# DETERMINANT FACTORS OF STRUCTURAL MODEL FOR THE CAPABILITY OF THE VERTICAL GREENERY SYSTEM APPLICATION TOWARDS ENERGY CONSERVATION

**MOHD DZULKARNAEN BIN SUDIRMAN**

**UNIVERSITI SAINS MALAYSIA**

**2024**

# DETERMINANT FACTORS OF STRUCTURAL MODEL FOR THE CAPABILITY OF THE VERTICAL GREENERY SYSTEM APPLICATION TOWARDS ENERGY CONSERVATION

**by**

**MOHD DZULKARNAEN BIN SUDIRMAN**

**Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy**

**October 2024**

# ACKNOWLEDGEMENT


BISMILLAHIRRAHMANIRRAHIM…

Firstly, I wish to thank Allah SWT for allowing me to embark on my PhD and for completing this long and challenging journey successfully.

My gratitude and thanks go to my supervisor Dr. Faizal Bin Baharum and co-supervisor Sr. Dr. Alia Abdullah Saleh.

My appreciation goes to the School of Housing, Building & Planning, Universiti Sains Malaysia, Penang, who provided the facilities and assistance in my research. Also, my special thanks to my colleagues and friends for helping me in completing this research.

Finally, this thesis is dedicated to Sudirman Bin Solbani and Che Suriati Bte Abdullah; my wife Adibah Binti Ishak; my son Zayd; my daughters Rayhan and Sofeya; all my family members.

This piece of achievement is dedicated to all of you.

ALHAMDULILLAH.

*"Puas sudah menanam ubi, Nanas juga ditanam orang,*
*Puas sudah ditabur budi, Emas juga dipandang orang…"*

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF SYMBOLS

| | |
|---|---|
| $\beta$ | Path Coefficient |
| $f^2$ | Effect Size |
| $q^2$ | Relative Impact |
| $Q^2$ | Predictive Relevance |
| $R^2$ | Coefficient of Determination |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| AVE | Average Variance Extracted Value |
| CA | Cronbach’s Alpha |
| CB-SEM | Covariance Based Structural Equation Modeling |
| CFA | Confirmatory Factor Analysis |
| $CO_2$ | Carbon Dioxide |
| CR | Composite Reliability |
| GoF | Goodness of Fit |
| HVAC | Heating, Ventilation and Air-Conditioning |
| IPTA | Institut Pengajian Tinggi Awam |
| IPTS | Institut Pengajian Tinggi Swasta |
| KMO | Kaiser-Meyer-Olkin |
| MOHE | Ministry of Higher Education |
| nos | Numbers |
| PLS-SEM | Partial Least Square-Structural Equation Modeling |
| SD | Standard Deviation |
| SEDA | Sustainable Energy Development Authority |
| SPSS | Statistical Packages for Social Science |
| UKM | Universiti Kebangsaan Malaysia |
| UM | Universiti Malaya |
| UPM | Universiti Putra Malaysia |
| USM | Universiti Sains Malaysia |
| UTM | Universiti Teknologi Malaysia |
| VGS | Vertical Greenery System |

