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BUILDING ENVELOPE RETROFIT FOR ENERGY SAVINGS IN MALAYSIAN GOVERNMENT HIGH-RISE OFFICES: A CALIBRATED ENERGY SIMULATION

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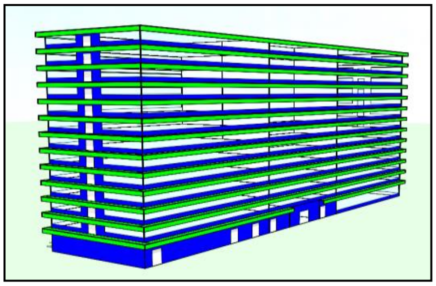
Graphical abstract



Abstract

With over a third of global energy used for building construction and operation, an optimum design for building envelopes is essential to improve the energy performance of the existing buildings. This study revealed that typical government high-rise office buildings in Malaysia have an average Building Energy Intensity (BEI) of 161 kWh/m^2/year before any upgrading works on the air-conditioning and mechanical ventilation (ACMV) systems were conducted. This value is higher than the recommended value in Green Building Index (GBI) for commercial office buildings (150 kWh/m^2/year) and the Economic Planning Unit (EPU) standard for public buildings (140 kWh/m^2/year). Therefore, this study employed a case study approach combined with calibrated computer simulation to determine the optimal building envelope retrofit strategies and identify the three levels of interventions (minor, moderate and major levels) with corresponding energy reduction. A validated model representing a typical existing government high-rise office building in Malaysia was chosen as the base case model for energy evaluation studies. The effectiveness of each level of intervention and its energy retrofit measures (ERMs) were evaluated compared to the actual electricity bills. The results showed that all levels of interventions provided between 4% to 7% savings in annual energy consumption. The proposed interventions demonstrated compliance with the BEI benchmark margins of the GBI and EPU standard, namely 116 kWh/m^2/year (minor intervention level), 113 kWh/m^2/year (moderate intervention level), and 110 kWh/m^2/year (major intervention level). This study provides the local building sector and the Government of Malaysia with a methodological framework for optimising the building envelope retrofit interventions.

Keywords: Building envelope retrofit, building energy simulation, retrofit interventions, office buildings, energy savings

Abstrak

Dengan satu pertiga daripada penggunaan tenaga global untuk pembinaan bangunan dan operasi, reka bentuk fakad bangunan yang optima adalah penting untuk meningkatkan kecekapan prestasi tenaga bangunan sedia ada. Kajian ini menunjukkan bangunan tinggi pejabat kerajaan sedia ada di Malaysia beroperasi dengan BEI 161 kWh/m^2/tahun sebelum kerja naik taraf sistem pendingin hawa dan pengudaraan mekanikal dilaksanakan. Nilai ini lebih tinggi daripada piawai Green Building Indek (GBI) iaitu 150 kWh/m^2/tahun bagi bangunan pejabat komersial dan Unit Perancangan Ekonomi (EPU) bagi bangunan kerajaan iaitu 140 kWh/m^2/tahun. Oleh itu, kajian ini memilih metodologi kombinasi kajian kes dan simulasi tenaga untuk fakad intervensi retrofit yang optima dan dicadangkan dalam tiga peringkat iaitu peringkat intervensi (minima, sederhana dan utama). Model tervalidasi mewakili reka bentuk tipikal bangunan tinggi pejabat kerajaan di Malaysia dipilih untuk menjadi model asas bagi kajian simulasi tenaga. Hasil keputusan simulasi tenaga setiap peringkat serta individu ERM telah dibandingkan dengan nilai penggunaan bil elektrik sebenar bangunan kajian. Keputusan memperlihatkan semua peringkat intervensi memperolehi penjimatan tenaga sebanyak 4% hingga 7%. Semua cadangan intervensi menunjukkan pematuhan piawai GBI dan EPU iaitu 116 kWh/m²/tahun (peringkat intervensi minima), 113 kWh/m²/tahun (peringkat intervensi sederhana) dan 110 kWh/m²/tahun (peringkat intervensi utama). Kajian ini menyediakan satu rangka metodologi bagi fakad retrofit secara intervensi berperingkat untuk digunapakai dalam sektor pembinaan tempatan dan Kerajaan Malaysia.

Kata kunci: Retrofit fakad bangunan, simulasi tenaga bangunan, intervensi retrofit, bangunan pejabat, penjimatan tenaga

1.0 INTRODUCTION

The building and construction sector accounts for 39% of global energy-related emissions [1]. In most countries, office buildings are the most substantial energy-consuming building type in the commercial sector, driven by their high electricity demand for space cooling, lighting and equipment [2, 3]. Moreover, the world's building stock is set to double by 2050. As such, new and existing buildings are equally required to reduce their energy consumption and carbon emissions to mitigate climate change. Building retrofits are crucial in the climate change mitigation plan to decarbonise the global building stock and improve energy performance [4, 5, 6]. The objectives of retrofit are not solely on energy savings but more on providing opportunities for better thermal and visual comfort, air quality, and maintenance cost reduction [2, 7, 8, 9, 30].

Many energy retrofitting projects conducted globally, including in Malaysia, focus mainly on active system interventions such as air-conditioning, mechanical ventilation (ACMV), and lighting systems. Little attention is paid to passive retrofit measures, such as building envelope interventions [10]. Building envelope design is also one of the critical factors affecting building energy demand for heating and cooling [5, 8, 9, 11]. In hot and humid climate regions, 10% to 50% energy savings can be achieved by reducing the energy demand for space cooling via building envelope retrofit [5, 12]. Because buildings typically have a long lifespan, their envelopes will eventually deteriorate and result in higher overall energy consumption (e.g. due to poor airtightness and overheating from excess solar gain in hot weather). Typically, a high-performance building envelope optimisation in a hot climate integrates advanced glazing technologies, optimum window-to-wall ratio (WWR), insulations, minimum infiltration, and reflective surfaces [11, 12, 13, 28].

Malaysia lacks synergic policies, finance mechanisms and project demonstrations on the greening of existing buildings. Additionally, there is no coordinated collection of energy-related data from existing building stock to meet the national sustainability goals [10]. A few studies have been conducted in Malaysia on retrofitting existing buildings involving various building typologies, namely office buildings, institutional buildings and residential [14, 15, 16, 17]. These studies highlighted a need for retrofitting existing buildings in Malaysia to achieve buildings' energy efficiency targets in Malaysia. Sadly, many building retrofits in Malaysia are commissioned without considering the buildings' energy efficiency enhancement [18, 19]. As a result, case studies to showcase the energy efficiency of renovated existing buildings in Malaysia are considered rare.

Surprisingly, most existing government office buildings have not optimised passive design strategies [15, 16]. This finding indicates a great necessity to assess these buildings' current energy performance and identify suitable retrofit measures for energy efficiency improvement.

Given the paucity of research on this topic, this study was conducted to understand and uncover the building envelope retrofit interventions that could improve the energy performance of existing government high-rise office buildings in Malaysia. Therefore, this study aims to develop a validated model of building envelope retrofit interventions that can contribute to the annual energy savings of a typical government high-rise office building. Specific objectives are as follows: i) to establish a case model from a selected case building to understand the influence of building envelope components on the overall building energy consumption, ii) to identify the energy retrofit measures (ERMs) and evaluate their impacts on the level of the building's energy efficiency; iii) to develop a systematic approach of optimising building envelope retrofit interventions and identify the range of intervention levels with their energy reduction levels.

2.0 METHODOLOGY

In order to achieve the stated objectives, this study opted for a case study approach combined with calibrated simulation to establish a validated case model of a typical government high-rise office. The calibrated simulation approach is an approach that measures energy savings through computer simulations. It calibrates the various inputs to the program, so that simulation predictions match closely with the measured energy data [20, 21].

