Building Envelope Retrofit: Enhancing Energy Performance in Existing Government Office Buildings in Malaysia

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***Abstract*—This paper aims to develop a validated model for building envelope retrofit that can contribute to annual energy savings with the main objectives to optimize building envelope retrofit intervention strategies and identify a range of intervention level in relation to their energy reduction levels. A case study combined with simulation approach was employed to examine the energy performance levels of three typical existing government office buildings in Malaysia and their potential energy performance improvement through various building envelope Energy Retrofit Measures (ERMs). The validated case model of an original typical government office design was chosen as the base case for the retrofit intervention simulations. The effectiveness of each three levels of interventions proposal with integrated ERMs was evaluated by comparing the simulated space cooling and annual energy consumption between the base case (before any intervention) and retrofit strategies (after interventions). The results show that all levels of intervention contribute to the decrease in space cooling energy level and annual energy consumptions of the buildings. The energy saving resulting from the major level of intervention is the largest, followed by the moderate level and the minor level of intervention, with the value of 23.88%, 22.07% and 18.96% respectively, in comparison to the base case. This study provides a methodological framework and staged approach of retrofit intervention strategies with integrated ERMs that can be applied by the building sector in general, and the Government of Malaysia in particular, to improve the envelope thermal performance of existing buildings. It is envisaged that the adopted measures will become a useful reference and guidance for the government in the energy-related policy making processes.**

Keywords*—*building envelope retrofit; energy perfomance simulation; office buildings; retrofit intervention

I. Introduction

Reseach confirms that buildings are responsible for over a third of global energy-related CO_2 emissions and also the key for low-cost climate mitigation globally [7][9][14]. The energy use in the building sector was responsible for 8.8 $GtCO_2eq$ emissons, 32% of the global total of energy-related emissions [16]. Therefore, new and existing buildings play a major role in reducing their energy usage in order to mitigate climate change [9]. In most countries, office buildings make up the largest energy consuming building type within the commercial sector due to their high operating energy requirements for lighting and air-conditioning systems. Retrofit forms a key part of mitigation strategy in countries with large quantity of building stocks [16]. In recent years, there has been an increasing interest in sustainable and building energy retrofit of existing building stock. While a significant literature exists on the reftrofitting strategies, effective strategies for energy savings through retrofits of existing buildings are still under-developed [15][2]. Many energy-related retrofitting projects around the world mainly concerned with active building system interventions and ignored aspects related to passive retrofit measures such as building envelope interventions and day lighting harvesting [4].

In Malaysia, energy audits carried out by Pusat Tenaga Malaysia (PTM) on selected government office buildings revealed that majority of these buildings had Building Energy Intensity (BEI) in the range of 200 to 250 kWh/m^2/year (a BEI level of less than 200 kWh/m^2/year is considered as energy efficient building under the MS 1525:2007). Previous studies pointed out that building retrofits in Malaysia are commissioned without due consideration for enhancing the buildings' energy performance [3][11]. Therefore, this study aims to develop a validated model for building envelope retrofit that can contribute to annual energy savings, with the following objectives: (1) To establish case models from selected case studies in order to help understand the influence of building envelope components on overall building energy consumption, (2) To identify the Energy Retrofit Measures (ERMs) and evaluate their impacts on the level of buildings' energy efficiency, and (3) To develop a systematic approach in optimising building envelope retrofit intervention strategies and identify a range of intervention levels in relation to their energy reduction levels.

II. METHODOLOGY

In order to achieve the stated objectives, this study was conducted in two phases: (1) Identification of case studies and extraction of their energy-related data to facilitate a simulation study, and (2) Simulation of energy performance and energy intensity on all case models in order to determine an optimised retrofit intervention strategies. Therefore, a case study combined with calibrated simulation approach was employed to analyse and calibrate the case models. The calibrated simulation approach is an approach for measuring savings by using a computer simulation software and calibrating the various inputs to the program so that predictions match closely with the measured energy data [1]. The validated case model of an original typical government office design that involved a validation process through comparison with the energy-related measured data was chosen as the base case for the retrofit intervention simulations. The levels of interventions are defined according to the selected pre-defined quantitative criteria of ERMs thermal characteristics that aim solely on building envelope improvement. The proposed three levels of interventions with a combination of several ERMs such as window-wall-ratio (WWR), external insulation, high performance window and external shading devices, were applied to the base case model. Specifically, this research explores how energy-related data of building case studies, energy modelling and research findings can be effectively combined to demonstrate a feasible and systematic approach in optimising retrofit intervention strategy by using staged approach that is integrated with building envelope ERMs.

