25 operating levels which include Lower Ground (LG), Ground (G), Mezzanine (M), and a small compound within the gated area. The three lowest levels which are labeled as Lower Ground (LG,) Ground (G), and Mezzanine (M) are allocated mainly for the vehicle parking area. However, there are several laboratories located at these levels. For instance, a Smart Transportation System laboratory is situated in LG and several medical laboratories are in M. On top of that, other rooms like the security room, control room, and the Wisma R&D management office are situated on level G.

Other facilities include various types of laboratories, lecture rooms, research rooms, conference rooms, a gymnasium, a restaurant, and a store for both staff and students. Based on its landscape, design, and functionality; it is best described as a general office building. From the building environment perspective, Wisma R&D is surrounded by various high-rise buildings such as the Telekom Malaysia Tower, a hotel, and a Light Rail Transit (LRT) station.

In terms of the gross floor area (GFA), Levels 1, 2, and 3 in Wisma R&D are having a similar GFA which is approximately 4100 meters square (m^2). The remaining levels from level 4 up to level 22 are found to be approximately 1100 m^2 each. A sample of the layout for some of the floors which was obtained from the management office is attached in Appendix B. On average, this building is occupied by 400 to 500 people (irregular occupancy) mainly during the office operating hour which is from 8 am to 5 pm. Wisma

R&D is operating from Monday to Friday which is 5 days a week which is estimated at around 22 days per month.

The said building is constructed of a reinforced concrete framework with plastered brick infill walls rendered externally and plastered internally. Part of the building walls is of glass panels. Furthermore, Wisma R&D has a flat concrete roof. All these pieces of information are obtained from the architectural and Mechanical and Electrical (M & E) drawings of Wisma R&D that were received from the building management and JPPHB of Universiti of Malaya.

Figure 3.1: Wisma R&D Universiti Malaya

The above-mentioned pieces of information were used throughout the research. In particular, information like the type of appliances/equipment, their power rating, and operating hours were used for the walk-through EA, whereas the LF performance analysis was carried out from the building's utility billing. On the other hand, the building material information, for instance, the building location, material, and internal temperature are indeed very crucial for the simulation-based analysis. Some of the information was obtained through observation and interview sessions with the respective personnel. The details are thoroughly explained in the following sections of this chapter.

3.4 The Organisation of the Research

The detailed step-wise methodology of this research is depicted in a comprehensive flow chart. Figure 3.2 illustrates the process flow of the research. Part of the initial steps taken in this research includes performing a detailed literature review and requesting and collecting building drawings and electricity bills from Wisma R&D's management and JPPHB, Universiti of Malaya. These processes took almost a year due to several challenges, mainly on the building drawings. Official authorization from the respective parties is necessary in obtaining the required documents. Furthermore, as Wisma R&D is an old building, some of the drawings were not available and unclear. Hence, a few walk-through observations and interviews with the respective personnel were conducted before the required data are made available for further analysis. The three main approaches that were carried out in this research are thoroughly explained in the following sections.

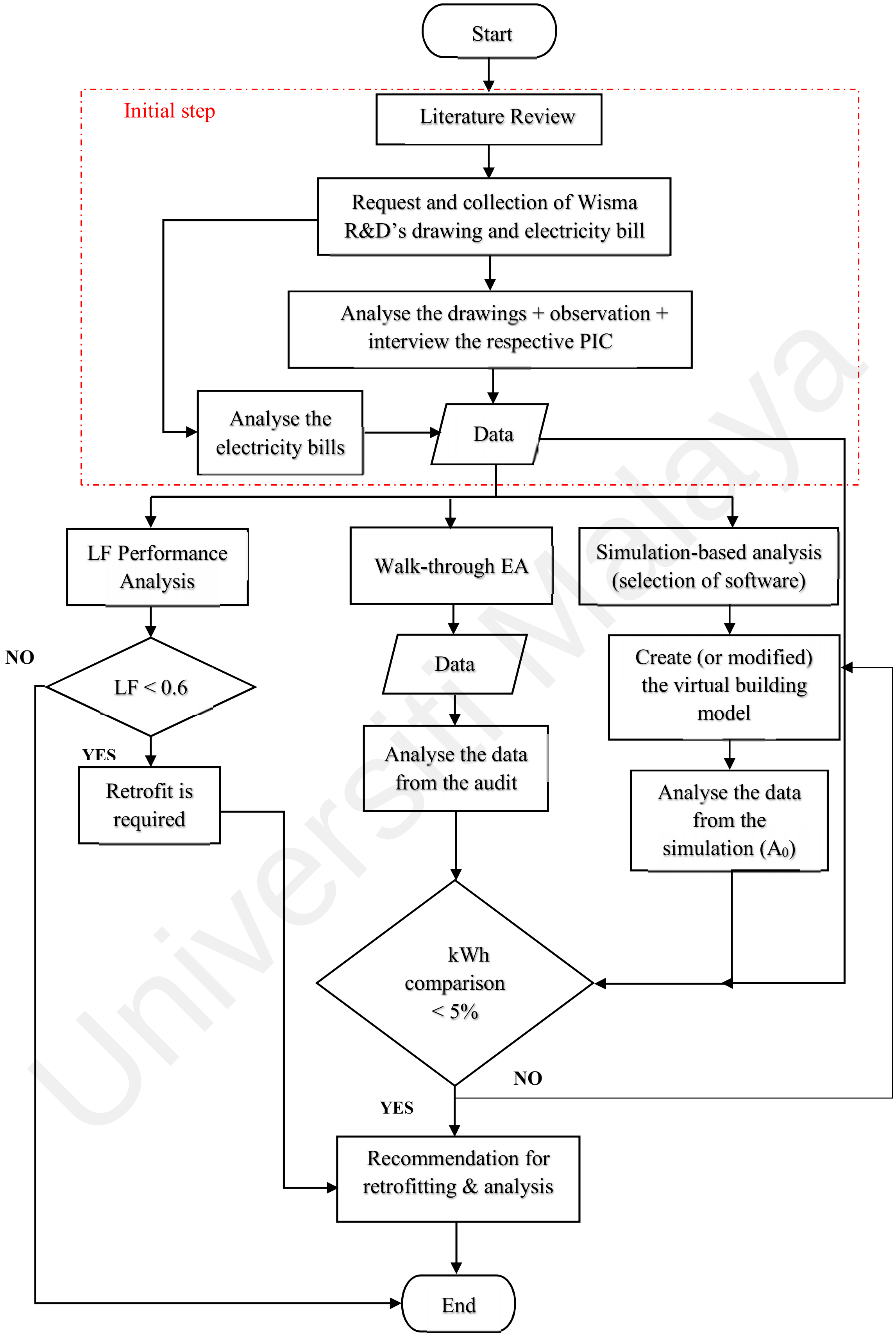

Figure 3.2: Flow chart of the research

3.5 Research Process Description

As outlined in Figure 3.2, the initial step of the research is to request the building's layout plan, electricity bills, conduct several building observations, and interview respective personnel, especially in the Wisma's management office. This is essentially needed before performing the next phases where three different approaches are carried out to analyse the building's electricity performances.

Figure 3.3 and Figure 3.4 are two examples of the building's layout plan that were referred to throughout this research, particularly for the preparation of the EA and modeling process. The size and type of room on each floor were observed. This information is essential in the preparation of the EA form and later for the modeling process too.

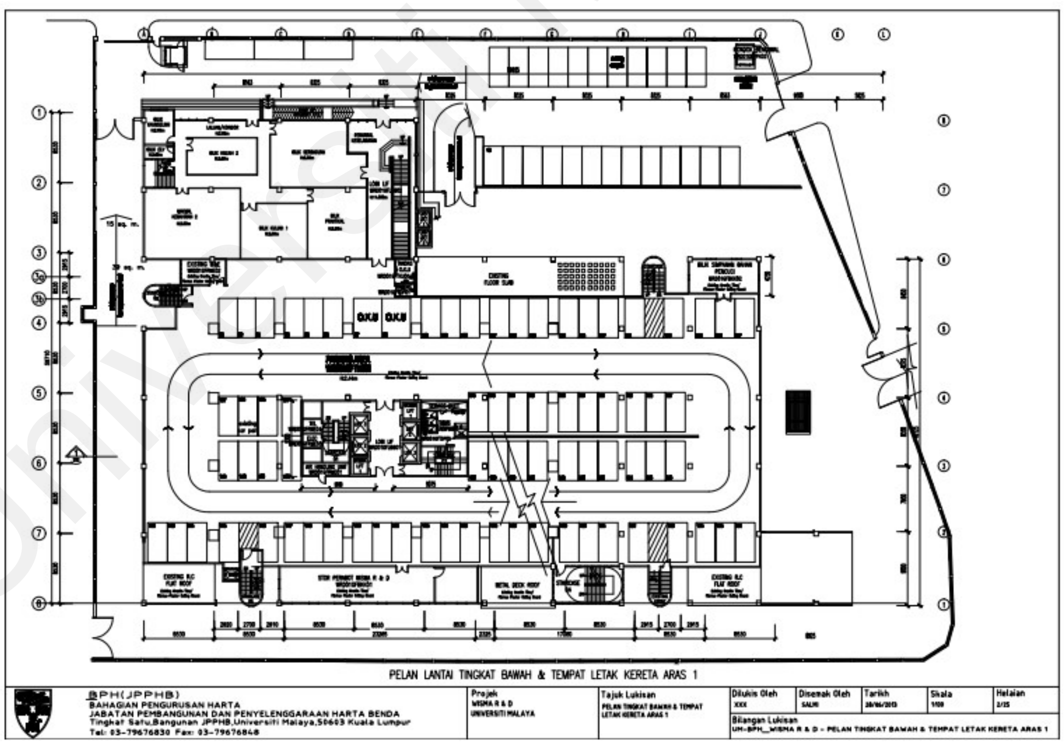

Figure 3.3: The layout plan of the M and LG of Wisma R&D

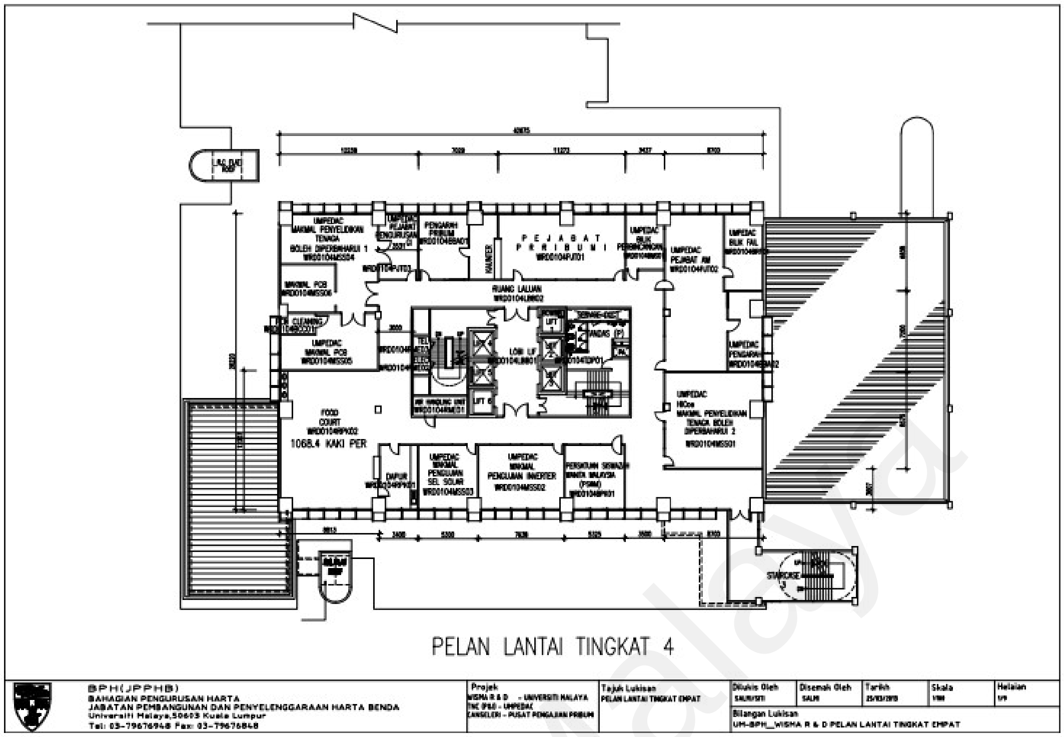

Figure 3.4: The layout plan of Level 4 of Wisma R&D

On top of the layout plan, the initial step of this research was to collect the building's electricity bills. Due to this, the request for the bills was forwarded to JPPHB, University of Malaya. A total of four conservative years of electricity bills were obtained and used in this research. The snapshot of one of the electricity bills is shown in Figure 3.5. The data extracted from the electricity bills were tabulated in a single table and used as the main reference throughout the research.

ANGGARAN HARGA: RM85,631.04

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WP KUALA LUMPUR

SALINAN

Jumlah Perlu Dibayar RM 592,269.46

Tarikh Bil: 10.02.2017

Bil LPC

		Amaun	Bayar Sebelum		
Tunggakan	RM	501,809.66	Segera		
Caj Semasa	RM	90,459.82	12.03.2017		
Penggenapan	RM	0.02-			
Jumlah Bil	RM	592,269.46			
Bil Terdahulu (01.01.2017)	RM	495,264.47	Bayaran Akhir (14.09.2016)	RM	228,383.19

Jenis Bacaan : Bacaan Sebenar
Tempoh Bil : 01.01.2017 – 31.01.2017 (31 Hari)
Tarif : C1:Perdagangan

Blok Tarif (kWh/kW)	Kegunaan (kWh/kW)	Kadar(RM)	Amaun(RM)
Kegunaan	173,510.00	0.3650	63,331.15
Kehendak Maksima	653.00	30.3000	19,785.90
Jumlah			83,117.05

Figure 3.5: A snapshot of the electricity bill obtained from JPPHB

Despite the building layout plan being obtained from the management office, some of the building information like the material of the wall and floor were not included. Hence, detailed observation was carried out. In addition, the process of collecting building information was done through several interview sessions with the management office's personnel. Numerous interviews and met-up were accomplished throughout the research duration. Next, the three approaches were carried out, starting with the LF performance analysis of Wisma R&D. It was based on the four conservative years of the building electricity bills. As mentioned earlier the data analysed from the electricity bills are used as a reference during the energy (kWh) comparison process. It is important to ensure that the other two approaches are capable of proposing practical retrofitting initiatives. The energy consumption (kWh) resulting from the EA and simulation-based approach was later compared with the LF performance analysis. The acceptable difference is set at less than 5% (in kWh value of each approach). If the comparison of the energy consumption from these three approaches is less than 5%, in-depth analyses are carried out based on the initiatives recommended. This requires several additional calculations and simulations. Particularly for the simulation-based approach, the virtual building model was simulated based on the recommended retrofitting parameters selected. This process includes changing several parameters repeatedly throughout the research. The result and discussion of each retrofitting recommendation are explained in the next chapter.

The step-by-step process of each approach is discussed in the next sub-sections.

3.6 First Approach: Load Factor (LF) Performance Analysis

Upon completing the initial step, the data obtained were used to analyse the existing building energy performances. As mentioned in sub-section 2.8.3, the LF performance analysis is capable of helping the building owner to gain a better understanding of the building's energy performance. Moreover, by first analysing the LF performance of a building, the building owners could have a clearer understanding of whether their building is in desire for retrofitting initiatives. By gaining a better understanding of a premise's load profile, a load factor improvement program could be identified, which will improve the premise's load balancing while also lowering its electricity bill (Ali, Hasanuzzaman, & Rahim, 2018). Despite the above reasons, LF performance analysis could portray how consistent the building electricity demand is across time. Due to these benefits, it is recommended that the LF performance analysis is been carried out.

Moreover, the performance of a building is measured in a variety of ways, one of which is by looking at the energy cost. In other words, a large utility bill can indicate one of two things: either the building's operation profile produced excessive electricity consumption, or the building's PL is much greater, resulting in a lower LF value. This is supported by (Power, 2018), who indicated that a building that had a high PL will suffer from expensive electricity billing. From Malaysia's perspective, the charge for one kW of PL is 80% greater than the average kWh spent. Figure 3.6 shows the details of the category and PL charges for different commercial tariffs in Peninsular Malaysia. It is indicated that Tariffs

C1 and C2 will cause the building owner an amount of RM30.3/kW and RM45.1/kW respectively for the recorded peak load. Due to this, it is important to measure and control the PL throughout the building operation.

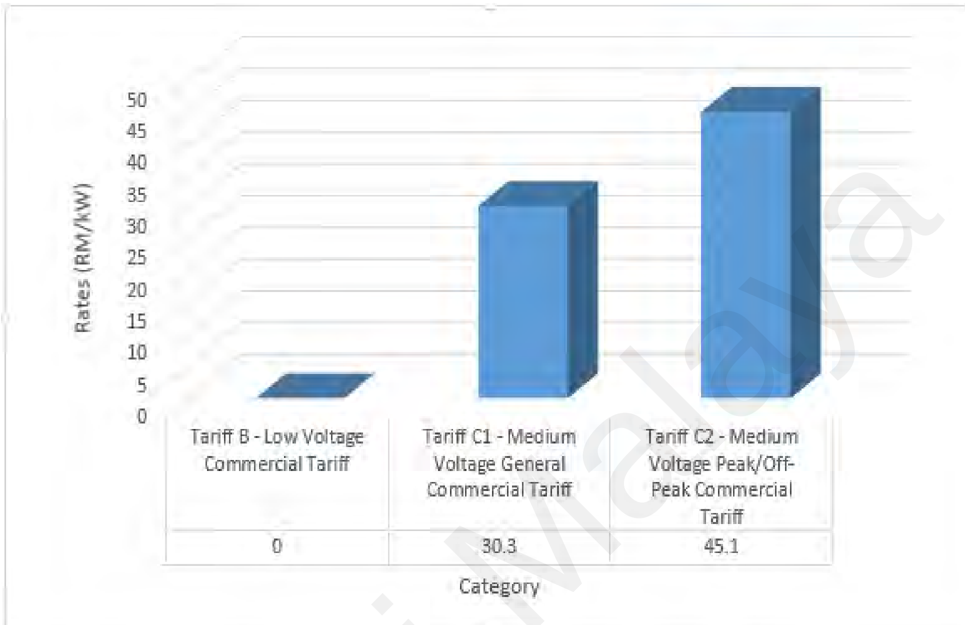


Figure 3.6: Tariff category and PL charges for commercial buildings in Peninsular Malaysia

(TNB, 2014)

On the other aspect, the load factor is a measurement of how consistent the building electricity demand is across time (Ali et al., 2018). It is determined as a percentage by dividing the average load by the peak load or labeled as *Kehendak Maksima*/Maximum Demand (MD) in the TNB. The mathematical equation is presented in Equation 3.1.

$$\boldsymbol{LF = AL \div MD} \qquad (3.1)$$

Where LF is the load factor; AL is the average load calculated and MD is the maximum demand obtained from the monthly electricity bill. Earlier, the average load (AL) is calculated based on Equation 3.2.

$$\boldsymbol{ALn = Qn \div (DAYn \times 24)} \qquad (3.2)$$

where AL_n is the monthly average load in kW, Q_n is the monthly energy consumption in kWh and DAY_n is the total number of days in the specific month.

As this research is examining the LF performance characteristics of the Wisma R&D building for four conservative years, hence the electricity bills from January 2015 until December 2018 were referred to and analysed thoroughly. The analysis was carried out through the mathematical equations which are labeled Equation 3.1 and Equation 3.2. Next, the monthly load factor value of Wisma R&D was analysed. The result of the LF was compared to the threshold value of best practices in a commercial building which is 0.6. The LF value which is lower than 0.6 indicates that the building required special attention for building operation management. Where else, an LF which is larger than 0.6 required less attention for retrofitting or enhancement of the building operation. In this research, the outcome from the LF performance analysis is used to support the requirement of whether the Wisma R&D building requires speedy retrofits or vice versa. Additionally, by gaining a better understanding of a premise's load profile, a load factor improvement program could be implemented, which will improve the premise's load balancing while also lowering its power bill.

3.7 Second Approach: Walk-through EA

The walk-through EA was carried out between March and May 2017. Prior to the audit, several EA forms were designed for this purpose. One of the examples is shown in Figure 3.7 and the remaining forms are attached in Appendix A. The whole building area of Wisma R&D was audited. Each floor was particularly audited which remarked various appliances/equipment used, quantity, operating hours, and their power rating. Based on the survey data, the appliances/equipment had been divided into eight categories which are air-conditioning, lighting, personal computer (PC)/laptop, server rack, kitchen appliances, printer/photocopy machine (printing devices), lift, and *others*. The details of the appliance/equipment and the mathematical calculation are explained in the following sub-sections.

SURVEY ON ELECTRICITY CONSUMPTION AT WISMA R&D, UM

ROOM CATEGORY: STAFF ROOM or OFFICE
LEVEL/ARAS:
ROOM/OFFICE NAME:

Please read the following instructions before filling up this form

1. The manufacturer/brand can be found on the label place at your appliance/equipment
2. If the power rating is available, please skip the information on the voltage and current
3. If the operating hours are based on daily and consistently applied for everyday, please skip the weekly operating hours

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts/HP)	Voltage	Current	Daily	Weekly
1	PC/Laptop							
2	Lighting							
3	Airconditioner							
4	Printer							
5	Water Filter							
6	Telephone							
7	Exit Sign							
8	Photocopy Machine							
9	Scanner							

4. On top the above appliances/equipments, kindly fill in all the other appliances/equipments that you have in your office

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts/ HP)	Voltage	Current	Daily	Weekly
1	Kettle							
2	Radio							

Figure 3.7: One of the audit forms used in this research

Next, the data obtained from the audit process were analysed. One of the most important information required during the EA process is the power rating of each appliance/equipment used in the building. Hence, throughout the audit process, the power rating of each appliance/equipment identified was noted from either the manufacturer's label on the product, the multiplication of voltage and current information available on the unit, or the information obtained from the website.

Four different mathematical equations are used in analyzing the energy consumption of the entire appliances/equipment available in Wisma R&D. The general mathematical calculation for the electrical power rating of the appliances/equipment in Wisma R&D is shown in Equation 3.3. Particularly, this basic equation was used to calculate the power rating of five (5) major categories of appliances/equipment groups which include lighting, PC/laptop, kitchen appliances, server rack, and *others*. *Others* category comprises various appliances/equipment which include light-duty appliances or rare-type laboratory equipment. This equation was used if the power rating information is not found on the appliances/equipment during the audit process. If the power rating information is obtained during the audit process and/or on the product specification label, hence, power rate is based on the exact information. The energy consumption from the remaining three (3) major categories of appliances/equipment such as air-conditioning, lift, and printing devices were measured variously and are explained in the following subsections.

$$P = VI \cos \emptyset \qquad (3.3)$$

Where P is the real power (W), V is the voltage (V), I is current (A), and cos $\emptyset$ is 0.85 (power factor in Malaysia).

The daily energy consumption (Ed) for each appliance and equipment identified during the EA is calculated using Equation 3.4.

$$Ed = N \, x \, P \, x \, t \qquad (3.4)$$

Where Ed is daily energy consumption (kWh), N is the quantity of the specific appliance/equipment, P is the power rating/calculated power of the appliance/equipment (Watts), and t is the daily operating hours used by the appliance/equipment (hours).

Later, the monthly energy consumption (Em) for each appliance/equipment is calculated using Equation 3.5.

$$Em = Ed \times d \qquad (3.5)$$

Where Em is the monthly energy consumption (kWh), Ed is the daily energy consumption (kWh), and d is the number of operating days per month. In this research, the number of operating days per month (d) is fixed as 22 days, taking into consideration 5 days per week. Later, the yearly energy consumption is calculated by multiplying the monthly energy consumption (Em) by 12 months. The detail is shown in Equation 3.6.

$$Ey = Em\ x\ 12 \qquad (3.6)$$

The details of all the appliances/equipment which has contributed to the energy consumption in Wisma R&D are discussed specifically in the next subsections. The overall energy consumption is later presented and analysed in Chapter 4. The final results include all the non-design factors that were earlier explained in Chapter 2.

3.7.1 Air-conditioning (AC) system

In many cases, as AC is known to be the highest contributor to a building's electricity consumption, it, therefore, is rigorously discussed in this research. Through the walk-through EA and interviewing session with the management office personnel, it was summarised that Wisma R&D consists of 66 outdoor units of the Daikin VRV II inverter air-conditioning system which are connected to 414 indoor units within the building. From the audit, the model of the Daikin VRV Inverter was identified as R407C and R410A and they are installed at various locations within the building.

Throughout the audit process, it was observed that each floor was utilizing only one AC system, and the second system was rarely used and remained on standby. The AC system serves all the rooms, laboratories, pathways, lobby, and many others. The maintenance schedules of the air-conditioning system are carried out systematically by the management office.

Both Variable Refrigerant Flow (VRF) and VRV are similar but VRF is a more common term used in many air-conditioning companies instead of VRV, which was mainly introduced by the leading air-conditioning manufacturer, Daikin. As Wisma R&D is equipped with the Daikin outdoor unit, hence the term VRV was used. VRV offers superior flexibility and energy efficiency, in an easy-to-install package and is widely used in commercial buildings. VRV is a commercially available, modular air-conditioning and heating system that transports refrigerant rather than water from the outdoor unit to many indoor units, resulting in efficiency, individual user control, and reliability all in one package (Daikin, 2017). In addition, the name VRF/VRV refers to a system's capacity to adjust the quantity of refrigerant flowing to various evaporators (indoor units), allowing the use of a large number of evaporators with varying capacities and configurations connected to a single condensing unit (Patel & Jain, 2015). The indoor units, on the other hand, consist of both Daikin and Mitsubishi brands.

Based on the interview session, it was informed that the building's AC systems were renovated ten years ago. As the standard life cycle of any AC system is recommended to be upgraded between 15 to 20 years from the day of installation (Elsafty & Al-Daini, 2002; Partnership, 2015), hence any green initiative on upgrading and improving the existing AC system to a more efficient one should be carried out in five to ten years.

In terms of the operating hours, except for levels LG, G, M,3,10,15,18,21, and 22; the AC operating hours for most of the levels were about 9 hours (office operating hours from 8.30 am until 5.30 pm). This information was obtained from the technical personnel in Wisma R&D’s management office and through observation during the audit process. Hence, 9 hours of operating time are used in the entire calculation, simulation, and discussion throughout this research. For the aforementioned levels, the specific operation time is stated in the following chapter.

Through the audit, it was discovered that several floors in the building were supplied with a larger AC system than was required, as evidenced by the types of rooms and activities carried out on those floors. The details are discussed as part of the retrofitting initiative for Wisma R&D in the upcoming chapter.

For the AC system, as this building has different quantities and sizes of condensers on each floor, hence, proper identification of the condenser quantity and sizes installed for each floor was identified during the EA process. For AC's energy consumption, the load element was divided into three different types. They are specified as base load (BL), average load (AL), and peak load (PL) and the operating time was dissimilar to one another. From the analysis, the condenser size and load determination are outlined in Table 3.1.

Table 3.1: Condenser size and load determination for each level

LEVEL\TIME	BASE LOAD	AVERAGE LOAD	PEAK LOAD	CONDENSER UNIT A (HP)	CONDENSER UNIT B (HP)	CONDENSER UNIT C (HP)
Time	5am - 10 pm	10am - 3 pm	10 am - 12 pm	16	16	Nil
LG	17	5	2			
Time	7 am - 6 pm	10 am - 3 pm	10 am - 12 pm	16	16	Nil
G	11	5	2			
Time	7 am - 6 pm	10am - 3 pm	10 am - 12 pm	16	16	Nil
M	11	5	2			
Time	8 am - 5 pm	10 am - 3 pm	10 am - 12 pm	10	10	16
1	9	5	2			
Time	8 am - 5 pm	10am - 3 pm	10 am - 12 pm	10	12	16
2	9	5	2			
Time	8am -3pm	10 am - 3 pm	10 am - 12 pm	10	14	Nil
3	7	5	2			
Time	8 am - 5 pm	10 am - 3 pm	10 am - 12 pm	10	10	16
4	9	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	10	12	16
5	9	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	10	12	16
6	9	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	10	12	16
7	9	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	10	12	16
8	9	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	16	16	16
9	9	5	2			
Time	8 am - 10 pm	10 am - 3 pm	10 am - 12 pm	16	16	Nil
10	14	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	12	16	16
11	9	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	16	16	Nil
12	9	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	16	16	16
13	9	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	16	16	16
14	9	5	2			
Time	8 am - 10 pm	10 am - 3 pm	10 am - 12 pm	10	10	16
15	14	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	16	16	Nil
16	9	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	14	16	Nil
17	9	5	2			
Time	7am - 10 pm	10 am - 3 pm	10 am - 12 pm	10	12	16
18	13	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	10	12	16
19	9	5	2			
Time	8am -5pm	10 am - 3 pm	10 am - 12 pm	16	16	16
20	9	5	2			
Time	8am -3pm	10 am - 3 pm	10 am - 12 pm	16	16	16
21	7	5	2			
Time	8am - 10pm	10 am - 3 pm	10 am - 12 pm	10	10	Nil
22	14	5	2			

As mentioned earlier, the assumption of the base load, average load, and peak load was made based on the activities which were observed during the EA. In general, most of the levels are operated between 8 am and 5 pm (9 hours) except for certain floors like levels LG, G, M, 3, 10, 15, 18, 21, and 22. The differences in operating hours were due to various reasons which were mainly based on the activities conducted. The number of units and size of the air-conditioning system located on each floor were provided by Wisma R&D's technical personnel during the audit. For instance, two units of 16 Horse Power (HP) Daikin VRV units are installed to accommodate the need of the LG level. Thus, the base load is set to have 16 HP, when only one unit of the air-conditioning is turned on, whereas, during the peak load, both units are turned on. The average load, on the other hand, is the average of the peak and base load. In summary, the number of units, their capacity, operation hours, and the determination of the load estimation in Wisma R&D are shown in Table 3.2.

