UNIVERSITI PUTRA MALAYSIA

# *IMPROVEMENT OF THERMAL PERFORMANCE OF EXISTING STANDARD GOVERNMENT HIGH-RISE OFFICE BUILDINGS IN MALAYSIA THROUGH ENVELOPE RETROFIT*

NOOR LAILY BT MOHAMAD

FRSB 2021 7

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**By**

**NOOR LAILY BT MOHAMAD**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science**

**November 2020**

## DEDICATION

This thesis is dedicated to Almighty Allah The Best Planner.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Master of Science

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**November 2020**

**Chairman : Assoc. Prof. Zalina Shari, PhD**
**Faculty : Design and Architecture**

In most countries, office buildings make up the largest energy-consuming building type within the commercial sector due to their high operating energy requirements. This study revealed that typical government high-rise office (before up-grading works of ACMV system) in Malaysia are operating at an average BEI of 161 kWh/m$^2$/year, which is higher than the GBI standard for a commercial office building and EPU standard for public buildings (140 kWh/m$^2$/year). Therefore, this study aims to develop a validated model for building envelope retrofit that can contribute to annual energy savings with objectives: 1) to establish a case model from selected case building 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 interventions and identify a range of intervention levels in relation to their energy reduction levels. The 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 using IES<VE> software to determine an optimised retrofit intervention strategies. The proposed three levels of interventions with a combination of selected building envelope ERMs were applied to the validated case model. The effectiveness of each intervention level and the ERMs was evaluated by comparing the simulated annual and space cooling energy consumption with the base case model. The simulation results in all levels of retrofit interventions demonstrated compliance with the BEI benchmark margins; 116 kWh/m$^2$/year in minor intervention level, 113 kWh/m$^2$/year in moderate intervention, and 110 kWh/m$^2$/year in major intervention level, respectively. The average reduction of BEI for all intervention levels in comparison with GBI standard was between 23% (minor level) to 27% (major level) and with EPU standard was between 18% (minor level) to 21% (major level). Moreover, the results indicated a lower OTTV value than MS 1525:2014 standards of 50 W/m$^2$; with 40.94 W/m$^2$ for minor level, 39.06 W/m$^2$ for moderate level and 37.90 W/m$^2$ for major level. It was observed that a combination of efficient glazing and opaque wall intervention with suitable external shading devices plays an important role in energy

reduction when retrofitting a building envelope. This study provides a methodological framework and staged approach of retrofit interventions with integrated ERMs that can be applied by the building sector in general, and the Government of Malaysia in particular, to improve the thermal envelope performance of existing buildings.

Abstrak tesis yang dikemukakan kepada SenatUniversiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

**PENAMBAHBAIKAN PRESTASI TERMAL BAGI BANGUNAN TINGGI PEJABAT KERAJAAN SEDIA ADA DI MALAYSIA MELALUI RETROFIT FASAD BANGUNAN**