## LIST OF APPENDICES

**FAKTOR PENENTUAN MODEL STRUKTUR BAGI KEUPAYAAN APLIKASI SISTEM KEHIJAUAN MENEGAK KE ARAH KONSERVASI TENAGA**

## ABSTRAK

Kampus universiti menghadapi cabaran besar disebabkan oleh penggunaan tenaga yang tinggi, terutamanya dari pertambahan populasi dan pelbagai aktiviti di dalam kampus. Statistik Kementerian Pendidikan Tinggi menunjukkan lebih daripada 1 juta individu menggunakan kemudahan kampus pada bila-bila masa. Situasi ini memerlukan pengurangan ketergantungan terhadap pembiayaan kerajaan, dengan mengekang perbelanjaan tenaga sambil meningkatkan penerimaan pelajar. Permintaan penyejukan, terutamanya dalam iklim panas dan lembap, menjadi pendorong utama penggunaan tenaga, yang dapat diatasi melalui konsep pembinaan hijau seperti *VGS*. Kajian ini menggariskan tiga objektif utama; (i) mengenalpasti faktor penentu bagi aplikasi Sistem Penghijauan Menegak (VGS) dan mengkategorikannya ke dalam kumpulan faktor, (ii) menentukan hubungan antara kumpulan faktor yang telah dikenalpasti, dan (iii) membangunkan model struktur bagi aplikasi VGS ke arah penjimatan tenaga di universiti. Metodologi kajian ini melibatkan kajian literatur, temu bual pakar, kajian rintis, dan tinjauan terhadap lima Universiti Penyelidikan di Malaysia. Analisis data menggunakan *Statistical Package for Social Science 19 (SPSS 19)* dan *Partial Least Square-Structural Equation Modelling 3.0 (PLS-SEM 3.0)* telah dapat mengenalpasti empat faktor utama iaitu *Kewangan, Risiko, Pengetahuan,* dan

*Sikap* sebagai faktor yang signifikan terhadap aplikasi sistem VGS dalam pemuliharaan tenaga lestari di universiti.

# DETERMINANT FACTORS OF STRUCTURAL MODEL FOR THE CAPABILITY OF THE VERTICAL GREENERY SYSTEM APPLICATION TOWARDS ENERGY CONSERVATION

## ABSTRACT

University campuses are grappling with significant challenges related to high energy consumption stemming from the large population and diverse activities on campus. Ministry of Higher Education statistics reveal that over 1 million individuals, including students and staff, utilize campus facilities, necessitating a reduction in reliance on government funding due to global economic constraints. This creates a dual challenge for universities: curbing energy expenses while expanding student intake, thus balancing financial and environmental considerations. Cooling demands identified as a major driver of energy consumption largely from air conditioning. Addressing to these challenges, sustainable construction, like green building, emphasizes eco-friendly practices, energy conservation, and recycling. Passive techniques such as Vertical Greening Systems (VGS) are gaining attention for reducing energy use, thanks to their thermal efficiency and alignment with sustainability goals. The research outlines three core objectives; (i) to identify determinant factors for the application of VGS and categorizing them into group factor, (ii) to determine the relationship between the identified group factors, and (iii) to develop the structural model for the application of VGS towards energy conservation in university. The methodology involves literature review, expert interviews, a pilot study, and survey on five Research Universities in Malaysia. Data analysis via *Statistical Package for Social Science 19 (SPSS 19)* and

*Partial Least Square-Structural Equation Modelling 3.0 (PLS-SEM 3.0)* identifies *Financial, Risk, Knowledge*, and *Attitude* as significant factors for VGS application towards sustainable energy conservation in universities.

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

The demand for energy is getting immensely nowadays due to rapid economic development and the high population densities across the globe. With the advent of industrialization and globalization, the demand for energy has increased exponentially which led to environmental issues such as pollutions, climate change and of course the decrease of the natural non-renewable energy resources. It is estimated that industrial energy use in developing countries is around 45–50% of the total commercial energy consumption (Ismail, Aziz, Nasir, & Mohd Taib, 2012; Suganthi & Samuel, 2012). Building energy demands especially electricity are also very significant. Rapid economic growth and high population densities will result in more and more building projects to cater the needs either for residentials or commercials. From the local perspective, Malaysia was the third-largest energy demand in South East Asia in 2013 after Brunei and Indonesia witnessing an increase of 80 percent from the year 2000 to 2013 which contribute 15 percent of the region's overall demand (IEA, 2013).

Generally, the issue regarding the increasing energy consumption in building is due to the increasing outdoor temperature and it's related with environmental issues such as global warming and heat island. However, the geographical factor also seems to have  a big effect where at mid and high latitudes and altitudes there will be a decline in heating requirements, but the cooling requirements will increase (Convención Marco de las Naciones Unidas sobre el Cambio Climático (UNFCCC), 2001). Malaysia lies between 1ºN and 7ºN of the equator, and 99.5ºE and 120ºE (Ministry of Natural Resources and Environment Malaysia, 2011), making the country is in the "right" range in facing the energy issues especially regarding the cooling demands in buildings. Furthermore, the climate change issues facing by the world today adding more to the burden as the energy demand for cooling purposes expected to increase up to 70 percent (Isaac & van Vuuren, 2009).