A. Phase 1: Building Selections and Energy-related Data Extractions

The first step of phase 1 involved selecting three case buildings for this study, which were the existing typical government office building of Wisma Persekutuan. The first two buildings (Building 1 and Building 2) were located in Kuala Lumpur, while the third building (Building 3) was located in Kuantan (Fig. 2). All of these buildings had the same layout plan (Fig. 1) with a form of hermetically sealed box, totally depending on air-conditioning and mechanical ventilation (ACMV) system but differ in terms of their façade renovation concept and construction materials. Building 1 (base case model) still maintains the original façade component until today. Currently, there are fifteen typical or unrenovated Wisma Persekutuan buildings in Malaysia. On the other hand, Building 2 and Building 3 had undergone some façade retrofits but without considering any energy saving measures. Detailed information of the case buildings is presented in Table 1.

The second step was extracting the energy-related data from document analysis (e.g. drawings, energy audit report and technical data) and gathering site visit data to be utilized in the simulation of base case model. The site visit data gathering through physical observations and walkthrough site observations with a photographic survey were conducted to verify the preliminary assessment of information gathered during the document analysis.

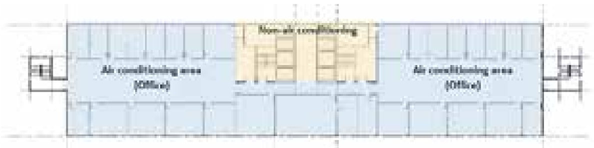

Fig. 1. Typical upper floor plan of Buildings 1 and 2 with two different thermal zones.

TABLE I. BUILDINGS INFORMATONS AND SUMMARY OF DIFFERENCES BETWEEN CASE BUILDINGS

	Case studies – Wisma Persekutuan office building		
	Building 1: Typical design of Wisma Persekutuan	***Building 2: Block F, JKR Headquarters***	***Building 3: Wisma Persekutuan Kuantan***
Floor area	Approximately 17,011 m^2	Approximately 24,345 m^2	Approximately 17,011 m^2
Floor height	Approximately 48.39 m	Approximately 63.31 m	Approximately 48.39 m
Volume	57,652.38 m^3	77,519.0 m^3	57,652.38 m^3
Façade renovation concept	Non-renovated	Modern concept	Modern but relatively maintained the original design concept.
Contruction materials of façade	Combination of timber frame window and opaque wall.	Aluminum frame glazing from floor to ceiling height.	Additional board installed on the existing external wall.

	Case studies – Wisma Persekutuan office building		
	Building 1: Typical design of Wisma Persekutuan	***Building 2: Block F, JKR Headquarters***	***Building 3: Wisma Persekutuan Kuantan***
Justification of selection	Non-renovated	Extensively renovated	Extensively renovated
Purpose of selection	Base case model	Case model 2	Case model 3

Fig. 2. a) Building 1, b) Building 2; and c) Building 3

B. Phase 2: Energy Performance Simulation

Energy simulations using eQUEST software were conducted on the three buildings for two purposes: (1) to demonstrate the buildings' energy consumptions, and (2) to conduct a comparative analysis by correlating the building envelope design properties with overall buildings' energy performance. In this study, the base case was simulated for a full year and a calibration process with monthly utility bills was conducted to validate the model. The validation was done by comparing the results from simulated and monthly utility bills data in terms of their Monthly Root Mean Squared Error (RMSE) and Mean Bias Error (ERR) values and their error indicators. The results were analysed by calculating the total per cent difference and the Coefficient of Variation of the Root Mean Squared Error, CV (RMSE). The equation of ERR and RMSE are shown in Figure 3. The validation of simulated base case model was essentially based on the models' compliance with the standard criteria for ERR and CV (RMSE). The five steps involved in developing the model using a calibrated simulation approach are shown in Fig. 4. Simultaneously, the effectiveness of each level of intervention and the ERMs was evaluated by comparing the base case (before any intervention) with the retrofit strategies (after the interventions) based on their simulated space cooling and annual energy consumption.