Each level of intervention (minor, moderate or major) is defined according to a few selected pre-defined quantitative criteria of ERMs related to thermal characteristics aiming solely for building energy performance improvements. These ERMs include high-performance glazing, external insulation, and WWR reductions. Also, the existing external shading device design was part of the ERMs. A range of building envelope retrofit interventions with a combination of selected building envelope ERMs was applied to the validated case model for energy simulations, and the simulation results between different interventions were compared.

This simulation study was conducted in two phases: 1) identification of a case study and extraction of its actual energy-related data; 2) energy performance simulation of each level of interventions and individual ERMs to determine the optimised retrofit intervention strategies.

2.1 Phase 1a: Case Study Building Selection

The case building selected for this study is located in Malaysia, which lies between 1° and 7° North latitude and 100° and 120° East longitude, north of the Equator in Southeast Asia. The local climate is hot and humid tropical, characterised by uniformly high temperatures and humidity with abundant rainfall throughout the year. The annual average temperature is 27.1°C.

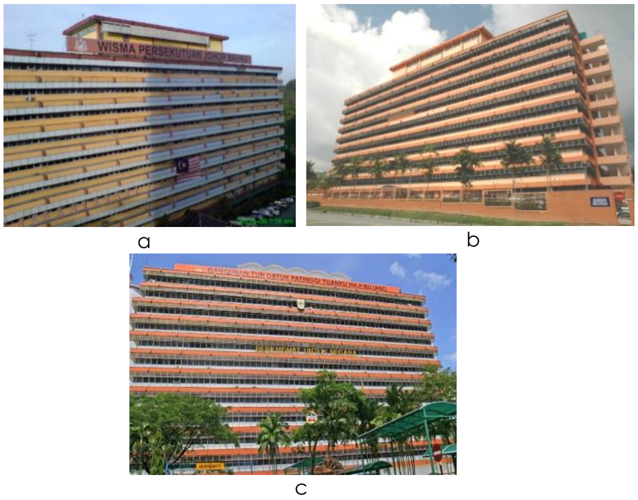
No guideline defines a high-rise building in Malaysia [14]; thus, this study referred to the definition by the National Fire Protection Association (NFPA) Code [29], namely a building with a total height exceeding 75 feet (22.9 meters), or about seven storeys above the ground level. As such, the 8 to 17-storey Wisma Persekutuan buildings, built in the 1970s or 1980s, were deemed qualified. Table 1 lists the twelve Wisma Persekutuan buildings in the country. The Ministry of Works Malaysia data showed that these buildings maintained almost 90% of their original building forms and façade designs [22]. These buildings were established as the models of typical government high-rise office buildings for this study.

The buildings are hermetically sealed boxes, depending on artificial lighting and ACMV systems for space cooling. They had high WWR values, repetitive and monotonous geometrical patterns on the facades, and glazing with low visible light transmission values. Figures 1 and 2 show several examples of typical Wisma Persekutuan office buildings and their typical floor plans. Previous studies revealed that the façade designs did not contribute to the quantity and quality of harvested daylight within the buildings [15, 16]. Only some buildings had upgraded ACMV systems to improve energy performance and reduce electricity costs.

Wisma Persekutuan Seremban, located in Seremban, Negeri Sembilan, was chosen as the case building for the simulation studies. The standard centre-cored building was a 13-storey rectangular plan (approximately 76.18 meters by 17.07 meters) and 18,391.09 m^2 in gross area. It had linear facades with almost identical designs with no history of modifications to its original façades. The front and rear elevations faced southwest and northeast, respectively. The original external shading devices were still intact. They consisted of concrete ledge shadings (890 mm wide and 825 mm high) and polycarbonate horizontal shadings fixed at the edge of the concrete ledge (Figure 3). This building has carried out energy retrofits on the ACMV system (completed in 2018), the energy-efficient lighting system (ongoing in 2020), and an energy management program.

Table 1 List of Wisma Persekutuan high-rise office buildings in Malaysia

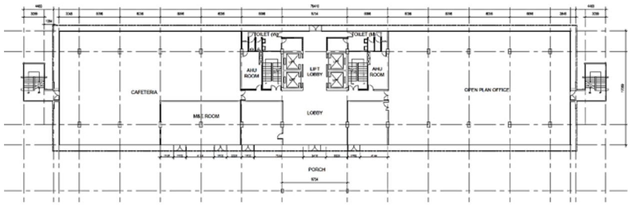
Building's Name	Year Built	Height of Floors
Kompleks Pejabat Kerajaan Jalan Duta, Kuala Lumpur	1974	17-storeys
Wisma Persekutuan Sandakan	1983	8-storeys
Wisma Persekutuan Tawau	1982	8-storeys
Wisma Persekutuan Kota Kinabalu	1972	8-storeys
Wisma Persekutuan Alor Setar	1973	10-storeys
Wisma Persekutuan Taiping	1986	10-storeys
Bangunan Tun Datuk Patinggi Tuanku Hj. Bujang (TDPTHB), Sarawak	1972	12-storeys
Wisma Persekutuan Johor Bharu	1976	10-storeys
Wisma Persekutuan Seremban	1979	13-storeys
Wisma Persekutuan Kota Bharu	1975	13-storeys
Wisma Persekutuan Kuantan	1979	13-storeys
Wisma Persekutuan Kuala Terengganu	1975	13-storeys


a

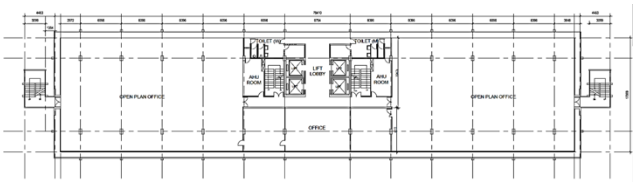
b

c

Figure 1 Examples of typical Wisma Persekutuan high-rise office buildings in Malaysia: (a) Wisma Persekutuan Johor Bharu, (b) Wisma Persekutuan Taiping; and (c) Bangunan TDPTHB, Sarawak



Ground floor plan

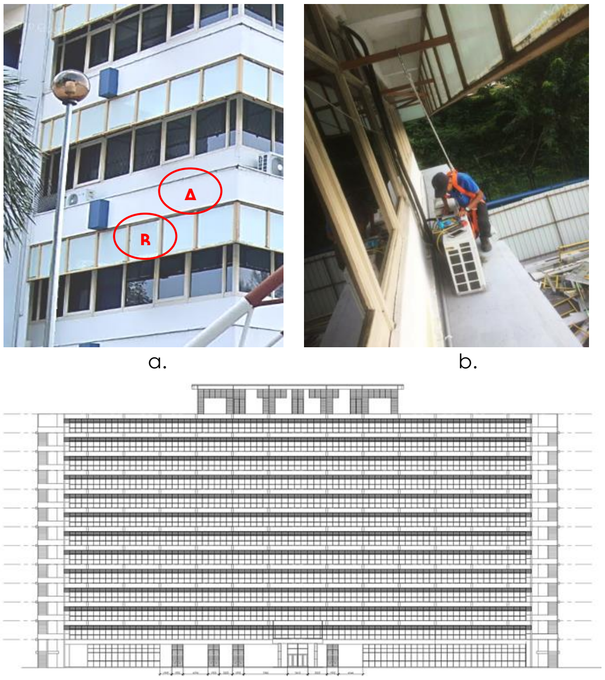


Typical upper floor plan

Figure 2 Typical floor plan of Wisma Persekutuan

2.2 Phase 1b: Extraction of Energy-related Data

The second step in Phase 1 involved energy-related data extraction, done using the following two methods: 1) document analysis (e.g. drawings, technical data and energy audit report); and 2) site visit data gathering. All collected documents were pre-studied to understand the building's architectural characteristics, mechanical and electrical systems, and climatic data before conducting the site visit. However, the Wisma Persekutuan Seremban has not undertaken any energy audit. All data sets were obtained from the building maintenance management and the Ministry of Works. This study followed the recommendation in the ASHRAE 90.1 standards, i.e. to use two years of monthly utility bills to analyse the previous building energy consumption and simulation study.



a. b.

c.