Oleh

**NOOR LAILY BT MOHAMAD**

**November 2020**

**Pengerusi : Prof. Madya Zalina Shari, PhD**
**Fakulti : Reka Bentuk dan Seni Bina**

Di dalam kebanyakan negara, bangunan pejabat merupakan penyumbang terbesar dalam penggunaan tenaga bagi bangunan komersial kerana beroperasi dengan menggunakan tenaga yang tinggi untuk pencahayaan serta sistem pendingin hawa. Kajian telah mendapati bangunan tinggi tipikal pejabat kerajaan (sebelum kerja naik taraf sistem pendingin hawa) mengesahkan ianya mempunyai BEI 161 kWh/$m^2$/tahun yang melebihi piawai GBI bagi kategori pejabat dan EPU bagi bangunan kerajaan. Oleh itu, kajian ini bertujuan untuk menghasilkan satu model simulasi bagi retrofit fasad bangunan yang memenuhi standard dan menyumbang kepada penjimatan tenaga dengan objektif berikut: 1) untuk menyediakan model simulasi daripada kajian kes bagi memahami pengaruh komponen binaan fasad bangunan terhadap penggunaan tenaga tahunan; 2) untuk mengenalpasti kaedah retrofit cekap tenaga (ERM) dan menilai kesannya terhadap kecekapan tenaga yang efisien; dan 3) untuk mendapatkan satu pendekatan sistematik dalam mengoptimumkan intervensi retrofit fasad bangunan dan mengenal pasti peringkat-peringkat intervensi yang bersesuaian dengan kadar penjimatan tenaga. Kajian ini dijalankan dalam dua fasa: 1) mengenalpasti kajian kes dan pengekstrakan data berkaitan tenaga bagi membantu kajian simulasi tenaga; dan 2) simulasi tenaga menggunakan perisian IES<VE>. Tiga peringkat intervensi (minima, sederhana dan utama) dengan kombinasi ERMs dan hasil simulasi dikaji secara analisis perbandingan keputusan simulasi. Kadar kecekapan penjimatan tenaga daripada setiap tahap intervensi dan ERM dianalisa dengan membandingkan keputusan simulasi kadar penggunaan tenaga ruang yang didinginkan dan penggunaan tenaga tahunan model asas. Hasil simulasi semua peringkat intervensi menyumbang kepada penurunan penggunaan tenaga dan memenuhi piawai GBI dan EPU; 116 kWh/$m^2$/year (peringkat minima), 113 kWh/$m^2$/year (peringkat sederhana) dan 110 kWh/$m^2$/year (peringkat utama). Kadar peratusan penurunan BEI pada semua peringkat intervensi adalah antara 23% (peringkat minima) hingga 27% (peringkat utama) dibandingkan dengan piawai GBI dan 18% (peringkat minima) hingga 21% (peringkat utama) dengan EPU. Penurunan nilai OTTV juga dibuktikan dengan nilai semua peringkat intervensi adalah 40.94 W/$m^2$ (peringkat minima), 39.06 W/$m^2$ (peringkat sederhana) dan 37.90 W/$m^2$ (peringkat utama). Hasil

pemerhatian mengenalpasti gabungan semua ERM dalam setiap peringkat intervensi menghasilkan penjimatan penggunan tenaga dalam bangunan. Hasil kajian ini dapat menyediakan satu rangka metodologi dengan pendekatan berperingkat dalam intervensi retrofit beserta integrasi ERM. Ianya boleh digunapakai dalam sektor bangunan, secara umum dan Kerajaan Malaysia, khususnya bagi meningkatkan keupayaan kecekapan tenaga bangunan sedia ada

## ACKNOWLEDGEMENTS

I would never have been able to finish my study without the guidance of Almighty Allah, my committee members, help from friends, and support from my family.

I want to express the most profound appreciation to my committee chair, Associate Professor Dr. Zalina Shari for her guidance, care, patience, and endless support throughout my research journey. Also, I want to thank my supervisor committee member Dr. Nur Dalilah Dahlan for her help. My appreciation also goes to all staff and members of the Faculty of Design and Architecture, Universiti Putra Malaysia for their hospitality and professionalism.

I would also like to thank my parents, in-laws, and my siblings who have always supported me and encouraged me with their prayers. Finally, I would like to thank my husband, who has always been there for me, cheering me up and believing in me completing this study.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement of the degree of Master of Science. The members of the Supervisory Committee were as follows:

**Zalina Shari, PhD**
Associate Professor
Faculty of Design and Architecture
Universiti Putra Malaysia
(Chairman)

**Nur Dalilah Dahlan, PhD**
Senior Lecturer
Faculty of Design and Architecture
Universiti Putra Malaysia
(Member)

---

**ZALILAH MOHD SHARIFF, PhD**
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 11 March 2021

**Declaration by graduate student**

I hereby confirm that:

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- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
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Name and Matric No.: Noor Laily Bt Mohamad, GS38911

**Declaration by Members of Supervisory Committee**

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ______________________________
Name of Chairman of Supervisory Committee: Assoc. Prof. Dr. Zalina Shari

Signature: ______________________________
Name of Member of Supervisory Committee: Dr. Nur Dalilah Dahlan