Table 3.2: Number of units, capacity, and operation hours of AC on each floor

LEVEL	No. of units	Base Load (HP) & Operating Hour (Hrs)		Average Load (HP) & Operating Hour (Hrs)		Peak Load (HP) & Operating Hour (Hrs)	
LG	2	16 HP	17 Hrs	16 HP	5 Hrs	32 HP	2 Hrs
G	2	16 HP	11 Hrs	16 HP	5 Hrs	32 HP	2 Hrs
M	2	16 HP	11 Hrs	16 HP	5 Hrs	32 HP	2 Hrs
1	3	10HP	9 Hrs	10 HP	5 Hrs	36 HP	2 hrs
2	3	10 HP	9 Hrs	11 HP	5 Hrs	38 HP	2 hrs
3	2	10 HP	7 Hrs	12 HP	5 Hrs	24 HP	2 hrs
4	3	10HP	9 Hrs	10 HP	5 Hrs	36 HP	2 hrs
5	3	10 HP	9 Hrs	11 HP	5 Hrs	38 HP	2 hrs
6	3	10 HP	9 Hrs	11 HP	5 Hrs	38 HP	2 hrs
7	3	10 HP	9 Hrs	11 HP	5 Hrs	38 HP	2 hrs
8	3	10 HP	9 Hrs	11 HP	5 Hrs	38 HP	2 hrs
9	3	16 HP	9 Hrs	16 HP	5 Hrs	48 HP	2 hrs
10	2	16 HP	14 Hrs	16 HP	5 Hrs	32 HP	2 Hrs
11	3	12 HP	9 Hrs	14 HP	5 Hrs	44 HP	2 hrs
12	2	16 HP	9 Hrs	16 HP	5 Hrs	32 HP	2 hrs
13	3	16 HP	9 Hrs	16 HP	5 Hrs	48 HP	2 hrs
14	3	16 HP	9 Hrs	16 HP	5 Hrs	48 HP	2 hrs
15	3	10HP	14 Hrs	10 HP	5 Hrs	36 HP	2 Hrs
16	2	16 HP	9 Hrs	16 HP	5 Hrs	32 HP	2 hrs
17	2	14 HP	9 Hrs	15 HP	5 Hrs	30 HP	2 hrs
18	3	10 HP	13 Hrs	11 HP	5 Hrs	38 HP	2 hrs
19	3	10 HP	9 Hrs	11 HP	5 Hrs	38 HP	2 hrs
20	3	16 HP	9 Hrs	16 HP	5 Hrs	48 HP	2 hrs
21	3	16 HP	7 Hrs	16 HP	5 Hrs	48 HP	2 hrs
22	2	10 HP	14 Hrs	10 HP	5 Hrs	20 HP	2 hrs

In producing decisive results of the energy consumed by the AC system, the loads are determined based on the following mathematical equation. This mathematical approach was used by (J.L.Seelke & Jr., 1982). Hence, the daily energy consumption ($E_{daircond}$) by the AC for each level is shown in Equation 3.7.

$$E_{daircond}\,(kWh) = (VRV_{BL}*746*t_1)/1000$$
$$+ (VRV_{AL}*746*t_2)/1000$$
$$+ (VRV_{PL} * 746*t_3)/1000 \quad (3.7)$$

Where VRV_{BL} is the size of the condenser rating run at baseload (horsepower), VRV_{AL} is the size of the condenser rating run at average load (horsepower) and VRV_{PL} is the size of the condenser rating run at peak load (horsepower), t_1 is the baseload operating time; t_2 is the average load operating time; t_3 is the peak load operating time of AC system. Later, the monthly energy consumption ($E_{maircond}$) of the AC in each level is calculated as Equation 3.8.

$$E_{maircond}\,(kWh) = E_{daircond}\,(kWh) \times 22\ days \qquad (3.8)$$

Then, the total monthly energy consumption by the whole AC system in Wisma R&D is calculated as Equation 3.9.

$$Etotal_{aircond} = \sum_{[LG,G,M,\ 1\text{-}22]} E_{maircond}\,(kWh) \qquad (3.9)$$

3.7.2 Lift System

From the walk-through EA, it is identified that Wisma R&D is equipped with six units of 1160 kg Fujitec elevators that are operating to accommodate the need of this building's daily operation. It can be estimated that the maximum pax that each lift could accommodate is up to 17 persons. In this research, the following Equations 3.10 until 3.13 were used to compute the lift system's power and energy.

$$P = V \times A \times \sqrt{3} \qquad (3.10)$$

where P is the power consumption of the lift (Watts), V is the voltage rating (Volts), and A is the current rating (Ampere). The normal trip time (TP) and basic lift energy consumption are estimated using the equations below, which were derived from the formula proposed by (Schroeder, 1988) and (Al-sharif, 1996). In most cases, the lift manufacturer provides the TP values for lift operation. However, as the TP values for buildings with more than 18 floors are not accessible, hence, the TP value in this research was derived using Equation 3.11.

$$TP = Rise(m)/Speed\ (\frac{m}{s}) \qquad (3.11)$$

where TP is the lift's trip time, which is computed by dividing the total height of the floors (meter) by the motor's speed (m/s), which can be found on the manufacturer's rating plate in the lift operation room of Wisma R&D. Next, the daily energy consumption ($E_{lift\ daily}$) is computed by using Equation 3.12 and 3.13.

$$Elift\ (kWh) = [P(watt) \times TP(s)]/3600 \qquad (3.12)$$

$$Elift(daily) = Elift\ (kWh) \times L \qquad (3.13)$$

Where L is the number of trips per day. For this research, the number of trips per day is assumed to be 400 based on the usage behaviour and activities within the building. The exact value of the Fujitec lift system installed in the R&D building, as well as the building construction information, were used to determine other parameters, including the motor's power rating, number of floors, motor speed, and floor height.

3.7.3 Printing devices

Printing devices' power consumption is as important as all other appliances in a building as it contributed to the total energy consumption. From the audit, it was found that most printing devices are not switched 'off' even though some of the devices are not regularly used in the offices (Shaleen, 2015a). Due to this, printing devices are included in the analysis even though the quantity of the devices and their power consumption is known to be low compared to other appliances/equipment in a building. According to (Shaleen, 2015b), managing the printing devices in the office could reduce energy bills and increase the profitability of your business. In addition, energy conservation that is obtained from printing devices is in line with green enterprises and is environmentally friendly. Hence, this research inculcated suitable techniques on how printing devices could be part of energy conservation in Wisma R&D.

In analysing the amount of power consumed by these printing devices, each printing was assumed to be at their different modes i.e.; 'on', 'standby', and 'sleep' modes. As there are a total of 177 units of printing devices which consist of three main brands. Mainly Hewlett Packet (HP), Canon, and Xerox, hence a reference of the device's power rating for "on", "standby", and "sleep" is assumed at 570 W, 8 W, and 8 W, respectively (Hewlett Packet, 2018). Off-mode power usage is not included because it is assumed that all printing devices have remained on all the time. The printing devices in Wisma R&D have a power rating range of 0.18 kW to 1.84 kW, according to the audit finding. Numerous models of printing devices were identified during the walk-through EA. In specific, 91.5% are printers, and the remaining 7.3% and 1.1% are inhere of photocopiers and fax machines respectively.

Other assumptions for the printing devices are detailed in Table 3.3.

Table 3.3: Assumptions for printing devices in Wisma R&D

Item (average)	Symbol	Specification
Speed per minute (ppm)	Xave	33 pages
Printed per day	Lave	20 pages
Print volume per hour (33 x 60 m)	Vave	1980 hours
Standby mode	$\%_{standby}$	75%
Sleep mode	$\%_{sleep}$	25%

Based on the data presented in Table 3.3, the total energy consumption for the printing devices in this building is calculated using Equation 3.14.

$$ETprint = Eon + Estandby + Esleep \qquad (3.14)$$

Where ET_{print}, E_{on}, $E_{standby}$, and E_{sleep} are the total calculated amount of printing devices' energy consumed in the building. Each mode's energy consumption is calculated using the equation outlined in Equation 3.15 until Equation 3.18.

$$Eon = Ton \times Pon \qquad (3.15)$$

where the printing hour is measured as T_{on} and P_{on} is the power assumed for the 'on' mode i.e. 570 W. Earlier, the printing hour labeled as T_{on} is calculated based on Equation 3.14. The value of printed per day (L_{ave}) and print volume per hour (V_{ave}) are taken from the assumption tabulated in Table 3.3

$$Ton = Lave \div Vave \qquad (3.16)$$

Subsequently, the energy consumption for the 'standby' and 'sleep' modes is as Equation 3.15 and Equation 3.16. The values of $\%_{standby}$ and $\%_{sleep}$ are taken from Table 3.3.

$$Estandby = 24hrs - [Ton \ \% \, standby] \times Pstandby \qquad (3.17)$$

$$Esleep = 24hrs - [Ton \ \% \, sleep] \times Psleep \qquad (3.18)$$

3.7.4 Lighting System

The audit process carried out in this research detailed the quantity, type, and rating of the lighting fixtures fixed in the entire Wisma R&D building and its surrounding area. Each room and the common area on each floor had been audited. In general, some common areas (which include the pathway, toilet, and lobby) and the surrounding area of Wisma R&D are installed with incandescent bulbs, and the majority of rooms and several common areas are fixed with fluorescent (CFL), rated 18 Watts (W) and 36 Watts (W) subsequently. In addition, there are places in this building that are fixed with a smaller wattage lighting fixture, for instance, 10 Watts. Figure 3.8 and Figure 3.9 show the type of fluorescent lamps installed in Wisma R & D.

Figure 3.8: Fluorescent lamps installed in Wisma R&D (18 Watt)

Figure 3.9: Fluorescent lamps installed in Wisma R&D (36 Watt)

In terms of mathematical calculation, the monthly energy consumption from the lighting system on each floor is calculated using Equations 3.4 and 3.5 as the power rating (P) of the lighting fixtures is easily identified during the audit process. Earlier, the daily energy consumption was computed, based on the data collected from the EA. As lighting is one of the appliances (non-design factors) that could be easily considered as part of retrofit initiatives, hence detailed analysis of the cost and energy-saving measures was conducted. Equation 3.19 shows the potential cost savings calculation by replacing the existing lighting fixture in Wisma R&D with the Light Emitting Diode (LED) type, which is known to be more energy-efficient compared to the existing fluorescent type.

$$EC = N \times P \times t \times Tariff \qquad (3.19)$$

Where EC is the energy cost (RM), N is the number of lighting fixtures, P is the power rating (Watts), t is the operating time (hours/day) and Tariff is the tariff charges set by TNB, based on RM 0.365/kWh for commercial building.

On the other hand, energy-saving is obtained by comparing the energy consumption of Wisma R&D before (fluorescent type) and after the LED type is replaced. The result is presented and discussed in the following chapter.

The environmental impact, pointedly to the CO_2 emission is later measured using Greentech's carbon calculator as shown in Figure 2.7. The result was directly based on the amount of energy-saving (kWh) gained from the retrofitting of the lighting fixture; from fluorescent to LED types.

3.7.5 Personal Computer (PC) and Laptop

One of the appliance categories found during the audit process is the PC and laptops. They were mostly found in the laboratories, lecturer rooms, classrooms, and cubicles across various levels in the Wisma R&D building. Hewlett Packard (HP) and Dell are two of the PC models used in Wisma R&D. Furthermore, the majority of the computers utilised are conventional 17-inch monitors with a central processing unit (CPU). Due to this, reference was made to the HP monitor model named *HP LE1901w LED*. Based on the data specification, the monitor's power consumption is less than 22.8W, whereas *HP*

Compaq 8000 elite CPU model is consuming approximately 240 W (Packet, 2017). An investigation by Griffith University found that the average desktop computer consumes between 80 and 250 watts of power (University). In parallel with the HP manufacturer's specification and the average PC power rating information obtained from the reference, one of the PC found in Wisma R&D has a label with a power rating of 130 W. As it is found to be in the power rating range of a standard desktop, hence all PC and laptop energy consumption analyses in this research were based on a 130 Watts rate. Next, the measurement of energy consumption is based on Equations 3.4, 3.5, and 3.6.

PC and laptops are normally turned to their 'standby' mode when they are found to be unused. However, due to their various functions, such as timing and sensing, the device continues to consume electricity (Pompermayer, Co, & Donadel, 2017). A study conducted in 2006, (Bray, 2006) stated that for the average computer, standby operation consumes around 1.5 to 3 Watts, and for monitors, 0.5 to 5 Watts. Based on this fact, switching them off when it is not used could assist in the energy saving of one building. In the walk-through EA, the total quantity of PC and laptops is counted for every floor of Wisma R&D. The monthly energy consumption was subsequently measured and analysed. The result is discussed in the upcoming chapter.

3.7.6 Server Rack

One of the equipment that runs 24 hours 7 days a week is the server rack. In Wisma R&D, each level is equipped with either one or two server racks except on LG, G, and M, levels 5,6,8, and 22. During the audit, it was observed that the server rack models are similar across all levels. The power rating of the equipment is 3120 W or 3.12 kW. It is labeled as R18-eRack model type. In the energy consumption analysis, the server rack's monthly consumption is measured using Equations 3.4 and 3.5. Figure 3.10 shows an example of the server rack available which is located on Level 18 of Wisma R&D.

Figure 3.10: One of the server racks available in Wisma R&D

3.7.7 Kitchen Appliances

The appliances which are categories under this category are mainly found in the office's pantries, cubicles, and laboratories. Examples include the water cooler, refrigerators (various sizes), microwaves, kettles, water coolers, and many others. The freezer is found in several medical laboratories mainly in Levels 1 and 2. They are used for storing the materials used by several courses which are conducted in Wisma R&D. From the audit process, the kitchen appliances are found on every level in this building except levels 5,6, 8, and 9. Only classrooms and computer labs are designed on these four levels, hence there were no kitchen appliances found throughout the audit process. Similar to the lighting, PC/laptop, and server rack, the analysis of the energy consumed by the kitchen appliances is measured using Equations 3.4, 3.5, and 3.6 accordingly.

3.7.8 *Others* Category of Appliances

Besides the seven categories of appliances/equipment found in Wisma R&D which were earlier discussed, numerous other appliances were found during the audit process. Hence, these remaining appliances are categorize as *others.* Some of the appliances that lie in this category are the emergency light, exit signs, speakers, routers, projectors, closed-circuit television (CCTV), laboratory equipment, and many others. Particularly, the equipment found in three different laboratory categories in Wisma R&D is shown in Figure 3.11. The location of each laboratory is shown in Table 3.4. It is found that level 10 is having the biggest number of laboratories in the building. Similar to the lighting, PC/laptop, server rack, and kitchen appliances; the analysis of the energy consumed by the *others* categorized appliances is measured using Equations 3.4, 3.5, and 3.6.

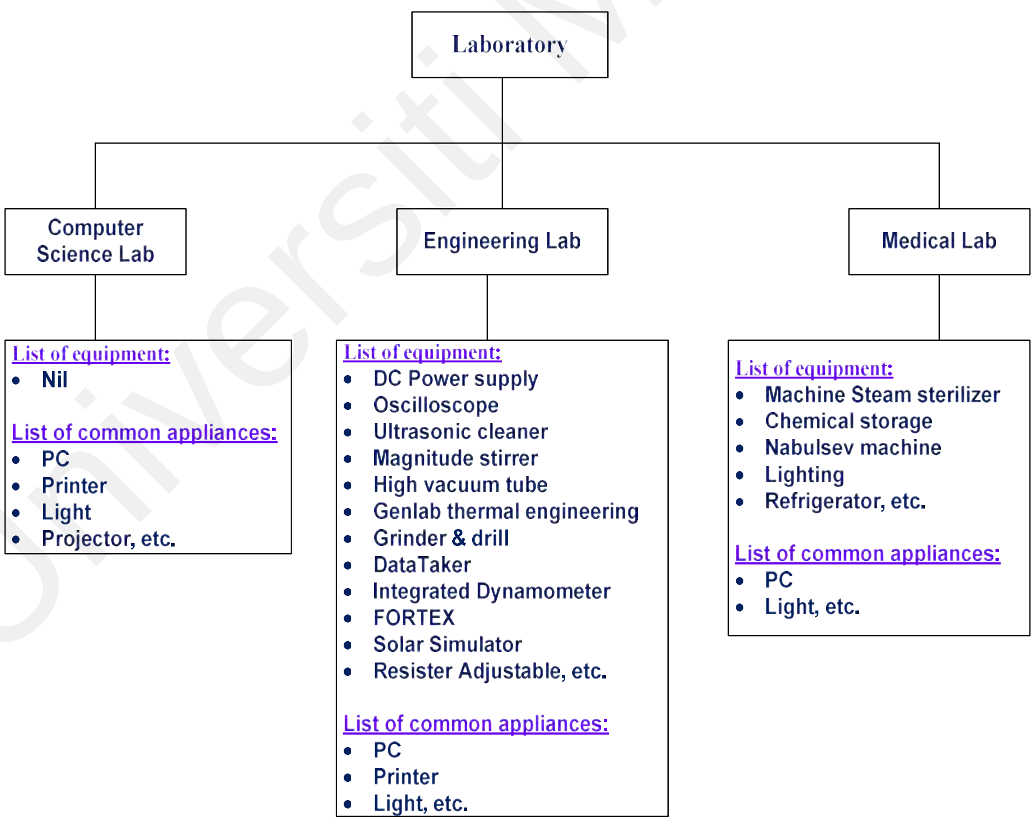


Figure 3.11: List of equipment available in three laboratories categories located in Wisma R&D

Table 3.4: Location of the laboratories in Wisma R&D

<table>
<tr><th>Lab Category</th><th>Level</th><th>Qty</th><th>Total</th></tr>
<tr><td rowspan="4">Medical Laboratories</td><td>LG</td><td>1</td><td rowspan="4">9</td></tr>
<tr><td>M</td><td>1</td></tr>
<tr><td>1</td><td>3</td></tr>
<tr><td>15</td><td>4</td></tr>
<tr><td rowspan="4">Engineering Laboratories</td><td>G</td><td>1</td><td rowspan="4">10</td></tr>
<tr><td>4</td><td>6</td></tr>
<tr><td>11</td><td>1</td></tr>
<tr><td>15</td><td>2</td></tr>
<tr><td rowspan="3">Computer Science</td><td>8</td><td>3</td><td rowspan="3">23</td></tr>
<tr><td>10</td><td>15</td></tr>
<tr><td>12</td><td>5</td></tr>
</table>

3.7.9 Summary of EA findings

In summary, data presented in Table 3.5 shows the total number of appliances and equipment found during the EA. From the data, it shows that lighting was recorded as having the highest quantity with 7593 units found throughout the levels in the Wisma R&D building. This is followed by the PC/Laptops and *Others* categories.

Table 3.5: Categories and quantity of appliances/equipment in Wisma R&D

No.	Appliances/Equipment	Quantity
1	Air-conditioning unit (outdoor unit)	66
2	Lighting	7593
3	PC/Laptop	1117
4	Printer/Photocopy machine/fax machine	177
5	Kitchen Appliances	107
6	Lift	6
7	Server rack	23
8	Others	1798

Moreover, the EA conducted allowed the author to summarize the type of room/areas available in Wisma R&D. Figure 3.12 represents the finding. The two pieces of data on the most right-hand side include the number of lifts and AC outdoor units in Wisma R&D in addition to the rooms/area described earlier. The finding shows that the laboratory is found to be the biggest room quantity in Wisma R&D, follows by the classroom and meeting, conference & multipurpose room. The details of quantity and room/area types for each floor found during the audit are tabulated in Table 3.6. The data assists the building owners to focus on either type of room/area or specific floors for potential retrofitting initiatives. For instance, the lighting retrofit could be based on the highest energy consumption by floors or by categories of the room/areas that operates regularly. The simplest comparison could be made for level 10 and level 15 where level 10 consists of more laboratory compared to level 15 which only consist of 6 laboratories. In the EA, detailing the categories and quantity of room is important for effective retrofit decision-making.

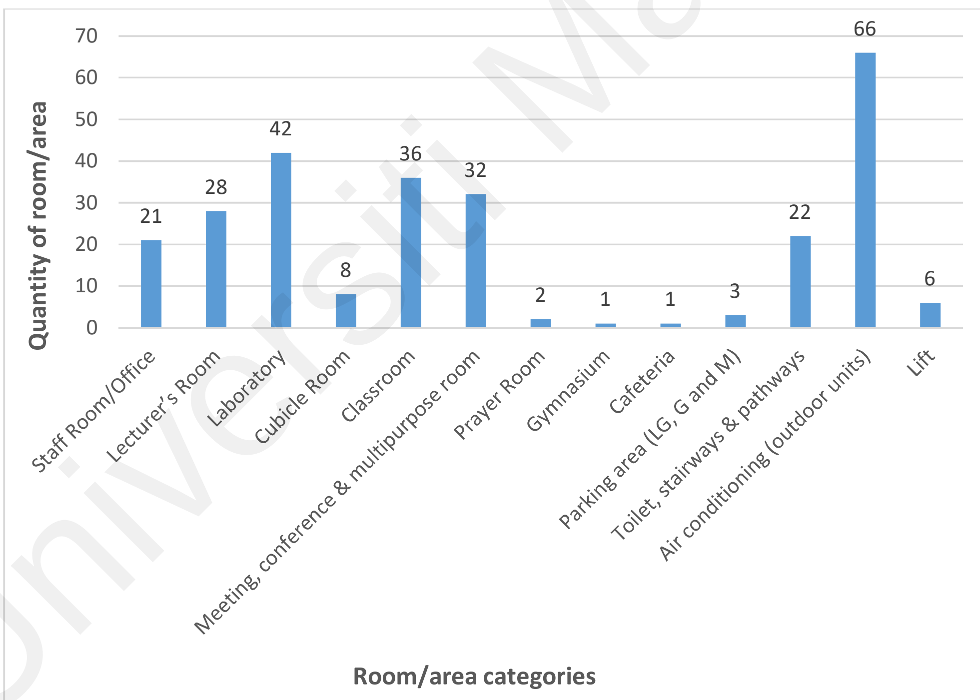


Figure 3.12: Room/area categories and their quantity in Wisma R&D

Table 3.6: Room/area categories and their quantity at each level of Wisma R&D

LEVELS/ AREAS	TYPES OF ROOM/AREA	QTY
Outside	Office (security room)	2
LEVEL LG	Parking, Stairways, Toilet	1
	Office (Security room)	1
	Laboratory	1
LEVEL G	Parking, Stairways, Toilet	1
	Office	2
	Laboratory	1
	Classroom	2
LEVEL M	Parking, Stairways, Toilet	1
	Laboratory	1
LEVEL 1	Toilet, stairways & pathways	1
	Laboratory	3
	Classroom	10
	Meeting, conference and multipurpose room	4
	Office	1
LEVEL 2	Toilet, stairways & pathways	1
	Lecturer's Room	1
	Office	1
LEVEL 3	Toilet, stairways & pathways	1
	Prayer Room	2
	Cafeteria	1
	Gymnasium	1
	Meeting, conference and multipurpose room	2
LEVEL 4	Toilet, stairways & pathways	1
	Meeting, conference and multipurpose room	1
	Laboratory	6
	Lecturer's Room	2
	Office	1

LEVELS/ AREAS	TYPES OF ROOM/AREA	QTY
LEVEL 5	Toilet, stairways & pathways	1
	Classroom	10
LEVEL 6	Toilet, stairways & pathways	1
	Classroom	8
LEVEL 7	Toilet, stairways & pathways	1
	Office	1
	Meeting, conference and multipurpose room	1
LEVEL 8	Toilet, stairways & pathways	1
	Classroom	4
	Laboratory	3
LEVEL 9	Toilet, stairways & pathways	1
	Office	2
LEVEL 10	Toilet, stairways & pathways	1
	Laboratory	15
	Meeting, conference and multipurpose room	1
LEVEL 11	Toilet, stairways & pathways	1
	Office	1
	Laboratory	1
	Meeting, conference and multipurpose room	1
LEVEL 12	Toilet, stairways & pathways	1
	Laboratory	5
	Office	2
	Cubicle Room	1
LEVEL 13	Toilet, stairways & pathways	1
	Office	3
LEVEL 14	Toilet, stairways & pathways	1
	Meeting, conference and multipurpose room	2
	Office	2
	Classroom	2

LEVELS/ AREAS	TYPES OF ROOM/AREA	QTY
LEVEL 15	Toilet, stairways & pathways	1
	Laboratory	6
	Meeting, conference and multipurpose room	2
LEVEL 16	Toilet, stairways & pathways	1
	Cubicle Room	7
LEVEL 17	Toilet, stairways & pathways	1
	Meeting, conference and multipurpose room	1
	Office	1
LEVEL 18	Toilet, stairways & pathways	1
	Lecturer's Room	19
	Meeting, conference and multipurpose room	3
LEVEL 19	Toilet, stairways & pathways	1
	Meeting, conference and multipurpose room	1
LEVEL 20	Toilet, stairways & pathways	1
	Lecturer's Room	6
	Meeting, conference and multipurpose room	1
LEVEL 21	Toilet, stairways & pathways	1
	Office	1
	Meeting, conference, and multipurpose room	8
LEVEL 22	Toilet, stairways & pathways	1
	Meeting, conference and multipurpose room	4

3.7.10 Building Energy Index (BEI) Analysis

Building Energy Index, in short BEI, is a metric for measuring how much energy a building has consumed over a year. In this research, BEI is used to evaluate the efficiency of the Wisma R&D building as of state. Hence, the Malaysian Standard, MS 1525:2014 (DOSM, 2014) is referred to, and the standard BEI for an energy-efficient building is set as 136 kWh/m^2/year. On the other hand, the standard BEI was stated as 135 kWh/m^2/year in another reference (Moghimi et al., 2014). The formula for measuring BEI is stated in Equation 3.20.

$$BEI = AEC \,/\, building\ area \qquad (3.20)$$

where BEI = building energy consumption (kWh/m^2/year), AEC = annual energy consumption (kWh), and building area in (m^2).

3.7.11 Summary of the Walk-Through Energy Audit (EA)

The audit process conducted in this research assisted in identifying the non-design factor that had contributed to the energy consumption of Wisma R&D. Nevertheless, the effect from other numerous building parameters such as the type of building material, wind and weather effect, internal temperature, and many others could not be evaluated through this process. In other words, the effect of the passive design factors on the building energy consumption could not be analysed through EA due to its limitation. In addition, the audit process carried out is incapable to analyse the environmental impact caused by different building parameters. Due to this, a different approach is required to analyse the effect of these passive design factors on building energy consumption, electricity cost, and environmental impact. Thus, the simulation-based approach is the most sensible solution to overcome the aforementioned issue. In the next section, the simulation-based analysis is described in detail.

3.8 Third Approach: Simulation-Based Analysis

Due to the limitation of the audit process, the effect of indirect building parameters or passive design parameters on the building energy consumption could not be analysed conceivably. Such parameters for instance include the type of building material (mainly wall, floor, and roof material), orientation, wind and surrounding weather situation, glazing material, and shading. In the literature review, numerous kinds of research have been carried out to analyse the significant contribution of these parameters. From those research, these passive design parameters are proven to be among the significant contributors to building energy consumption. Since some of the above-listed parameters, if and only if being incorporated in a new building design or a retrofits initiative could potentially improve the building's efficiency (in terms of its energy consumption), a simulation-based approach is found to be the sensible approach to be executed. Nevertheless, for a retrofit initiative to a specific existing building, a couple of parameters among the passive design parameters are contemplated. For instance, the effect of building material, orientation, wind, and surrounding weather is normally examined and considered only for new building design, but not so much on the retrofitting initiative for the existing one. On the other hand, the effect of glazing and opaque material as well as shading is vital for a retrofitting initiative of an existing building due to their high probability and effectiveness for the short and long-term building energy performances. Hence, this research examined the effect of the three passive design parameters that could positively contribute to the improvement of the energy consumption for the Wisma R&D building. In parallel, the economic and the environmental effect obtained from the simulation result are discussed.

3.8.1 Selection of Software

As there is more than 150 software available in today's market that could probably assist in making the simulation-based analysis a success, it is highly recommended that the selection of software should include the capability of having both BIM-BEM simulation within a single platform. This will lead to more efficient and effective solutions. The aforementioned is based on its capability to expedite the process of relating the building parameters selected (BIM-based) to the building energy performances (BEM-based). Otherwise, the virtual building that has been modelled has to be transferred to a different type of software that is capable to perform the energy performance evaluation. Due to this, ArchiCAD software is selected. In ArchiCAD, the building energy performances can be carried out once the virtual building is completely modeled. ArchiCAD V.22 is used throughout this research.

3.8.2 The Virtual Building Model

Upon the selection of software, the virtual building is modelled. This phase determined and modeled the architecture and structural features such as floor space, walls, and apertures such as doors and windows, frames, slabs, and roofs. The basic reference during this process is the building layout. As Wisma R&D is an old building, most of the architectural and structural drawings are not available, and some are found to be unclear. Hence, the general building layout obtained from the management office was referred to. At the very least, the virtual building model requires the structure envelope, fenestration, and all main internal structures that contribute considerable heat storage mass within a building. Adding up to that, a walk-through observation was carried out in completing the virtual building model.

In terms of the duration, the process of developing the complete virtual building of Wisma R&D in ArchiCAD has taken around one year. Beforehand, a virtual model of a single floor in Wisma R&D was performed. Level 4 had been selected as the reference floor. This is due to the similarities in terms of the gross floor area on most of the buildings from level 4 onwards. In specific, the gross floor area (GFA) and the structure of level 4 up to level 22 are similar. On the other hand, Level 3 consists of the internal and open areas, whereas the cross-sectional floor sizes on levels 1 and 2 are greater than the remaining floors. As a result, these three-floor were modelled after the completion of the level 4 modeling process. Finally, the lowest three levels; LG, G, and M, which are primarily the parking spaces, were modelled. In conclusion, there are two key phases in the modelling process. Phase 1 includes the creation of a three-dimensional (3D) construction model based on the building layout. In addition, this phase determined and modeled the architecture and structural features such as floor area, walls, and openings like windows, doors, and opaque. Phase 2 entails the creation of thermal blocks for each of the building's floors. This is the following step in the modelling process once the 3D model has been created, along with the architectural and structural aspects.

Figure 3.14 shows the complete virtual building model of level 4, Wisma R&D. In ArchiCAD, the building model can also be viewed from a different side. Figure 3.15 illustrates the overall, top, and side views of level 4, Wisma R&D in ArchiCAD software. The three different colors which are shown in Figure 3.15 represent the thermal block design in the building model. The pink area represents the *offices*' thermal block, the grey is the *circulation and common area* and the peach represented the *services and facilities*. Thermal blocks are a collection of one or more rooms or spaces in a building that have similar orientations, operation profiles, and internal temperature requirements (Graphisoft, 2019). In addition, each thermal block can be assigned to different building systems. For instance, some of the options available on the supply building system in ArchiCAD software include the VRF, natural ventilation, fresh air supply, and many others. Figure 3.13 shows the type of building systems options that are available in ArchiCAD software. In Wisma R&D, there are two different types of supply building systems; the VRF and fresh air supply, hence in the Wisma R&D building model, VRF is assigned for the *offices* and *circulation and common area* thermal blocks, whereas the fresh air supply is assigned for the *services and facilities* thermal blocks.