Figure 3 Case building of Wisma Persekutuan Seremban: (a) Existing shading devices, A – concrete ledge, B – polycarbonate horizontal shading, (b) Concrete ledge shading; and (c) Front elevation drawing

The site visit data gathering through walkthrough observation was conducted to verify the preliminary findings from the document analysis. A photographic and planimetric survey was conducted during the site visit. Overall, this method helped to understand the building envelope thoroughly and organise the data-gathering process systematically.

2.3 Phase 2: Energy Performance Simulation

This study opted for IES<VE> simulation software to conduct the energy analysis due to its corresponding principles and applicability that satisfy the simulation program requirements stipulated in the Malaysian Standard MS1525: 2019 [23]. By using the software's thermal simulation package, the program analyses the performance of different opaque and glazing wall materials using real climate data in response to various variables for 8760 hours a year.

2.3.1 Establishment of Design Building Model

The model must be developed as precisely as possible to increase the accuracy of the simulation results [21, 24, 25]. Hence, the 3D design building model was established from the architectural drawings, and the opaque and glazing wall properties were modelled based on their actual specifications. The layout plan was divided into two thermal zones: non-air-conditioned and air-conditioned spaces. The ACMV and electrical systems, operating times and occupancy patterns were based on actual building operational data extracted from Phase 1. However, to simplify the modelling, the internal wall partitions in the office areas, furniture and external fire escape staircases were ignored. This study utilised the readily available hourly weather data of Subang, Kuala Lumpur, for the simulations.

2.3.2 Calibration and Validation

Previous studies have confirmed that model calibration and validation is critical for the accuracy and reliability of the energy model in predicting the actual energy performance of the specified building [21, 24, 25]. The calibrated simulation approach in this study was based on several previous studies [21, 24, 25], as no methodology standard is available in Malaysia. Due to the possible difficulty in gathering the building input data for the calibration process, this study employed Level 2 calibration, as described in Table 2.

Next, the validation of the calibrated model was based on the statistical indices approach to evaluate the accuracy of the simulated model. Previous literature has recognised this approach as the global reference criteria in studies and practices to evaluate the error between the simulated and the measured building energy consumption [21, 24]. The validation of the simulated model was done by using monthly utility bills. Other common statistical indices adopted in this study are the combination of Mean Bias Error (MBE) and the Coefficient of variation of the Root Mean Square Error (Cv(RMSE)). The MBE measures how closely the simulated data correlate with the measured data. Cv(RMSE), on the other hand, is a measure of the differences between the values predicted by the simulation software and the measured values [21]. The MBE and Cv(RMSE) equations are shown in Figure 4.

The international standards that define the protocol of calibration and validation procedures are ASHRAE Guidelines 14; the International Performance Measurements and Verification Protocol (IPMV); and the mechanical and ventilation guidelines for the Federal Energy Management Programme (FEMP) [20, 24]. According to these standards, simulated models are considered successfully 'calibrated and validated' if they meet the accepted tolerances between the simulated and measured data. Nevertheless, it should be highlighted that this validation approach did not consider the detailed error analysis of uncertainties in the model and other calibrated parameters such as occupancy, indoor conditions and temperature trend [24, 25].

2.3.3 Identification of Retrofitting Intervention Strategy

Building envelope ERMs mainly regulate heat gain and losses, improving the thermal comfort level and reducing the building's energy consumption for cooling and lighting. On this basis, retrofit strategies were proposed based on their energy-related features, degree of difficulty to install during the building operation stage, affordability in the local market, and priority for interventions. The retrofit strategies were defined in three levels of interventions, with each level adopting satisfactory levels of efficient ERMs. Table 3 presents the different levels of retrofit interventions and their respective ERMs.

Each level of intervention begins with a minor level of interventions, followed by a moderate and a major level. Each level is differentiated by integrating or replacing one or two ERMs. The ERMs are as follows:

i) installation of suitable insulation to the existing opaque wall or construction of a new opaque wall using materials with better thermal properties;
ii) replacement of existing glazing with high-performance glass;
iii) design evaluation of existing shading devices;
iv) reduction of WWR on the building envelope.

Table 2 Types of building input data and calibration levels

Calibration Levels	Building Input Data Available					
	Utility Bills	As-Built Data	Site Visit or Inspection	Detailed Audit	Short-Term Monitoring	Long-Term Monitoring
Level 1	X	X				
Level 2	X	X	X			
Level 3	X	X	X	X		
Level 4	X	X	X	X	X	
Level 5	X	X	X	X	X	X

$$MBE_{month}\,(\%) = \left[\frac{(M-S)_{month}}{M_{month}}\right]\times 100\% \qquad (1)$$

$$MBE_{year} = \sum_{year}\left[\frac{ERR_{month}}{N_{month}}\right] \qquad (2)$$

Where,
M: measured electricity (kWh) or fuel consumption
S: simulated electricity (kWh) or fuel consumption
N_{month}: number of utility bills in the year

$$CV(RSME_{month})(\%) = \left[\frac{RSME_{month}}{A_{month}}\right]\times 100\%$$

$$RSME_{month} = \left\{\frac{\left[\sum_{month}(M-S)_{month}{}^{2}\right]}{N_{month}}\right\}^{1/2}$$

$$A_{month} = \left[\frac{\sum(M_{month})}{N_{month}}\right] \qquad (3)$$

Where,
RMSE: root-mean-squared monthly error
A_{month}: mean of the monthly utility bills

Figure 4 Equation for MBE and Cv(RMSE) formulas (*Source*: Fabrizio and Monetti, 2015)

Essentially, each ERM is a component of the building envelope but with different performance values to differentiate the levels of intervention. Subsequently, retrofit strategies were simulated using the validated case model by integrating the proposed ERMs into the envelope components. The impact of these ERMs on the overall energy and space cooling annual consumptions was evaluated and analysed by comparing the results of the simulated model and the original case model. Specifically, the WWR and selected individual ERMs for each level of interventions are as follows:

Table 3 Description of the proposed interventions and individual ERMs

Retrofit Intervention	ERMs	Code for individual ERMs	*U*-value (W/m^{2}K) of overall assembly		Simulation strategy
			Existing	Proposed	
Initially established 3 case models	40% reduction of WWR for Southwest (front) and Northeast (rear) façade orientations	A1	NA	NA	ERMs combination
	35% reduction of WWR for Southwest (front) and Northeast (rear) façade orientations	A2	NA	NA	ERMs combination
	30% reduction of WWR for Southwest (front) and Northeast (rear) façade orientations	A3	NA	NA	ERMs combination
A - Minor level of intervention	Reduction of WWR	A1, A2 & A3	NA	NA	**S1:** A1+B1+B2+B3 **S2:** A2+B1+B2+B3 **S3:** A3+B1+B2+B3
	Glazing replacement with low-e tinted single glass panes (SHGC 0.75) and metal frames	B1	5.7	2.63	
	Exterior wood panel wall (existing) + external cement board (40mm) + insulation board (12mm)	B2	1.03	0.68	
	Existing concrete balcony and polycarbonate shading	B3	NA	NA	
	Without existing concrete balcony and polycarbonate shading	B4	NA	NA	**S3A:** A3+B1+B2+B4
B - Moderate level of intervention	Reduction of WWR	A1, A2 & A3	NA	NA	**S4:** A1+C1+C2+B3 **S5:** A2+C1+C2+B3 **S6:** A3+C1+C2+B3
	Glazing replacement with double low-e glass panes - Double Low-E (Argon fill, SHGC 0.44)	C1	5.7	1.97	
	Lightweight concrete block (100mm) + polyurethane board (50mm) + gypsum plasterboard (12.5mm)	C2	1.03	0.36	
	Existing concrete balcony and polycarbonate shading	B3	NA	NA	
	Without existing concrete balcony and polycarbonate shading	B4	NA	NA	**S6A:** A3+C1+C2+B4
C - Major level of intervention	Reduction of WWR	A1, A2 & A3	NA	NA	**S7:** A1+D1+D2+B3 **S8:** A2+D1+D2+B3 **S9:** A3+D1+D2+B3
	Glazing replacement with double low-e glass panes - Double Low-E (Argon fill, SHGC 0.35)	D1	5.7	1.47	
	Lightweight concrete block (100mm) + polyurethane board (75mm) + gypsum plasterboard (12.5mm)	D2	5.7	0.26	
	Existing concrete balcony and polycarbonate shading	B3	NA	NA	
	Without existing concrete balcony and polycarbonate shading	B4	NA	NA	**S9A:** A3+D1+D2+B4