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| | |
|---|---|
| ACMV | Air conditioning, Mechanical and Ventilation |
| ASHRAE | American Society of Heating Refrigerating and Air-conditioning Engineers |
| BEI | Building Energy Index/Intensity |
| Cv(RMSE) | Coefficient of variation of the Root Mean Square Error |
| ERM | Energy Retrofit Measures |
| FEMP | Federal Energy Management Programme |
| EPU | Economic Planning Unit of Malaysia |
| GBI | Green Building Index |
| GoM | Government of Malaysia |
| HVAC | Heating, Ventilation and Air conditioning |
| IPMVP | International Performance Measurement and Veification Protocol |
| kWh/m$^2$/year | Kilowatt hours per square metre per year |
| kWh | Kilowatt-hour |
| LSG | Light-to-Solar Gain |
| MBE | Mean Bias Error |
| MS1525 | Malaysian Standard 1525 |
| MWh | Megawatt-hour |
| SHGC | Solar Heat Gain Coefficient |
| SC | Shading Coefficient |
| VLT | Visible Light Transmission |
| VT | Visible Transmittance |
| WWR | Window-wall-ratio |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

It has been well proven and documented that global energy demands and consumptions are the largest contributions to carbon dioxide ($CO_2$) emissions, which also the leading cause of world climate change (Lucon et al., 2014; Pérez-Lombard, Ortiz and Pout, 2008; Levine et al., 2007). The past decade has seen rapid urbanisation globally, where cities are growing in population density and complexity. Research confirms that buildings are responsible for over a third of global energy-related $CO_2$ emissions and the key for low-cost climate mitigation globally (Harvey, 2014; Levine et al., 2007; UNEP, 2007). By the same token, Edenhofer et al. (2014) highlighted that in 2010, the energy use in the building sector was responsible for 8.8 GtCO2eq emissions, 32% of the global total of energy-related emissions.

In relation to the built environment, sustainable architecture integrated with energy efficiency concepts has become one of the key elements in the physical development framework for most developed and developing countries based on international treaties and cooperation (e.g., Kyoto Protocol and Bali Road Map 2007). In the same vein, Intergovernmental Panel on Climate Change (IPCC) has emphasised the importance of new buildings and the existing buildings to play a major role in reducing their energy usage to mitigate climate change (and associated reductions in $CO_2$ emissions) (Levine et al., 2007). According to the World Business Council for Sustainable Development (WBCSD, 2008), around 80% of a building's energy consumption occurs during the operational phase. Furthermore, due to the significant contribution of buildings to greenhouse gas (GHG) emissions, it is of paramount importance for building professionals to become deeply involved in the drive to reduce their buildings' energy consumption, both in the design of new buildings and through retrofitting of existing buildings (Levine et al., 2007; Ürge-Vorsatz, Danny Harvey, Mirasgedis and Levine, 2007). Moreover, the IPCC Fifth Assessment Report concludes that retrofit forms a vital part of the mitigation strategy in countries with a large number of existing building stocks (Edenhofer et al., 2014). Predominantly, populations and development activities are rising rapidly, notably in developing countries such as Malaysia. Moreover, $CO_2$ emissions from Malaysia's building are considered uncontrolled and set to continue to rise due to the rising trend of electricity consumption per capita in the building sector (Yong, Lesjak, Hor, Rowse and Tandon, 2017).

Factors found to influence the sustainable strategies in retrofitting the building stock have been explored in a large and growing body of case studies and literature. Appropriate energy retrofit interventions can minimise the time and cost involved in improving energy efficiency (Lucon et al., 2014; Carbon Trust, 2008; Shiel, 2009). Similarly, Harvey (2006, ch. 14) summarised numerous published studies and showed that 50-70% energy savings could be achieved in commercial buildings through aggressive implementation of integrated sets of retrofits measures. The concept of building energy retrofit is frequently based on the following consolidated and simplified strategies: site and building survey; energy consumption estimates; predesign; benefit estimates; effectively achieved energy-saving and enhancing assessment (Aste and Del Pero, 2013; Carbon Trust; 2008; Harvey, 2009)

While significant literature exists on retrofitting strategies, energy savings through retrofits of existing buildings are still under-developed and lack effective strategies (Aste and Del Pero, 2013; Dascalaki et al., 2010). Also, retrofits are considered difficult due to the lack of well-established methods and precise information on energy saving potential (Lucon et al., 2014; Aste and Del Pero, 2013). Dascalaki and Santamouris (2002) argued that many energy-related retrofitting projects were carried out worldwide. However, they were mainly concerned with active building system interventions and ignored aspects related to passive methods of building energy savings such as building envelope, solar heating, daylighting and passive cooling of the building. Put differently, there has been little empirical research into integrated interventions with the objectives of optimising the building's energy performance while maintaining thermal and visual comforts and its operational features and relationship with the surrounding environment. Shiel (2009) highlighted that retrofit and new buildings should be designed in an integrated and holistic manner with passive retrofit measures adopted to achieve better results with enhanced building energy performances.