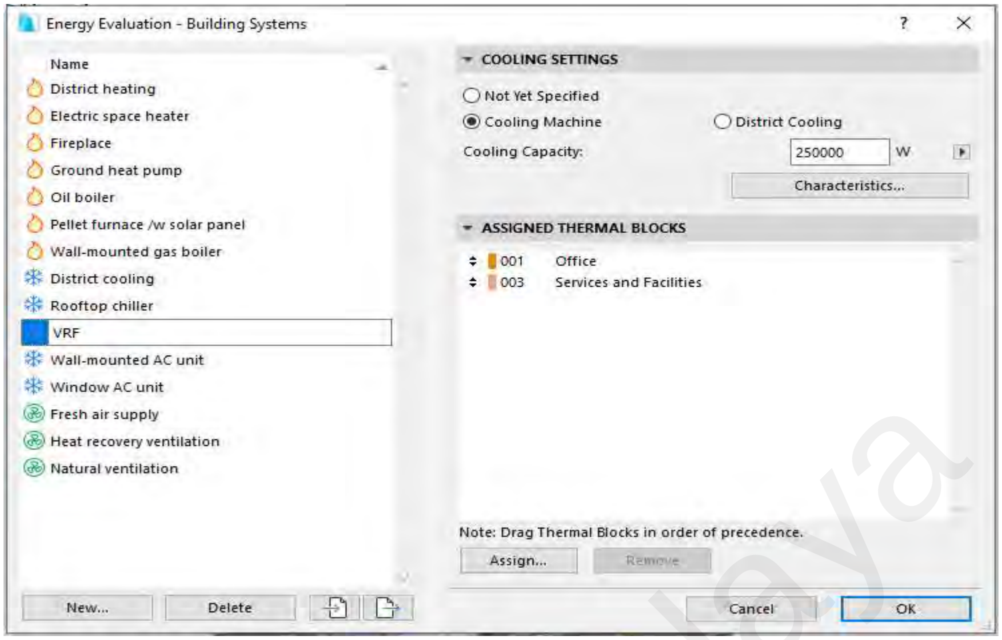


Figure 3.13: Building systems options in ArchiCAD

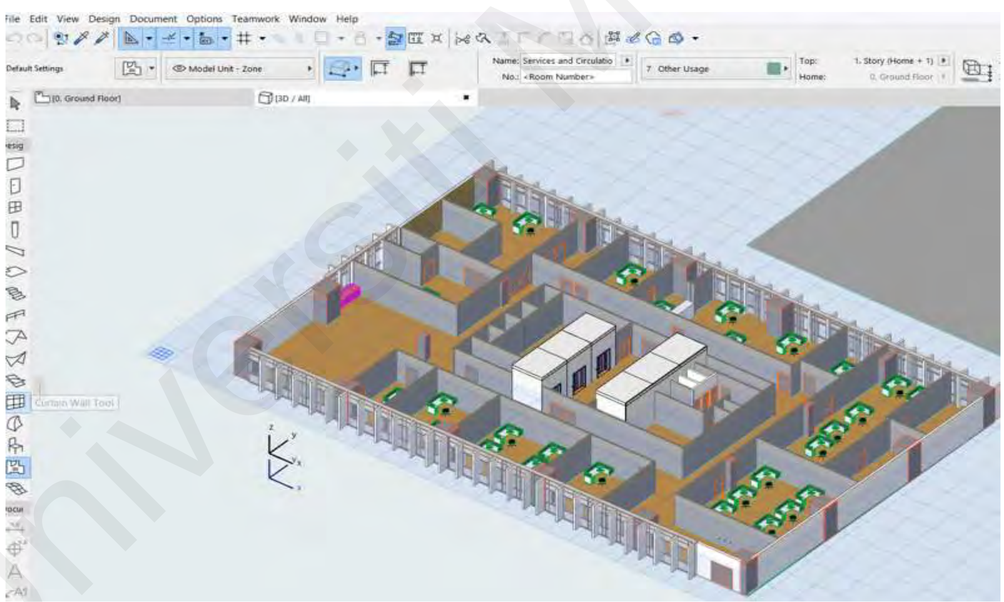


Figure 3.14: The complete virtual building model of Level 4

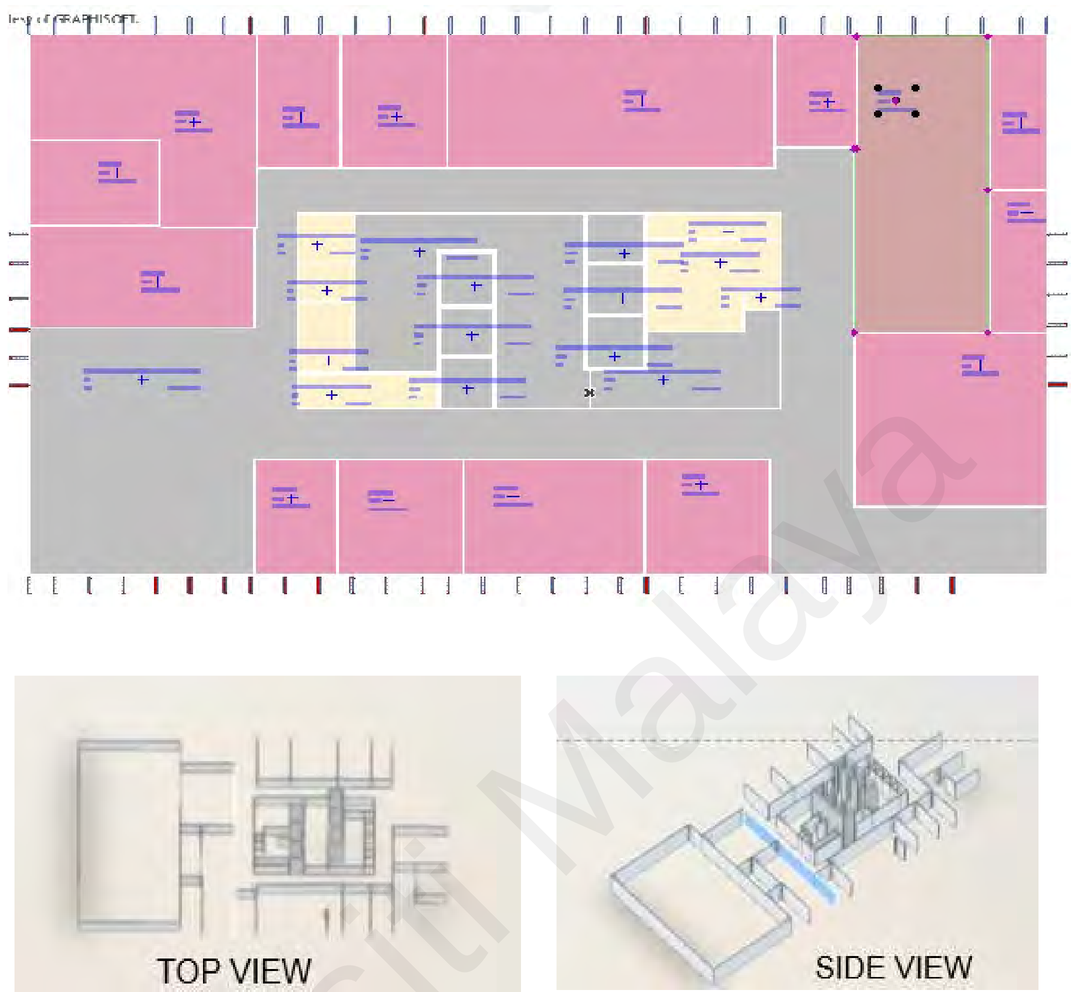


Figure 3.15: The overall, top, and side views of Level 4

The modelling process was accomplished with the assistance and collaboration of one of the modelers in BIM Management Sdn. Bhd. In addition, this research has received countless assistance from Malaysia's Graphisoft representative, as ArchiCAD software is owned by Graphisoft. There were lots of observations and pre-simulation being carried out before the virtual building model of the whole Wisma R&D building was finalized. The final approval of the building model is made based on the building geometry values which were obtained from the simulation process. Beforehand, this was cross-checked on the level 4 model layout and simulation outcome. Upon completing the modelling process, the total area measurement of this building is 42171.87 m^2. Based on the model developed, it is proved to be acceptable. This is based on a small percentage difference

(2%) from the total floor area of Wisma R&D from the layout plan which is 41316.55 m^2. This is very crucial as the model that is nearly accurate to the real building will assist in getting high accuracy of the energy performance evaluation result. The thermal blocks, operation profile, and the total area (m^2) details of the virtual building are summarized in Table 3.7.

Table 3.7: The designated thermal blocks' properties

Thermal blocks	**Colour**	**Operation profile**	**Total area (m^2)**
Offices	Pink	General office	11333.42
Circulation and Common Area	Grey	Unconditioned	22928.09
Services & Facilities	Peach	Toilets and Sanitary Facilities	7910.36
		Total building area	42171.87

Apart from the structure development, the building materials information needs to be inserted during the modeling process. On top of that, numerous related information such as the occupancy ratio, building type, operating hours, and many others are essential too. As this research is focusing on the potential parameters that are usually involved in retrofitting initiatives, the structural and various other parameters such as the wall, floor, and door material, occupancy ratio, building type, and operating hours were set as default throughout the simulation. The details are explained in the next subsections.

3.8.2.1 Structural Development of Wisma R&D

In ArchiCAD, the structural analytical model is a reduced depiction of the physical building. It helps both the architect and the structural engineer to work hand in hand through the modeling process and communicate on any issue during the modeling stages. As Building Information Modeling (BIM) is used to minimize the problem at the later stages of building development, hence ArchiCAD is used as the platform to design a building. Likewise, ArchiCAD has been used for analysing the advantages of any retrofit initiatives. The complete virtual model of Wisma R&D which is used for the simulation-based approach is shown in Figure 3.16.

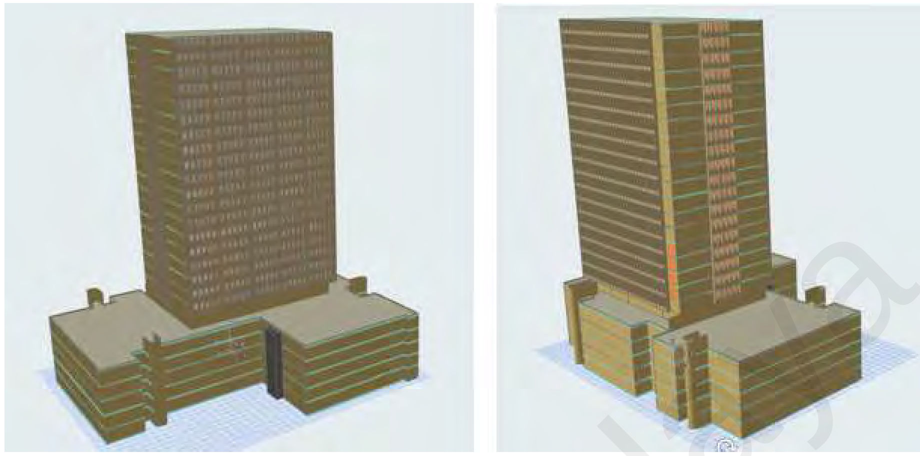


Figure 3.16: The virtual model of the Wisma R&D building

3.8.2.2 Material Selection

Upon completing the modeling process in ArchiCAD, the material of the building façades was included in the model. This information was set as default parameters throughout this research as these parameters were the very least potential to be considered in retrofit exercises. It is as well not practical and cost-effective to consider the building facades like the wall, floor, and roof in retrofitting initiatives. Due to this, the entire architecture and structural elements remain unchanged throughout the simulation process, including the material of the building facades. As mentioned earlier some of the structure and finishing materials were obtained from the Sales and Purchase (S&P) document as well as through observation during the walk-through EA process. A list of the fixed input values set for the virtual building of Wisma R&D is listed in Table 3.8.

Table 3.8: The building material and its properties used in the virtual model

Parameter	Detail properties	u-value (W/m²K)	Reference
External wall	Structure Brick Double Plastered Thickness: 125 mm Solar absorption: 85%	2.74	Drawing Layout
Internal wall	Stud partition Thickness: 100 mm	1.18	Drawing layout & EA
	Concrete block Thickness: 200 mm	1.74	
	Structure brick wall double plastered Thickness: 125 mm	2.21	
Slab	Structure Reinforced Concrete Thickness: 310 m	N/A	Drawing Layout
Floor	IC: 03 Tile-Floor Colour: Light brown Thickness: 10 mm	N/A	EA
Roof	Flat roof Thickness: 380 mm	N/A	EA

The material's thermal transmittance or u-value of the external and internal walls was obtained from the ArchiCAD library. Even though the wall is one of the biggest contributors to energy loss (heat) in a building, it is the least cost-effective element to look up to for a retrofitting initiative. Due to this, the second most contributor to heat loss in a building is the window, which is why it is the main focus of this research. The whole building material specifications and the u-value shown in Table 3.8 remain unchanged throughout the simulation. On the other hand, the existing glazing, opaque, and shading material of the windows in the Wisma R&D building was substituted with several other materials throughout the simulation process. The impact of the trio effect of these three window elements was analysed in detail. Initially, the window specification, which is labeled as A_0 was chosen and inserted in the virtual building model. The details specification is shown in Table 3.9. Similarly, the u-value of the initial window material, A_0 is obtained from the ArchiCAD library.

Table 3.9: Existing window specification of the Wisma R&D building

Parameter	Window specification				
A_0	**Glazing material**	**u-value (W/m^2K)**	**Opaque**	**u-value (W/m^2K)**	**Shading**
	Single glazing		Frame metal (steel basic)		No shading

3.8.2.3 Operation Profile

As mentioned earlier, the initial simulation was based on the existing building parameters (labeled as A_0), which served as a baseline for the subsequent energy performance results. As part of the simulation process, the selection of a suitable (or nearest) operational profile for the building is very important. Figure 3.17 depicts the operational profile feature and the parameters that are inculcated in ArchiCAD software for this research. It is divided into three main categories which include the *building type*, *occupancy data*, and *daily schedules*. The values inserted in the ArchiCAD software were based on the nearest Wisma R&D building profiles.

In this research, the suitable operation profile that suited Wisma R&D is *General Office*. Based on ArchiCAD's library, the *human heat gain (HHG)* for *General Office* is 120 W per capita and this value is supported by the fact released by the American Society of HVAC Engineering, or ASHRAE. (ASHRAE, 1997) states the *HHG* of a general office is 120 W per capita which was based on the non-residential cooling and heating load calculation. This is taken as an average between the female heat gain (130 W) and the male heat rate (140 W). In addition, (NGE, 2019) states that the typical energy load per person is 400 BTU/hr (116 W) for a typical worker and up to 1000 BTU/hr (293 W) for sports activities. Hence, it has been proved that the ArchiCAD default setting for *HHG* for the *General Office* is relevant and valid for the simulation process. In the ArchiCAD library, the default humidity load value set for *General Office* is 10.00 g/day per meter. The research agreed to use the default data as the humidity load value found from the psychometric chart for 23° C dry bulb temperature is 9 g/day (B.V., 2019) at a 50% Relative Humidity (RH). This is found to be the most suitable humidity load for the general room as the RH setpoint is suggested to be between 30% to 60%. (Ltd., 2010). The RH specified is claimed to be the optimum humidity range for human comfort and health too. In addition, the Department of Standards Malaysia is suggesting an RH not exceeding 70% for indoor comfort conditions (DOSM, 2019b). Hence, 10 g/day per meter was remain unchanged throughout the simulation.

As Wisma R&D does not have any hot water services, hence the value set for the *service hot water load* is zero.

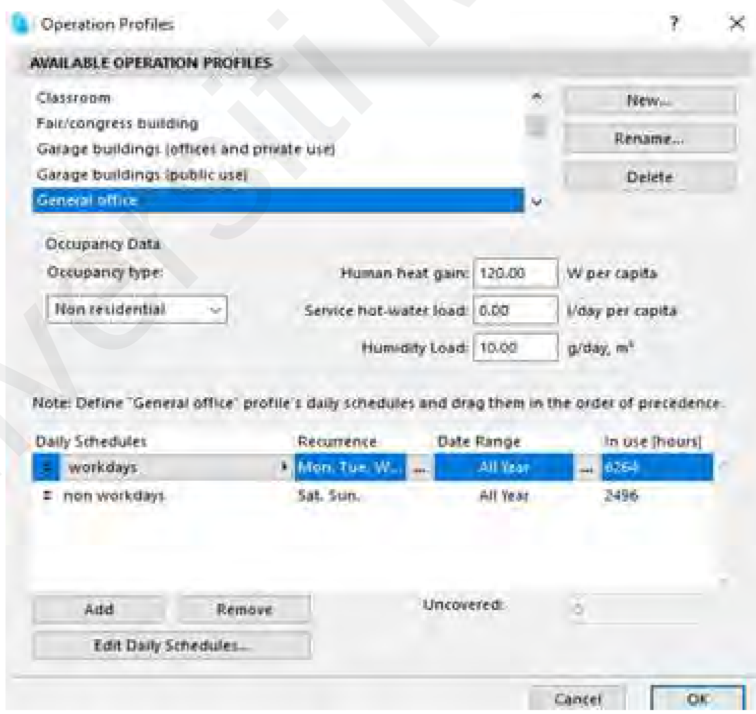


Figure 3.17: The operation profile parameters for Wisma R&D

For the *daily schedules* category, the information required includes the operating hours, internal temperature, and internal heat gain of the building. The normal operating hours for offices in Malaysia, which are generally from 0800 to 1700 (9 hours per day) were set in the default setting. It accumulates to 6264 hours per year in operation. On the other hand, the non-working hours which cover the weekend were not counted in the simulation. These values were set as default throughout the simulation process. Figure 3.18 shows the *daily schedule* features for the simulation. For the internal temperatures, the duration was set between 16°C and 23°C. The setup of the internal temperatures was based on the observation during the walk-through EA.

The final input in the *daily schedules* is the internal heat gain. The occupancy count was set at 1.8 m^2 per capita based on the standard guideline of the per body surface for an office building. According to (Ahmed, Kurnitski, & Olesen, 2017), the average body surface area (in m^2) is used as a guideline in determining the heat loss from the occupant in a building. It is thought to be the most important factor in determining varying heat losses from the body, even when occupants have the same muscle activity. This is also used as an input variable to calculate heat losses from the occupant's body via convection, radiation, vapor, and perspiration. Hence, for the office building, 1.8 m^2 is specified as the most suitable internal heat parameter for the occupant. The value was inserted into the *daily schedule*. Figure 3.18 shows the detail value set as the default setting in ArchiCAD.

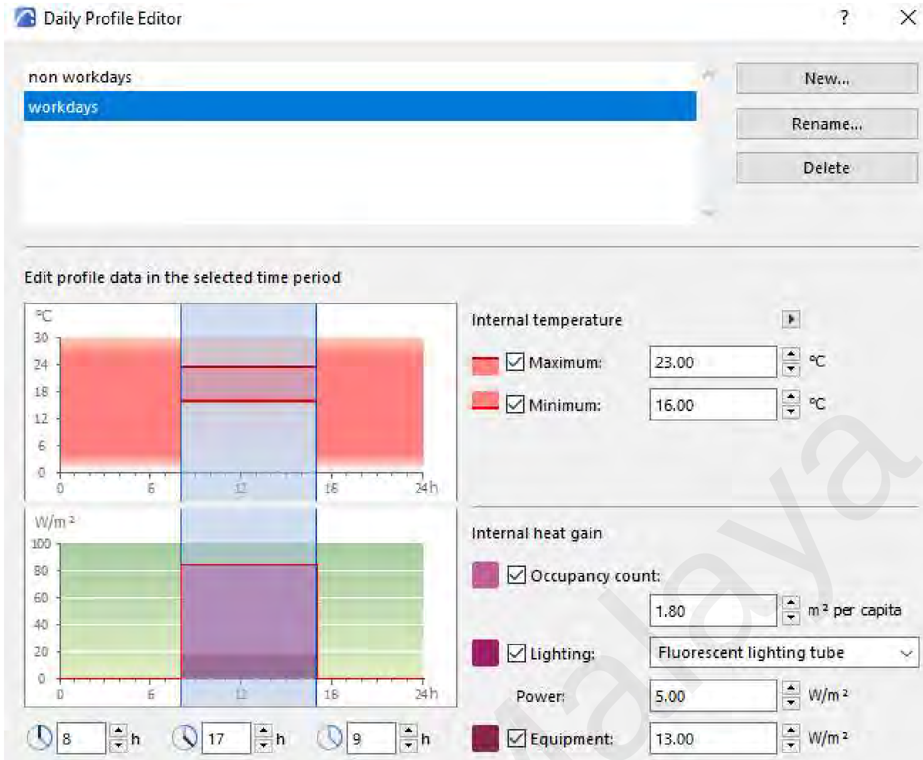


Figure 3.18: The default parameters set in the *daily schedule* setting

Furthermore, the operation profile includes the lighting and equipment's heat gain. As most of the lighting types used in Wisma R&D are fluorescent, hence the *Fluorescent lighting tube* was selected. The 5.00 W/m^2 is the default internal heat gain value set in ArchiCAD for the *Fluorescent lighting tube*. Before the author decided to retain the value set by ArchiCAD, a thorough analysis was carried out based on the standard light heat load calculation shown in Equation 3.21.

$$P = b / (\eta_e \, \eta_r \, l_s) \qquad (3.21)$$

Where P is the installed electric power (W/m^2 floor area), b is the recommended light level (lux, lumen/m^2), ηe is the light equipment efficiency, ηr is the room lighting efficiency, and ls is the emitted light from the source (lumen/W, lm/W). For this research, as the recommended average illuminance levels for general offices are in the range of 300 – 400 lux or lumen/m^2 (DOSM, 2019b) hence 350 lumen/m^2 is selected. From equation 3.21, the measured internal heat gain/lighting load for a fluorescent lamp is found to be 10 W/m^2. The detailed calculation is shown below.

$$P = (350 \text{ lumen/m}^2) / (0.5\ (70 \text{ lumen/W})) = 10 \text{ W/m}^2$$

The 70 lumen/W was inserted based on the typical lumen/W value (ToolBox, 2001) which was shown in Table 3.10, where the range stated for Fluorescent is between 50 – 90 lumen/W. On top of that, the manufacturer specification of Philips 36 W TL-D 36W/54-765 1SL/25 (Lighting, 2016), which is one of the lamp types used in Wisma R&D stated the lumens per watt is calculated as 2500 /36 W = 69.4 lumens/W, which is close enough to 70. However, the default value for lighting power is set at 5.00 W/m^2 in the virtual building model for Wisma R&D as numerous different lighting power rates are installed in Wisma R&D. Besides 36 W, 18W, and 10 W fluorescent lighting tubes are used across the building. Another method is used for internal heat rate from lighting features through the value of power obtained from the EA exercise. From the EA data analysis, the total power consumed by the lighting unit for the whole building is 195,440 W. This value is then divided by the total building area which is 42171.87 m^2 which resulted in 4.6 W/m^2. Hence, 5.00 W/m^2 was selected.

Table 3.10: Typical lumen/Watt value for several lamps type

Lamp Type	Emitted Light from the Source (lumen/Watt)	Lifetime (hours)
GLS Light Bulb	10 - 15	1000
Low Voltage Halogen	20	2000 - 5000
Mercury Vapor	40 - 60	22000
Fluorescent	50 - 90	more than 7000
Metal Halide	70 - 90	more than 12000
White LED	80+	N/A
High-Pressure Sodium	90 - 125	25000
Low-Pressure Sodium	120 - 200	20000

Furthermore, the internal heat gain value inserted for the equipment category as shown in Figure 3.18 was 13 W/m^2. The same method is applied, where the total power consumption from all equipment (excluding the air-conditioning and lighting) that was obtained from the EA is 534,590 W was then divided by the total building area. Hence, the internal heat gain contributed by the equipment category was measured at 12.7 W/m^2. Due to this, the fixed value inserted in the ArchiCAD software for this category was 13 W/m^2. In summary, the parameters set in the *Operation Profiles* are listed in Table 3.11. These parameters remained unchanged throughout the *Energy Performance Evaluations* so that the effect of glazing, opaque, and shading elements could be analysed.

Table 3.11: The operation profile parameters which are fixed in this research

Parameter	Details
Internal temperature	Min = 16ºC, Max = 23ºC
Occupancy data	Non-residential
Operating time	8 am – 5 pm (9 hours)
Occupancy count	total area/1000 person
Human heat gain	120 W/capita
Lighting type & heat gain	Fluorescent lighting tube; 5 W/m^2
Total equipment heat gain	13 W/m^2

3.8.2.4 Environmental Setting

Besides the *Operation Profiles* feature, this software is equipped with the *Environment Settings* feature, in which parameters inclusive of the location and climate of the reference building are included. In addition, information like soil type, surrounding area surface, surface heat transfer, wind protection, and horizontal shading surrounding the building are included as part of the factor in *Energy Performance Evaluation*. Each of these features allows details information such as air temperature, humidity, and wind speed to be included as factors throughout the simulation. This is one of the great features of ArchiCAD that makes it ideal especially for building retrofitting. Figure 3.19 depicts the *Environment Settings* profile and the parameters added before the simulation.

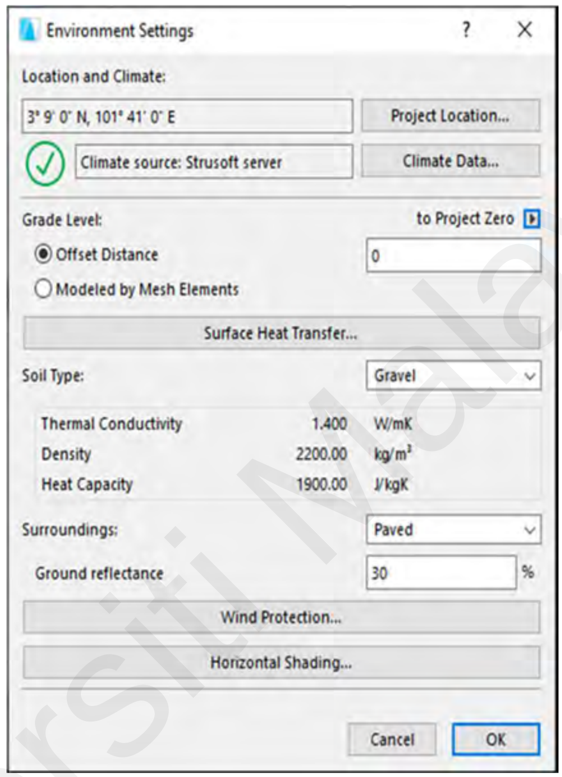


Figure 3.19: Environment setting features in ArchiCAD

For instance, once the address of Wisma R&D was added to the Site's Full Address, the *latitude* and *longitude* were automatically set into the model. Next, the *time zone (UTC)* parameter automatically reflected the weather data where the reference building is situated. In this research, the Kuala Lumpur weather data was extracted. Furthermore, the *Soil Type* selection specifies the soil type of the building site as accurately as possible. This value is used to calculate heat flow via ground-contact structures (Graphisoft, 2021). The applicable *Thermal Conductivity*, *Density,* and *Heat Capacity* values were then displayed below the chosen *Soil Type*. On top of that, the *Surrounding* option allows the selection of the surroundings that best describe the environment of the reference building.

Options include *Waterfront*, *Garden, Paved,* or *Custom*. The setting is used when calculating the effect of indirect solar irradiation (Graphisoft, 2021). The *Wind Protection* option allows the selection between *Protected*, *Partly Protected,* or *Unprotected*. As this research excluded the wind effect on energy consumption, hence the parameter selection for *Wind Protection* was *Unprotected* throughout the simulation. In summary, the *Environment Setting* feature in ArchiCAD reflected the exact orientation of the building, which automatically puts into effect the sun's position and temperature surrounding the building. Figure 3.20 shows the address details of Wisma R&D, which was added to the virtual building model in ArchiCAD. Technically, the outcome of the *Energy Performance Evaluation* comprises both direct and indirect parameters of one building. All the parameters set up in the *Environment Settings* remained unchanged except for the *Horizontal Shading (HS)*. *HS* represents the amount of shading resulting from an external object such as other nearby buildings, trees, and others. The options available in the ArchiCAD library includes *None*, *Low*, *Medium*, and *High*. From the observation, the amount of external shading protection of Wisma R&D is between low to high. In summary, the fixed parameters under the *Environment Setting* features selected for the simulation are listed in Table 3.12. In this research, the effect of horizontal shading was too observed and analysed as the outcome could assist the building owner or the urban planning personnel to initiate the external shading initiative in reducing the building energy consumption.

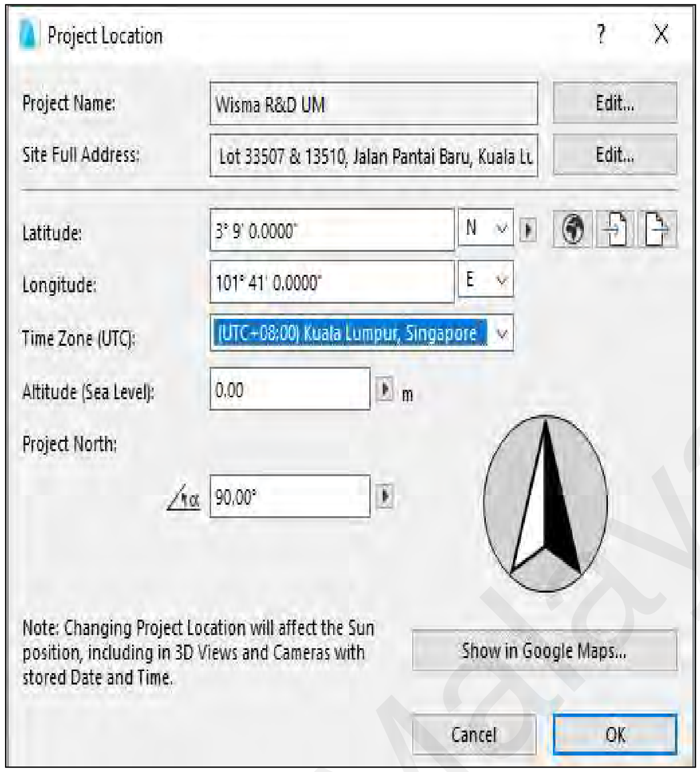


Figure 3.20: Location details added to the *Environment Settings* feature

Table 3.12: Fixed parameter in *Environment Settings* feature

Parameter	Details
Project location	Kuala Lumpur
Project coordinate	3° 9' 0" N, 101° 41' 0" E
Soil type	Gravel
Surrounding	Paved
Wind protection	Unprotected
Horizontal Shading	East = Low
	South East = Low
	South = Low
	South West = Medium
	West = High
Climate type	Moist
Annual average external temperature	28°C

The *HS* selection for Wisma R&D was based on general observation by the author. A compass was used to locate the direction of the building which later determined the level of the horizontal shading for Wisma R&D.

3.8.2.5 Energy Source and Energy Cost Factor

As building performances are measured from various dimensions, hence energy cost and carbon emission analysis are vital in any building performance evaluation. In this research, on top of the energy consumption (kWh/m^2), the energy cost (RM/m^2), and the carbon emission (kg/m^2) were analysed too. In short, these three elements are referred to as the trio effect. ArchiCAD software, through the *Energy Performance Evaluation* result, published the trio effect from each simulation. Therefore, interactive analysis of different building parameters toward the trio effect could be carried out intensively.

As part of the pre-simulation setup, the energy source factors and cost values are important information that needs to be inserted in the *Energy Source and Energy Cost Factor* features, which are embedded within the software. Particularly for the *Energy Source Factors* inputs, the data inserted is unique as the information varies year by year depending on the government's plan and resource allocation. In this research, the portion of the energy sources is extracted from the NEB 2018 (EC, 2018b). The sources of electricity reported in NEB 2018 include NG (44%), Coal (43%), Hydro (9%), and others (4%). Hence, these values are inserted in the *Energy Source Factors* feature. These setups later contributed to the electricity consumption, cost, and CO_2 emission published in the energy performance evaluation report.

Meanwhile, the primary energy and CO_2 emission factors are the default values available in ArchiCAD's *Source Factors* setup. From the analysis, these values apply to Malaysia's energy source production. According to Malaysia Energy Statistic Handbook 2016 (EC, 2016a), the primary energy factor for electricity is measured at 2.5, hence, all the sources' factors remain as in the initial ArchiCAD setup. Figure 3.21 shows the details.

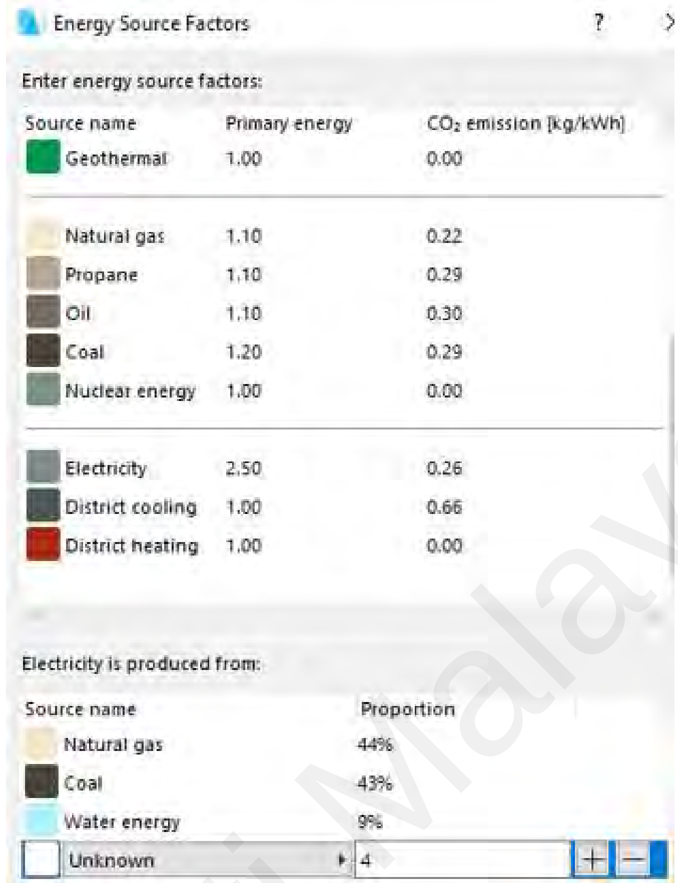


Figure 3.21: The Source Factors and proportion used for the Wisma R&D model

However, the information inserted in the *Energy Cost* feature is impractical. This is due to the limitation of the software that allows a single energy price to be set as the cost per unit/kWh. As in the case of Malaysia, the energy cost is based on the electricity tariff set by the government. For instance, as Wisma R&D is categorised as an office building (Tariff C1-Medium Voltage General Commercial Building), hence, RM0.365/kWh is inserted as the Energy Cost. Yet, the kilowatt of the Maximum Demand (MD) could not be counted. Due to this, the *Energy Cost* value resulting from the *Energy Performance Evaluation* is inaccurate as it excludes the charges on MD utilization. Hence, the outcome of the *Energy Performance Evaluation* report will not be comparable to that of the TNB electricity bill. Figure 3.22 shows the energy cost inserted in ArchiCAD. The current commercial tariff rate in Peninsular Malaysia was shown in Figure 3.6.