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

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

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

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

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

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

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

Fig. 3. ERR and RMSE equation.

III. RESULTS AND ANALYSIS

A. Results from Phase 1: Energy-related Data Extraction

For this study, a base case simulation model is defined by a base case building that is integrated with energy-related data extracted from Phase 1. These data include geometrical characteristic, building envelope component specifications, main operative parameters of the ACMV systems and energy provider data (Table 2). The climate data set in .bin format of Kuala Lumpur was downloaded from doe2 website [6].

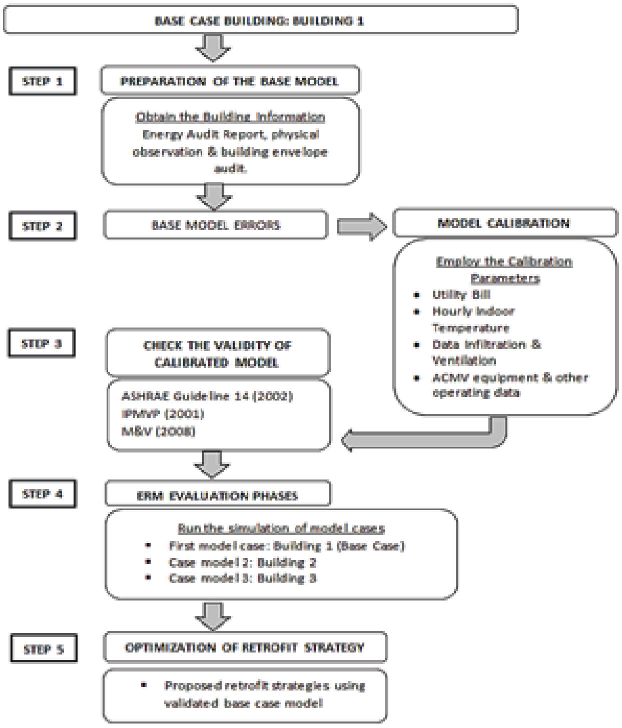

Fig. 4. Five steps in developing model cases and retrofit strategies using a calibrated simulation approach.

TABLE II. DESCRIPTION OF ENERGY-RELATED DATA EXTRACTED FROM PHASE 1

General Data and Geometrical Characteristic
Location: Malaysia (latitude 4.2105° N, longitude 101.9758° E) Building type: Office building, 13 storey above ground Floor area: Total gross floor area = 17,282.6 m^2 & air-conditioned floor area = 15, 163.2 m^2 Dimension and height: 76.58 m x 17.36 m (rectangular); floor-to-floor height = 3.048 m Operating hours: Monday to Friday – 7.00 am – 6.00pm (11 hours) Saturday & Sunday – closed Un-conditioned space: Stairs & Toilets Data Center: Max. power consumption 105.325 kW
Building Envelope Components Specifications
Opaque walls: Wood frame (50mm x 100mm, 400mm c/c), 12.5mm plywood + 50mm air space (ASHRAE *U*-value = 0.45 W/m^2K) Glazing walls: 6mm reflective glass with tinted film (shading coefficient = 0.43, U-value = 4.8 W/m^2K) Roof: 150mm thick concrete flat roof (ASHRAE *U*-value = 0.23 W/m^2K)
Main operative parameters of ACMV
ACMV system type = Chilled water coils, 2 AHU systems per floor Air-conditioned space = office space and lift lobby 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, 40-60%

B. Results from Phase 2: Energy Performance Simulation

1) Base Case Model Calibration and Validation

The ERR results for simulated and 2013 electrical bill monthly data were obtained through an iterative calibration process and the results represented a range between -18.59% (underestimation) and 25.09% (overestimation) (Fig. 5). The yearly ERR value based on monthly energy consumption of the base case building was -0.47%. This implies the underestimation trend of simulation predicted values in comparison to measured data [5]. The average value of CV (RMSE) for simulated and measured data was 9.0%, which represented the inaccuracy level of the calibration model in predicting the monthly consumption values. In other words, the base case simulation model was 91.0% accurate with most of the monthly electricity use and peak demands matched the monthly data within acceptable differences. The validation of simulated base case model was basically based on the model's compliance with standards criteria for ERR and CV (RMSE). In summary, the accuracy of the calibrated base case model in predicting the overall energy consumption was in the benchmark margins (Table 3). Hence, this calibrated model was valid for further applications of the possible ERMs.