Retrofitting existing buildings also gained interest during the past few years in Malaysia. Under the United Nations Development Programme (UNDP), there are only three retrofit government office building projects ever completed in the country: the JKR Blok F Building, the Prime Minister's Office, and the Ministry of Natural Resources and Environment's Building. In line with these initiatives, there is still a strong need to further demonstrate energy performance improvement in existing government buildings' operations through retrofits. It is feasible to improve the average BEI of a building from 205 to 187 kWh/m2/year through simple interventions in the design of new buildings and the incorporations of energy efficiency elements/systems in existing buildings with little or minimal additional cost compared to business type-as-usual type construction/renovation projects (UNDP, 2011). The improvement of overall BEI is estimated at 10-15% (Stephen, 2012).

## 1.2 Problem Statement

Malaysia's present lack of policy and financing framework for driving energy efficiency in the building sector has created a condition where the collected energy-related data from the building stock are coordinated or synchronised to meet the national sustainability goals (Yong et al., 2017). It has conclusively been shown that many building industry professionals only adopt new practices if they are required by the regulations (Lucon et al., 2014; Sisson and Van Aerschot, 2007). Surprisingly, given the importance of building retrofits to achieve low carbon cities and the voluminous literature on urban carbon governance, there is little discussion available on enabling retrofitting through governance (Bulkeley and Castán Broto, 2013; IEA, 2010). Our national energy policies have ignored the potential and effectiveness of energy retrofit on Malaysia's building stock. By the same token, conducting case studies to showcase the potential energy savings by retrofitting existing buildings in Malaysia are considered rare. CK Tang highlighted that Malaysia's retrofitted buildings are mainly commissioned without considering enhancing the buildings' energy performance (Stephen, 2012).

However, Malaysia's above-mentioned retrofit projects focused primarily on active energy retrofit interventions and neglected passive energy efficiency strategies such as external building envelope. Most of the existing government office building designs have not optimised passive design strategies (Yong et al., 2017; Rashid et al., 2011). Passive energy efficiency strategies are susceptible to meteorological factors and require a broader understanding of the climatic factors (Sadineni, Madala, and Boehm, 2011; Dascalaki and Santamouris, 2002). Therefore, this study's main purpose is to understand how interventions in building envelope components could improve energy performance, particularly in existing government office buildings in Malaysia. It aims to provide a systematic approach to the current energy consumption patterns and properly identify the best envelope retrofit measures for existing buildings to ensure that they perform efficiently in the local climate.

## 1.3 Research Questions

**Main research question:** What are the best retrofit strategies to be made to the envelope system of existing government high-rise office buildings to improve their energy performance? The following sub-research questions have been identified for this study:

1. How can building envelope components of existing government high-rise office buildings in Malaysia be retrofitted to maximise their annual energy consumption savings?
2. How can retrofit intervention strategy for existing government high-rise office buildings be optimised to achieve energy efficiency and BEI reduction?

## 1.4. Research Objectives

The study aims to develop a validated model for building envelope retrofit to contribute to annual energy savings. To achieve this goal, the following objectives have been formulated:

1. To establish a case model from selected case building to help understand the influence of building envelope components on overall building energy consumptions.
2. To identify the Energy Retrofit Measures (ERMs) and evaluate their impacts on the level of buildings' energy efficiency.
3. To develop a systematic approach in optimising building envelope retrofit intervention strategies and identify a range of intervention levels concerning their energy reduction levels.