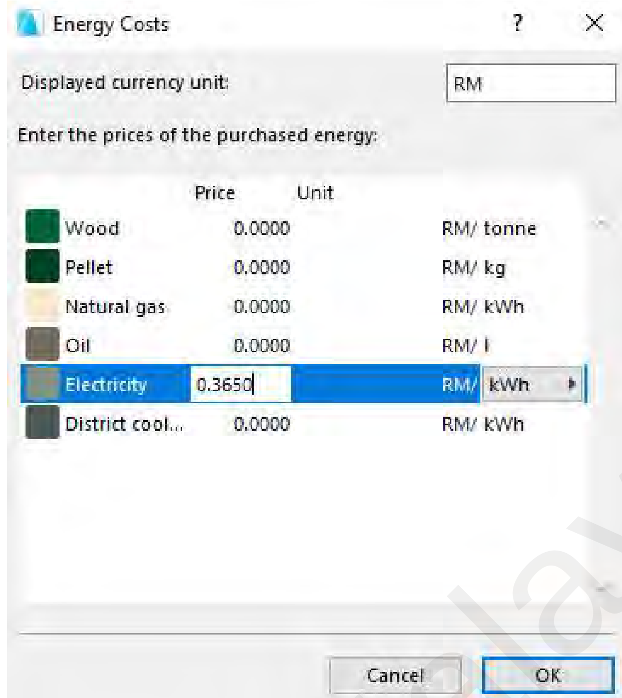


Figure 3.22: The *Energy Costs* value inserted for the simulation

3.8.2.6 Energy Performance Evaluation

Several cycles of *Energy Performance Evaluation* simulation were executed. It is important to ensure that the virtual building of the first reference floor is modelled as accurately as possible. The built-in feature of *Energy Evaluation* in ArchiCAD software (the report's title is published as *Energy Performance Evaluation*) which is shown in Figure 3.23 allows the user to examine the effect of numerous building parameters on the trio effects. This is seen as one of its advantages as it combined the elements of BIM-BEM within one platform. Through this feature, the building's *Operation Profile* (or the closest to the mentioned building), its *Environment Settings*, and *Building Systems* could be inserted or linked to the real-time data before the simulation is conducted. In addition, the *Energy Source Factor* and *Energy Costs*, which are based on a specific country's energy planning, arrangement, and tariff, are inserted as input parameters under the *Energy Evaluation* feature. The final feature in the *Energy Evaluation* setting is the

Thermal Bridge Simulation. This is excluded in the *Energy Performance Evaluation* throughout the research.

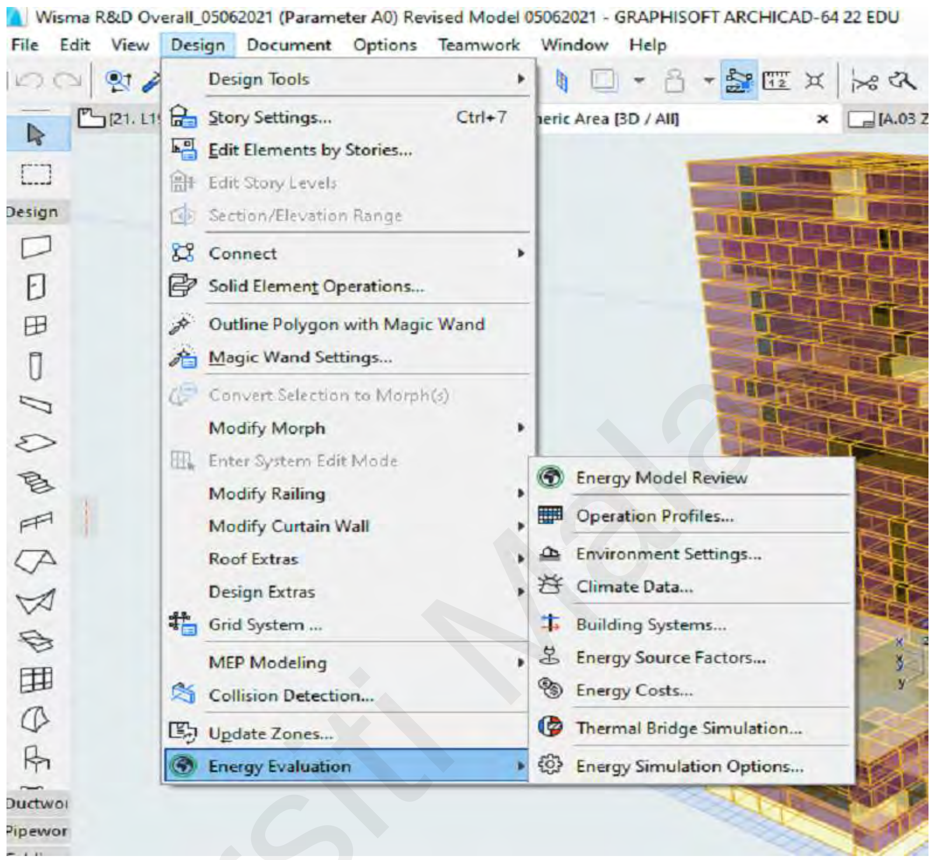


Figure 3.23: The *Energy Evaluation* feature in ArchiCAD software

Upon setting up these parameters into the virtual building model, the trio effect (energy consumption, energy cost, and CO_2 emission) was analysed thoroughly. Before the comprehensive analysis is carried out, the virtual building model needs to be error-free and the energy consumption for the initial simulation must be less than 5% of kWh different compared to the average utility bills and the EA finding. This is to ensure the accuracy of the initial model, which was labeled as A_0. On the other hand, if the kWh resulting from the initial model is more than 5%, the virtual building model needs to be checked and modified. Once the kWh result of the initial virtual building model is similar and closest to the reference building (Wisma R&D), the recommendation for retrofitting initiative is to be identified. The changes outlined through the retrofitting initiative were simulated and the trio effect was examined. The correlation effects between several combinations of building parameters are thoroughly discussed in Chapter 4.

3.8.3 Glazing Ratio (GR) or Window-to-Wall Ratio (WWR)

On top of the GFA, the Glazing Ratio (GR) or Window-to-Wall Ratio (WWR) value could be examined to ensure the accuracy of the virtual building model. Equation 3.22 shows the basic calculation for GR/WWR. Hence, in this research, the total glazed area is pointed out in detail and the simulated GR/WWR is examined.

$$GR/WWR = Glazed\ Area\ \div\ External\ Envelope\ Area \qquad (3.22)$$

In addition, the GR/WWR value is one of the parameters that describe the building energy performance of one building. Hence, in this research, the GR/WWR was analysed based on the virtual building model of Wisma R&D.

3.8.4 Heat Transfer Coefficient (u/R-value)

One of the main parameters analysed through the simulation-based approach is the heat transfer coefficient. The u-value was obtained from the *Energy Performance Evaluation* results. The finding and discussion are based on the fundamental of heat transfer that is based on equation 3.23.

$$u = q/A(dt) \qquad (3.23)$$

Where q is the heat flow rate of the building, A is the wall area and dt is the temperature difference between two areas (internal and external building temperature). However, there is no detailed calculation involved in this research for the heat transfer coefficient as the results were analysed directly from the simulation outcomes.

3.9 The Novelty of the Research

Referring to the research gap on the importance of inculcating the load factor (LF) performance prior to the energy audit (EA), this research has proven that the LF performance analysis has allowed firm decision to the building owner the critically of the need of retrofitting their existing buildings. With LF less than 0.6 has indicated that the existing building required attention. This research finding could encourage more researchers to consider the LF performance analysis before any EA is carried out. The implications of this research have enabled some new methodologies within the field of building energy performance study. The outcome has been presented as part of the methodology process and the result of the LF performance study of Wisma R&D is thoroughly explained in the next chapter. It was the first research work that related to the LF performance analysis for high-rise buildings in Malaysia.

In addition, this research made use of ArchiCAD, one of the tools/software available for BIM-BEM analysis that is rarely used in Malaysia. Research conducted on building energy performances through virtual building models using ArchiCAD was not available until recently when CIDB starts to introduce it as one of the software for building design and energy simulation. Hence, the research conducted has contributed to the new tools/software that is available in supporting the government's vision of digitalizing the construction field. This has allowed more options for bringing BIM into practice among practitioners in Malaysia. The publication titled *Modeling and performance analysis for high-rise buildings using ArchiCAD: initiatives towards energy-efficient building* has become the first building energy performance study that utilizes the ArchiCAD tool/software for high-rise buildings in Malaysia. The outcome of this research has proven the capability of ArchiCAD in merging the BIM-BEM analysis that can be carried out simultaneously from its built-in features.

Another gap found in various energy audit (EA) practices was the unaccounted lift energy consumption as part of the total building energy consumption. This may be acceptable for the low-rise building as the consumption may not be as high as the high-rise, especially the institutional-based operation building like Wisma R&D. This is one of the uniqueness of this research, where the lift energy consumption was added as part of the non-design factors that contributed to the total energy consumption. Hence, the result proved that it is important to not overlook the lift operation as part of the retrofitting initiative for reducing the total energy consumption of the building. There is very little evidence in previously published works that emphasize this matter. This makes this research different from other EA analyses-based research. In summary, lift operation should be inculcated in the EA, especially for the high-rise building and it will allow significant retrofitting initiatives carried out by the building owner upon the audit outcomes.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

In general, this chapter discusses the outcome obtained from the in-depth analysis of three different approaches; LF performance analysis, walk-through EA, and simulation-based analysis (using ArchiCAD), which were conducted on Wisma R&D, UM building. Beforehand, building parameters that commonly affect the overall building performance were identified through an in-depth study and thoroughly discussed in Chapter 2. These parameters were observed and analysed through walk-through EA and simulation-based analysis using ArchiCAD. The LF performance analysis was first carried out to observe the performance level of the existing operation of Wisma R&D. These three approaches were performed so that the capacity and accuracy of each approach are intensively analysed.

Ultimately, from the finding, this research aims to provide insights for future retrofitting initiatives, mainly for high-rise commercial buildings in Malaysia. Due to that, the economic and environmental impact of several retrofitting initiatives proposed for Wisma R&D were examined. In specific, three main criteria of building performance were analysed excessively; i.e. energy consumption, cost, and carbon emission at the end of this research. These criteria are referred to as the trio effect. The units of measure representing them are kilowatt-hours (kWh), Ringgit Malaysia (RM), and kilogram (kg). Finally, at the end of this chapter, several frameworks are proposed as a guideline for future sustainable building development and effective retrofitting, especially for high-rise buildings in Malaysia.

4.2 Load Factor (LF) Performance Analysis of Wisma R&D Building

This approach is effective in assisting the building owners to have a better understanding of their building energy consumption, hence it was decided to be the first approach carried out in this research. This approach assisted in building load balancing as well as lowering its electricity billing. In addition, LF performance analysis ultimately portrays the consistency of electricity usage over time. This is very important as Wisma R&D, UM is one of the buildings registered under the commercial building and the charge of the MD is considerably high. Reverting to Figure 3.6, the charge for MD is RM 30.30/kW, hence by observing the LF performance, the load factor improvement program could be conducted effectively, mainly to reduce the MD charges laterally. In short, the higher the MD, the higher the utility bill is to be expected by the building owner.

Commercial building owners in Malaysia are charged based on their monthly electricity consumption (in kWh) and maximum demand (in watts), hence, it is vital to perform the LF Performance analysis for overall building operation improvement. Principally, the LF is between the range of zero to one, with one as its ideal value. However, as the baseline of considerably good building performance is recommended at 0.6, this research has analysed the optimum MD that Wisma R&D should control during its operation.

This analysis was carried out purely based on the monthly electricity bills obtained from TNB. In summary, the monthly electrical bills for four conservative years (2015 – 2018) of Wisma R&D, UM were collected, tabulated, and analysed. Table 4.1 and Figure 4.1 present the details.

Table 4.1: Monthly electricity bill of Wisma R&D for 4 conservative years

Month	Energy Consumption (kWh)	Max Demand (kW)	Monthly Bill (RM)	2016 (kWh)	Max Demand (kW)	Monthly Bill (RM)	2017 (kWh)	Max Demand (kW)	Monthly Bill (RM)	2018 (kWh)	Max Deman d (kW)	Monthly Bill (RM)
	2015			2016			2017			2018		
Jan	209,701	707	99,530	222,735	858	111,861.44	173,510	653	90,459.82	163,198	541	79,103.50
Feb	182,637	785	91,895	201,904	838	103,363.84	167,006	724	86,503.56	160,811	664	82,214.00
March	242,237	792	108,762	239,573	799	116,279.54	198,962	691	99,315.89	192,286	715	95,731.29
April	240,373	830	115,732	234,668	906	117,920.68	188,826	764	96,025.69	195,354	724	97,180.21
May	228,704	824	111,231	224,839	811	111,121.53	206,616	747	102,233.02	169,359	721	87,291.96
June	211,017	746	102,164	190,993	679	94,070.61	166,561	684	85,213.20	153,127	645	74,314.29
July	209,728	831	104,459	179,729	705	90,675.95	202,440	718	99,653.38	192,809	686	95,222.59
August	222,464	832	109,190	218,142	734	106,088.84	205,110	754	101,993.27	191,070	728	95,847.18
Sep	219,659	787	106,688	193,038	683	94,971.23	175,572	659	87,610.58	160,329	634	81,138.41
Oct	230,848	1,001	117,793	203,615	754	101,269.62	200,545	711	98,711.47	191,144	652	93,853.38
Nov	215,476	776	104,787	194,607	785	98,887.64	183,896	628	90,279.83	165,773	599	82,153.30
Dec	210,874	770	102,893	177,786	685	89,292.11	166,405	653	83,962.41	165,063	569	80,956.87
AVERAGE	218,643	806.75	106,260.49	206,802	769.75	102,983.59	186,287	698.833	93,496.84	175,027	656.5	87,083.92
TOTAL	2,623,718		1,275,125.82	2,481,629		1,235,803	2,235,449		1,121,962.12	2,100,323		1,045,006.98

The MD of this building is inconsistent, with values ranging from 569 kW (minimum) to 1001 kW (highest) within these four conservative years. From the tabulated data, in October 2015, the highest MD of 1001 kW was recorded, followed by 906 kW in April 2016, 764 kW in April 2017, and 728 kW in August 2018. On the other hand, the lowest recorded MD which is 707 kW was recorded in January 2015, 679 kW in June 2016, 628 kW in November 2017, and 541 kW in January 2018. Looking at the data, the difference between the highest and the lowest MD in Wisma R&D is about 500 kW, which is considered a huge gap and an effective control mechanism needs to be introduced for this building.

The LF performance of Wisma R&D could be analysed by calculating the AL from the total electricity consumption (kWh) in a specific year. Hence, based on Equation 3.2, the AL for four conservative years of Wisma R&D is presented in Table 4.2. The MD values presented were based on the highest MD in the mentioned years. For instance, in 2015, the highest recorded MD is 1001 kW which took place in October. Then, based on Equation 3.1, the LF for four conservative years was computed. It can be seen that the LF for Wisma R&D was consistently measured at below 0.4 and based on the recommended LF by TNB, it shows that this building is not operating at its optimum level. The computed LF for four conservative years of the Wisma R&D building is shown in Table 4.2.

Table 4.2: The MD, AL, and LF values for four conservative years of Wisma R&D

Year	From utility bill	From Equation	
	MD	AL	LF
2015	1001	299.51	0.299
2016	906	283.29	0.313
2017	764	255.19	0.334
2018	728	239.76	0.329

In this research, the monthly LF performance of Wisma R&D for these four years was as well analysed. Table 4.3 and Table 4.4 detail the finding. It is seen that there were approximately only 10% out of the monthly LF hit the 0.4 value. Hence, it can be concluded that the building energy performance of Wisma R&D is lower than the recommended and good building practices. In other words, it is a clear indicator that the building is inefficient and thus required effective retrofitting initiatives.

To improve the LF of Wisma R&D, it is important to control both the electricity consumption (kWh) as well as the MD. Generally, the energy-efficient building will focus on achieving both concurrently.

Table 4.3: The monthly LF values at Wisma R&D for 2015-2016

Year	Month	MD	AL	LF
2015	Jan	707	281.86	0.40
	Feb	785	271.78	0.35
	Mac	792	325.59	0.41
	Apr	830	333.85	0.40
	May	824	307.40	0.37
	June	746	293.08	0.39
	July	831	281.89	0.34
	Aug	832	299.01	0.36
	Sept	787	305.08	0.39
	Oct	1,001	310.28	0.31
	Nov	776	299.27	0.39
	Dec	770	283.43	0.37
Year	**Month**	**MD**	**AL**	**LF**
2016	Jan	858	299.38	0.35
	Feb	838	290.09	0.35
	Mac	799	322.01	0.40
	April	906	325.93	0.36
	May	811	302.20	0.37
	June	679	265.27	0.39
	July	705	241.57	0.34
	Aug	734	293.20	0.40
	Sept	683	268.11	0.39
	Oct	754	273.68	0.36
	Nov	785	270.29	0.34
	Dec	685	238.96	0.35

Table 4.4: The monthly LF values at Wisma R&D for 2017-2018

Year	Month	MD	AL	LF
2017	Jan	653	233.21	0.36
	Feb	724	248.52	0.34
	Mac	691	267.42	0.39
	April	764	262.26	0.34
	May	747	277.71	0.37
	June	684	231.33	0.34
	July	718	272.10	0.38
	Aug	754	275.69	0.37
	Sept	659	243.85	0.37
	Oct	711	269.55	0.38
	Nov	628	255.41	0.41
	Dec	653	223.66	0.34
Year	**Month**	**MD**	**AL**	**LF**
2018	Jan	541	219.35	0.41
	Feb	664	239.30	0.36
	Mac	715	258.45	0.36
	April	724	271.33	0.37
	May	721	227.63	0.32
	June	645	212.68	0.33
	July	686	259.15	0.38
	Aug	728	256.81	0.35
	Sept	634	222.68	0.35
	Oct	652	256.91	0.39
	Nov	599	230.24	0.38
	Dec	569	221.86	0.39

Figure 4.1 to Figure 4.4 show the graphical presentation of Wisma R&D's electricity consumption, AL, MD, and LF performances. From these data, it provides detail inside on the relationship between these building performances. For instance, the energy consumed in March 2015 was the highest consumption throughout the year. However, due to being considerably low than the average recorded MD for 2015, its monthly LF performance proved to be the highest compared to other months. In specific, the LF was measured as 0.41. With higher LF, the electricity charges for March 2015 were recorded to be RM 108,762.40, just above the average bill charge which was RM 106,260.49. On the other hand, even though the energy consumption recorded in October 2015 was lower than the one recorded in March, had turned out to be the highest monthly charge compared to other months in 2015. This is due to the MD being recorded as the highest demand in

the year. In addition, from the four conservative years of data analysis, the lowest LF performance (0.31) was taken place in October 2015. Figure 4.4 illustrated this in detail. Eventually, the monthly charges turned out to be very high, as both the energy consumption and the MD contributed to the final electricity charges. The relationship between energy consumption (kWh), electricity charges (RM), and MD is shown in Figure 4.5.

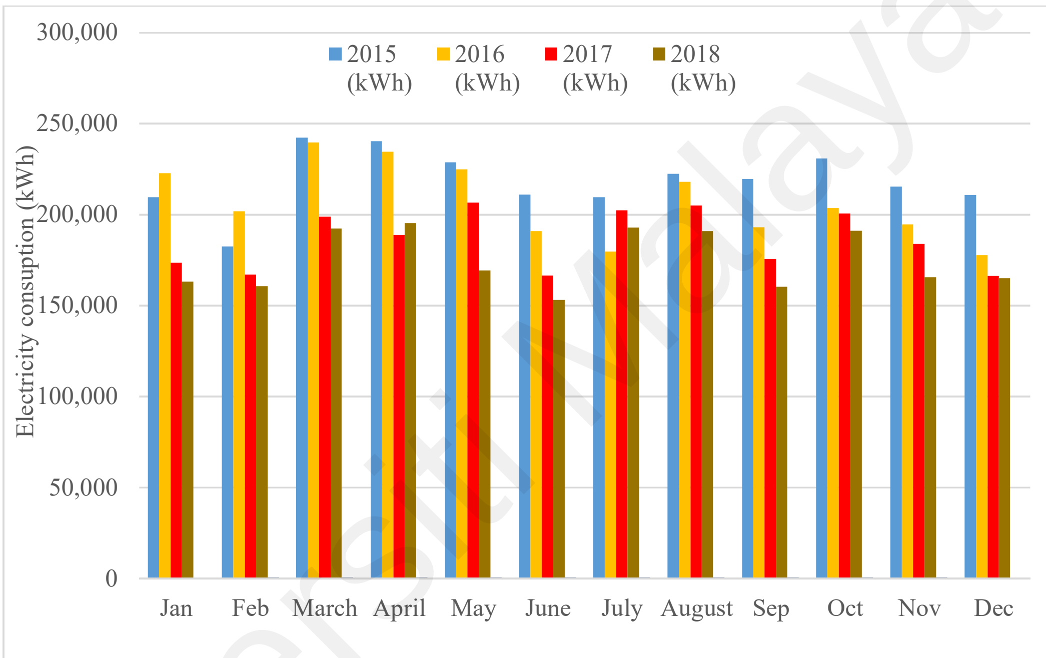
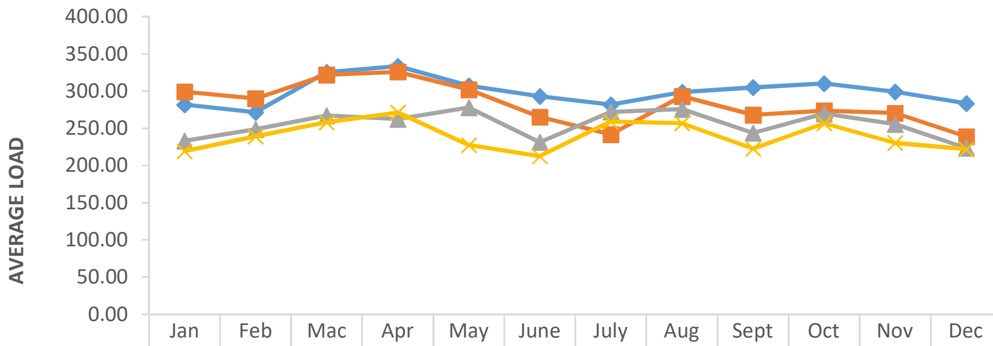


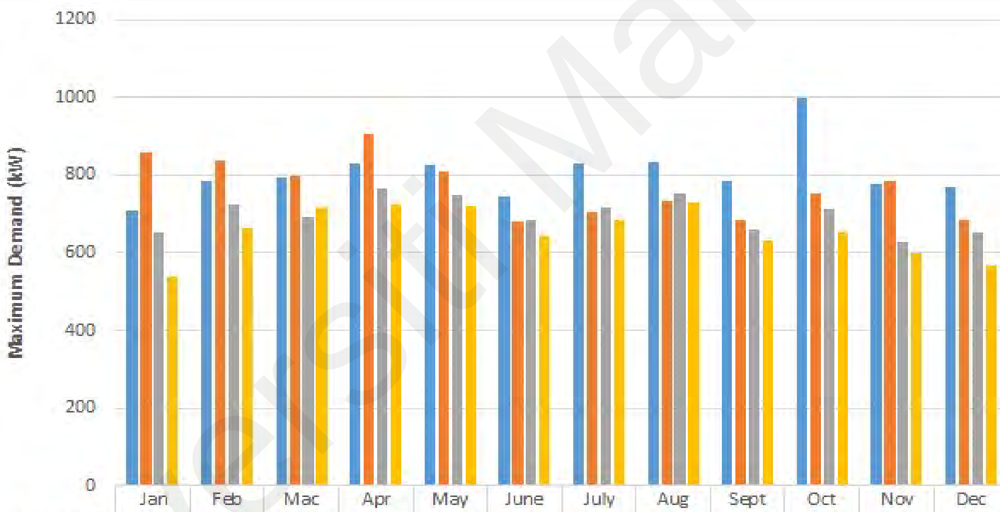
Figure 4.1: Electricity consumption at Wisma R&D between 2015-2018

Looking at the energy consumption trend shown in Figure 4.1, March was seen consistently recording the highest energy consumption within these four years. This was due to the number of occupants and activities held upon the semester registration in late February. In short, many rooms and areas, appliances, and equipment were utilised within the semester, whereas, June, September, and November show some reduction in energy consumption due to the semester break, which is normally between one to two weeks. This proves that the operation hour (t) is one of the main contributing factors toward building energy consumption.



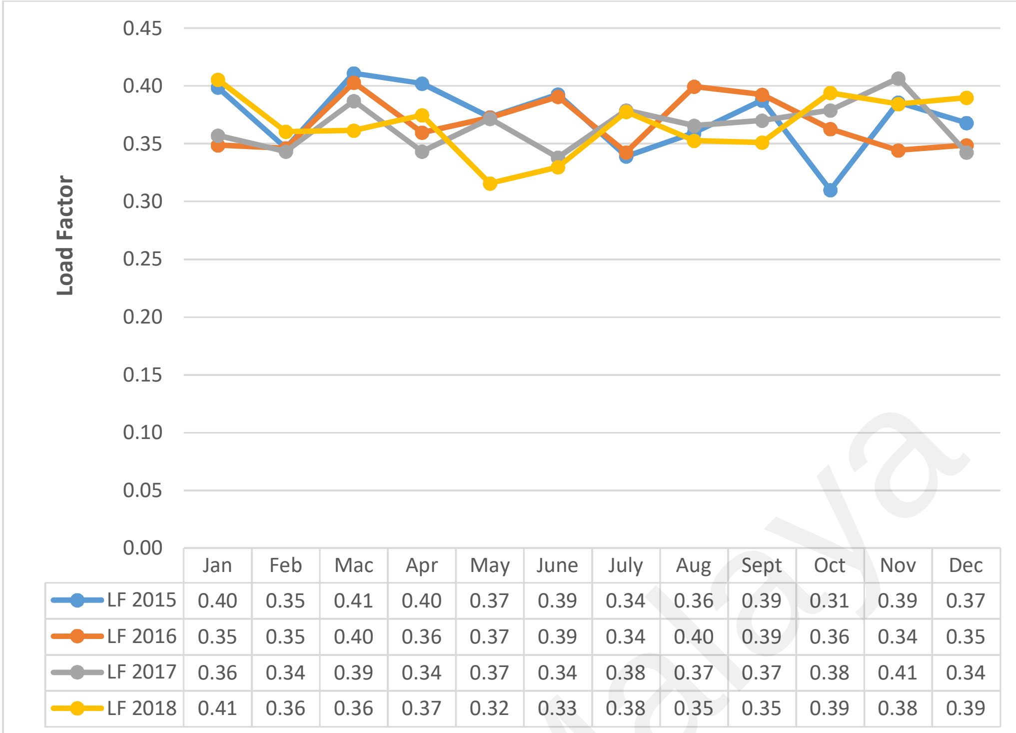
	Jan	Feb	Mac	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
AL 2015	281.86	271.78	325.59	333.85	307.40	293.08	281.89	299.01	305.08	310.28	299.27	283.43
AL 2016	299.38	290.09	322.01	325.93	302.20	265.27	241.57	293.20	268.11	273.68	270.29	238.96
AL 2017	233.21	248.52	267.42	262.26	277.71	231.33	272.10	275.69	243.85	269.55	255.41	223.66
AL 2018	219.35	239.30	258.45	271.33	227.63	212.68	259.15	256.81	222.68	256.91	230.24	221.86

Figure 4.2: AL measurement at Wisma R&D between 2015 - 2018



	Jan	Feb	Mac	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
MD 2015	707	785	792	830	824	746	831	832	787	1001	776	770
MD 2016	858	838	799	906	811	679	705	734	683	754	785	685
MD 2017	653	724	691	764	747	684	718	754	659	711	628	653
MD 2018	541	664	715	724	721	645	686	728	634	652	599	569

Figure 4.3: MD recorded at Wisma R&D between 2015 - 2018



	Jan	Feb	Mac	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
LF 2015	0.40	0.35	0.41	0.40	0.37	0.39	0.34	0.36	0.39	0.31	0.39	0.37
LF 2016	0.35	0.35	0.40	0.36	0.37	0.39	0.34	0.40	0.39	0.36	0.34	0.35
LF 2017	0.36	0.34	0.39	0.34	0.37	0.34	0.38	0.37	0.37	0.38	0.41	0.34
LF 2018	0.41	0.36	0.36	0.37	0.32	0.33	0.38	0.35	0.35	0.39	0.38	0.39

Figure 4.4: Load Factor Performance of Wisma R&D between 2015 – 2018

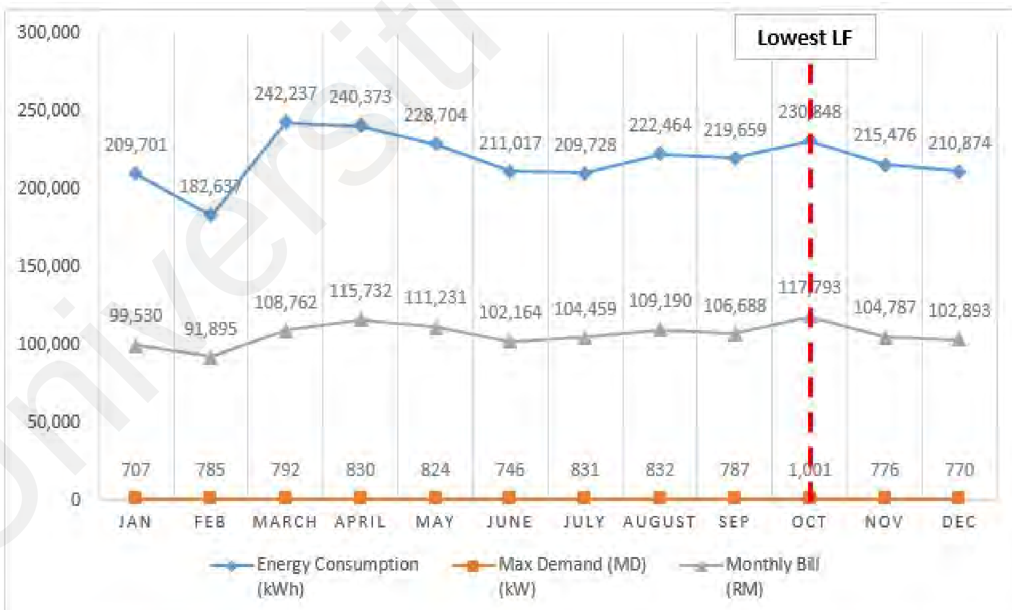


Figure 4.5: The relationship between the energy consumption, electricity charges, and MD in Wisma R&D for 2015

In conclusion, commercial building owners need to pay serious attention to the type of appliances/equipment selection, and their power rating as well as establishing a good control monitoring system. The improvement required should base on some baseline, hence several mathematical analyses were carried out in this research. The discussion is detailed in the next section.

4.2.1 Improvement in the LF Performances for Wisma R&D

Generally, commercial building operations should at least aim for an LF performance of 0.6 or preferably higher to meet the criteria of an energy-efficient building. This is the baseline of a good commercial building operation. Due to that, this research has conducted a straightforward improvement and detailed analysis based on the 2018 utility bills. The analysis aims to identify the optimum MD value that could assist the building to meet the LF of 0.6. The existing MD is labeled as MD_0 and the newly calculated MD value is labeled as MD_1. The new MD is calculated based on Equation 3.1 and is presented in Table 4.5. In summary, to achieve a targeted LF, the MD needs to be controlled effectively. There are numerous ways and solutions that could be initiated by the building owner to achieve this estimated MD. This includes and is not limited to the selection of the proper size and capacity of the equipment, installing the sensor and other suitable control devices, enhancing awareness of energy efficiency among the occupants, and many others.