2) Identification of ERMs and their Impacts on Energy Consumptions

This study intends to highlight the energy-relevant characteristics of the models' building envelopes which include WWR and the overall u-value (in relevance to glazing and opaque wall properties). Subsequent to the base case model calibration for energy simulation, modifications were made to the calibrated base case model's building envelope design parameters in order to create the case models of Building 2 and

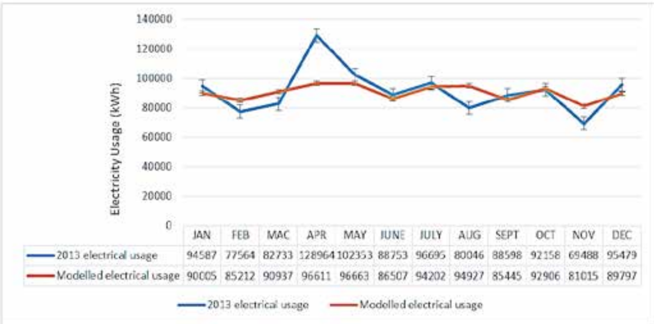

Fig. 5. Monthly comparison of 2013 case model electrical usage (utility bills) with simulated model of monthly electrical usage.

TABLE III. CALIBRATED BASE CASE MODEL VERIFICATION AND VALIDATION WITH STANDARDS GUIDELINES

Calibration type	Acceptable index and value						
	ASHRAE 14 (%)		IPMVP (%)		FEMP (%)		
	ERR month	CV (RMSE)	ERR month	CV (RMSE)	ERR month	ERR year	CV (RMSE)
	±5	±15	±20	±5	±15	±10	±10
Base case monthly calibration (average values)	-0.5	9	-0.5	9	-0.5	-0.47	9
*ERR: Mean bias error CV (RMSE): Coefficient of variation of the root mean squared error							

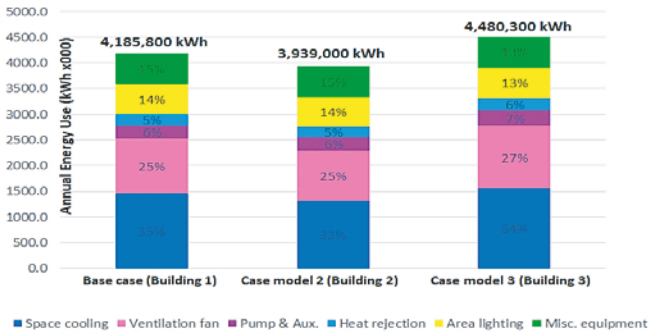

Fig. 6. Comparison of modelled annual energy consumption by end use components for all simulated case models.

Building 3 for the purpose of conducting energy performance simulations. In other words, the case models 2 and 3 were created by modifying the base case model according to case models 2's and 3's actual renovated design features.

After comparing the total energy usage among all three case models, it is evident that case model 3 had the highest total annual energy consumption (4,480,300 kWh), while case model 2 consumed the least (3,939,000 kWh) (Fig. 6). The result also shows that the average percentage of annual energy consumption for building space cooling system and internal load (area lighting and equipment) account for 70% and 30% respectively. This confirms previous findings in the literature that office buildings' space cooling system consumes the most energy.

The result from the BEI benchmarking analysis revealed that the case model 3 had the highest BEI of 296.0 kWh/m^2/year compared to the base case and case model 2 with 276.50 kWh/m^2/year and 260.2 kWh/m^2/year respectively. Generally, all models' BEI values were higher than the energy benchmark for office buildings recommended in the Malaysian Standards MS1525:2007 (135 kWh/m^2/year) as well as the base point stated in the Green Building Index rating tool (150 kWh/m^2/year). Specifically, the models consume 80% more energy than the value stated in both standards. The results so far suggest that the energy performance of the typical and renovated Wisma Persekutuan are poor and far falls short of the requirements specified in building energy efficiency standards.