## 1.5 Research Methodology

To achieve the stated objectives, this research implemented a case study combined with a calibrated simulation approach. This study was conducted in two phases: 1) identifying a case building and energy-related data extraction, and 2) energy performance simulation. In the first phase, an existing typical government high-rise office building of Wisma Persekutuan Seremban was selected as the case building study. The energy-related information was extracted to facilitate the simulation of the case model. The sources of energy-related data were extracted from document analysis (i.e., drawings, technical data, and energy audit report) and site visits data gathering of the selected case building.

In the second phase, the simulation of energy performance and energy intensity calculation on all case models were performed using IES<VE> software to determine optimised retrofit interventions. Energy simulation was conducted on the case building by utilising the energy-related data gathered in the first phase 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 the overall buildings' energy performance. Basically, the following five steps were taken in developing the model using a calibrated simulation approach: 1) preparation of the base case model; 2) model calibration; 3) model validation, 4) ERMs evaluation phase; and 5) optimisation of retrofit interventions strategy.

## 1.6 Significance of the Study

This study intends to provide a systematic methodological framework and staged approach to integrating ERMs in retrofitting existing government high-rise office buildings in Malaysia. Specifically, this research explores how energy-related data, energy modelling and research findings can be effectively combined to demonstrate a feasible and systematic approach to optimising retrofit intervention strategy. The study employed a staged approach integrated with selected pre-defined quantitative criteria of building envelope ERMs. The established validated case model that considers the buildings' design parameters offers a platform for the impacts of ERMs technologies to be well understood, based on Malaysia climatic condition, material and feasibility in the local market. Findings from this study provide a source of reference points for specific energy savings for different retrofit intervention levels. There also provides the building sector, particularly the Government of Malaysia (GoM), with a tool for investment prioritisation and objectives setting to improve buildings' energy efficiency. It is also expected that the adopted measures will become a useful guide for the GoM in the energy-related policymaking processes to maximise the effectiveness of its energy efficiency actions.

## 1.7 Scope and Limitations of the Research

This study focused on investigating an envelope retrofitting strategy with three levels of interventions (minor, moderate, and major) for the standard government high-rise office building that reduces energy usages. A range of building envelope ERMs (i.e., an improvement on opaque and glazing wall energy efficiency and WWR) with pre-defined quantitative criteria related to thermal characteristics were applied to the validated case model energy simulations. The simulation results between different interventions and selected individual ERMs were compared. Notably, the investigation did not include building rooftops as the study focused on understanding the impacts of opaque and glazing wall thermal mass and their properties on the overall buildings energy performance. Due to time, cost and equipment constraints, energy audit and questionnaire survey to investigate the case building's indoor thermal comfort were not performed. This limitation did not affect the results considering this study employed Level 2 calibration level. Furthermore, the calibrated model was validated based on the statistical indices approach using 2-year monthly utility bills, drawings, and interviews with the facility manager.

## 1.8 Research Framework

In answering the research questions and achieving the research aim, the following tasks were identified and carried out. The research framework is divided into two phases (refer to Figure 1.1). The first presents a theoretical discourse that reviews energy scenario, envelope elements, thermal properties, and best practices within tropical countries. It also reviews the approaches found globally to address energy efficiency using building envelope retrofits for high-rise office buildings. This study also attempts to test and appraise calibrated energy simulation notions in building envelope retrofit domain, as suggested by scholars and practices.

The second phase aims to increase general insight focussing more on demonstrating a calibration process and explains how to create a reliable model to serve as a base case for evaluating the energy performance. The research method is divided into two parts; 1) identifying case study and extract its energy-related data for the simulation study, and 2) conducting energy performance simulation of the case study and base case models. This study developed multiple acceptable base case models for evaluating retrofit intervention levels and selected individual ERMs. The empirical case study of typical government high-rise office buildings aims to describe and examine a representative sample, the relations, and the mutual impacts and influences. Consequently, it serves as a vehicle to link the ideas and propositions and cross-examine specific building envelope retrofitting strategies.

The simulation results were analysed to evaluate the energy savings in terms of electricity usage, BEI and OTTV indicators, and financial performance using a simple cost-based calculation. The results were discussed to understand the effects of ERMs on the building envelope thermal performance and their energy savings. Conclusions were drawn from the main findings according to the study's objective. A systematic methodological framework for standard government high-rise office buildings in Malaysia was proposed based on Wisma Persekutuan Seremban building as the case study. Finally, recommendations for further study on the subject of building envelope retrofits were proposed.