Table 4.5: The optimum MD for an LF of 0.6

Year	Month	A.L	MD_0	LF_0	MD_1	Targetted LF (LF_1)
2018	Jan	219.35	541	0.41	365.59	0.60
	Feb	239.30	664	0.36	398.84	
	Mac	258.45	715	0.36	430.75	
	April	271.33	724	0.37	452.21	
	May	227.63	721	0.32	379.39	
	June	212.68	645	0.33	354.46	
	July	259.15	686	0.38	431.92	
	Aug	256.81	728	0.35	428.02	
	Sept	222.68	634	0.35	371.13	
	Oct	256.91	652	0.39	428.19	
	Nov	230.24	599	0.38	383.73	
	Dec	221.86	569	0.39	369.76	

Furthermore, as highlighted earlier, the reduction of MD will impact the monthly utility cost of a building, especially for the commercial building where the MD charges are very high. Due to this, the research continues by analysing the predicted monthly bill if the MD is reduced to MD_1. Table 4.6 shows the analysed results. It can be concluded that an amount between RM 5000 to RM 10000 could be saved by Wisma R&D building management if the MD is controlled efficiently. Moreover, this proves that significant savings on the electricity bill could be achieved through managing and controlling the MD compared to the reduction of energy consumption (kWh). However, if energy consumption could be reduced simultaneously, it would give a bigger impact on the total monthly and yearly utility bills. The outcome of the analysis should become an eye-opener to all building owners on the importance of taking initiative in controlling the activities and selecting the equipment/appliances which later on is a push factor to embark on retrofitting initiatives. Based on 2018's electricity bill presented, a total saving of RM 93445.42 could be obtained if the improvement in the LF performances is initiated by the Wisma R&D management. Eventually, the outcome presented support that the Wisma

R&D building requires a retrofitting plan and the findings proved the economic impact of embarking on the LF performance initiatives.

Table 4.6: The predicted monthly bill based on the MD_1 value

Year	Month	2018 (KWh)	MD_0	Recorded Monthly bill (RM) A	MD_1	Predicted Monthly bill (RM) B	Saving A - B (RM)
2018	Jan	163,198	541	75959.57	365.59	70644.55	5315.02
	Feb	160,811	664	78815.22	398.84	70780.77	8034.45
	Mac	192,286	715	91848.89	430.75	83236.06	8612.83
	April	195,354	724	93241.41	452.21	85006.12	8235.29
	May	169,359	721	83662.34	379.39	73311.50	10350.84
	June	153,127	645	75434.86	354.46	66631.51	8803.35
	July	192,809	686	91161.09	431.92	83462.46	7698.63
	Aug	191,070	728	91798.95	428.02	82709.68	9089.27
	Sept	160,329	634	77730.29	371.13	69765.38	7964.91
	Oct	191,144	652	89523.16	428.19	82741.72	6781.44
	Nov	165,773	599	78656.85	383.73	72134.28	6522.57
	Dec	165,063	569	77488.70	369.76	71451.87	6036.83

4.2.2 Economic and Environmental Impact of LF Performances Improvement

A straightforward economic and environmental impact was estimated from the LF Performances analysis proposed for Wisma R&D. As stated earlier, the yearly energy cost saving (A-B) is RM 93445.43, which is about 9%. This can be achieved by ensuring an LF of 0.6 by controlling the maximum demand (MD) within the building. This, on the other hand, did not directly impact the CO_2 emission, as the main aim of the LF performance approach is to reduce the building energy cost due to high charges on MD. Hence, the environmental impact is not further discussed through this approach. However, the environmental impact is further analysed in EA and simulation-based approaches as the retrofitting initiatives are particularly contributing to lower kWh consumption.

4.3 EA and Energy Performances Analysis of Wisma R&D building

As stated in section 3.8, the walk-through EA approach aimed to identify and analyse the building's energy consumption by detailing the appliances that are used, their power ratings, the types of rooms, and their usage schedules. Following the investigation, the building's potential energy savings, as well as its realistic and economical energy conservation opportunities (ECOs), was analysed. The final energy consumption resulting from the EA conducted in Wisma R&D is shown in Table 4.7. The results tabulated consist of the monthly, and yearly energy consumption. It can be concluded that the monthly energy consumption found through the EA is indifferent to the average TNB's utility bill presented in Table 4.1. In specific, the EA revealed that 220,534 kWh was consumed every month which is not so much different compared to the 196,689 kWh calculated from the average consumption of four conservative years recorded. When compared to typical use, the walk-through EA revealed a 10% increase in energy use. With the small difference, the data obtained from the EA approach is considered justifiable.

Table 4.7: Total energy consumption at Wisma R&D

No	LEVELS/ AREAS	Energy Consumption in kWh	
		Monthly	Yearly
1	Outside	673.97	8087.64
2	LEVEL LG	9704.82	116457.79
3	LEVEL G	8931.56	107178.72
4	LEVEL M	5615.46	67385.47
5	LEVEL 1	10594.76	127137.12
6	LEVEL 2	13174.48	158093.76
7	LEVEL 3	9010.89	108130.70
8	LEVEL 4	9015.05	108180.60
9	LEVEL 5	4970.02	59640.24
10	LEVEL 6	4429.92	53159.04
11	LEVEL 7	9000.42	108005.04
12	LEVEL 8	7175.52	86106.24
13	LEVEL 9	6707.89	80494.66
14	LEVEL 10	12962.75	155553.02
15	LEVEL 11	7051.48	84617.81
16	LEVEL 12	8266.50	99198.00
17	LEVEL 13	7568.00	90816.00
18	LEVEL 14	8068.19	96818.30
19	LEVEL 15	10368.34	124420.03
20	LEVEL 16	10593.79	127125.50
21	LEVEL 17	8341.96	100103.52
22	LEVEL 18	7890.81	94689.67
23	LEVEL 19	6521.90	78262.80
24	LEVEL 20	7590.66	91087.92
25	LEVEL 21	6244.81	74937.72
26	LEVEL 22	3692.92	44315.04
27	Lift	16368.00	196416.00
	Total	**220534.86**	**2646418**

The result presented in Table 4.7 is made available from a detailed walk-through EA conducted on every floor and the surrounding areas of Wisma R&D. As the appliances/equipment were divided into eight categories, hence the data for each appliance/equipment are presented and analysed respectively. Table 4.8 to Table 4.14 tabulate the findings.

Table 4.8: Energy consumption by the air-conditioning system in Wisma R&D

No	LEVELS/ AREAS	Energy Consumption in kWh	
		Monthly	**Yearly**
1	Outside	0	0
2	LEVEL LG	4989.25	59870.976
3	LEVEL G	3413.69	40964.352
4	LEVEL M	3413.69	40964.352
5	LEVEL 1	2986.98	35843.808
6	LEVEL 2	2461.8	29541.6
7	LEVEL 3	2396.15	28753.824
8	LEVEL 4	2986.98	35843.808
9	LEVEL 5	2461.8	29541.6
10	LEVEL 6	2461.8	29541.6
11	LEVEL 7	2461.8	29541.6
12	LEVEL 8	2461.8	29541.6
13	LEVEL 9	3413.69	40964.352
14	LEVEL 10	4201.47	50417.664
15	LEVEL 11	2954.16	35449.92
16	LEVEL 12	2888.51	34662.144
17	LEVEL 13	3413.69	40964.352
18	LEVEL 14	3413.69	40964.352
19	LEVEL 15	3151.10	37813.248
20	LEVEL 16	2888.51	34662.144
21	LEVEL 17	2658.74	31904.928
22	LEVEL 18	3118.28	37419.36
23	LEVEL 19	2461.8	29541.6
24	LEVEL 20	3413.69	40964.35
25	LEVEL 21	2888.51	34662.14
26	LEVEL 22	2625.92	31511.04
	Total	**75987.56**	**911851**

Table 4.9: Energy consumption by the printing devices in Wisma R&D

No	LEVELS/ AREAS	Energy Consumption in kWh	
		Monthly	**Yearly**
1	Outside	0	0
2	LEVEL LG	17.03	204.34
3	LEVEL G	51.08	613.01
4	LEVEL M	0	0
5	LEVEL 1	8.514	102.17
6	LEVEL 2	212.85	2554.2
7	LEVEL 3	0	0
8	LEVEL 4	76.63	919.51
9	LEVEL 5	0	0
10	LEVEL 6	0	0
11	LEVEL 7	272.36	3268.32
12	LEVEL 8	0	0
13	LEVEL 9	0	0
14	LEVEL 10	221.32	2655.84
15	LEVEL 11	51.08	613.01
16	LEVEL 12	17.03	204.34
17	LEVEL 13	85.14	1021.68
18	LEVEL 14	34.06	408.672
19	LEVEL 15	68.11	817.344
20	LEVEL 16	51.08	613.01
21	LEVEL 17	42.57	510.84
22	LEVEL 18	161.77	1941.19
23	LEVEL 19	34.06	408.67
24	LEVEL 20	85.14	1021.68
25	LEVEL 21	17.03	204.34
26	LEVEL 22	0	0
	Total	**1506.85**	**18082.15**

The consumption from the printing devices was recorded as zero for a few levels within the building. For instance, as level 3 is consist of a cafeteria, gymnasium, and prayer room, hence there is no consumption for it. Moreover, level M is the parking area and during the EA, there were no printing devices found in the security room that is located at this level. A similar observation was recorded during the EA process at levels 5, 6, 8, 9, and 22.

Table 4.10: Energy consumption by the lighting features in Wisma R&D

No	LEVELS/ AREAS	Energy Consumption in kWh	
		Monthly	**Yearly**
1	Outside	558.62	6703.49
2	LEVEL LG	1514.92	18179.04
3	LEVEL G	1498.95	17987.38
4	LEVEL M	1451.78	17421.36
5	LEVEL 1	2385.5	28626.05
6	LEVEL 2	4621.98	55463.76
7	LEVEL 3	1400.3	16803.6
8	LEVEL 4	1126.84	13522.08
9	LEVEL 5	1545.94	18551.28
10	LEVEL 6	1286.12	15433.44
11	LEVEL 7	1754.94	21059.28
12	LEVEL 8	1515.58	18186.96
13	LEVEL 9	1501.72	18020.64
14	LEVEL 10	1470.04	17640.48
15	LEVEL 11	1165.78	13989.36
16	LEVEL 12	1209.34	14512.08
17	LEVEL 13	1178.54	14142.48
18	LEVEL 14	1712.92	20555.04
19	LEVEL 15	1268.74	15224.88
20	LEVEL 16	1558.48	18701.76
21	LEVEL 17	1438.14	17257.68
22	LEVEL 18	1555.49	18665.86
23	LEVEL 19	1494.24	17930.88
24	LEVEL 20	1267.2	15206.4
25	LEVEL 21	966.9	11602.8
26	LEVEL 22	248.16	2977.92
	Total	**38697.16**	**464366**

Table 4.11: Energy consumption by the PC/laptops in Wisma R&D

No	LEVELS/ AREAS	Energy Consumption in kWh	
		Monthly	**Yearly**
1	Outside	54.34	652.08
2	LEVEL LG	388.08	4656.96
3	LEVEL G	280.28	3363.36
4	LEVEL M	2.86	34.32
5	LEVEL 1	640.64	7687.68
6	LEVEL 2	1967.68	23612.16
7	LEVEL 3	0	0
8	LEVEL 4	654.94	7859.28
9	LEVEL 5	205.92	2471.04
10	LEVEL 6	183.04	2196.48
11	LEVEL 7	1612.6	19351.2
12	LEVEL 8	2699.84	32398.08
13	LEVEL 9	22.88	274.56
14	LEVEL 10	3271.84	39262.08
15	LEVEL 11	416.24	4994.88
16	LEVEL 12	2056.78	24681.36
17	LEVEL 13	702.24	8426.88
18	LEVEL 14	697.84	8374.08
19	LEVEL 15	1701.7	20420.4
20	LEVEL 16	2134.88	25618.56
21	LEVEL 17	480.48	5765.76
22	LEVEL 18	474.32	5691.84
23	LEVEL 19	228.8	2745.6
24	LEVEL 20	489.28	5871.36
25	LEVEL 21	91.52	1098.24
26	LEVEL 22	0	0
	Total	**21459.02**	**257508**

Table 4.12: Energy consumption by the server racks in Wisma R&D

No	LEVELS/ AREAS	Energy Consumption in kWh	
		Monthly	**Yearly**
1	Outside	0	0
2	LEVEL LG	0	0
3	LEVEL G	0	0
4	LEVEL M	0	0
5	LEVEL 1	3294.72	39536.64
6	LEVEL 2	1647.36	19768.32
7	LEVEL 3	1647.36	19768.32
8	LEVEL 4	1647.36	19768.32
9	LEVEL 5	0	0
10	LEVEL 6	0	0
11	LEVEL 7	1647.36	19768.32
12	LEVEL 8	0	0
13	LEVEL 9	1647.36	19768.32
14	LEVEL 10	3294.72	39536.64
15	LEVEL 11	1647.36	19768.32
16	LEVEL 12	1647.36	19768.32
17	LEVEL 13	1647.36	19768.32
18	LEVEL 14	1647.36	19768.32
19	LEVEL 15	3294.72	39536.64
20	LEVEL 16	3294.72	39536.64
21	LEVEL 17	3294.72	39536.64
22	LEVEL 18	1647.36	19768.32
23	LEVEL 19	1647.36	19768.32
24	LEVEL 20	1647.36	19768.32
25	LEVEL 21	1647.36	19768.32
26	LEVEL 22	0	0
	Total	**37889.28**	**454671.36**

During the EA, there was no server rack found at levels LG, G, M, 5, 6, 8, and 22. This is due to space limitations, especially for levels LG, G, and M. The parking is located on these three levels, all of which are outfitted with vehicles. In addition, level G, where the building lobby is located, is crowded with people. On the other hand, levels 5, 6, and 8 have fewer occupants and are less frequently used. As the server rack is used to store and arranged the IT-based equipment, there is an unnecessary need for these levels to be located with a unit of the server rack.

Table 4.13: Energy consumption by the kitchen appliances in Wisma R&D

No	LEVELS/ AREAS	Energy Consumption in kWh	
		Monthly	**Yearly**
1	Outside	0	0
2	LEVEL LG	510.4	6124.8
3	LEVEL G	1087.68	13052.16
4	LEVEL M	422.4	5068.8
5	LEVEL 1	571.12	6853.44
6	LEVEL 2	1693.56	20322.72
7	LEVEL 3	3144.02	37728.24
8	LEVEL 4	819.5	9834
9	LEVEL 5	0	0
10	LEVEL 6	0	0
11	LEVEL 7	950.18	11402.16
12	LEVEL 8	0	0
13	LEVEL 9	0	0
14	LEVEL 10	192.28	2307.36
15	LEVEL 11	599.28	7191.36
16	LEVEL 12	172.48	2069.76
17	LEVEL 13	371.36	4456.32
18	LEVEL 14	202.62	2431.44
19	LEVEL 15	60.5	726
20	LEVEL 16	524.83	6297.98
21	LEVEL 17	245.43	2945.18
22	LEVEL 18	677.6	8131.2
23	LEVEL 19	497.42	5969.04
24	LEVEL 20	541.86	6502.32
25	LEVEL 21	136.4	1636.8
26	LEVEL 22	699.6	8395.2
	Total	**14120.52**	**169446.29**

During the EA, no kitchen appliances were discovered on levels 5, 6, 8, or 9. Similar to the justification for the server rack, these levels are less commonly used and have no or few occupants.

Table 4.14: Energy consumption by *Others* appliances in Wisma R&D

No	LEVELS/ AREAS	Energy Consumption in kWh	
		Monthly	Yearly
1	Outside	61.01	732.07
2	LEVEL LG	2284.92	27419.04
3	LEVEL G	2599.96	31199.52
4	LEVEL M	324.72	3896.64
5	LEVEL 1	707.3	8487.6
6	LEVEL 2	569.30	6831.61
7	LEVEL 3	423.06	5076.72
8	LEVEL 4	1702.8	20433.6
9	LEVEL 5	756.36	9076.32
10	LEVEL 6	498.96	5987.52
11	LEVEL 7	301.18	3614.16
12	LEVEL 8	498.3	5979.6
13	LEVEL 9	122.23	1466.78
14	LEVEL 10	311.08	3732.96
15	LEVEL 11	217.58	2610.96
16	LEVEL 12	275.66	3307.92
17	LEVEL 13	169.66	2035.97
18	LEVEL 14	359.7	4316.4
19	LEVEL 15	823.46	9881.52
20	LEVEL 16	141.28	1695.41
21	LEVEL 17	181.87	2182.49
22	LEVEL 18	255.99	3071.90
23	LEVEL 19	158.22	1898.69
24	LEVEL 20	146.08	1752.96
25	LEVEL 21	497.09	5965.08
26	LEVEL 22	119.26	1431.14
	Total	**14507.05**	**174085**

The results presented above excluded the lift system as it required further investigation based on the type of lift, number, or person instead of standard energy calculation. In this case, Equations 3.10 to 3.13 were referred. Based on the calculation, when compared to the other appliances and equipment in the Wisma R&D building, it was discovered that the lift uses the least energy. Given that lift energy consumption depends on the actual application, it was anticipated throughout the analysis that there would be about 400 trips per day based on the yearly student enrollment. The result shows that the R&D building's energy use of 7% of the total energy measured falls within the allowed range. This is in line with a study's findings which stated that the energy used by lifts accounts for between 1% and 15 % of the overall energy used by the building (Al-sharif, 1996). Figure 4.6 shows the percentage of energy consumption from eight appliance/equipment categories outlined in this research. According to the findings, the R&D building's power expenditure was largely accounted for by the air conditioner (34%), followed by lights (18%), server rack (17%), PC/laptop (10%), kitchen appliances (6%), and printer/photocopier (1%). In addition to the aforementioned, lift and the *others* categories both made contributions of 7% respectively. Apart from the server rack categories, it is determined that lighting and PC/laptop had exhibited a considerable impact on the overall building energy usage. From the EA analysis, both categories consumed approximately 17.5% and 9.7% of the total energy consumed in Wisma R&D. These two groups used daily amounts of energy totaling 1758.96 kWh and 975.4 kWh, respectively. The EA findings revealed that air conditioning has the biggest impact on building energy consumption, which covers approximately 34.5% of the total consumption. Based on the EA findings, air-conditioning, lighting, and PC/laptops are the main appliances/equipment that should be paid attention to in the retrofitting initiatives for this building. Further discussion and analysis are discussed in the next sub-sections.

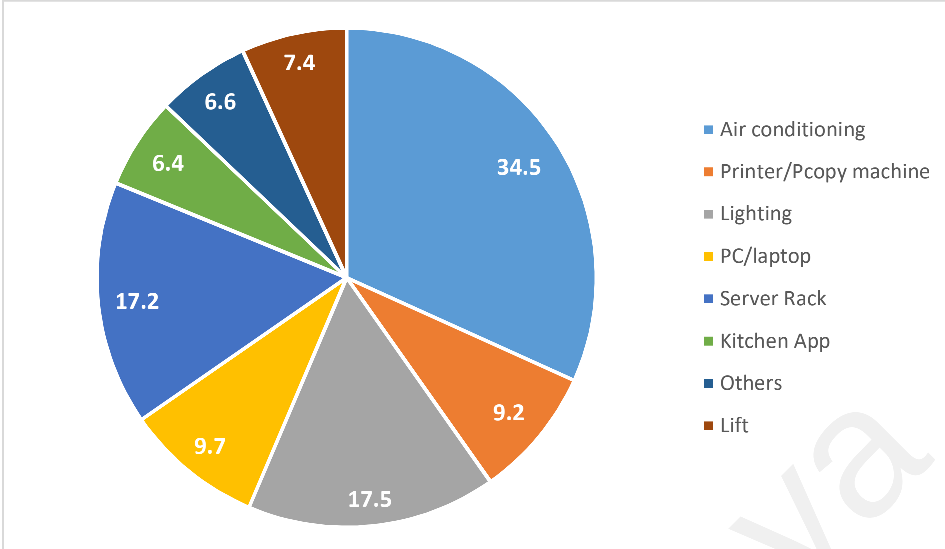


Figure 4.6: Percentage of energy consumption by eight selected categories of appliances/equipment in Wisma R&D

4.3.1 Air conditioning (AC) energy consumption and potential energy savings

The previous floor layout and the activities in the R&D building served as the basis for the quantity and sizes of condensers that were needed when the existing air conditioning systems were fixed and structured in 2009. As air-conditioning is normally sustained for ten to twenty years, hence it is impractical to replace the units in the building. Hence, another practical and cost-effective method is required in reducing the energy consumed by air-conditioning units. Prior to any retrofit initiative is to identify which floors that are among the highest consumption. Figure 4.7 depicts the monthly and yearly energy usage of the AC system on each floor of the R&D building.

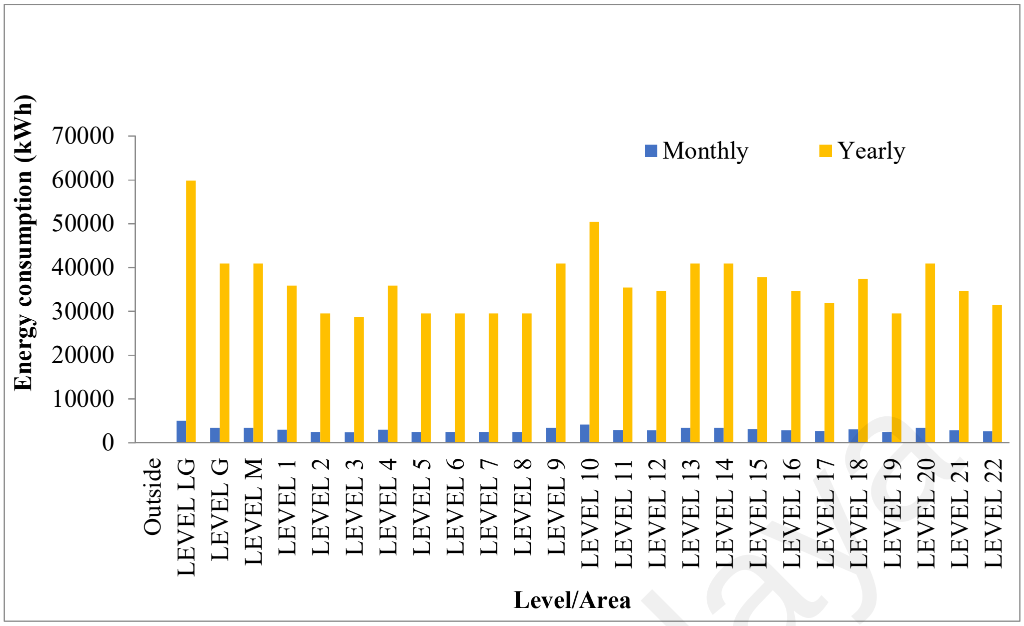


Figure 4.7: Energy used by the air conditioners in the Wisma R&D building

The energy consumption details tabulated in Table 4.8 is based on the load arrangement estimated for each floor. These loads were categorised in accordance with the types of rooms/areas, operating hours, and the activities found on each floor during the walk-through EA. Furthermore, the result from the audit observation showed that the three highest consumption floors are where the lobby, laboratories, security control room, and parking lots are situated. For the third floor (remark as Level 1), the operating hour is less than the normal operating hour. This is because, the third floor is where the cafeteria, gymnasium, and prayer room are situated in the building and most of these rooms and areas were utilized up to 3 pm only. On the other hand, levels 10, 15, and 18 are operating more than the standard operating hours as there are several laboratories, lecturer's rooms, and postgraduate working areas situated on these floors. The operation hours contributed directly to the AC's energy consumption presented in Table 4.8.

As mentioned earlier, the total number of AC units currently available in Wisma R&D was selected a decade ago, hence it is not cost-effective to replace all the units at once, knowing AC systems usually last for fifteen to twenty years. The information obtained from the Wisma R&D personnel mentioned that the amount and sizes of the AC available were determined based on the earlier floor design and Wisma R&D operations in 2009. Due to this, effective energy-saving initiatives for Wisma R&D should exclude the plan of replacing all the existing condenser units. Hence, it is practical to look into other potential savings on the AC consumption for this building. Based on the need, a detailed analysis of the daily energy usage from each floor at Wisma R&D was conducted. Table 4.15 has the details.

In general, level LG was discovered to be the floor with the largest air conditioning usage due to the security office's operating hours, with a total consumption of 226.8 kWh per day. Level 10 has the second-highest daily air conditioning energy use at 190.9 kWh, followed by levels G, M, 9, 13, 14, and 20 at 155.2 kWh each. Due to the high number of students enrolled in the Universiti Malaya Centre for Continuing Education (UMCCed), level 9 was found to have significant energy consumption for AC usage. However, levels 2, 5, 6, 7, 8, and 19 are among those that had the least energy usage by their air conditioning system based on the quantity and size of the outdoor units connected.

Table 4.15: Daily energy consumption of AC in Wisma R&D

Level	Energy @ base load (kWh)	Energy @ average load (kWh)	Energy @ peak load (kWh)	Total Consumption (kWh)
LG	131.3	47.8	47.8	226.9
G	59.7	47.7	47.7	155.2
M	59.7	47.7	47.7	155.2
1	22.4	59.7	53.7	135.8
2	22.4	32.8	56.7	111.9
3	7.5	65.6	35.8	108.9
4	22.4	59.7	53.7	135.8
5	22.4	32.8	56.7	111.9
6	22.4	32.8	56.7	111.9
7	22.4	32.8	56.7	111.9
8	22.4	32.8	56.7	111.9
9	35.8	47.8	71.6	155.2
10	95.5	47.7	47.7	190.9
11	26.9	41.8	65.6	134.3
12	35.8	47.7	47.7	131.2
13	35.8	47.7	71.6	155.2
14	35.8	47.7	71.6	155.2
15	59.7	29.8	53.7	143.2
16	35.8	47.7	47.7	131.2
17	31.3	44.8	44.8	120.9
18	52.2	32.8	56.7	141.7
19	22.4	32.8	56.7	111.9
20	35.8	47.7	71.6	155.2
21	11.9	47.7	71.6	131.2
22	59.7	29.8	29.8	119.3

As levels G, M, and 10 have been recorded to be the second highest AC consumption in Wisma R&D, it is ideal to install split units in each lab for the air conditioning as most laboratories are located on these floors. This allows the utilization of AC consumption only if an individual or group of individuals is working in the laboratories. This will potentially reduce the need to turn on the second condenser unit which directly reduces the average and peak load consumption. In addition, this recommendation is made based on the number of laboratories summarized in Figure 3.12. Unlike the current arrangement (centralized system) which had shown a high contribution to energy consumption as the

AC units are both turned on whether the laboratories are occupied or not. For a more cost-effective retrofitting strategy, installation of the split AC units should be prioritized on level 10 laboratories compared to others, as 35% or 15 out of 42 laboratories are situated on this level. This is listed clearly in Table 3.4.

Furthermore, although the VRV system is well renowned for being an energy-efficient system, the Wisma R&D building's excessive consumption was due to the lack of control measures. Power meter installation is crucial and part of the requirement in any building energy management system. This will allow close and accurate monitoring of the consumption by the building AC system, especially on the floors that recorded large consumption. Additionally, as the building areas consist of several operational divisions and tasks, it is challenging to manage how the spaces and levels are used. In this case, it is highly recommended that the building management could review the arrangement of the building layout, area, and activities associated with each level of Wisma R&D. This prospectively allows the utilization of the area/room more intensively and effectively. For instance, if all classrooms are designated on specific floors, the AC units could be turned off during the weekend and semester break. Instead, it can be switched off earlier, once all the classes are completed on weekdays. This will reduce the total energy consumption of the AC system. In addition, levels 20, 18, and 14 are a few specific examples that have sizable empty spaces and are not fully occupied, which unfortunately show a high-level AC's energy consumption. Additionally, it is advised to make a small financial investment to set up sensory systems in designated locations, such as stairways and lobbies, to enable auto power off when required.

4.3.2 Lighting Energy Consumption and Potential Energy Savings

Among the eight listed categories that have contributed to the overall electricity consumption in Wisma R&D buildings, lighting is found to be the second-highest appliance (18%) following AC. As listed in Table 3.5, a total of 7593 installed lights were identified in the entire building. The energy used by the lighting on each floor of this building is shown on a daily, monthly, and annual basis as in Table 4.10, whereas Figure 4.8 illustrates the monthly and annual consumption on each floor. From the investigation, levels 1, 2, and 7 are the three floors that, according to the data, used the most energy each day for lighting. With 755 units, 590 units, and 294 units of lights, respectively, daily energy consumption was calculated to be 210.09 kWh, 108.43 kWh, and 79.77 kWh. From the audit observation and floor layout, levels 1 and 2 of the Wisma R&D building have wider sectional areas than the other levels, which affects both the number of lights used and the amount of energy consumed. In addition, office spaces, laboratories, and classrooms occupy the majority of these three levels. Additionally, it had been noted that the following floors with the highest lighting usage were levels 14, 16, 18, 5, and 9.

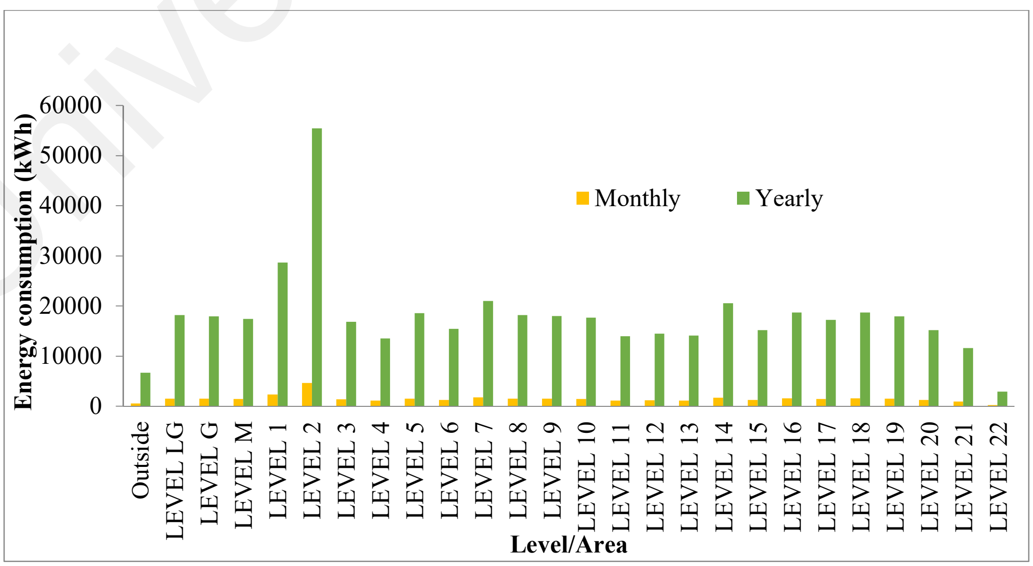


Figure 4.8: Energy consumption from lighting features at Wisma R&D

Even though it is well known that replacing all of a building's lights will result in the greatest energy savings, this research examined the potential energy and financial savings, as well as the investment and payback period, based on the replacement of a subset of the top nine floors with the highest energy consumption in the R&D building. Hence, retrofitting that include the lighting replacement involved levels 2, 1, 7 and followed by level 14, 16, 18, 5, 8, and 9. From the analysis, the top three levels consumed a total of 1758.96 kWh each day, accounting for 12%, 6%, and 4.5% of the total energy used for lighting. In summary, these nine levels collectively use 47.4% (1758.96 kWh) of the daily lighting energy used in the Wisma R&D building. Three different types of Philips fluorescent tubes and a 10 W Osram bulb are used in these nine levels, which account for 43% (3286 lights) of the building's total lighting. Annually, these nine levels consumed 261,269.7 kWh, or 47.4% of the total lighting consumption. Due to this, an in-depth analysis was carried out to examine the effect of replacing the existing lighting features on these nine levels with LED types. Three level categories were analysed thoroughly, and Level A is inclusive of the three highest lighting consumption floors identified as levels 1,2, and 7. Level B indicates the six highest consumption floors and Level C includes all nine floors that are identified to have the highest consumption from the lighting fixture. The analysis was done gradually and labeled as levels A, A+B, and A+B+C, and the details are shown in Table 4.16. As mentioned earlier, these three level categories involved a total of 261,269.7 kWh of energy consumption yearly and this research tends to observe the amount of savings that could be obtained from the retrofitting initiative.