i. **WWR modification:** The study opted to reduce the original WWR of the case building model only for the southeast and northeast façade orientations that exceeded the ASHRAE 90.1:2014 standards, i.e. minimum 40% of the gross wall area for tropical climate. The proposed WWR reduction, 40%, 35% and 30%, were developed as three modified validated case models (i.e. A1, A2 and A3) and were simulated as a combination with other ERMs in every level of interventions.

ii. **Opaque wall retrofit:** For all levels of intervention, the proposal was either additional materials to the existing wall or new opaque wall construction. Low absorption coefficients characterised the chosen materials to minimise heat gain through opaque surfaces and improve their thermal transmittance (lower u-value). For the minor level, new outer layers, a combination of cement board (40 mm) and insulation board (12 mm), were selected for this intervention level. New construction of the opaque wall was proposed for both moderate and major levels, i.e. a combination of lightweight concrete block (100 mm), polyurethane board (50 mm and 75 mm for moderate and major levels, respectively) and gypsum plasterboard (12.5 mm). The overall u-value for the entire material assembly was calculated and presented in Table 3.

iii. **Glazing wall retrofit:** The selected glazing properties were able to minimise solar heat from entering the building while still providing an excellent opportunity for daylight harvesting. The existing glazing was replaced with single low-e glass panes for the minor level and double-glazing low-e glass panes with SHGC values of 0.44 and 0.35 for moderate and major levels, respectively.

iv. **Existing shading elements:** This simulation study evaluated the impact of the existing shading design on the building's overall energy consumption. First, for all intervention levels, the simulations employed the whole components of the shading devices. Then, the simulations used the modified case model with 30% WWR reduction but without the shading devices (i.e. simulation strategies of S3A, S6A and S9A).

Next, the Overall Thermal Transfer Value (OTTV) of the case building was calculated using the equations specified in MS1525: 2019 [23]. While the OTTV procedure in the MS1525 is only applicable for commercial buildings, it is still considered a reliable local standard to analyse the building envelope thermal performance of a public/government office building. Thus, this study aimed to calculate the OTTV of the simulated modified case models for energy benchmarking purposes.

2.3.4 Simple Cost-based Analysis

A simple cost analysis was carried out to estimate the annual energy and cost savings for opaque and glazing wall ERMs. This simple cost analysis was calculated based on the cumulative energy savings before and after a retrofit. The estimated savings were determined from the OTTV reduction from each level of intervention [26], as shown in Figure 5. The unit prices for the ERMs were obtained from the selected manufacturers and the Public Works Department of Malaysia. The latest energy tariff of RM0.509 per kWh was acquired from Tenaga Nasional Berhad Malaysia.

$$ER = \frac{(OTTV_1 - OTTV_2)\ A_w}{SCOP\ x\ 1000}\ x\ H_{ac}$$

Where,

ER	is the energy reduction per year (kWh/year)
$OTTV_1$	is the computed OTTV based on option 1 (W/m²)
$OTTV_2$	is the computed OTTV based on option 2 (W/m²)
A_w	is the area of walls (inclusive of glazing areas) (m²)
H_{ac}	is the Hours of air-conditioning per year (approximately 2700 hours)
SCOP	is the Air-Conditioning System Coefficient of Performance Recommendation: 2.8 for Split Unit AC, 4.0 for Central Plant or Check with your HVAC engineer.

Figure 5 Formula for simple cost-based analysis

3.0 RESULTS AND ANALYSIS

3.1 Result from Phase 1: Energy-related Data Extraction

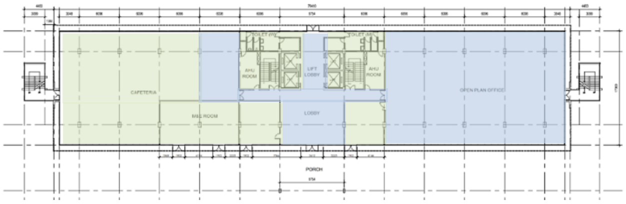
The extracted data from the documents and site visits of the case building covered the building's general information, construction details, electrical system, ACMV systems, and architectural geometrical characteristics to establish the case building model (Table 4). Notably, the case building had a high overall WWR, i.e. approximately 42.2% of the total gross wall area. Specifically, the front and rear façades had the highest window percentage of 45.1%, followed by both side facades at 36.89% (Table 5). Also, it was observed that the infiltration of outdoor air into air-conditioned spaces mostly came from the operable windows. The thermal zones and spaces of the ground floor level and the typical office floor plan (2nd to 13th floor) are illustrated in Figure 6.

Table 4 Detail technical information of case building

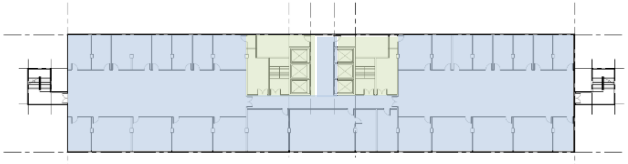
General Data and Geometrical Characteristics
Location: Seremban, Malaysia (latitude 2°43'31.1"N, longitude 101°56"E) Building type: Office building, 13 storey above ground Floor area: Total gross floor area: 17,044.9 m^2 Air-conditioned floor area: 13,877.35 m^2 Dimension and height: 76.81 m x 17.07 m (rectangular); floor-to-floor height = 3.275 m Operating hours: Monday to Friday – 7.30 am – 5.30 pm Saturday & Sunday – closed
Building Envelope Components Specifications
Opaque walls: Wood frame (50mm x 100mm, 400mm c/c), 9.5mm plywood + 50mm air space (ASHRAE *U*-value = 2.12 W/m^{2}K) Glazing walls: 6mm reflective glass with tinted film (shading coefficient = 0.76, U-value = 5.7 W/m^{2}K, SHGC = 0.659) Roof: 150mm thick concrete flat roof (ASHRAE *U*-value = 0.23 W/m^{2}K)
Main operative parameters of ACMV
ACMV system type: Central – water cooled chilled system Air-conditioned space: office space and lift lobby Un-conditioned space: Stairs & Toilets Occupancy density: 20m^2/person Lighting load & type: 11.70 W/m^2, fluorescent lighting Computers load: 4.10 W/ m^2 Infiltration rate: 1.65 AC/h Space design temperature & humidity: 24° Celsius

Table 5 Data for envelope geometrical characteristic of the case building

Façade orientation	Gross Area (Including Windows)	Average Thickness of Wall (mm)	Height of the Façade (excluding rooftop M&E room)	External Shading Devices	Window-wall-ratio (WWR)
Southwest (front)	3479.3 m² (Glazing: 1570.0 m²)	20	44.2m	Cantilever concrete slab with polycarbonate shading fixed at the edge of the slab	45.1%
Northeast (rear)	3479.3 m² (Glazing: 1579.0 m²)	20	44.2m	Ditto	45.1%
Southeast (Right)	745.5 m² (Glazing: 275.0 m²)	20	44.2m	Ditto	36.89%
Northwest (Left)	745.5 m² (Glazing: 280.0 m²	20	44.2m	Ditto	36.89%
				Total exterior envelope area: 8449.6 m² Total glazing area: 3564.0 m²	Overall: 42.2%