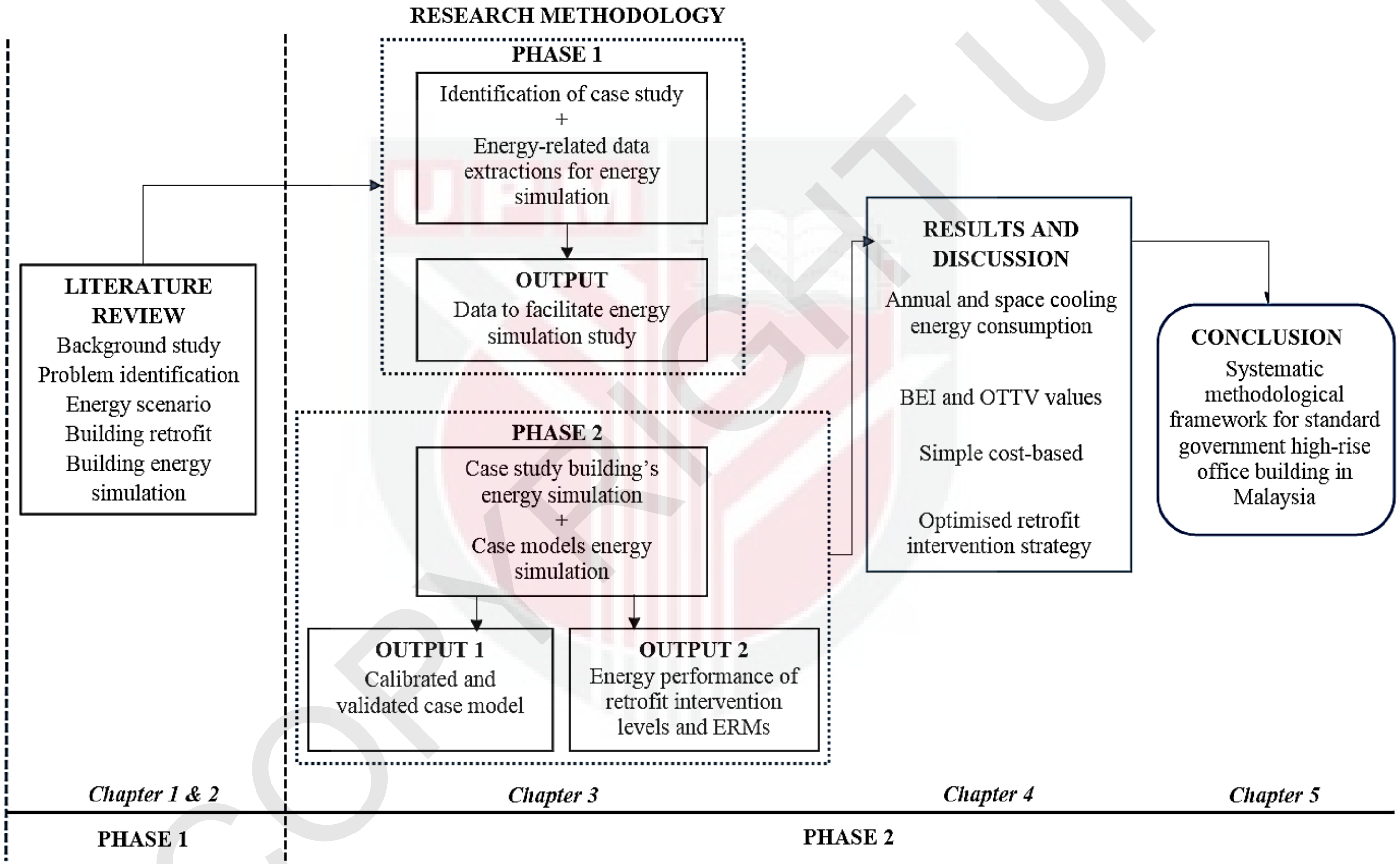


**Figure 1.1: The research framework**

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