Unsurprisingly, the WWRs of all case models were higher than the minimum requirement prescribed by ASHRAE 90.1-2007 for hot and humid climate zone – east and west orientations of the base case model; west orientation of case model 2; and all orientations of case model 3. The window percentage of the base case model as well as case models 2 and 3 were 32%, 23% and 50% respectively. The simulation results show that the case models with higher overall WWR and percentage of window glazing had higher overall energy consumptions (Fig. 7). The highest annual energy consumption was evident in case model 3, which was designed with the highest u-factor for the entire wall assembly. However, the lowest was in case model 2, which was designed with the lowest WWR and additional insulation on the external walls.

The comparison of energy performance among case models that were retrofitted based on different envelope design concepts could provide some ideas on the ERMs (selected materials and their composition) and their impacts on the building's overall thermal performance. In hot and humid climate, the WWR and envelope properties are the key factors in a building's thermal performance as they indicate the amount of heat absorbed from the building envelope. Therefore, an improvement in fenestration design is very much needed to achieve energy efficiency.

3) Identification of Retrofit Intervention Levels and their Impacts on Energy Consumptions

Table 4 shows the proposed three levels (minor, moderate and major) of retrofit interventions (strategies A, B and C) with their respective combinations of ERMs (A1-A4; B2-B4; C2-C4) and their u-values. These were simulated using the modified and calibrated base case model (integrated with proposed ERMs to the envelope components) to evaluate their space cooling and overall annual energy consumptions. The WWR of all orientations for base case model were reduced to

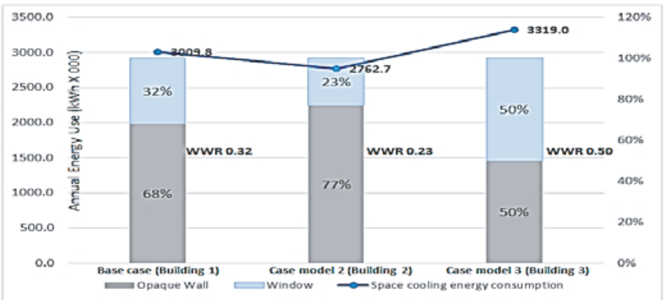

Fig. 7. Comparison of modelled annual energy consumption by opaque and window components for all simulated case models.

TABLE IV. DETAIL RETROFIT INTERVENTION STRATEGIES AND INDIVIDUAL ERMS

Strategy	ERMs	Code		U-value (W/m²K)	
		Individual ERMs	Strategy	Existing	Proposed
Minor level of intervention	Reduction of WWR for all orientations to 0.20 ratios.	A1	A	3.33 (overall)	2.69 (overall)
	Exterior wood panel wall (existing) + external board polystyrene insulation (40mm) + additional insulation R-11 batt.	A2		1.75 (overall)	0.42 (overall)
	Glazing replacement with low-e glass single panes (SHGC 0.72).	A3		1.03	0.75
	New window external shading as an overhang (West and East@2.80 feet depth, North and South@1.50 feet depth).	A4		NA	NA
Moderate level of intervention	Reduction of WWR for all orientations to 0.20 ratios.	A1	B	3.33 (overall)	2.69 (overall)
	Exterior wood panel wall (existing) + external board polystyrene insulation (50mm) + additional insulation R-13 batt.	B2		1.75 (overall)	0.43 (overall)
	Glazing replacement with double low-e glass panes - Double Low-E (e2=.04) Clear (Air fill, SHGC 0.44)	B3		1.03	0.30
	New window external shading as an overhang (West and East@3.00 feet depth, North and South@2.00 feet depth).	B4		NA	NA
Major level of intervention	Reduction of WWR for all orientations to 0.20 ratios.	A1	C	3.33 (overall)	2.69 (overall)
	Exterior wood panel wall (existing) + external board polystyrene insulation (75mm) + additional insulation R-15 batt.	C2		1.75 (overall)	0.44 (overall)
	Glazing replacement with double low-e glass panes - Double Low-E (e2=.04) Clear (Argon fill, SHGC 0.28)	C3		1.03	0.23
	New window external shading as an overhang (West and East@3.20 feet depth, North and South@2.00 feet depth).	C4		NA	NA

comply with the requirement by ASHRAE 90.1-2007 (an overall WWR of 0.20) and were applied to strategies B and C as a new baseline design before adopting the proposed ERMs to the envelope components (Fig. 8).