Ground Floor Plan



Typical floor plan (2nd – 13th floor)

Legend:

🟦 Air-conditioned area – lobby & offices

🟩 Non air-conditioned area – staircases, AHU, toilets, M&E room

Figure 6 Thermal zones and usages of case building

Table 6 Detail technical information of case building

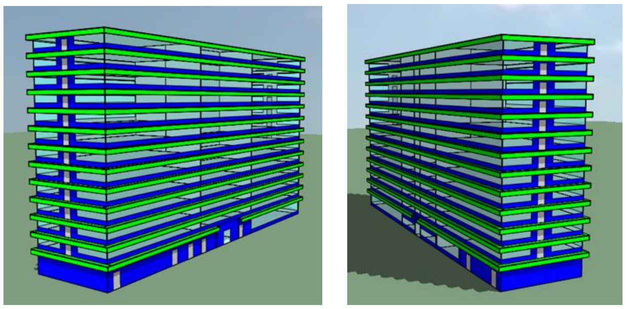
Year	Annual Electricity Consumption (kWh)	BEI calculation: Annual Electricity Consumption (kWh)/ Total Air-conditioned Area (m²)
2017	2,156,032.00	2,156,032.00 / 13,877.35 m² **= 161.63 kWh/m²/year**
2018	1,870,893.00	1,870,893.00 / 13,877.35 m² **= 134.0 kWh/m²/year***
2019	1,752,816.00	1,752,816.00 / 13,877.35 m² **= 126.31 kWh/m²/year***

* BEI levels after the completion of ACMV refurbishment works

The BEI of the case building was calculated by using the annual electricity bills (in kilowatt-hours, kWh) from the previous years of 2017, 2018 and 2019. From the data in Table 6, it is apparent that the BEI in 2017, which was before the ACMV up-grading works were completed, was the highest (161.63 kWh/m²/year), followed by the BEI in 2018 and 2019 with the values of 134.0 kWh/m²/year and 126.31 kWh/m²/year, respectively. These BEI results exceed the recommended BEI in the GBI (150 kWh/m²/year for commercial office buildings) and Economic Planning Unit (EPU) standards (140 kWh/m²/year for government/public buildings). It should be noted that the building started to undergo lighting retrofit in 2019, and since then, the energy consumption has started to reduce. This work is expected to complete by the end of 2020. The energy-saving percentage via ACMV up-grading works and lighting retrofit was 13.23% to 18.70% compared to the 2017 annual energy consumption. These results were compared with those from the proposed building envelope retrofit interventions conducted in this study. The case building's OTTV value was 61.75 W/m² indicating a non-compliance with MS1525: 2014 that recommends the OTTV for the building envelope not to exceed 50 W/m².

3.2 Results from Phase 2: Energy Performance Simulation

All relevant building attributes must be keyed accordingly to enable a detailed whole building energy simulation to be appropriately performed using the IES<VE> software. The process began by modelling its architectural geometrical characteristic and inputs of the building components and materials using the ModelIT module. The glazing wall construction for the model was described, along with the balcony projection as the local shading. The opaque wall assembly consisted of a hardwood panel with wood-framed, and the original roof was a 150mm concrete slab. Next, the building parameters for thermal zones, space usage, ACMV system, occupancy pattern and internal loads were assigned. The design temperature was 24°C with the operating time from 7.30 am to 5.30 pm on working days (Monday to Friday). The study opted for the ApacheSim module for the dynamic thermal simulation of the case model. The established model is shown in Figure 7.



a b

Figure 7 The established model: (a) southeast (front) and southwest (right) elevation; and (b) northeast (rear) and northwest (left) elevations

3.2.1 Calibration and Validation of the Case Building Model

Subsequently, a comparative assessment of the simulated and measured energy consumption data was performed by calculating and comparing their error indicators. The MBE and Cv(RMSE) results represent the error margin percentage between the calibrated model results and the two-year data of monthly electricity bills (i.e. 2018 and 2019). The calibrated case model estimated that the overall annual electricity consumption was 1,679.93 MWh, which was lower than the measured electricity consumption for 2018 (1,870.89 MWh) and 2019 (1,752.82 MWh). The overall load calculation percentage of the MBE year appeared to be consistent and within the tolerable error range.

Table 7 shows the calculated percentage values from the error analysis with MBE and Cv(RMSE) indices compared to 2018 and 2019 measured annual electricity consumptions. It is apparent from this table that the MBE values for 2018 and 2019 represent a range between -25% (underestimation) and 26% (overestimation). The MBE index exceeded more than 20% acceptable margin in January (+26%), May (+21%), and October (+24%) for the 2018 year and only in June (-25%) for the 2019 year. The measured annual electricity consumption of both years and the annual ERR of the simulated case model produced values of 9.7% and 3.7%, respectively. The Cv(RMSE) results revealed more than 15% error bound in January (+26%), May (+23%), and October (+25%) for the 2018 year, as well as January (+20%), May (+22%), and October (+19%) for the 2019 year. The largest difference in peak demand occurred in January 2018 and 2019; however, no further adjustment was made to calibrate as the discrepancy may have been caused by uncertainties in the building operating data, such as the internal and occupancy loads. The average Cv(RMSE) values were 13.6% and 10.45% for 2018 and 2019, respectively.

Table 7 Calculated percentage values of MBE and Cv(RMSE) for 2018 and 2019

Months	2018		2019	
	MBE month (%): max ±20	Cv(RMSE) (%): max ±15	MBE month (%):max ±20	Cv(RMSE) (%): max ±15
January	26*	26*	20	20*
February	9	9	1	1
Mac	3	3	-5	6
April	11	12	2	2.1
May	21*	23*	10	11
June	-11	10	-25*	22*
July	10	10	3	3
August	15	16	11	11
September	-12	10	-11	10
October	24*	25*	18	19*
November	11	10	12	12
December	9	8	9	9
	MBE year: 9.7%	Cv(RMSE) year: 13.6%	MBE year: 3.7%	Cv(RMSE):110. 4%

* Calculated values that exceed than calibration index.

Table 8 Calibrated case model verification and validation with ASHRAE 14, IPMVP and FEMP standards

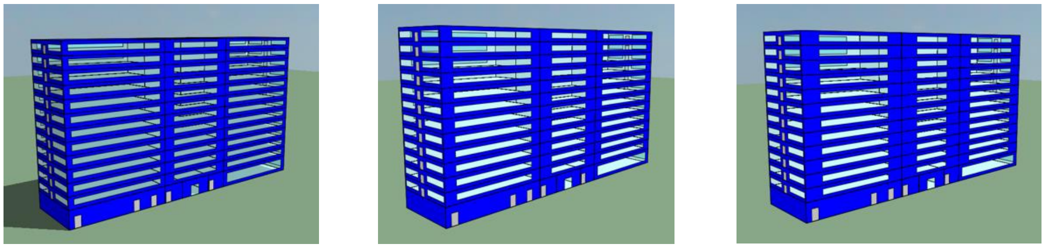
Calibration type	Acceptable index and value					
	ASHRAE 14 (%)		IPMVP (%)		FEMP (%)	
	MBE month	Cv(RMSE)	MBE month	Cv(RMSE)	MBE month	Cv(RMSE)
	±5	±15	±20	±5	±15	±10
Monthly calibration (average values of 2018)	9.7	13.6	9.7	13.6	9.7	13.6
Monthly calibration (average values of 2019)	3.7	10.4	3.7	10.4	3.7	10.4

i. MBE: Mean bias MBE
ii. Cv(RMSE): Coefficient of variation of the root mean squared

The validation of the case model was based on the model's compliance with the standard criteria for MBE and Cv(RMSE) as outlined by ASHRAE 14, IPMVP and FEMP standards (see Table 8). It is clear from the table that the error analysis for the monthly energy consumption of the case model provides the average ERR and Cv(RMSE) values that were within acceptable margins (i.e. from ±5% to ±20%). Hence, this calibrated model was valid for further applications of the proposed retrofit interventions. However, it is essential to note that simulating the model-predicted performance could be hard due to uncertainties, errors between the indices, and inconsistent internal loads (e.g., lighting, equipment and occupancy).