Table 4.16: Annual lighting energy analysis from the nine floors in Wisma R&D

Level	Existing lighting type & quantity				Total power consumption (kW)	Operating hours (h/y)	Total Energy Consumption (kWh)	Energy Cost (RM)
	36 W	28 W	18 W	10 W				
A	1436	24	149	30	55.4	2376	131511.6	48002
A+B	2161	48	239	60	84.0	2376	199683.8	72885
A+B+C	2823	72	301	90	110.0	2376	261269.7	95363

Direct comparison is made between the existing lighting features with the LEDs types (e.g. replacement of 36 W and 28 W fluorescence to 16 W LED Tube, 18 W fluorescence to 8.5 W LED Tube, and 10 W Osram bulb to 3.5 W G4 Bright Philips LED). This decision is based on the fixture's length and similar luminaire so that the cost and process of replacement are maintained to a minimum. If some floors are retrofitted toward a greener building valuation, the annual energy and bill savings that the building could have is shown in Table 4.17. The outcome revealed that the lighting retrofitting process on the top three, six, and nine levels had saved annually up to 72,750 kWh, 110,381 kWh, and 144,386 kWh, respectively and the cost saving is further discussed in the next subsection. Due to its abundance across these levels, replacing a Philips fluorescent bulb rated 36 W with an LED tube rated 16 W results in the greatest savings. Added to that, it is discovered that this replacement choice offers the same 2500 lm luminaire for the corresponding rooms or areas nevertheless, with lifespans up to 50,000 hours longer than the existing fixture which is 20,000 hours.

4.3.2.1 The economic impact of the retrofitting initiative

In terms of cost savings, it was discovered that switching to LED lighting for the top three highest consumption levels might result in yearly cost savings of up to RM 26,554 and up to RM 52,701 yearly if all the existing lighting fixtures on the nine selected levels are replaced. Table 4.17 is referred to.

Table 4.17: Annual savings from the potential lighting retrofit on the nine floors at Wisma R&D

Level	LED lighting type & quantity				Operating hours (h/y)	Total Energy Consumption (kWh)	Energy saving (kWh)	Cost saving (RM)
	16 W	16 W	8.5 W	3.5 W				
A	1436	24	149	30	2376	58762.0	72750	26554
A+B	2161	48	239	60	2376	89303.1	110381	40289
A+B+C	2823	72	301	90	2376	116883.8	144386	52701

On top of the cost saving from the energy consumption, Table 4.18 shows the total investment cost (TIC) required for retrofitting process of the lighting fixtures on the selective floors in the Wisma R&D building. The TIC needed is RM 27,058 because level A represents the third highest level that consumes electricity from utilising light. If all nine of the top-level consumers are to be upgraded with LED lights in place of the current ones, the total investment might reach RM 54,177.

Table 4.18: Total investment cost (TIC) for the potential retrofitting of the lighting fixture in Wisma R&D

Level	LED lighting type & quantity		Cost/unit (RM)	Investment per lighting (RM)	TIC per level (RM)
A	16 W	1460	17	24820	27,058
	8.5 W	149	12	1788	
	3.5 W	30	15	450	
A + B	16 W	2209	17	37553	41,321
	8.5 W	239	12	2868	
	3.5 W	60	15	900	
A + B + C	16 W	2895	17	49215	54,177
	8.5 W	301	12	3612	
	3.5 W	90	15	1350	

The Payback period (PBP) for switching to LEDs from the present lighting is shown in Table 4.19. Based on 22 days per month and 9 hours of operation per day, the PBP is estimated roughly a year. If the building management could afford to invest around RM 54,177, hence it is recommended that the lighting retrofitting involved all the nine respective floors. This is due to the PBP duration which is almost similar to either the retrofit initiatives carried out for Level A, Level A+B, or Level A+B+C. In summary, the cost saving that is obtained from the replacement of LED gradually increased with the number of lighting fixtures being replaced in the building.

Table 4.19: PBP for retrofitting the lights on the respective floors based on 9 hours/day operations

Level	LED lighting type & quantity		Total Investment cost (RM)	Cost saving (RM)	PBP (years)
A	16 W	1460	27058	26553.6	1.02
	8.5 W	149			
	3.5 W	30			
A + B	16 W	2209	41321	40288.9	1.03
	8.5 W	239			
	3.5 W	60			
A + B + C	16 W	2895	54177	52700.9	1.03
	8.5 W	301			
	3.5 W	90			

Further investigation was carried out on the potential cost saving that could be achieved if the operating hours of the building are extended to 12 hours/day. Table 4.20 tabulates the result. It demonstrated that the PBP is less than one year based on 12 hours and 22 days of operation per month. The cost-saving achievement is 50% larger if the replacement of the lighting fixture is carried out for all nine selective floors. This proves that the retrofitting initiatives provide bigger savings to the building if the operating hours are longer than usual. This finding hence leads to the crucial need for the building owners to replace their inefficient bulbs with the LED-based type mainly if their operation of the selective room/areas/floors is utilized longer than usual operating hours.

Table 4.20: PBP for retrofitting the lights on the respective floors based on 12 hours/day operations

Level	LED lighting type & quantity		Total Investment cost (RM)	Cost saving (RM)	PBP (years)
A	16 W	1460	27058	35,404.8	0.76
	8.5 W	149			
	3.5 W	30			
A + B	16 W	2209	41321	53,718.6	0.77
	8.5 W	239			
	3.5 W	60			
A + B + C	16 W	2895	54177	70,267.8	0.77
	8.5 W	301			
	3.5 W	90			

Figure 4.9 differentiates the energy and cost savings based on three distinct stages of light retrofitting initiatives. It has been demonstrated that longer running hours result in greater energy and cost savings for the building, which indicates a decrease in PBP from 1 year to 0.7 years (around 8 months).

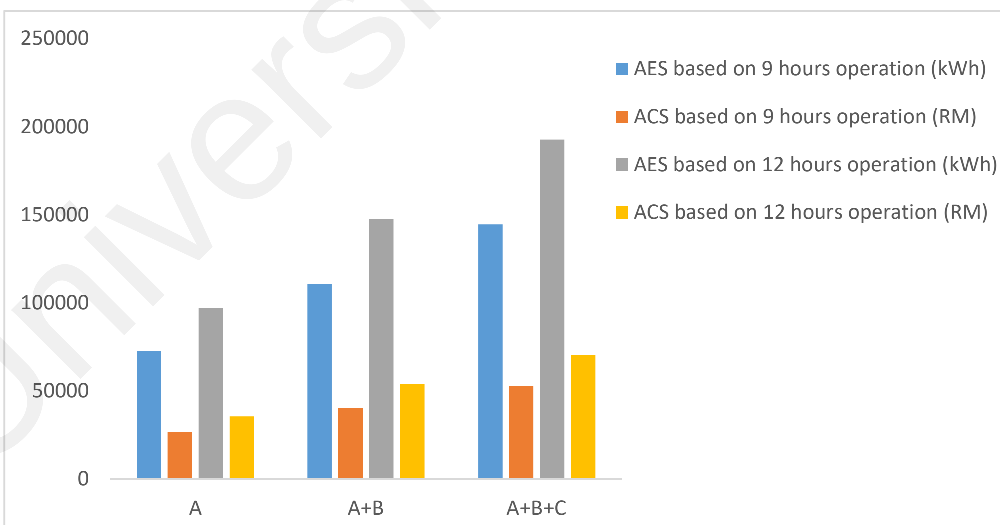


Figure 4.9: Energy and cost savings resulted from three different stages of the lighting retrofitting analysis for Wisma R&D

The PBP comparison based on the lighting retrofitting initiative in the Wisma R&D building is shown in Figure 4.10. Based on the analysis, replacing the existing lights with LEDs resulted in shorter PBP due to longer working hours. Higher savings should be possible if the retrofitting of the lighting extends to the remaining floor. However, since they are the least populated and include the fewest number of activities, the external area, LG, G, M, and level 22 (suite) were not recommended for this exercise.

Figure 4.10: PBP comparison for retrofitting the lighting for selective levels based on 9h and 12h operation

4.3.2.2 The environmental impact of the retrofitting initiative

As part of the trio effect discussed in the earlier chapter, the efficient energy consumption of one building could positively contribute to reducing the environmental effect. In this research, an online Greentech carbon calculator was utilized in estimating the impact of lighting retrofitting initiatives in Wisma R&D. The result includes the amount of CO_2 emission in kg and tonne. In addition, the online calculator provides the number of trees required in neutralizing the amount of carbon released from energy consumption. Based on the lighting-based retrofitting initiatives tabulated in Table 4.17, the amount of CO_2 reduction is presented in Table 4.21. It can be seen that the amount of energy saving (kWh) from retrofitting the three highest consumption floor lighting fixtures summed up to 72750 kWh. This saving turned up to reduce around 50 tonnes of CO_2 emission. The analysis continues with the six highest consumption floors. When the existing lighting fixtures of the floor were replaced with the more energy-efficient, the energy savings turned to be 110381 kWh, which contributed to a reduction of 76.6 tonnes of CO_2 emission. Finally, from the lighting retrofitting initiative conducted on the top nine floors of Wisma R&D has provided around 100 tonnes reduction of CO_2 emission.

Table 4.21: The environmental impact of the lighting retrofitting initiatives

Retrofitting Level	Operating hours (h/y)	Total kWh (existing) C	Total kWh (retrofitting) D	Energy saving (kWh) C-D	CO_2 emission saving
					tonne
A	2376	131511.6	58762	72750	50.49
A+B	2376	199683.8	89303.1	110381	76.62
A+B+C	2376	261269.7	116883.8	144386	100.2

In addition, the equivalent amount of tree required in neutralizing the amount of carbon release is shown in Table 4.22. The CO_2 reduction has significantly impacted the environment in a way that less space is required for tree planting to neutralize the amount of emission. This is very crucial, especially for a country like Singapore which has very limited space for tree planting. From this research, around 50% reduction in the number of trees is needed to neutralize the emission. This proved that the analysis of the lighting retrofitting initiative carried out in the Wisma R&D building could contribute significantly to the environmental impact if the retrofitting is taking place.

Table 4.22: The number of trees required to neutralized the carbon released

Retrofitting Level	No. of the tree to neutralised CO_2			
	Existing	After Retrofitting	Reduction	%
A	2340	1045	1295	55.34
A+B	3553	1589	1964	55.28
A+B+C	4649	2080	2569	55.26

On top of the above findings and potential saving advice, this building needs to have a proper lighting control system. It is one of the practical and cost-effective ECO that could assist in efficient energy consumption in building operations. This can be done by utilizing the presence of daylight penetration. It needs to be designed and initiated by the Wisma R&D management as the control lighting system is proven to be one of the effective methods in building energy-saving that could offer total annual energy savings varying from 18% to 46%.

4.3.2.3 Summary of potential lighting retrofitting initiatives

In summary, the following savings are typically realised as a result of installing lighting control systems (Delvaeye et al., 2016)and this research has highly supported them.

- The effect of the absence detector installed helps to automatically turn off the lights in the respective rooms.
- Controlling the luminaire's requirement of a certain room to reduce energy consumption for the lighting system in the building is one of the potential options. There is a linear relationship between the dimming level and the system power in building operation

According to the results of the Wisma R&D building's walk-through EA, the high energy consumption of lighting is mostly caused by four influencing factors, i.e. the types of lights, the floor area, the right luminaires, and the number of lights. Hence, one of the practical and cost-effective improvements for energy conservation can be achieved through the lighting control system upon replacing the existing lighting fixture with the LED-based type.

The administration of the facility should also be aware of how lighting contributes to energy savings. The GBI assessment criteria for non-residential new construction (NRNC) rules specifically mention lighting in two places. It receives evaluations for both Design (item EE2) and Lighting, Visual, and Acoustic Comfort (items EQ8, EQ9, EQ10, EQ11, and EQ12), which together account for 8 marks. On the other hand, the high points received in these areas have a direct impact on other categories like EE performance, BEI, and others. This amount is a direct measure in the GBI tool assessment. In other words, a building's GBI score will improve with better design and light selection for its lighting systems.

4.3.3 PC/Laptop Energy Consumption and Potential Energy Savings

. The results from the walk-through EA in Wisma R&D summarized that 10% (975.41 kWh/day) of total energy consumption was utilized by PCs and laptops, as demonstrated in Figure 4.6. This was consumed by 1117 units of PC/laptops within the building, which was identified during the EA (refer to Table 3.5). The final analysis of the monthly and yearly energy consumption from the PC/laptops was presented in Table 4.11. The majority of the PCs and laptops are located in the R&D building's laboratories, lecture halls, classrooms, and cubicles. Figure 4.11 displays the building's PC and laptop energy usage by floor. The chart shows that levels 10, 8, and 16 have the largest energy usage, using 143, 118, and 96 units of PC/laptop to produce 39,262 kWh, 323,982 kWh, and 25,618 kWh yearly consumption, respectively.

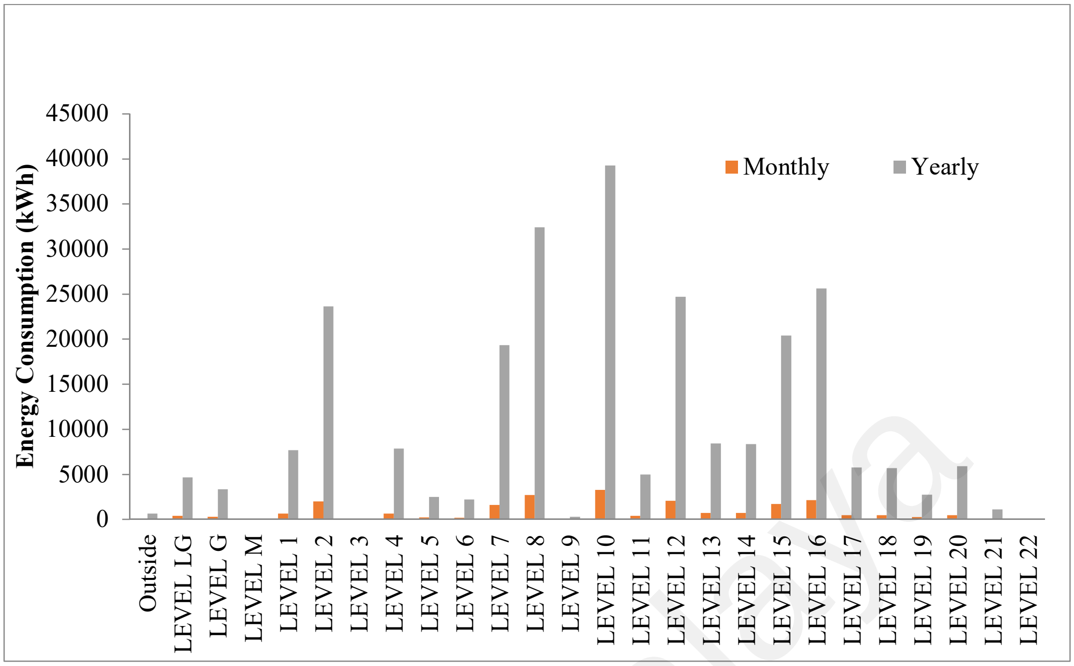


Figure 4.11: The PC/laptop energy consumption in the Wisma R&D building

Two particular PC brands that are installed in various rooms of the Wisma R&D facility are Hewlett-Packard (HP) and Dell. According to what was seen during the walk-through EA, the majority of the computers used are paired with a conventional 17-inch monitor and a CPU and various laptop models and sizes. According to the handbook data specifications, the HP LE1901w LED monitor only used 22.8 W or less. Additionally, the HP Compaq 8000 elite CPU user manual states that the CPU uses 240 W of standard efficiency (Packet, 2017), and the typical desktop computer uses 80 to 250 watts of power (University). The above information was referred to in analysing the energy consumed. As PC/laptop consumption was measured to be 10% of the total building energy consumption, hence it is wise to look into the potential energy saving. Due to some functions (such as timing, sensing, remaining active, etc.), the apparatus continues to consume energy even while it is working in standby mode. From a study, it was found that for the typical computer, a standby operation uses 1.5 W to 3 W of energy, while a monitor uses 0.5 W to 5 W. As there are 1117 laptops and PCs in this building, turning them off while not in use is one way to save energy. In specific, by considering a minimum of 2 W consumption from each PC/laptop, an estimation of 33 kWh per day could be saved from Wisma R&D's utility bill.

4.3.4 Building Energy Index (BEI) Analysis for Wisma R&D Building

Based on the energy usage listed in the electricity bills for four conservative years, Table 4.23 tabulates the BEI value for the Wisma R&D building that was measured by using Equation 3.20. It was based on the annual energy consumption and the building's total area. The information obtained from the management office stated that the facility's total floor area, or building area, is 444,727.66 square feet or 41331.6 m^2. The BEI was measured using Equation 3.20 which was earlier specified in Chapter 3. According to the data presented in Table 4.23, the BEI value for the Wisma R&D building ranges from 50.82 to 63.5 $kWh/m^2/year$. On one hand, this concludes that the Wisma R&D building is rated as an energy-efficient building by the MS 1525 since its energy consumption is far lower than 136 $kWh/m^2/year$. However, this research revealed that a building's energy efficiency cannot be judged just by looking at its BEI. This was supported in a different case study carried out at Universiti Tun Hussien Onn, where a similar pattern is demonstrated (UTHM)(Noranai & Kammalluden, 2012). Hence, to be able to evaluate the performance of one building, it is necessary to periodically do a walk-through EA. As in this research, even though the building's BEI number indicates that it is an energy-efficient structure, the EA found that the building's area is not being used to its full potential. There are still a lot of empty areas, some with very low occupancy values. A higher value was calculated when all of these floors are fully occupied. Therefore, it is crucial to implement the ECOs as suggested above to make sure the building keeps operating at its peak level over time.

Table 4.23: BEI for Wisma R&D building for 2015 – 2018

Year	AEC (kWh/year)	BEI (kWh/m^2/year)
2015	2,623,718	63.5
2016	2,481,629	60.04
2017	2,235,449	54.01
2018	2,100,323	50.82

4.4 Simulation-Based Analysis of Wisma R&D Building

The entire parameters setting that was outlined in section 3.9.2 is the key principle in ensuring reliable outcomes from the simulation-based analysis. The results displayed in this section are based on the *Energy Performance Evaluation* which was carried out using ArchiCAD software. As stated earlier, the initial *Energy Performance Evaluation* was performed on the existing building parameters of the Wisma R&D building which is labeled as A_0. The four passive design parameters (glazing, opaque, shading, and horizontal shading) that are set in the A_0 simulation are shown in Table 4.24. The energy consumption, energy cost, and carbon emission resulting from the A_0 simulation are shown in Table 4.25. This is summarized from the *Energy Performance Evaluation* result and the snapshot is shown in Figure 4.12. The annual energy consumption (kWh) is then compared with the results obtained from 2018's utility bills and walk-through EAs.

Table 4.24: Four passive design parameters selected in the simulation

Parameter	Window design parameters			Horizontal Shading				
	Glazing	Opaque	Shading	East	South East	South	South West	West
A_0	Single glazing	Frame metal [steel basic]	No shading	Low	Low	Low	Medium	High

Table 4.25: The trio effect of the existing building parameters (A_0)

Indicator		Annual Energy consumption (kWh)	Annual Energy cost (RM)	Annual CO_2 emission (kg)
A_0	Existing parameter	2177755.4	794880.72	460938.54

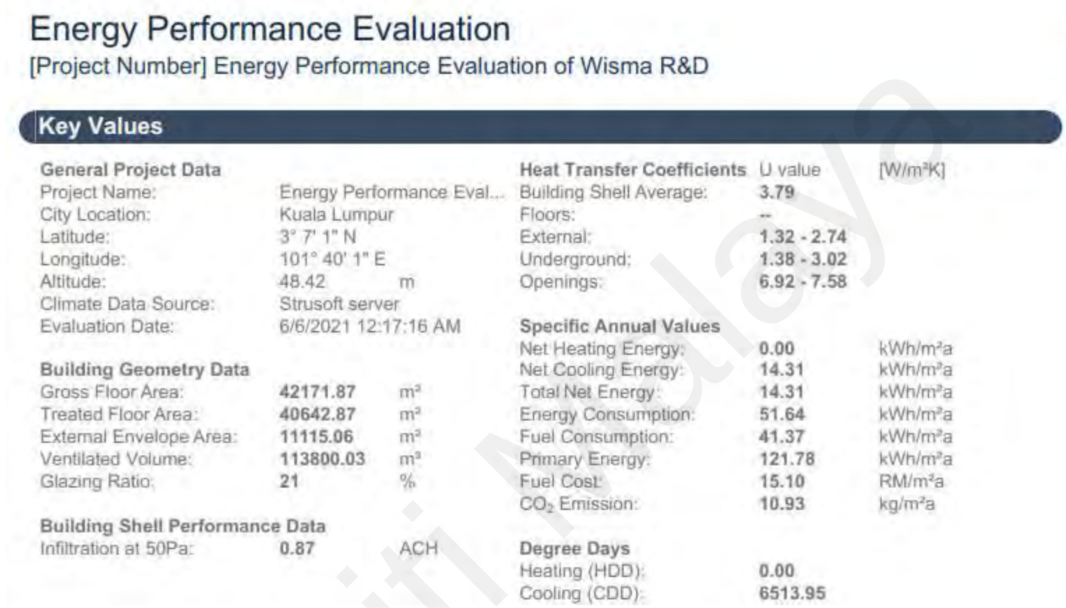


Figure 4.12: A snapshot from the *Energy Performance Evaluation* for A_0 parameters

On top of the energy consumption and CO_2 emission outcomes, the *Energy Performance Evaluation* for A_0 has proved that the virtual model of the Wisma R&D building was accurately modeled based on the gross floor area (GFA). This is vital to ensure the accuracy of the simulation-based analysis. The GFA of the building obtained through the simulation is indifferent by 840.27 m^2 (2%) from the one obtained through the EA. In specific, the total GFA was summarized from the building layout drawing for each floor obtained from the management office. The details of both analysed GFA are differentiated in Table 4.26 and some of the layout drawings of the Wisma R&D building are attached in Appendix B.

In addition, the information obtained from the *Energy Performance Evaluation* such as the infiltration rate and heat transfer coefficient (u-value) is useful for further analysis of building energy performances. For the existing building parameters, A_0, the infiltration rate is measured as 0.87 ACH and the u-value for the openings (windows and doors) is 6.92 – 7.58 W/m^2K. It is considerably high due to the existing window specifications as outlined in Table 4.24. Due to this, it is important to review and analyse the impact of different window design parameters as well as horizontal shading on building energy performances, to assist in new building development as well as retrofitting initiatives.

Table 4.26: Results obtained from three different approaches

Parameters	ArchiCAD simulation	EA (EA)	Utility bill (2018)
Gross Floor Area, GFA (m^2)	42171.87	41331.6	N/A
External Envelope Area (m^2)	11115.06	N/A	N/A
Glazing ratio (%)	21 %	N/A	N/A
Infiltration at 50Pa	0.87	N/A	N/A
Openings u-value (W/m^2K)	6.92 - 7.58	N/A	N/A
Annual energy consumption (kWh)	**2177755.4** [51.64 kWh/m^2a]	2646418	2100323
CO_2 emission (kg/m^2a)	10.93	N/A	N/A

In this research, the effect of several combinations of window design parameters and horizontal shading on building energy performances was analysed. The first part was to analyse the effect of several window design parameters together with the existing horizontal shading. Later on, the existing window design parameter (A_0) was combined with several horizontal shading. Hence, the result of the simulation-based analysis is divided into two parts; part A and part B.

4.4.1 Simulation-Based Analysis (Part A)

As mentioned earlier, the first part of the simulation-based analysis includes the analysis of several window design parameters with the existing horizontal shading. The existing horizontal shading is determined based on the observation of what has surrounded the building. Hence, it is concluded that the existing Wisma R&D buildings are having *low shades* on their east, southeast, and south sides and *medium* shading southwest, and *high* shading on the west. Figure 4.13 shows the orientation of the Wisma R&D building based on the *Qibla Direction*'s compass apps. In part A, the existing horizontal shading is set as default and remains unchanged throughout the simulation. In other words, the horizontal shading is set as in Table 4.24. Only the window design parameters are replaced with several combinations.

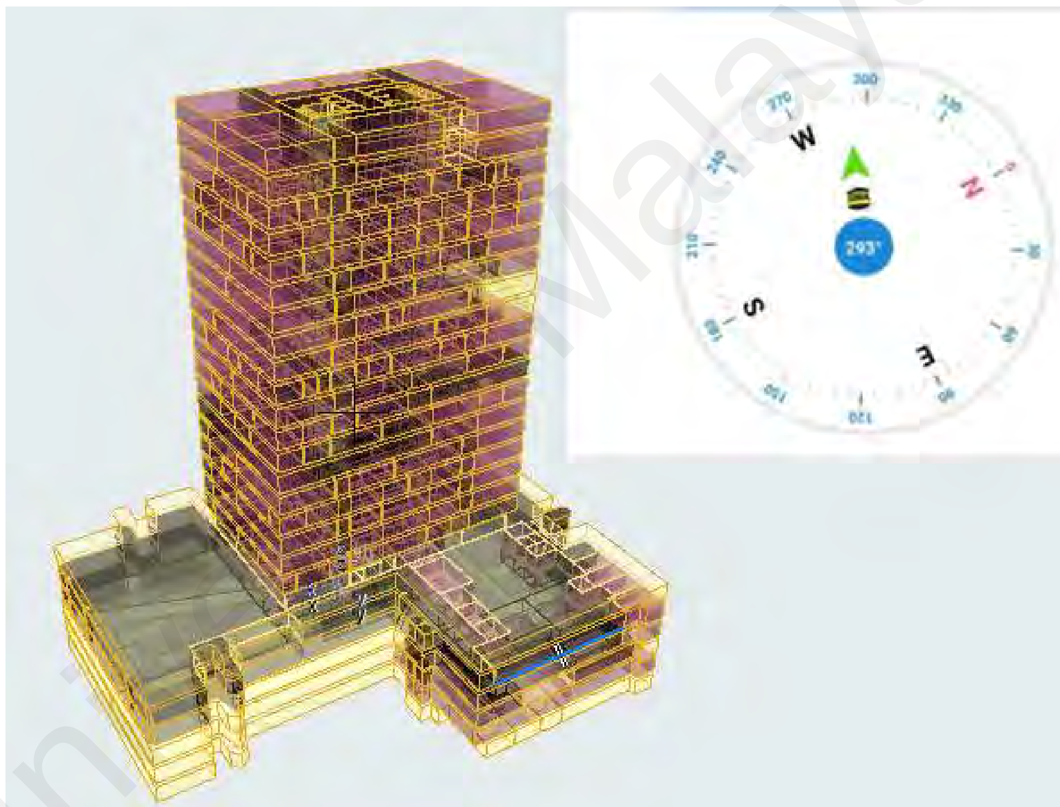


Figure 4.13: The orientation of the building through a compass-app

Table 4.27 shows the various combination of window design parameters that were analysed in this research. A_o is the initial parameter representing the existing window design parameters for the Wisma R&D building. As mentioned earlier, the outcomes from the *Energy Performance Evaluation* that was obtained during the simulation include the Heat Transfer Coefficient (u-value). The inverse of the u-value is the R-value. Later on, the average R-value was calculated for each parameter. The effect of each combination was thoroughly discussed.

Table 4.27: Varieties of window design parameters combinations

Parameter	Window details			Opening U-value (W/m²K)	Opening R-value (m²K/W)	Average R-value (m²K/W)
	Glazing material	Opaque	Shading Element			
A_0	Single glazing	Frame metal [steel basic]	No shading	6.92 - 7.58	0.132 - 0.144	0.138
A_{1-1}	Double glazing [Basic-Air filled clear]	Frame metal [steel basic]	No shading	4.18 - 7.09	0.141 - 0.23	0.1855
A_{1-2}	Double glazing [Basic-Air filled clear]	Frame metal [steel basic]	80% shading sunscreen	4.18 - 7.09	0.141 - 0.23	0.1855
A_{1-3}	Double glazing [Basic-Air filled clear]	Frame metal [steel basic]	External blind	4.18 - 7.09	0.141 - 0.23	0.1855
A_{1-4}	Double glazing [Basic-Air filled clear]	Frame metal [steel basic]	External louver	4.18 - 7.09	0.141 - 0.23	0.1855
A_{2-1}	Double glazing [Basic-Air filled clear]	Frame metal [Aluminium standard]	No shading	3.06 - 7.09	0.141 - 0.32	0.1855
A_{2-2}	Double glazing [Basic-Air filled clear]	Frame metal [Aluminium standard]	80% shading sunscreen	3.06 - 7.09	0.141 - 0.32	0.1855
A_{2-3}	Double glazing [Basic-Air filled clear]	Frame metal [Aluminium standard]	External blind	3.06 - 7.09	0.141 - 0.32	0.1855
A_{3-1}	Double glazing [Basic-Air filled dark]	Frame metal [Aluminium standard]	No shading	3.06 - 7.09	0.141 - 0.32	0.1855
A_{3-2}	Double glazing [Basic-Air filled dark]	Frame metal [Aluminium standard]	80% shading sunscreen	3.06 - 7.09	0.141 - 0.32	0.1855

Table 4.27, continued.

Parameter	Window details			Opening U-value (W/m²K)	Opening R-value (m²K/W)	Average R-value (m²K/W)
	Glazing material	Opaque	Shading Element			
A_{4-1}	Double glazing [Standard-argon fill dark low E]	Frame metal [Aluminium standard]	No shading	1.69 - 2.42	0.413 - 0.59	0.5
A_{4-2}	Double glazing [Standard-argon fill dark low E]	Frame metal [Aluminium standard]	80% shading sunscreen	1.69 - 2.42	0.413 - 0.59	0.5
A_{5-1}	Double glazing [Standard-argon fill dark low E]	Frame metal [Aluminium ultimate]	No shading	0.78 - 1.49	0.67 - 1.28	0.98
A_{5-2}	Double glazing [Standard-argon fill dark low E]	Frame metal [Aluminium ultimate]	80% shading sunscreen	0.78 - 1.49	0.67 - 1.28	0.98

The results clearly show that the replacement of window glazing from single to double glazing has provided a significant impact on the heat transfer coefficient. In specific, the glazing material chosen was *Double glazing [Basic-Air Filled Clear]* for parameters labeled from A_{1-1} to A_{1-4}. The simulation analysis showed that the average heat transfer coefficient improved from 0.138 m^2K/W to 0.1855 m^2K/W, approximately a 26% improvement. In the A_{1-1} simulation, both the opaque material and shading remain unchanged. This shows that the glazing material had a big impact on the improvement of the heat transfer coefficient value of a building. From A_{1-2} until A_{1-4}, the effect of shading was analysed. Three different types of shading elements; which include 80% shading, external blind, and external louvers were utilized. From the simulation, there was no effect on the heat transfer coefficient values upon changing the different types of shading material. Similar outcomes were shown throughout the simulation process. The changes made to the shading devices repeated on the A_5 combinations further supported the earlier finding. On the other hand, the simulation result has shown the effect of the opaque material. For instance, the window design parameters labeled as A_{2-1} until A_{2-3} involved the replacement of the steel frame type with an aluminum frame type. In this research, the opaque material, in particular, was been replaced from *Frame metal [steel basic]* with *Frame metal [Aluminum Standard]*. This has allowed an improvement of heat transfer coefficient up to 19.5% (from 0.1855 m^2K/W to 0.2305 m^2K/W) compared to the steel frame type.

Next, combinations that were labeled as A_{3-1} until A_{3-2} involved the change to the glazing material only. In particular, the *Double glazing [Basic-Air filled clear]* was replaced with a better double-glazed material which is named *Double glazing [Basic-Air filled dark]*. From the simulation result, there was no effect seen on the heat transfer coefficient compared to A_2's set of combinations. Hence, it can be concluded that changing different types of double glazing is not going to provide a significant effect on the heat transfer coefficient for the Wisma R&D building. Particularly, A_2 and A_3 combinations are providing similar effects on the heat transfer coefficient.

Next, the *Double glazing [Standard-argon fill dark low E]* was selected, while remaining the opaque material and shading devices as earlier setup. Amazingly, the argon-fill type of material has shown a significant effect on the heat transfer coefficient value. The improvement is very huge. In particular, it resulted in an improvement of 54% (from 0.2305 m²K/W to 0.5 m²K/W). This shows that double-glazed argon is superior to the double-glazed basic-air-filled type in terms of improving the heat transfer coefficient of the Wisma R&D building. Finally, the window design parameters labeled as A_5 have shown a bigger improvement in the heat transfer coefficient for the building. The argon-type glazed which combined with aluminum ultimate opaque material had further improved the R-value up to 49% (from 0.5 m²K/W to 0.98 m²K/W). This is in line with research findings that suggested the need of keeping the thermal coefficient below 0.5 m^2K/W for the building situated in a hot region (Mirrahimi et al., 2016). Looking at the window parameters combination presented in this research, only A_5 parameters could fulfill the requirement of thermal coefficient as stated.