The simulation result shows that retrofit strategy A produced an annual energy consumption of 3,392,200 kWh, a reduction of 18.96% (793,000 kWh) in comparison to the base case. Specifically, each of the ERMs, A2, A3 and A4, produced an annual energy savings of 4% (128,756 kWh), 2% (94,871 kWh) and 8% (316,692 kWh) respectively, relative to the baseline design.

Fig. 8. Energy modelling of new base line model for retrofit intervention strategies evaluation.

Compared to retrofit strategy A, strategy B produced lower annual energy consumption (3,261.700 kWh) and higher energy savings (22.07%) Strategy B provided 4% (158,054 kWh), 9% (336,251 kWh) and 8% (332,820 kWh) energy reduction for B2, B3 and B4 respectively. Interestingly, strategy C offered even higher energy savings (23.88% with an annual energy consumption of 3,186,300 kWh) than strategy B, with saving percentages of 4% (158,054 kWh), 9% (336,251 kWh) and 8% (332,820 kWh) for C2, C3 and C4 respectively.

Overall, retrofit strategy C offered the highest level of energy efficiency improvement compared to the other two strategies. Hence, it is sensible to suggest that strategy C could be considered as the most effective building envelope retrofit strategy for the case building. However, it should be noted that the reduction difference of 1.81% between strategy C and B was not considered significant.

The results also show that all strategies contribute to annual reduction in space cooling consumption (Fig. 9) with 22.19%, 25.45% and 28.0% for strategies A, B and C respectively, in comparison to the base case. Notably, retrofit strategy of C provides major decrease in space cooling with a reduction of 406,000 kWh.

Fig. 9. Comparison for space cooling energy consumption reduction of retrofit strategies.

Figure 10 shows the effect of individual ERMs on annual energy consumption in comparison to the base case. A1 results in 6.17% and 5.59% reduction for space cooling and annual consumption, respectively in comparison to base case results. By adding insulation as of A2, B2 and C2 led to a reduction of 8.97%, 10.29% and 9.29% in cooling load respectively. B2 led to the highest savings in annual energy consumption (9.51%), followed by C2 (8.61%) and A2 (8.31%). It should be noted that the moderate intervention level of B2 has a higher value of savings in comparison to those under minor and major intervention levels.

The reduction of space cooling consumption for all glazing retrofit measures of A3, B3 and C3 were 8.44%, 14.94% and 17.98%, respectively. These ERMs also showed a similar level of improvement in overall energy consumption with a reduction of 7.86% (A3), 13.63% (B3) and 16.20% (C3). Clearly, in terms of glazing strategy, C3 offered the highest energy reduction for both space cooling and overall energy usage.

Regarding the external window overhang measures in A4, B4 and C4, their total space cooling energy reduction was 13.68%, 15.42% and 15.77% respectively; whilst their reduction in annual energy consumption was 12.45%, 12.83% and 13.12% respectively. Hence, in terms of overhang, C4 seemed to be the most effective retrofit strategy.

Overall, the results show that the major level of intervention (strategy C) offered the largest energy savings, followed by moderate level (strategy B) and minor level of intervention (strategy A). This suggests that energy consumption corresponds to the application of ERMs such as

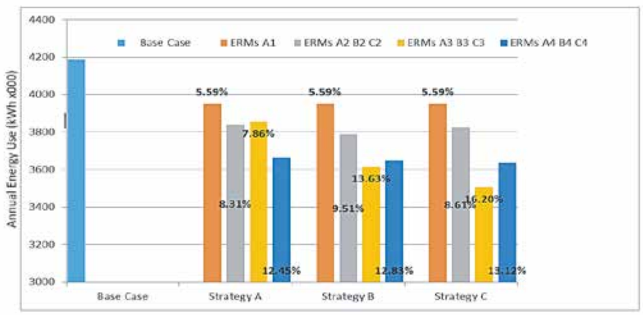

Fig. 10. Comparison for annual energy consumption of ERMs with base case.

reduction of WWR, external wall insulation, high performance window and external shading devices for window.

IV. Discussion

The case studies and their simulation models for energy analyses have provided the staged approach and integration of ERMs in building envelope retrofit. The identified three levels of retrofit interventions were intended to identify the optimal order in which a range of retrofit measures should be prioritised and implemented to reduce the building energy consumption, considering their efficiency and technology availability in the local market. This study suggests that it is very crucial to identify the scope and level of detail energy efficiency in stages, with the possibility to conduct one measure after another through staged retrofit interventions [10] [17].