3.2.2 Simulation of Proposed Retrofit Interventions

Subsequently, modifications were made to the validated case model, and three modified case models were produced. These modified case models were designed according to the proposed WWR reductions from the original WWR of the front and rear façades: 40% (A1), 35% (A2) and 30% (A3) (Figure 8). The original case model's total energy consumption and cooling load were initially simulated. Later, the modified case models were simulated using twelve (12) simulation strategies (as listed in Table 9) from three retrofit intervention levels, each comprising a different composition of proposed ERMs. The exclusion of existing shading devices as part of the ERMs was presented by simulation strategies S3A (minor level), S6A (moderate level) and S9A (major level). Subsequently, the annual energy consumption and cooling load results from these modified models were compared with the original case model.



a. Southwest facade – 40% (A1) b. Southwest facade – 35% (A2) c. Southwest facade – 30% (A3)

Figure 8 The modified case models according to the proposed WWR reductions

Table 9 Simulation results for all simulation strategies in comparison with the original case model

Retrofit Intervention	Simulation strategy: individual ERMs	Annual energy consumption (MWh)	The difference in annual energy consumption (%)	Annual cooling load (MWh)	The difference in cooling load (%)
A – Minor level of intervention	**S1:** A1+B1+B2+B3	1630.38	-2.95	1097.46	-4.32
	S2: A2+B1+B2+B3	1620.26	-3.55	1087.34	-5.20
	S3: A3+B1+B2+B3	1599.58	-4.78	1066.66	-7.00
	S3A: A3+B1+B2+B4	1813.39	7.94	1031.59	-11.63
B - Moderate level of intervention	**S4:** A1+C1+C2+B3	1612.27	-4.03	1079.35	-5.90
	S5: A2+C1+C2+B3	1608.88	-4.59	1069.97	-6.72
	S6: A3+C1+C2+B3	1577.68	-6.09	1024.76	-10.66
	S6A: A3+C1+C2+B4	1758.37	4.67	1225.45	6.84
C - Major level of intervention	**S7:** A1+D1+D2+B3	1577.95	-6.07	1045.03	-8.89
	S8: A2+D1+D2+B3	1569.39	-6.58	1036.47	-9.64
	S9: A3+D1+D2+B3	1527.34	-9.08	994.42	-13.30
	S9A: A3+D1+D2+B4	1707.42	1.64	1174.50	2.39

Notes:
i. The original case model's annual energy consumption: 1679.94 MWh
ii. The original case model's annual space cooling consumption: 1147.03 MWh
iii. The code of individual ERMs – refer to Table 3.

3.2.3 Energy Reduction from Retrofit Interventions

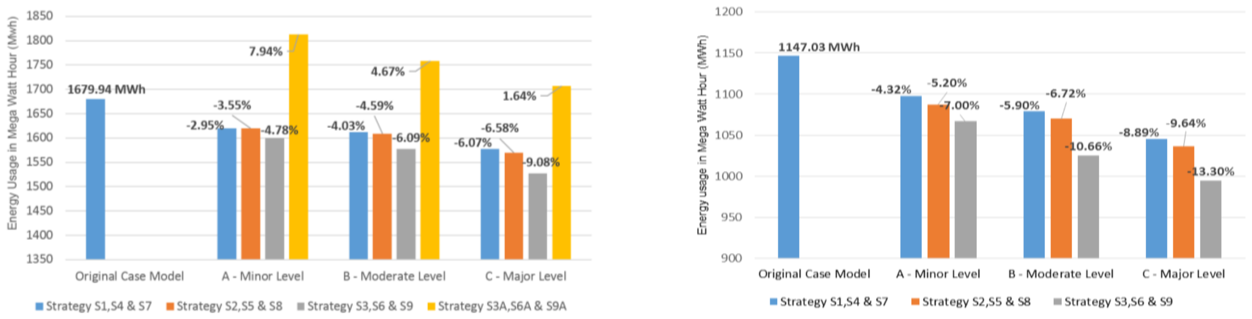
The initial simulation revealed that the original case model's annual energy consumption and the annual space cooling load were 1679.94 MWh and 1147.03 MWh, respectively. In terms of annual energy reduction from the three modified models compared to the original model, the result revealed that case model A3 had the highest reduction percentage of -2.87%, followed by A2 (-2.14%) and A1 (-1.57%).

Table 9 shows the total annual energy consumption and cooling loads after applying all ERMs within the three levels of retrofit intervention as well as their differences in comparison with the original case model. The table indicates a clear trend of decreasing annual energy consumption from simulation strategy S1 until S9, or from minor to major level of intervention, with S1 having the most energy consumption of 1630.38 MWh and S9 the least (1527.34 MWh).

For retrofit intervention A (minor level), simulation strategies S1, S2, and S3 produced an annual energy reduction of -2.95% (1630.38 MWh), -3.55% (1620.26 MWh) and -4.78% (159.58 MWh), respectively. Interestingly, however, the energy reduction of S6 (-6.09%) in the moderate level is slightly higher than S7 (-6.07%) in the major level intervention. However, when existing shading devices were excluded as part of the retrofit strategies (represented by simulation strategies S3A, S6A and S9A), no energy reduction was produced (i.e. all values were positive). The highest increment in total energy consumption was 7.94% for S3A (minor intervention), followed by 4.67% for S6A (moderate intervention), and 1.64% for S9A (major intervention).

Simulation strategies within retrofit intervention B (moderate level) generally had higher energy savings than retrofit intervention A (minor level). The energy-saving percentages for S4, S5, and S6 were -4.03% (1612.27 MWh), -4.59% (1608.88 MWh), and -6.90% (1577.68 MWh), respectively. Retrofit intervention C (major level) offered the highest energy efficiency improvement among all three levels of interventions. Among all simulation strategies within this level, S9 produced the highest energy saving of -9.08% (1527.34 MWh).

Besides, there was a trend of increasing annual cooling load savings from minor to moderate and major levels of intervention (A, B and C), with S1 (minor level) having the least savings (-4.32%) and S9 (major level) having the greatest savings (-13.30%). Notably, the strategy using the modified case model of WWR 30% reduction within all levels of interventions provided the highest annual cooling loads reductions: -7.00% (S3 of minor level), -10.66% (S6 of moderate level), and -13.30% (S9 of major level).



a. b.