In conclusion, the effect of glazing and opaque material is more significant compared to the shading devices. This is based on the combinations shown in Table 4.27. The finding has proved that a proper selection of window design parameters is capable to provide an effective reduction of the opening's U/R-value of one building. Additionally, the material used in high-performance glazing, which is now on the market, typically has very low shading coefficients, which eliminates the need for exterior shading devices(WBDG, 2018). As a general rule, when the heat transfer coefficient improved, the energy consumption will improve too. Surprisingly, the outcome from the *Energy Performance Evaluation* simulation carried out from various window design parameters of Wisma R&D did not show any changes in energy consumption. Perhaps, the changes were too small to notice through simulation. In short, from the thirteen different combinations simulated as in Table 4.27, the annual energy consumption remains at 51.64 kWh/m^2 which is equivalent to 2,177,755.4 kWh. Hence, an in-depth analysis was further carried out through the Glazing Ratio (GR) or Window-to-Wall Ratio (WWR) and the orientation of the window. Some of the *Energy Performance Evaluation* results for Part A are shown in Appendix C.

4.4.1.1 Measurement of GR or WWR

The analysis of the building energy performances continues by examining the GR/WWR of the building. Hence, the position of each window was identified from the virtual building model. This in-depth analysis can be carried out through the simulation-based approach, where particularly in ArchiCAD, which allows the user to view each window position from its embedded feature. The data were summarized in Table 4.28 which consists of the position, location, opaque, and glazing areas of the windows.

Table 4.28: Window position and its area for the Wisma R&D building

Position	Location/Building Block	Opaque (m^2)	Glazed (m^2)	Total Window Area (m^2)
East	Offices	110.49	712.47	822.96
West	Offices	94.25	607.75	702
South	Offices	24.65	158.95	183.6
West	Circulation and Common Area	17.4	112.2	129.6
North	Offices	15.95	102.85	118.8
East	Circulation and Common Area	15.66	100.98	116.64
West	Services and Facilities	15.08	97.24	112.32
East	Services and Facilities	11.6	74.8	86.4
North	Services and Facilities	8.7	56.1	64.8
East	Circulation and Common Area	7.25	49	56.25
East	Services and Facilities	3.76	41.04	44.8
North	Circulation and Common Area	4.06	27.44	31.5
North	Services and Facilities	3.4	26.6	30
North	Services and Facilities	3.48	23.52	27
East	Circulation and Common Area	3.06	23.94	27
North	Circulation and Common Area	2.9	18.7	21.6
East	Services and Facilities	2.03	13.72	15.75
South	Circulation and Common Area	1.7	13.3	15
South	Circulation and Common Area	1.74	11.76	13.5
East	Services and Facilities	1.36	10.64	12
South	Circulation and Common Area	1.45	9.35	10.8
South	Services and Facilities	1.45	9.35	10.8
Total area		351.42	2301.7	2653.12

Based on Equation 3.22, the GR or WWR was calculated. The result proved that ArchiCAD's *Energy Performance Evaluation* is capable to simulate the GR or WWR of one building from the virtual building that is accurately modelled. The calculated value of the GR or WWR for Wisma R&D is 20.7% (as shown below) and the simulated GR shown in the *Energy Performance Evaluation* is 21%. (Refer to Figure 4.12). Based on numerous findings, 20% GR is considered acceptable for a hot and humid country like Malaysia. In other words, the simulation result proves that the window design of the Wisma R&D building is acceptably good. In addition, the GR value proves that the glazing improvement is unnecessary. This result was consistent with that of (Evola et al.,

2017) which showed that shade is a highly effective design element for a structure with a lot of glass surfaces. Hence, the retrofitting initiative should focus on the glazing and opaque material improvement, which was proven to provide a better heat transfer coefficient for the building.

$$GR/WWR = 2301.7\ m^2 / 1115.06\ m^2 = 20.7\%$$

As recommended above, the retrofitting initiative for Wisma R&D should be focusing on glazing and opaque materials. However, from the cost perspective, the building owner could decide on the amount that could be possibly spent for this purpose. If budget is not a constraint, the entire windows could be retrofitted with better glaze and opaque materials. However, if there is a limitation in their budget, priority should be given to the windows which are positioned on the south side, followed by the east and west. This is based on the general sun path diagram in Malaysia. Based on the sun path diagram, the highest solar angles, and shadow angles could be determined.

The location of the best window position and the total area for each side could be done through the simulation-based approach. For the existing building, ArchiCAD allows the identification of the window position and its total area from the virtual building model. For the Wisma R&D building in specific, the virtual building that is modelled has allowed the author to summarise the total window areas for each position, and Table 4.29 is referred to. The result shows that most of the window orientation is at the east and west positions, which received a high penetration of sunlight within a short period. Based on the virtual building model, estimated about 36% or 943.92 m^2 is the west-faced window. On this point, in particular, the building was designed by considering the amount of sunlight penetration based on the sun path of Kuala Lumpur (Aminuddin, Rao, & Thing, 2012; DOSM, 2019b; Tahbaz, 2013).

In addition, by referring to the overall window area of the Wisma R&D building, only 19.8% or 527.4 m^2 are designed to the south and north sides. The east-positioned window is summarised as the highest window area, follows by the west-positioned window, which is 45 % and 36% respectively. In building design, the window that is positioned to the north side received the lowest sunlight penetration and for this case, the Wisma R&D building had only 11% of its window position to this side. Hence, south-positioned windows are to be given the highest priority in the retrofitting initiatives of the Wisma R&D building, followed by east, west, and north-positioned windows subsequently. This is in line with the finding by (Mirrahimi et al., 2016) which stated that for hot climate countries, it is suggested that the window elongation could be extended to east and west-positioned to control excessive heat gain into the building.

Table 4.29: Summary of window area for different positions in Wisma R&D

Position	Opaque (m^2)	Glazed (m^2)	Total Window Area (m^2)
East	155.21	1026.59	1181.8
North	38.49	255.21	293.7
West	126.73	817.19	943.92
South	30.99	202.71	233.7
	351.42	2301.7	2653.12

In summary, this research has provided insight into how the building window design could impact the building's energy performance. The interactive analysis of building energy performances could then assist in making an informed decision on prioritizing the effective retrofitting initiatives that suited the budget and capability of the building owner.

4.4.1.2 Impact on the infiltration rate (AHD) of a building

On top of the heat transfer coefficient and the GR/WWR analysis, the simulation-based approaches allow the building owner to analyse its building performances through the infiltration rate. Similar to the heat transfer coefficient (U/R-values), the infiltration rate was obtained from the *Energy Performance Evaluation* and is referred to estimate the cooling load demand of one building, which is required to remove moisture in a leaky building/room. Alike the U/R-value, the simulation concluded that the infiltration rate has no impact from changing the building shades. This finding is in line with the finding by (WBDG, 2018), which asserted that the solar orientation of a particular building façade is a key factor in the effectiveness of shading devices, and as mentioned earlier, the window position in Wisma R&D is considered acceptable for a Malaysian building design. Particularly, the shade design does not have any contribution towards the infiltration rate of the building. However, the glazing and opaque material selection had shown a significant impact on the infiltration rate when the thirteen different window design parameters are simulated in ArchiCAD. In short, the glazing and opaque selection do contribute to the air leakage and tightness of one building which is shown in its infiltration rate value, represent in ACH.

As mentioned earlier, the infiltration rate amount will contribute to the cooling load demand of one building. This is because removing moisture from a building requires more energy than removing heat from solar radiation, which is spread throughout the building (DOSM, 2019b; Razad, 2007). The 13 window design parameters combinations that are earlier presented in Table 4.27 is again referred to. From the simulation, ArchiCAD's *Energy Performance Evaluation* has provided the infiltration rate for the Wisma R&D building resulting from different window design combinations. Table 4.30 has the detail. The first simulation that involved replacing the initial glazing material (single-glazed) with double-glazing (Basic Air-Filled clear) did not show any changes in the infiltration rate. Only up until the steel window frame was switched over to the aluminium frame type, was the infiltration decreased by 50% (from 0.87 to 0.44 ACH). Two further varieties of double-glazing materials, namely *Basic-Air filled dark* and *Standard-argon* *fills dark low E*, were included in the simulation. However, switching from double-glazed *Basic-Air-filled clear* (A_2) to double-glazed *Basic-Air filled dark* (A_3) did not show any impact on the infiltration rate. Later, the infiltration of the structure was lowered to 0.31 ACH by combining an argon-filled glazed window with an aluminium frame material.

Table 4.30: The infiltration rate of various window design parameters for Wisma R&D

Parameter	Window details			Average R (m^2K/W)	Infiltration at 50 Pa (ACH)
	Glazing material	Opaque	Shading Element		
A_0	Single glazing	Frame metal [steel basic]	No shading	0.138	0.87
A_{1-1}	Double glazing [Basic-Air filled clear]	Frame metal [steel basic]	No shading	0.1855	0.87
A_{1-2}	Double glazing [Basic-Air filled clear]	Frame metal [steel basic]	80% shading sunscreen	0.1855	0.87
A_{1-3}	Double glazing [Basic-Air filled clear]	Frame metal [steel basic]	External blind	0.1855	0.87
A_{1-4}	Double glazing [Basic-Air filled clear]	Frame metal [steel basic]	External louver	0.1855	0.87
A_{2-1}	Double glazing [Basic-Air filled clear]	Frame metal [Aluminium standard]	No shading	0.1855	0.44
A_{2-2}	Double glazing [Basic-Air filled clear]	Frame metal [Aluminium standard]	80% shading sunscreen	0.1855	0.44
A_{2-3}	Double glazing [Basic-Air filled clear]	Frame metal [Aluminium standard]	External blind	0.1855	0.44
A_{3-1}	Double glazing [Basic-Air filled dark]	Frame metal [Aluminium standard]	No shading	0.1855	0.44
A_{3-2}	Double glazing [Basic-Air filled dark]	Frame metal [Aluminium standard]	80% shading sunscreen	0.1855	0.44
A_{4-1}	Double glazing [Standard-argon fill dark low E]	Frame metal [Aluminium standard]	No shading	0.5	0.44
A_{4-2}	Double glazing [Standard-argon fill dark low E]	Frame metal [Aluminium standard]	80% shading sunscreen	0.5	0.44
A_{5-1}	Double glazing [Standard-argon fill dark low E]	Frame metal [Aluminium ultimate]	No shading	0.98	0.31
A_{5-2}	Double glazing [Standard-argon fill dark low E]	Frame metal [Aluminium ultimate]	80% shading sunscreen	0.98	0.31

As stated in the literature review, the infiltration rate recommended by Jabatan Kerja Raya for Malaysian government buildings is 0.5 ACH (Razad, 2007), whereas according to (ASHRAE, 2001), a building is regarded to be airtight if its infiltration reading is between 0.33 – 0.38 ACH. From this research, it was demonstrated that the type of glazing and opaque materials chosen had a direct impact on the air infiltration during the simulation. In specific, the best window-building material combination, according to the summary, was found in A_5 with an infiltration value of 0.31. In conclusion, A_0 and A_1 combinations are rated as loose airtightness, while A_2, A_3, and A_4 are rated as medium airtightness. Thus, a retrofitting initiative on the window material is an effective move in enhancing the building energy performance for the short and long term as it assists in improving the air tightness of a building and the infiltration rate. Finally, air tightness is known to be closely related to the cooling load and is further discussed in the next subsection.

4.4.1.3 Summary of Part A evaluation of the trio effect

The result obtained from the *Energy Performances Evaluation* in ArchiCAD has allowed the users to evaluate the impact of the window design parameters on several building performances mainly the heat transfer coefficient (u/R-value) and the infiltration rate (ACH). The findings then led to the cooling and heating load requirement of a building, which in this research only involved the cooling load demand.

Earlier, the simulation results had allowed the author to conclude that the south-facing windows are the ones that most benefitted from effective shade design and this applies mainly to the hot weather country. Due to the Wisma R&D building model's predominantly east and west-facing windows, it was determined that the choice of shading material had no impact on both the heat transfer coefficient and infiltration rate of the building.

The given results have highlighted possible energy conservation measures for the management to examine the necessity for an appropriate retrofitting activity for Wisma R&D. It is crucial that the building is able to lower its cooling load, which has so far accounted for the majority of energy use (34%) throughout building operation. This can be effectively carried out by retrofitting the windows by improving the glazing and opaque material. Because of the building's high electricity expenses and poor load factor performances, it is essential to identify the energy-saving strategies that will have a major influence on energy consumption, energy costs, and CO_2 emissions. It is up to the management of Wisma R&D either to retrofit the whole windows or only focus on the specific position. All the decision is made based on the budget and ROI expectation of the building owner.

According to (S.Sadrzadehrafiei, K.Sopian S.Mat, & C.Lim, 2012), the infiltration accounts for 3% to 4% of the building cooling load. In parallel, several studies on window glazing assert that switching from single clear to double low E glazed material has resulted in an annual cooling energy savings decrease of 6% (Alajmi, 2012) (Cuce, 2018). On the basis of the ideal window material combination from this research (A_5), the author chose to analyse the impact of a 3% reduction on the cooling load. Hence, the lower load value for the air conditioning system was added to the model. The new air-conditioning load added in the ArchiCAD building model is 242,500 kW due to the 3% drop from the current air-conditioning system load, which is about 7500 kW.

As this research focuses on the trio effect, hence data presented in Table 4.31 tabulates the impact of the 3% cooling load reduction due to the selection of ideal window design parameters for Wisma R&D. However, the cost displayed resulted from the *Energy Performance Evaluation* only includes the fuel cost, hence, the TNB's tariff for commercial buildings is used to manually compute the cost of energy consumption and saving. Based on the C1 TNB's business tariff, which has a per-unit cost of RM 0.365/kWh, the annual energy cost was determined. The maximum demand charge was not included in the computation, thus the calculated energy cost was less than the utility bill recorded in 2018 (RM 1.045, 006.98).

Next, the environmental impact was analysed. The kWh consumption obtained from ArchiCAD's *Energy Performance Evaluation* was inserted in the online *Greentech carbon calculator*. The results show that the existing building parameters (A_0) turned out to emit 460938 kg CO_2 whereas the proposed building parameters (A_5), which ultimately contribute to a 3% lower cooling load (B) had turned out to emit 459673 kg CO_2, a saving of 1265 kg CO_2 annually. From the standpoint of offsetting the carbon emission, the reduction in CO_2 release has reduced the number of trees required from 42460 to 42113, a saving of 347 mature trees (>5 years). In summary, savings of 18133.9 kWh, RM6618.18, and 1265.16 kg CO_2 were obtained from retrofitting the existing window design (A_0)to A_5 annually.

Table 4.31: Energy conservation and its saving for Wisma R&D

Indicator		Annual Energy consumption (kWh)	Annual Energy cost (RM)	Annual CO_2 emission (kg)
A_0	Existing parameter	2177755.4	794880.72	460938
B	3% cooling load reduction	2159621.5	788261.84	459673
	Saving (A-B)	18133.9	6618.88	1265
	Estimate saving (A-B)/A_0 in %	1	1	0.3

4.4.2 Simulation-Based Analysis (Part B)

As mentioned earlier, the second part of the simulation-based approach involves the analysis of horizontal shading. Based on Table 3.12, the initial *Horizontal Shading* was set based on the author's observation around the building. For instance, it appears that the west (W) side of the building is shaded by the 310-meter-tall Menara Telekom building.

This Skyscraper building consists of 55 floors which have provided *high shade* for the Wisma R&D building and are clearly shown in Figure 4.14. In addition, the southwest (SW) side of the building is set as *medium shade* due to the Victoria Hotel that is situated at that particular location. The remaining sides are set at *low shade*. Hence, the entire simulation in Part A was carried out with the default shade set in the *Horizontal Shading*. However, the outcomes from the Part B simulation were based on the below combinations which are tabulated in Table 4.32. The aim was to analyse the effect of the *Horizontal Shading* on the Wisma R&D building. The *Energy Performance Evaluation* was performed to specifically analyse the *Horizontal Shading* effect on the heat transfer coefficient, infiltration rate, and indirectly the trio effect from Wisma R&D's passive building design.

Table 4.32: The arrangement for Horizontal Shading in Part B simulation

Parameter	**Window details**			**Horizontal Shading**				
	Glazing material	**Opaque**	**Shading Element**	**E**	**SE**	**S**	**SW**	**W**
A_0B_1	Single glazing	Frame metal [steel basic]	No shading	L	L	L	M	H
A_0B_2			No shading	H	H	L	M	H
A_0B_3			No shading	H	H	H	H	H
A_5B_1	Double glazing [Standard-argon fill dark low E]	Frame metal [Aluminium ultimate]	No shading	L	L	L	M	H
A_5B_2			No shading	H	H	L	M	H
A_5B_3			No shading	H	H	H	H	H

Figure 4.14: The TM Skyscraper beside the Wisma R&D building

Referring to Figure 3.19, one of the useful built-in features of ArchiCAD software is the *Environmental Setting*. It allows the building owner to analyse the effect of the shades that are surrounded the building, in specific, it is called *Horizontal Shading (HS)*. One of the examples of the *HS* setup in Part B is shown in Figure 4.15. In this example, the shade setup was changed from the initial setup (B_1) to the east (E) = High, southeast (SE) = High, south (S) = Low, southwest (SW) = Medium, and west (W) = High and is labeled as B_2. In other words, S, SW, and W shades remain unchanged from the initial setup and this setup is labeled as B_2. From the simulation outcomes, it was found that when the *HS* for the E and SE sides were changed to *high shade*, the effect is only seen with the *Double glazing Standard Argon fill dark low E* material with the combination of the *Aluminium*

Ultimate metal frame (A_5). The results for A_5B_2 provide a significant effect on to heat transfer coefficient (u/R-value) of the building. Earlier, a similar setup for the *HS* (B_2) was done with the single glazing material (A_0), but there was absolutely no impact seen on the outcomes (A_0B_2). A further simulation on the *HS* was carried out and is labeled as B_3. In specific, the B_3 setup constructs the *HS* for Wisma R&D as High for all angles. Figure 4.16 is referred to. Similar to A_5B_2, the A_5B_3 setup showed the same effect. However, there was no impact seen on A_0B_3. In conclusion, the simulation results on the *HS* analysis showed that there were no effects with the A_0's glazed and opaque materials, but provide a significant impact on the higher glazed and aluminum-based opaque-type materials (A_5). In summary, B_1, B_2, and B_3 are the different *HS* setup selections in the Part B assessment of this research and the results are shown in Table 4.33. Some of the *Energy Performance Evaluation* results for Part B are shown in Appendix C.

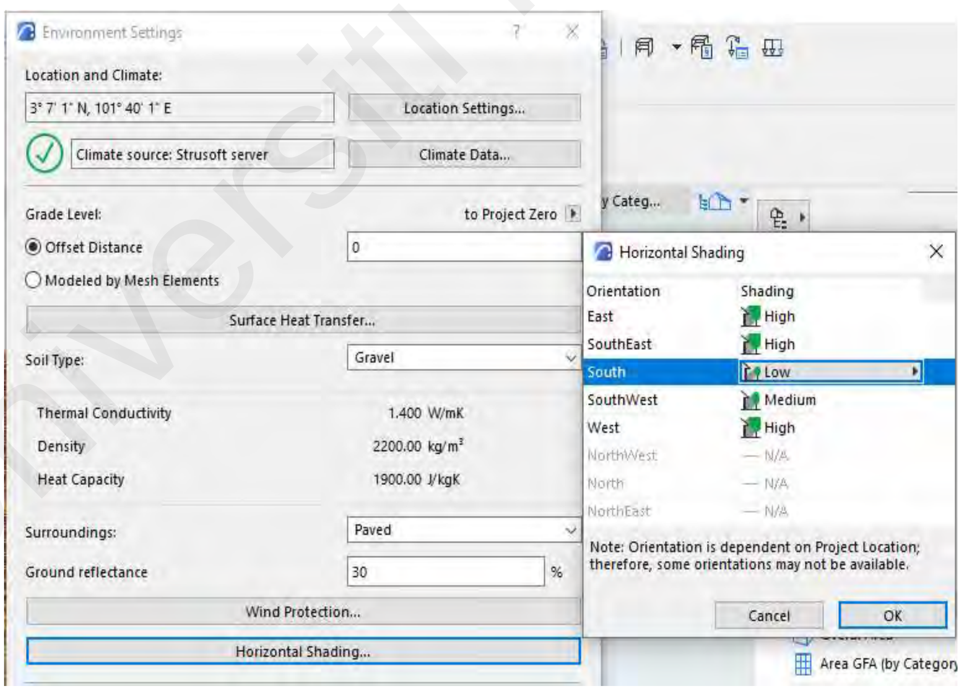


Figure 4.15: The Horizontal Shading setup labeled as B_2

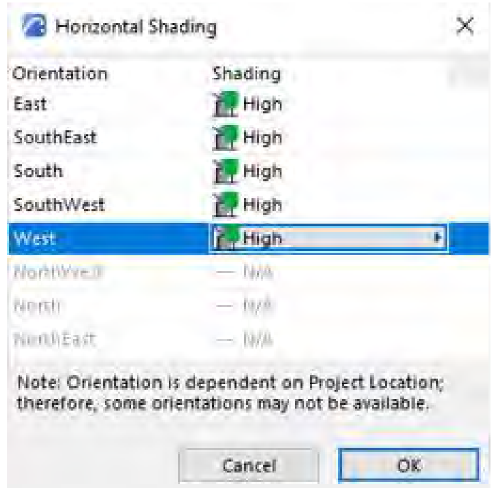


Figure 4.16: The Horizontal Shading setup labeled as B_3

Table 4.33: Outcomes from Part B simulation

Parameter	Window details			Horizontal Shading					Opening U-value (W/m²K)	Infiltration at 50 Pa (ACH)
	Glazing material	Opaque	Shading Element	E	SE	S	SW	W		
A_0B_1	Single glazing	Frame metal [steel basic]	No shading	L	L	L	M	H	6.92 - 7.58	0.87
A_0B_2			No shading	H	H	L	M	H	6.92 - 7.58	0.87
A_0B_3			No shading	H	H	H	H	H	6.92 - 7.58	0.87
A_5B_1	Double glazing [Standard-argon fill dark low E]	Frame metal [Aluminium ultimate]	No shading	L	L	L	M	H	0.78 - 1.49	0.31
A_5B_2			No shading	H	H	L	M	H	1.42 - 7.09	0.31
A_5B_3			No shading	H	H	H	H	H	1.42 - 7.09	0.31

4.4.2.1 Discussion from the Part B analysis outcomes

Based on Equation 3.23, the heat transfer coefficient (u/R-value) of one building is determined by measuring the heat flow rate (q) over the different temperature values between the two environments. In the case of a building, the two environments are referred to as the building's internal and external temperatures. In the case of the single-glazed material (A_0), the heat flow rate (q) is high and the temperature difference is estimated at around 8°C. Hence, even though the temperature difference was reduced due to Horizontal Shading improvement, the effect is not significant. However, for the double-glazed Standard-Argon material (A_5), as the heat flow rate is very low, the reduction in the temperature difference between the internal and external has resulted in a higher heat transfer coefficient (u/R-value). Hence, if the decision is made to retrofit the window-glazed material to a higher-glazed type, it is not advisable to consider higher shades for the building.

4.5 Practical Retrofitting Plan for High-Rise Buildings in Malaysia

Based on the findings explained in the earlier sections, it is highly recommended that the Wisma R&D management conduct the LF performance analysis urgently based on the latest TNB utility bill (2019 – 2022). This will assist in understanding the LF of the building based on the latest building operation. The LF improvement initiatives suggested earlier should be embarked especially in controlling the MD throughout the operation. It could assist the management to cut down around 9% to 10% of the utility bills.

Next, the most practical retrofitting plan for high-rise buildings is to improve the AC system, lighting, and PC/laptop energy consumption. Changing the lighting bulb to LED has a sound impact on the trio effect and the ROI is considered short and affordable to many.

Furthermore, as the A_5 window parameters combination provides the optimum improvement to the cooling load demand, it is highly recommended that the building owner work on replacing the window's glazing and opaque material. The reason is due to the obvious impact on the infiltration rate upon replacing the opaque from aluminium standard to aluminium ultimate material (A_4). A good air tightness within a building is achieved mostly when the infiltration rate is measured between 0.33 to 0.38; therefore, the A_5 window parameter combinations are recommended for Wisma R&D. By achieving an infiltration rate of 0.31, the cooling load reduction of 3% is assumed. Figure 4.17 illustrates the linkages between the R-value and the infiltration rate. It displays the precise point at which the R-value significantly affects the infiltration rate. The R-value was calculated as the inverse of the u-value obtained from the results of the ArchiCAD Energy Performance Assessment simulation. The graphical representation emphasises the significance of using a simulation-based strategy to prevent ineffective retrofitting activities. As an illustration, the combination designated as A4 would not considerably reduce the cooling load because the infiltration rate would remain constant despite an increase in the overall R-value.

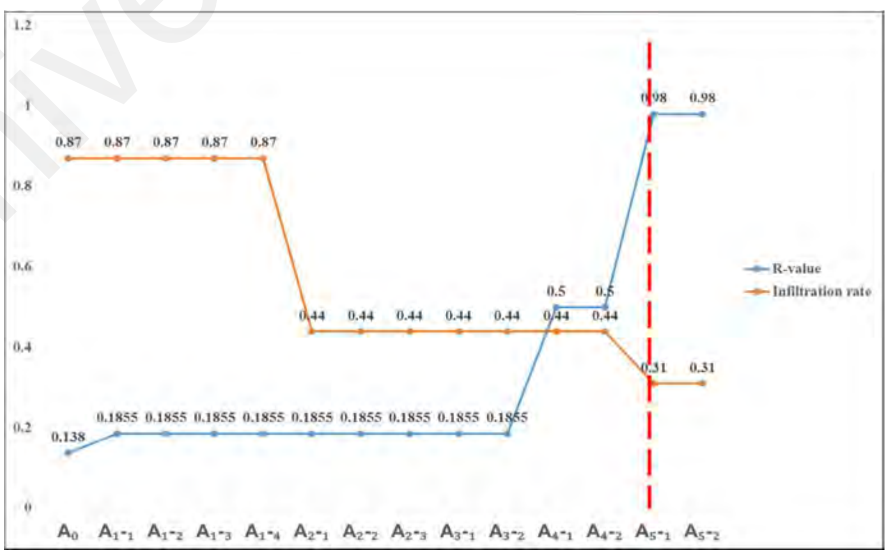


Figure 4.17: The relationships between the infiltration rate and the window settings' combined R-value

4.6 Summary of Findings

In summary of the three approaches, this research has outlined the linkages of the findings with the aim/objectives of this research. Table 4.34 is referred to. It can be concluded that the research has covered and met the objectives. However, additional research could be conducted in the future to examine other building design aspects that are not covered in this study. Further elaboration is explained in the next chapter.

Table 4.34: Linkages between the outcome and the objectives (OBJ)

Approach	Outcome	OBJ 1	OBJ 2	OBJ 3	OBJ 4
LF Performance	Control of MD based on best-building practices	NO	NO	YES on economic only	YES
Energy Audit	Identify the non-design factor and propose a retrofitting plan	YES	NO	YES	YES
Simulation-based	Model the virtual building and identify the passive design factor and propose a retrofitting plan.	NO	YES	YES	YES

4.7 Limitations of the Research

There are some potential drawbacks to this study. The lack of prior research on LF performance analysis has made the author refer to the TNB recommendation which is 0.6. The results obtained are susceptible to biases and based on interventional studies, which are entirely based on Wisma's R&D operation. The second limitation concern on time and budget constraints. As buildings should have power meters installed, especially if energy efficiency measures are to be implemented, hence it will be more precise if power meters are installed on each floor or at least to monitor the main appliances/equipment like AC and lighting consumption that have highly contributed to the building energy consumption. Furthermore, it will assist in making firm decisions for retrofitting initiatives upon the analysis carried out through the integrated approach. At the time of writing, the electricity meters were being installed throughout the building. Hence, future investigation on the building energy performances of Wisma R&D has to be carried out based on the data obtained from the power meter units. The study's conclusions must be viewed in light of significant limitations in the aspects of the economic and environmental impact. From the aspect of economics, the energy cost published by ArchiCAD's *Energy Performance Evaluation* data did not include the MD charges. Hence, a detailed calculation has to be carried out as the commercial building in Malaysia is charged with the MD charges on top of per kWh consumption. Finally, as the online *Greentech carbon calculator* required other information like the petrol and diesel consumption by the building owner, hence the CO_2 emission value presented in this research may be lower than expected. Hence, future research should consider getting further information from the building management/building owner on their petrol and diesel consumption as this is part of the factors that contributed to the CO_2 release through building operation.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The outcomes from this research have enabled the authors to support the research objectives. In general, any retrofitting plan for an existing building, specifically a high-rise building must be thoroughly carried out, and numerous methods should be used to recognize the most significant parameters that are impacting the building's energy consumption. Guidelines from ASHRAE, related Malaysian Standards (MS) and Building Energy Index (BEI), and many others are useful references in any building retrofitting initiative that acts towards sustainable, efficient, and healthy buildings. These references must be included as part of the building energy performance study for both new and existing buildings.

This research identified three main building factors that are impacting the overall building performance throughout the building operation. There are categorised as the non-design factors, passive design factors, and the maximum demand of a building. In a nutshell, these factors had proven to impact energy consumption, energy cost, and environmental effect, which is referred to as the trio effect from a building operation. Consequently, constructive judgment is required before any retrofitting initiatives are carried out. The building owners could make a sensible judgment based on their constraints, mainly the cost requirement and the ROI. On top of that, this research provides relevant information to show and motivate building owners in analysing the possible reduction of the carbon footprint from building retrofit initiatives. The aforementioned conclusions can be reached using a variety of methods, including LF performance analysis, EA, and simulation-based methods. Combinations of approaches proved to allow high accuracy in retrofitting decision-making.

In general, the retrofitting initiatives for one building can be carried out immediately by the building owner depending on the budget and ROI expectation. However, relying solely on one approach is not advisable. For instance, EA is one of the simplest ways towards making a building greener and more efficient, but the impact could be greater if the retrofitting initiative is given a larger scope.

Many factors had been identified from numerous research and guidelines. However, the final retrofit initiative decision must be compelled based on the exact design, material, and location of the referred building. In summation, it can be said that thorough modeling and interactive analysis are vital to attain the sustainable development aim of the construction sectors.

It is advised that integrated approaches be taken into account in future retrofitting initiatives. The results of this research thus demonstrate that it is possible to find a variety of potential factors in EE retrofitting programs for high-rise buildings, notably in Malaysia by integrating LF performance analysis, EA, and simulation-based approaches progressively. The outcome of this research proved that 9% cost saving could be obtained by controlling the MD, 9% energy, cost, and CO_2 reduction through retrofitting part of the lighting feature, and 1% energy and cost saving from improving the window design performances. Finally, a practical retrofitting effort plan that works for the high-rise building in Malaysia is suggested based on the constructive analysis that was accomplished through this research.

5.2 Recommendation for future research

Upon completing the research, it is foreseen that numerous other building parameters can be analysed using the available building model. Building parameters such as wind protection, and internal temperature are among the parameters that could be improvised for the betterment of overall building performances. On the non-design factors, the number of occupants can be one of the parameters that need to be considered in the future. This may indirectly be affecting the *Internal Heat Gain* which leads to higher internal heat when the number of occupants increased. As in this research, the default value of *Internal Heat Gain* was set based on the standard guideline of the per-body surface for an office building, hence future research could analyse the effect of the increased number of occupants within a building. Furthermore, once there is a new technological upgrade on the glazing and opaque material in the market, it is wise to analyse the new material using ArchiCAD. As this software allows the users to add-in material information to the library, hence further investigation is worth carrying out upon the arrival of new materials. This will provide better insight into any further improvement that those materials could provide for future retrofitting initiatives for high-rise buildings in Malaysia, particularly the Wisma R&D.