Since the effect of ERMs on the reduction of annual energy consumption was around 23%, it is feasible to define an optimised retrofit strategy for standard retrofit project and suggest for it to be implemented on any typical government office buildings. Similar studies point out a retrofit project targeting an energy use reduction of less than 45% fall under standard retrofit types [8][10][17]. The standard retrofit measures outlined in all interventions are based on predefined measures for opaque and glazing wall suitable for hot and humid regions [4][8][13]. The efficiency level of each ERM under the three different levels of interventions or strategies was pre-determined with specifications aiming for enhancing the thermal efficiency of the building envelope.

The study shows that an optimised retrofit strategy provides a notable reduction in the annual energy consumption. The effectiveness of combined ERMs for opaque and glazing wall in reducing the overall energy usage of 18% to 23% has been demonstrated by the building envelope's thermal efficiency. In general, all selected ERMs have directly reduced the building's cooling energy demands and annual energy consumption. The results also indicate that the glazing improvement with window overhang ERMs contributes greater impact to the building energy efficiency in comparison to opaque wall ERMs. Among the selected glazing ERMs on each level of retrofit interventions, the high performance low-e double glazing (with argon gas filled) with SHGC value of 0.28 is the most effective ERM, offering up to 17% energy reduction; whilst the average energy reduction from integrating external insulation ERMs (in all intervention levels) is 10%. Such saving is achieved due to the implementation of better-performance glazing to improve the building envelope's thermal resistance and light transmission. A nearly 16% reduction in space cooling energy consumption is possible when window overhang as glazing shading device is considered [2][12][13]. Thus, it can be confirmed that building envelope retrofit that combines both glazing replacement and glazing shading device installation could produce a significant energy reduction.

The case study energy simulation results revealed that typical government offices (original and renovated versions) in Malaysia are operating at BEI higher than the recommended value stated in the MS1525:2007. This finding appears to be well supported with studies whose findings suggest that refurbishment or retrofit projects in Malaysia were executed without consideration for building energy performance enhancement [3][11]. Consequently, the simulation results from all levels of retrofit interventions do not comply with the BEI baseline of 200 kWh/m^2/year to satisfy the requirement of MS1525. The average reduction of BEI for all interventions level is 21% with the major level of intervention achieving the lowest BEI of 210 kWh/m^2/year.

V. CONCLUSION

This study was set out to explore how the energy consumption of existing office buildings could be reduced through building envelope retrofit interventions. As such, typical existing government office buildings in Malaysia were selected as case studies. Previous studies suggest that building refurbishment or retrofit projects in Malaysia have been commissioned without consideration for energy performance improvement. Accordingly, this study was motivated by the lack of systematic methods in retrofitting existing building in Malaysia. The study also sought to identify how much energy reduction could be realised through different building envelope retrofit strategies. Findings from the study reveal that the implementations of identified building envelope retrofit strategies result in lower BEI. In this case, retrofit strategies that focus on improvement to building envelope thermal performance need to be based on Malaysia climatic condition, material and feasibility in the local market.

The approach adopted in this study demonstrates the application of the whole-building calibrated simulation approach in establishing and evaluating the potential ERMs and their energy savings. This approach has generated reliable simulation case models regardless of unavoidable uncertainties. The established calibrated base case models that take in account the buildings' design parameters offer a platform for the impacts of ERMs technologies to be well understood. They also provide the basis for decision makers in developing a retrofit plan to achieve any level of energy savings. Additionally, the calculated BEIs of all case models in this study are important information for building energy benchmarking. They also help in providing reference points for energy performance, energy saving strategies assessment and goals setting to improve buildings' energy efficiency. The methodology adopted in this study involves simulation model calibration and validation processes with prescribed ERMs selections that can be customised to the needs of typical government office buildings and other similar type of office buildings in Malaysia. If the methodology is followed in retrofitting existing buildings, the government would strengthen their existing slogan of leading by example in energy efficiency.

Lastly, further studies are recommended to include ERMs concerning to building envelope thermal performance (such as reduction of air leakage, moisture control, day lighting analysis and indoor thermal performance) that were not considered in this study. Further evaluations on the investment/payback of ERMs identified in this study are also recommended to determine the ERMs' return of construction costs in relation to their energy savings.

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