Figure 9 Comparison of all simulation strategies in comparison with the original case model: (a) Comparison of annual energy consumptions; and (b)Comparison of annual cooling load consumptions

Table 10 Simulation results for glazing and opaque wall ERMs on annual and cooling load all intervention levels in comparison with the original case model

Retrofit Intervention	**ERMs**	**Code for individual ERMs**	***U*-value (W/m²K) of overall assembly**		**Difference in energy consumption (%)**	
			Existing	**Proposed**	**Annual energy**	**Cooling load**
Minor level	Glazing replacement with low-e tinted single glass panes (SHGC 0.75) and metal frames	B1	5.7	2.63	2.10	3.07
	Exterior wood panel wall (existing) + external cement board (40 mm) + insulation board (12 mm)	B2	1.03	0.68	-2.64	-3.86
Moderate level	Glazing replacement with double low-e glass panes and metal frame (Argon fill, SHGC 0.44)	C1	5.7	1.97	0.27	0.40
	Lightweight concrete block (100mm) + polyurethane board (50 mm) + gypsum plasterboard (12.5 mm)	C2	1.03	0.36	-3.44	-5.04
Major level	Glazing replacement with double low-e glass panes and metal frame (Argon fill, SHGC 0.35)	D1	5.7	1.47	-1.41	-2.06
	Lightweight concrete block (100 mm) + polyurethane board (75 mm) + gypsum plasterboard (12.5 mm)	D2	5.7	0.26	-3.61	-5.30

Similarly, it is apparent from Figure 9 that the highest energy savings were obtained from all strategies using the similar modified model of WWR 30% reduction, namely S3 (minor level), S6 (moderate), and S9 (major level) with the values of -4.78%, -6.09% and -9.08%, respectively. Overall, the evidence gathered here is sufficient to assert that the major level of intervention C was the most effective retrofit intervention proposed for the case building.

3.2.4 Analysis of Individual ERMs – Opaque and Glazing Wall Improvements

The effect of individual ERMs proposed as part of the glazing and opaque wall improvements to the existing building envelope was compared to the original case model. The results revealed that a single ERM could lead to -3.61% annual energy savings and -5.30% annual cooling load reduction (Table 10).

The proposed opaque wall retrofit measures included adding an insulation board to the existing wall (B2) and new wall construction (C2 and D2). The use of wall insulation in each level of retrofit interventions allowed a lower u-value option for the overall wall assembly. The result showed that the annual energy reductions for B2 (minor), C2 (moderate) and D2 (major) were -2.64%, -3.44% and -3.61%, respectively. Although D2 produced the highest energy savings, the difference in saving between D2 and C2 was relatively small. A similar pattern could be seen for annual cooling loads: -3.86% (B2), -5.04% (C2) and -5.30% (D2).

Regarding glazing retrofit measures, it is interesting to observe that only ERM with the lowest u-value, namely D1 (major level), resulted in some energy savings (-1.4%). Other glazing ERMs, i.e. B1 (minor level) and C1 (moderate level), produced slightly higher annual energy consumption than the original case model, with values of 2.10% and 0.27%, respectively.

As mentioned in the previous section, the modified case model of A3 with 30% WWR reduction produced the highest energy savings among all three modified models. Hence, the BEI and OTTV of this modified case model using simulation strategies S3 (minor level), S6 (moderate level) and S9 (major level) were calculated. The BEIs for S3, S6 and S9 were 115.63 kWh/m²/year, 113.00 kWh/m²/year and 110.06 kWh/m²/year, respectively. These values were lower than the GBI benchmark of 150 kWh/m²/year (refer to Table 11). Additionally, the OTTV results were 40.94 W/m², 39.06 W/m² and 37.90 W/m² for S3 (minor), S6 (moderate) and S9 (major), respectively, which were lower than the MS1525: 2014 recommended value of 50 W/m².

Table 11 Calculated BEI and OTTV for all interventions

Retrofit Intervention	Simulated Annual Electricity Consumption (kWh)	BEI calculation: Annual Electricity Consumption (kWh)/ Total Air-conditioned Area (m^2)	OTTV
A - Minor level of intervention (S3)	1,599,580.00	1,599,580.00 / 13,877.35 m^2 = **115.63 kWh/m^2/year**	**40.94 W/m^2**
B - Moderate level of intervention (S6)	1,577,680.00	1,577,680.00 / 13,877.35 m^2 = **113.00 kWh/m^2/year***	**39.06 W/m^2**
C - Major level of intervention (S9)	1,527,340.00	1,527,340.00 / 13,877.35 m^2 = **110.06 kWh/m^2/year***	**37.90 W/m^2**

Notes:
i. Case building BEI: 126.31 kWh/m^2/year
ii. BEI benchmark for GBI: 150 kWh/m^2/year, BEI benchmark for EPU: 140 kWh/m^2/year
iii. OTTV benchmark for MS 1525:2014 50 W/m^2

Table 12 Calculated energy reduction and simple payback for all interventions using the OTTV reduction formula

Retrofit Intervention	OTTV value of simulated models	Energy reduction calculation (refer formula in Figure 4.19)	Calculation for simple payback (years)
A - Minor level of intervention	40.94 W/m^2	$\frac{[(61.75\ \text{W/m}^2 - 40.94\ \text{W/m}^2)\ 8449.60\ \text{m}^2] \times 2700}{4.0 \times 1000}$ = **118,689.42 kWh/year**	a) Energy saved per year (RM) = 118,689.42 kWh/year x RM0.509/kWh = **RM60,412.91** b) Total additional cost (RM) of wall material (glass and opaque) RM75/m^2 x 8449.60 m^2 = RM633,720.00 c) Simple payback (years) RM633,720.00 / RM60,412.91 = **10.5 years**
B - Moderate level of intervention	39.06 W/m^2	$\frac{[(61.75\ \text{W/m}^2 - 39.06\ \text{W/m}^2)\ 8449.60\ \text{m}^2] \times 2700}{4.0 \times 1000}$ = **129,411.96 kWh/year**	a) Energy saved per year (RM) = 129,411.96 kWh/year x RM0.509/kWh = **RM65,870.69** b) Total additional cost (RM) of wall material (glass and opaque) RM105/m^2 x 8449.60 m^2 = RM887,208.00 c) Simple payback (years) RM887,208.00 / RM65,870.69 = **13.5 years**
C - Major level of intervention	37.90 W/m^2	$\frac{[(61.75\ \text{W/m}^2 - 37.90\ \text{W/m}^2)\ 8449.60\ \text{m}^2] \times 2700}{4.0 \times 1000}$ = **136,028.00 kWh/year**	a) Energy saved per year (RM) = 136,028.00 kWh/year x RM0.509/kWh = **RM69,238.25** b) Total additional cost (RM) of wall material (glass and opaque) RM115/m^2 x 8449.60 m^2 = RM971,704.00 c) Simple payback (years) RM971,704.00 / RM69,238.25 = **14 years**

Notes:
i. OTTV value for case building: 61.75 W/m^2 ii. Overall wall area: 8449.60 m^2 iii. Energy tariff from TNB: RM0.509/kWh

In general, it was found that the higher the level of retrofit intervention, the higher the annual energy consumption and space-cooling energy load reduction. The major level intervention C produced the most considerable energy savings for energy efficiency improvement, followed by moderate level B and minor level A. Reducing WWR and u-values of glazing and opaque wall reduced the annual space cooling loads. A similar trend could also be seen when existing external shading devices were in place (i.e. ERM B3) for all levels of interventions. The results of all simulation strategies (S1 to S9) showed that the existing external shading design had a significant impact on energy savings compared with their omission (S3A, S6A and S9A). The calculated BEI and OTTV for energy benchmarking of all intervention levels, particularly S3, S6 and S9, indicated that the values were within the benchmark margin of the Malaysian standards.

3.2.5 *Simple Cost-based Analysis of ERMs*

In this study, a simple cost-based evaluation for each level of intervention was conducted using the identified OTTV to evaluate the cost savings of implementing the retrofit strategies. The detailed calculations of energy saved due to the OTTV reduction and simple payback value are shown in Table 12. The calculations for all levels of interventions included additional investments for the costs of adding new materials to the existing opaque wall and new single low-e glazing. Table 12 shows that the retrofit intervention A (minor level) offered the shortest payback period of 10.5 years with RM60,412.91 energy-saving per year. Intervention B (moderate level) provided RM65,870.69 energy-saving per year with a payback period of 13.5 years, while the major level of intervention C produced the largest energy-saving per year of RM69,238.25 but with the longest payback period of 14 years. Although all measures resulted in a payback period of more than ten years, evaluating them in relation to other benefits, such as a longer lifetime due to a new building envelope and the improvement in indoor thermal and visual performance, is essential.