In addition to the three methods described in this research, analysing the data gathered from power meters can be used to conduct a study on a building's energy performance. Primarily, power meters need to be installed on each floor or tied to specific equipment or appliances utilized in the building. This allows the building owner or building management team to analyse the energy consumed and recommend best practices for the potential saving solution. This approach required capital investment and financial support from the building owner/top management. For the Wisma R&D building, a certain amount of budget has been allocated for this purpose. While this research is conducted, the power meter installation is in progress. Future researchers who study building energy performances in Wisma R&D could benefit from the data obtained from the installed power meters.

LIST OF PUBLICATIONS AND PAPERS PRESENTED

1. Ali, S.B.M.; Mehdipoor, A.; Samsina Johari, N.; Hasanuzzaman, M.; Rahim, N.A. Modeling and Performance Analysis for High-Rise Building Using ArchiCAD: Initiatives towards Energy-Efficient Building. *Sustainability* 2022, 14, 9780. https://doi.org/10.3390/su14159780

2. Ali, S.B.M.; Hasanuzzaman, M.; Rahim, N.A.; Mamun, M.A.A.; Obaidellah, U.H. Analysis of energy consumption and potential energy savings of an institutional building in Malaysia. *Alex. Eng. J*. 2021, 60, 805–820.

3. Siti Birkha Mohd Ali, Amirhosein Mehdipoor, Niloufar Lotfi, Saharmehdipoor, Md.Hasanuzzaman, Nasrudin Abd. Rahim. Application of Building Information Modelling (BIM) in Analysing the Building Energy Performances of an Office Building. *International Journal of Advanced Science and Technology*. Vol 29 (1), pages 262-282, Elsevier

4. Ali, S. B. M., M.Hasanuzzaman, N.A.Rahim, & M.Amirhosein. (2019). *Analysing The Effect of Glazing Materials Towards Building Energy Consumption in Different Climate Zones*. Paper presented at the 23rd PAQS Congress 2019, Kuching Sarawak.

5. Ali, S.B.M.; Hasanuzzaman, M.; Rahim, N.A. Investigation on the load factor performance at Wisma R&D Universiti Malaya building. In Proceedings of the 5th IET *International Conference on Clean Energy and Technology* (CEAT2018), Kuala Lumpur, Malaysia, 5–6 September 2018.

6. Ali, S.B.M.; Hasanuzzaman, M.; Rahim, N.A; Mehdipoor, A.;.Analysing The Impact Of Glazing Material And Shading Devices Towards Energy Consumption, Cost Saving and Carbon Reduction In Home Design Application Using BIM. *International Journal of Renewable Energy Resources*; Vol. 8 No. 1 (2018)

APPENDIX

Appendix A: The Audit Forms used for the Energy Audit (EA) study

SURVEY ON ELECTRICITY CONSUMPTION AT WISMA R&D, UM

ROOM CATEGORY: STAFF ROOM or OFFICE
LEVEL/ARAS:
ROOM/OFFICE NAME:

Please read the following instructions before filling up this form

1. The manufacturer/brand can be found on the label place at your appliance/equipment
2. If the power rating is available, please skip the information on the voltage and current
3. If the operating hours are based on daily and consistently applied for everyday, please skip the weekly operating hours

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts/HP)	Voltage	Current	Daily	Weekly
1	PC/Laptop							
2	Lighting							
3	Airconditioner							
4	Printer							
5	Water Filter							
6	Telephone							
7	Exit Sign							
8	Photocopy Machine							
9	Scanner							

4. On top the above appliances/equipments, kindly fill in all the other appliances/equipments that you have in your office

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts/ HP)	Voltage	Current	Daily	Weekly
1	Kettle							
2	Radio							

SURVEY ON ELECTRICITY CONSUMPTION AT WISMA R&D, UM

ROOM CATEGORY: LABORATORY/MAKMAL

LEVEL/ARAS:

Name:

Position/Role:

Please read the following instructions before filling up this form

1. The manufacturer/brand can be found on the label place at your appliance/equipment
2. If the power rating is available, please skip the information on the voltage and current
3. If the operating hours are based on daily and consistently applied for everyday, please skip the weekly operating hours

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts or HP)	Voltage	Current	Daily	Weekly
1	PC/Laptop							
2	Lighting							
3	Airconditioner							

4. On top the above appliances/equipments, kindly fill in all the other appliances/equipments that you have in your laboratory

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts or HP)	Voltage	Current	Daily	Weekly

SURVEY ON ELECTRICITY CONSUMPTION AT WISMA R&D, UM

ROOM CATEGORY: CUBICLE ROOM

LEVEL/ARAS:

ROOM NO.

Please read the following instructions before filling up this form

1. The manufacturer/brand can be found on the label place at your appliance/equipment
2. If the power rating is available, please skip the information on the voltage and current
3. If the operating hours are based on daily and consistently applied for everyday, please skip the weekly operating hours

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts or HP)	Voltage	Current	Daily	Weekly
1	PC/Laptop							
2	Lighting							
3	Airconditioner							
4	Printer							
5	Water Filter							
6	Telephone							
7	Exit Sign							

4. On top the above appliances/equipments, kindly fill in all the other appliances/equipments that you have in your cubicle room

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts or HP)	Voltage	Current	Daily	Weekly

SURVEY ON ELECTRICITY CONSUMPTION AT WISMA R&D, UM

ROOM CATEGORY:MEETING/CONFERENCE/CLASSROOM

LEVEL/ARAS:

Please read the following instructions before filling up this form

1. The manufacturer/brand can be found on the label place at your appliance/equipment
2. If the power rating is available, please skip the information on the voltage and current
3. If the operating hours are based on daily and consistently applied for everyday, please skip the weekly operating hours

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts or HP)	Voltage	Current	Daily	Weekly
1	Projector							
2	Lighting							
3	Airconditioner							
4	Sound System/Speaker							

4. On top the above appliances/equipments, kindly fill in all the other appliances/equipments that you have in your meeting/conference room/classroom.

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts or HP)	Voltage	Current	Daily	Weekly

SURVEY ON ELECTRICITY CONSUMPTION AT WISMA R&D, UM

ROOM CATEGORY:CANTEEN UMPEDAC

LEVEL/ARAS: 3

Please read the following instructions before filling up this form

1. The manufacturer/brand can be found on the label place at your appliance/equipment
2. If the power rating is available, please skip the information on the voltage and current
3. If the operating hours are based on daily and consistently applied for everyday, please skip the weekly operating hours

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts or HP)	Voltage	Current	Daily	Weekly
1	Refrigerator							
2	Lighting							
3	Airconditioner							
4	Freezer							
5	Fan							
6	Rice Cooker							
7	Blender							
8	Heater							

4. On top the above appliances/equipments, kindly fill in all the other appliances/equipments that you have in your canteen.

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts or HP)	Voltage	Current	Daily	Weekly
1	Exit Sign							

SURVEY ON ELECTRICITY CONSUMPTION AT WISMA R&D, UM

ROOM CATEGORY: COMMON ROOM (PRAYER ROOM, TOILET, PATHWAY, LOBBY, PARKING, STAIRWAYS)
LEVEL/ARAS:

Please read the following instructions before filling up this form

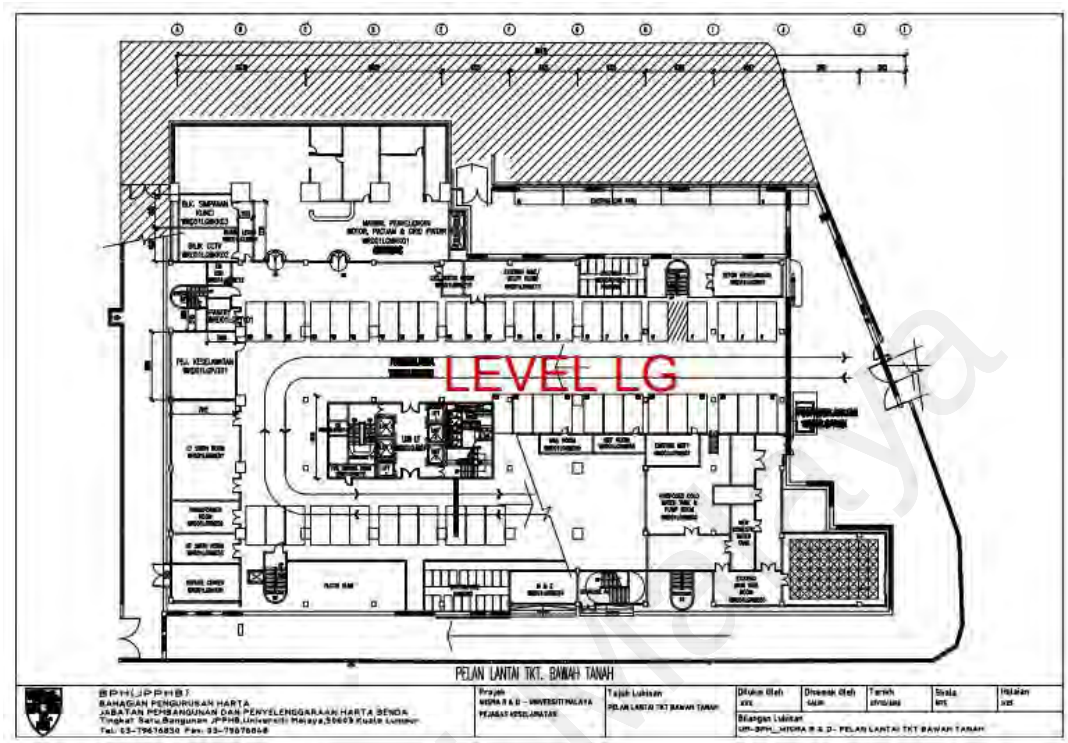
1. The manufacturer/brand can be found on the label place at your appliance/equipment
2. If the power rating is available, please skip the information on the voltage and current
3. If the operating hours are based on daily and consistently applied for everyday, please skip the weekly operating hours

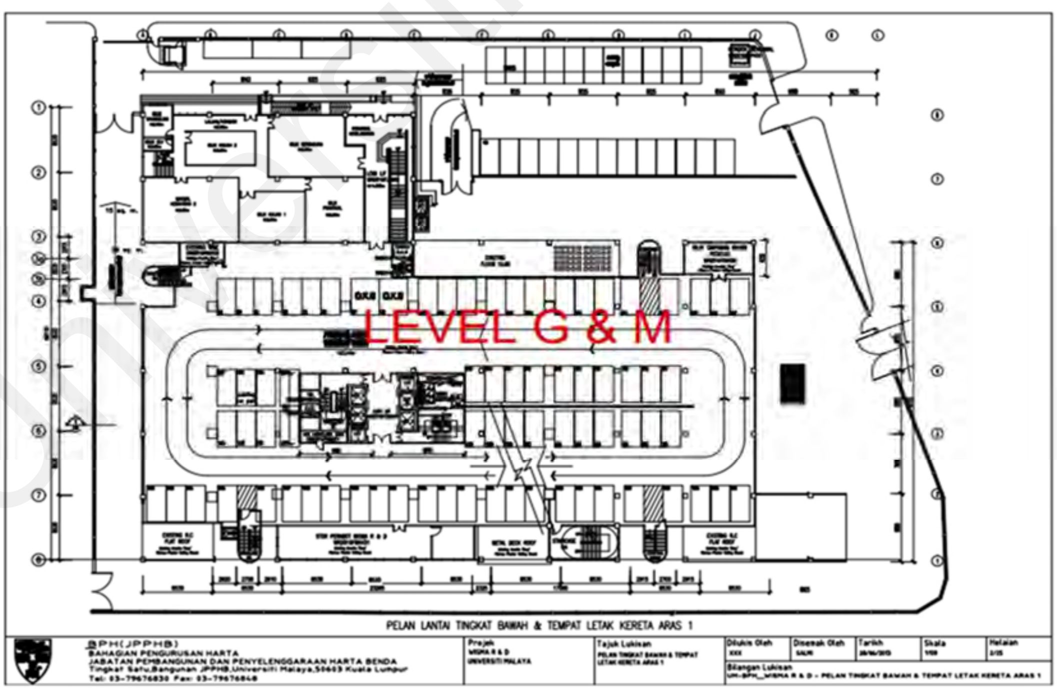
No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts or HP)	Voltage	Current	Daily	Weekly
1	Exit Sign							
2	Lighting Type A							
3	Lighting Type B							
4	Lighting Type C							
5	Airconditioner							

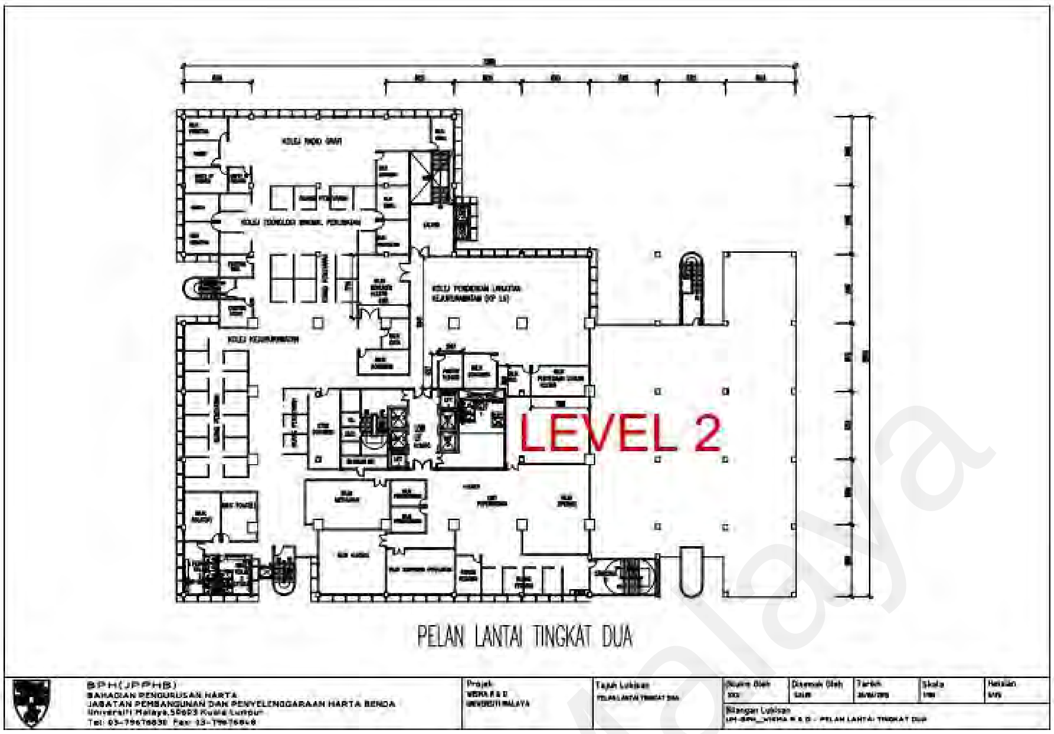
4. On top the above appliances/equipments, kindly fill in all the other appliances/equipments that you have in the respective room.

No.	Type of Equipment	Manufacturer/Brand	No. of Unit	Rating			Operating Hours	
				Power (Watts or HP)	Voltage	Current	Daily	Weekly

Appendix B: Some of the Wisma R&D Building Layout Plan



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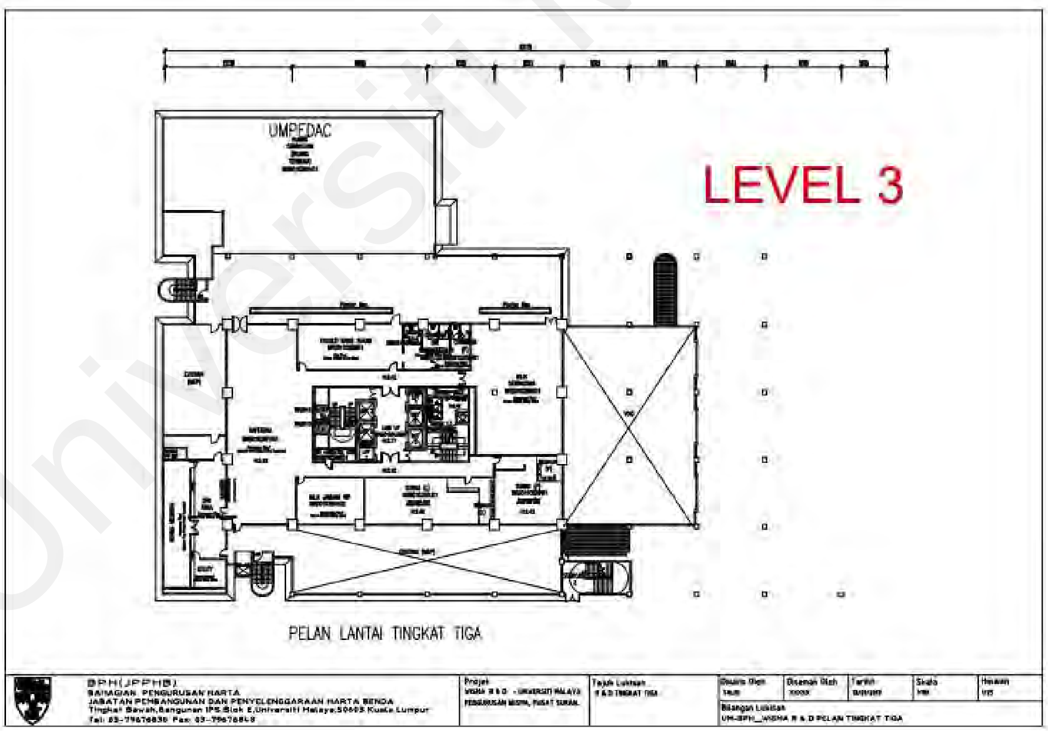
BPH(JPPHB)


UMPEDAC
LEVEL 3
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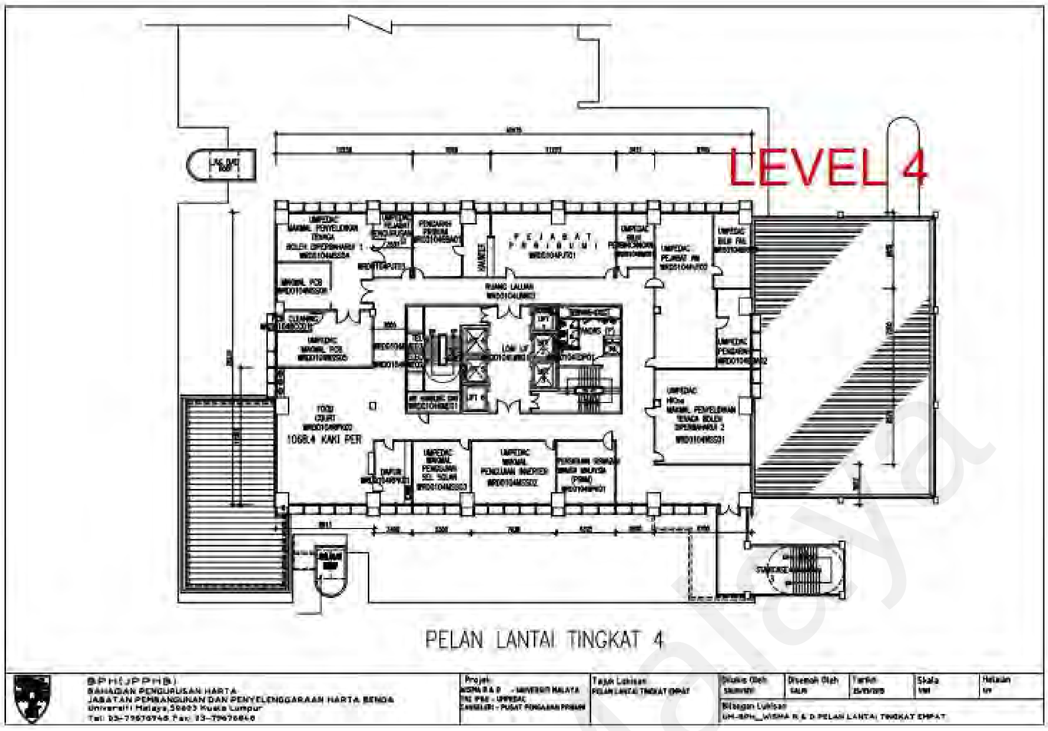
BPH(JPPHB)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FOOD COURT
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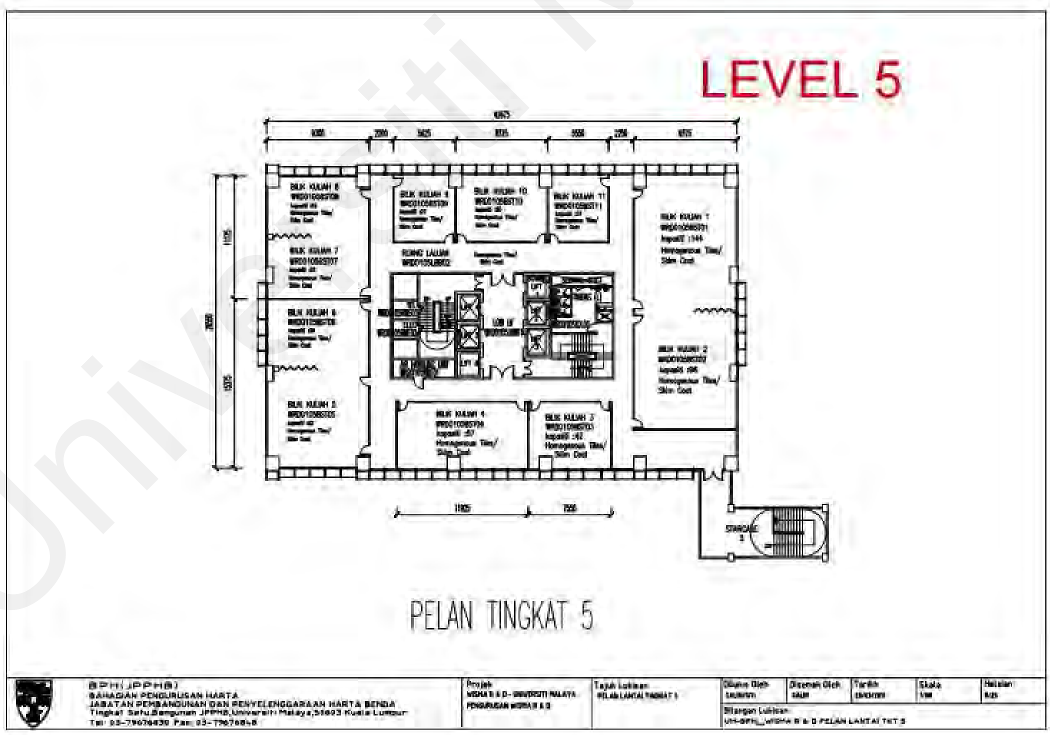
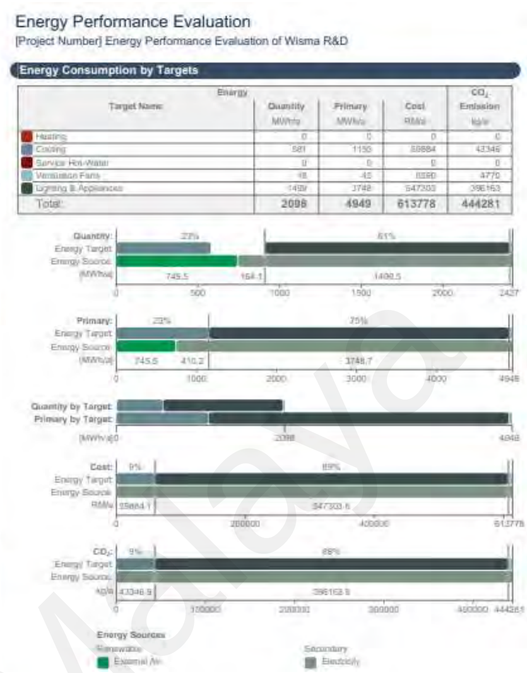
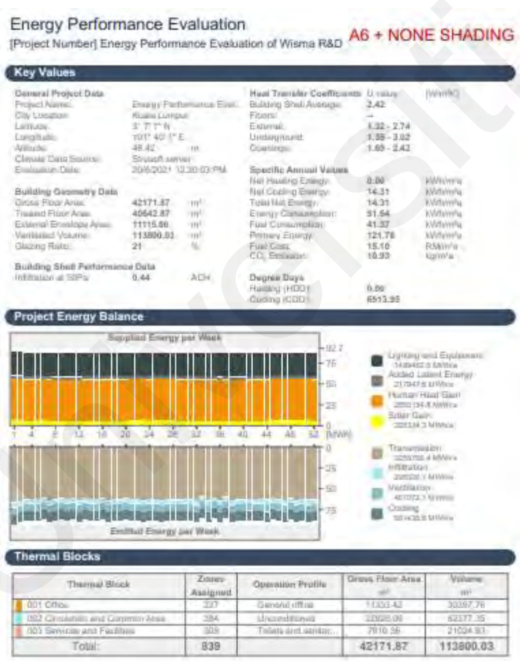
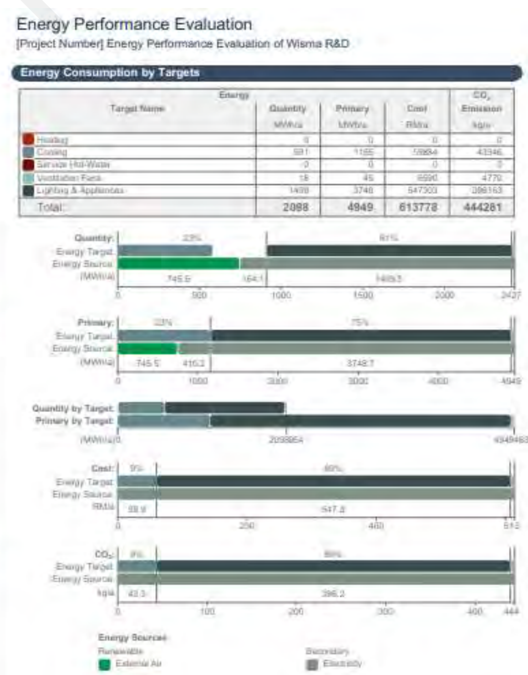
PELAN LANTAI TINGKAT 4
BPH(JPPHB)
BAHAGIAN PENGURUSAN HARTA
JABATAN PEMBANGUNAN DAN PENYELENGGARAAN HARTA BENDA
Universiti Malaya,50603 Kuala Lumpur


LEVEL 5
PELAN TINGKAT 5
BPH(JPPHB)
BAHAGIAN PENGURUSAN HARTA
JABATAN PEMBANGUNAN DAN PENYELENGGARAAN HARTA BENDA

Appendix C: *Energy Performance Evaluation* Results from ArchiCAD







Energy Performance Evaluation

[Project Number] Energy Performance Evaluation of Wisma R&D

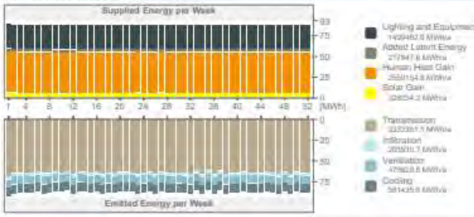
A7 + NONE SHADING

Key Values

General Project Data		
Project Name:	Energy Performance Eval...	
City Location:	Kuala Lumpur	
Latitude:	3° 7' 1" N	
Longitude:	101° 40' 1" E	
Altitude:	48.42	m
Climate Data Source:	Strusoft server	
Evaluation Date:	21/6/2021 11:09:18 AM	
Building Geometry Data		
Gross Floor Area:	42171.87	m²
Treated Floor Area:	40642.87	m²
External Envelope Area:	11115.06	m²
Ventilated Volume:	113800.03	m³
Glazing Ratio:	21	%
Building Shell Performance Data		
Infiltration at 50Pa:	0.31	ACH

Heat Transfer Coefficients	U value	[W/m²K]
Building Shell Average:	2.31	
Floors:	—	
External:	1.32 - 2.74	
Underground:	1.38 - 3.02	
Openings:	0.78 - 1.49	
Specific Annual Values		
Net Heating Energy:	0.00	kWh/m²a
Net Cooling Energy:	14.31	kWh/m²a
Total Net Energy:	14.31	kWh/m²a
Energy Consumption:	51.64	kWh/m²a
Fuel Consumption:	41.37	kWh/m²a
Primary Energy:	121.78	kWh/m²a
Fuel Cost:	15.10	RM/m²a
CO_2 Emission:	10.92	kg/m²a
Degree Days		
Heating (HDD):	0.00	
Cooling (CDD):	6513.95	

Project Energy Balance



Thermal Blocks

Thermal Block	Zones Assigned	Operation Profile	Gross Floor Area m²	Volume m³
001 Office	237	General office	11333.42	30397.78
002 Circulation and Common Area	294	Unconditioned	22928.09	62377.35
003 Services and Facilities	308	Toilets and sanitar...	7910.36	21024.93
Total:	839		42171.87	113800.03

Energy Performance Evaluation

[Project Number] Energy Performance Evaluation of Wisma R&D

Energy Consumption by Targets

Target Name	Energy Quantity MWh/a	Primary MWh/a	Cost RM/a	CO_2 Emission kg/a
Heating	0	0	0	0
Cooling	581	1156	59884	43346
Service Hot-Water	0	0	0	0
Ventilation Fans	18	45	6590	4770
Lighting & Appliances	1499	3748	547303	396163
Total:	2098	4949	613778	444281

Energy Performance Evaluation

[Project Number] Energy Performance Evaluation of Wisma R&D

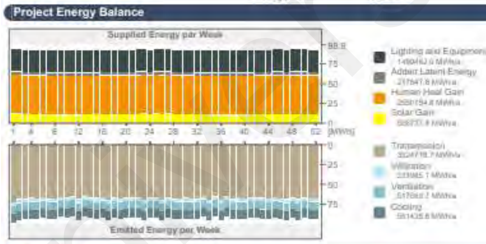
A9 + NONE SHADING

Key Values

General Project Data		
Project Name:	Energy Performance Eval...	
City Location:	Kuala Lumpur	
Latitude:	3° 7' 1" N	
Longitude:	101° 40' 1" E	
Altitude:	48.42	m
Climate Data Source:	Strusoft server	
Evaluation Date:	25/6/2021 2:22:47 PM	
Building Geometry Data		
Gross Floor Area:	42171.87	m²
Treated Floor Area:	40642.87	m²
External Envelope Area:	11115.06	m²
Ventilated Volume:	113800.03	m³
Glazing Ratio:	21	%
Building Shell Performance Data		
Infiltration at 50Pa:	0.31	ACH

Heat Transfer Coefficients	U value	[W/m²K]
Building Shell Average:	2.16	
Floors:	—	
External:	1.32 - 2.74	
Underground:	1.38 - 3.62	
Openings:	0.78 - 0.88	
Specific Annual Values		
Net Heating Energy:	0.00	kWh/m²a
Net Cooling Energy:	14.31	kWh/m²a
Total Net Energy:	14.31	kWh/m²a
Energy Consumption:	51.64	kWh/m²a
Fuel Consumption:	41.37	kWh/m²a
Primary Energy:	121.78	kWh/m²a
Fuel Cost:	15.10	RM/m²a
CO_2 Emission:	10.93	kg/m²a
Degree Days		
Heating (HDD):	0.00	
Cooling (CDD):	6513.95	

Project Energy Balance



Thermal Blocks

Thermal Block	Zones Assigned	Operation Profile	Gross Floor Area m²	Volume m³
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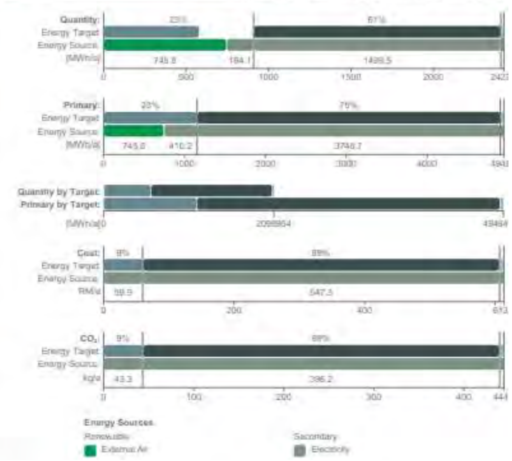

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