4.0 DISCUSSION

4.1 Optimised Retrofit Interventions Strategy

The minor, moderate and major levels of retrofit interventions were intended to identify the optimal order of intervention, within which a range of retrofit measures was prioritised and implemented to reduce the building's energy consumption, considering their efficiency and the technology availability in the local market. This study suggests that it is crucial to identify the scope and level of detail energy efficiency in stages, with the possibility of conducting one ERM within one level of retrofit intervention at a time. Since the effect of ERMs on the annual energy reduction was around 7%, it is feasible to define an optimised retrofit strategy for a standard retrofit project and suggest that such a strategy be implemented on any typical government high-rise office buildings. Similar studies pointed out that a retrofit project with a target of reducing less than 45% energy consumption falls under shallow retrofit types [13, 27].

Specifically, the efficiency level of each opaque and glazing ERM was pre-defined with specifications that aimed to enhance the thermal efficiency of the building envelope and were appropriate for hot and humid regions [13, 26]. Whilst the MS1525: 2019 provides the recommended measures and prescribes the energy performance standards for different building elements, the standard does not prescribe the minimum energy efficiency for building envelope glazing and opaque surface that have a direct impact on the thermal performance of the overall envelope assembly (i.e. minimum u-value for overall glazing or wall assembly). Besides, the prescriptive requirements and energy targets are essential to developing an efficient retrofit framework that meets the minimum energy efficiency performance for buildings and their systems.

4.2 Reduction of Energy Consumption

The study has determined that an optimised retrofit intervention with combined ERMs provided a notable decrease in annual energy consumption. The effectiveness of the combined ERMs for opaque walls and glazing in reducing the overall energy usage by 3% to 9% has successfully been demonstrated by enhancing the thermal efficiency of the building envelope. Substantially, all selected ERMs directly reduced the building energy consumption through savings in the space cooling load except for S3A, S6A and S9A simulation strategies, of which the existing concrete balcony and polycarbonate shading were omitted in their proposed combination of ERMs. In other words, these strategies resulted in higher annual energy consumption and cooling loads, which indicates that the existing external shading design is efficient for the case building. Individual ERMs of B2, C2 and D2 produced lower annual energy consumption than ERMs B1, C1 and D1. This finding is consistent with the increased thermal mass of the selected wall insulation specification with a lower u-value, combined with either existing opaque or new wall assembly. As such, insulation specifications outlined in all intervention levels are considered sufficient and practical.

The study also revealed that a glazing improvement combined with the existing shading devices (S3A, S6A and S9A) provided better energy efficiency in the building compared with ERM S3A, S6A and S9A. Among the selected glazing ERMs, ERM D1, described as high-performance low-e double glazing (argon gas fill) with an SHGC value of 0.35, was the most effective individual ERM as there was up to a 1.41% reduction in the building's total energy consumption. No energy reduction value was observed for other glazing ERMs, namely B1 and C1. The study also found that the energy savings expected from installing better glazing properties alone (at all levels of retrofit interventions) were insignificant. Given the findings from this research, it can be argued that for a building envelope retrofit to result in total building energy reduction, it should involve a combination of excellent glazing properties, optimum insulated opaque wall interventions, and an appropriate external shading device.

4.3 Building Energy Standard Compliance

This study revealed that typical government high-rise office buildings in Malaysia (before upgrading works of ACMV systems) operate at an average BEI of 161 kWh/m^2/year. This value is higher than the recommended value in GBI for commercial office buildings (150 kWh/m^2/year) and the EPU standard for public buildings (140 kWh/m^2/year). This result supports Tang and Chin's [26] findings that refurbishment or retrofitted projects in Malaysia are executed without consideration for enhancing the building's energy performance.

However, the calculated BEI and OTTV for energy benchmarking of all retrofit intervention levels showed that all values were within the benchmark margin of the GBI and EPU standards: 115.63 kWh/m^2/year, 113.00 kWh/m^2/year and 110.06 kWh/m^2/year for minor, moderate and major intervention levels, respectively. The average BEI reduction for all retrofit intervention levels in comparison with the GBI standard was between 23% (minor level) to 27% (major level) and between 18% (minor level) to 21% (major level) compared with the EPU standard. Similarly, all retrofit intervention levels resulted in lower OTTV values than the MS1525: 2019 benchmark of 50 W/m^2: 40.94 W/m^2 for the minor level, 39.06 W/m2 for the moderate, and 37.90 W/m^2 for the major level.

5.0 CONCLUSION

This study was motivated by the lack of systematic methods for retrofitting existing buildings in Malaysia, especially for improving the energy performance of government buildings. It explored how retrofit interventions for building envelope design parameters and components could reduce energy consumption, particularly in Malaysia's typical government high-rise office buildings. Therefore, the retrofit strategies outlined in this study were based on the Malaysian climatic conditions, typical materials and feasibility in the local market. Although energy savings were expected after different building envelope retrofit strategies were employed, the study compared the BEI results with the BEI baseline of Malaysia's GBI and EPU standards. Furthermore, the study calculated the OTTV of all simulated retrofit interventions for energy benchmarking evaluation.

The case study of existing Wisma Persekutuan government high-rise office buildings has proven that their typical energy performances are poor, and their BEIs exceed the maximum value recommended in the GBI and EPU standards. The calculated BEI and OTTV of all retrofit intervention levels are valuable information in helping to provide the reference points for building energy performance, energy-saving strategies assessment, and goals setting to improve the building energy efficiency. A simple cost-based analysis was also conducted using the OTTV reduction calculation method to estimate the savings and payback periods. These estimates can be a quick reference for designers and building owners in the early design stage to find suitable retrofit strategies for their projects.

The approach adopted in this study demonstrates the application of the whole-building calibrated simulation to establish and evaluate the potential ERMs and energy savings in the proposed retrofit interventions. It is essential to be reminded that in establishing a case model and evaluating the building envelope retrofit strategy, it is vital to obtain specific building data. These include 2-year electricity bills; detailed data on the building's geometrical characteristics; and primary energy-related data such as building load, ACMV and lighting systems. A validated model is critical in providing reliable and accurate information on building energy performance.

The pre-determined retrofit interventions have the potential to assist building owners, and stakeholders to at least consider implementing different levels of measures that could reduce the annual energy and space cooling loads before embarking on a larger scale of retrofit intervention. The prescribed energy performance of different ERMs in each level of interventions was referred from ASHRAE 90.1 for tropical climatic condition regions, which can provide reference points for the government to establish building energy performance standards. Moreover, the validated case models with a selection of prescribed ERMs developed in this study offer valuable references for building professionals to understand the potential energy reduction offered by the ERMs. The professionals could also use the models and ERMs to develop a plan for any level of retrofit intervention and set the performance target to drive down their buildings' BEI or OTTV values. Furthermore, the models or ERMs can be customised to meet the needs of typical government high-rise and private-owned high-rise office buildings in Malaysia.

The results can be used as energy benchmarking for understanding a building's energy performance and comparing that performance with similar building typology. Also, it can be utilised as the basis for setting the performance target to drive down the BEI and proposing suitable retrofit action plans for poorly performing buildings. Most importantly, if this methodology is followed in retrofitting existing buildings, the government would strengthen their current slogan of leading by example in energy efficiency.

Lastly, further studies are recommended to include other building envelope ERMs related to thermal performance, such as the reduction of air leakage, moisture control, and indoor thermal performance, that were not considered in this study. Further economic analysis using net present value (NPV) calculations is recommended to understand the financial implications of implementing ERMs and retrofit interventions. It is also beneficial to analyse building envelope retrofit with the sustainable use of mechanical and natural technology systems to further enhance the building's thermal performance.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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