Cooling purposes identified as to be the major contributor for high energy consumption in buildings especially in hot and humid climate. A study done by Wan & Yik, (2004) resulted with a statistic that electricity use dominated the energy use in public and private residential buildings while electricity consumption patterns of residential units would be significantly affected by the seasonal utilization of air-conditioners and electric water-heaters. Then, an audit conducted by Lam, Wan, & Yang, (2008) regarding residential, office and commercial buildings in Hong Kong concluded that HVAC was the single largest electricity end-user in these three building sectors while electric lighting was the second large electricity consumer in both office and commercial sectors. The finding was the same as Ma & Wang, (2009) in their study that buildings in Hong Kong are subjected to high cooling demands for their air-conditioning systems throughout most of the year, and their contribution toward the total energy consumption is about 40%.

Interestingly, Malaysia also share almost the same result when Saidur, Sattar, Masjuki, Abdessalam, & Shahruan, (2007) found that most of the energy usage in commercial buildings dedicated for the indoor air cooling purposes. However, on a similar study by Saidur, Masjuki, & Jamaluddin, (2007) found that most of the energy usage in residential went to refrigerator-freezer followed by air conditioner, washing machine, fan, rice cooker, iron, VCD/VCR/DVD player, and TV. Although there were some slight differences in both of the findings, we can acknowledge that indoor air cooling purposes still amongst the major contributor in energy consumption in buildings. In tandem with the situation, local university buildings are also no exception.

University buildings are categorized as commercial buildings which consume a lot energy regarding to its activities and populations (Abu Bakar et al., 2013). With the increasing number and development projects of new and existing campuses to cope with high demand of study opportunities, it is fair to believe that the demand for energy will also increase tremendously.

Responding to the issues, the concept of sustainable construction also called as green construction has been introduced in the industry. Green construction aims to develop environmental-friendly construction practices that contribute to energy saving, reduction of emissions, reuse, and recycle of materials (Spence R et.al., 1995). Greening the building envelope with living plants in a controlled system seems to fit the concept which also known as Vertical Greenery System (VGS). The thermal and energy performance of VGS has attracted the attention of many researchers, architects, engineers, property developers and local authorities. A number of 62 percent of scientific research conducted on greenery systems between the year 2000 to 2014 focusing on the thermal behaviour or microclimates (Chu, 2014).

VGS thermal behaviour reflects to the energy saving for cooling purposes in buildings through four passive mechanisms which are the shade effect, cooling effect, insulation effect and wind barrier effect (Julià Coma, Gabriel Pérez, Cristian Solé, Albert Castell, 2014). The shade effect becomes the most influential of all due to high plants capability to intercept the solar radiation from the sun before reaching the building skin thus making less heat entering the building. The cooling effect achieved by the transpiration process creating a thin layer of vapour which then reducing the temperature of the building's exterior (microclimate). The insulation and wind barrier effect only concerns energy for heating purposes which are not related into the Malaysian climate and therefore will not be discussed further in the study.

The use of horizontal and vertical greening has an important impact on the thermal performance of buildings and on the effect of the urban environment as well (Perini, Ottelé, Fraaij, Haas, & Raiteri, 2011). Study done by Chinese researchers Chen, Li, & Liu (2013) found that the living wall system has a notable cooling effect compared to the bare wall. Mazzali et al., (2013) also in their experimental work concluded that the use of green architectural cladding can significantly contribute to cooling energy reduction by offering a valid alternative of retrofit also in existing buildings. Another study conducted by Perini et al., (2012) concluded by applying green façades, which is an established feature of contemporary urban design, can offer multiple environmental benefits on both new and existing buildings and can be a sustainable approach in terms of energy saving considering materials used, nutrients and water needed and efficient preservation of edifices. As cited by Nigel Dunnet, (2013) from Peck et al.,(1999), VGS can reduce the temperature fluctuation of the external wall from between 10°C and 60°C down to between 5°C and 30°C. It has also been calculated that with a 5.5°C temperature reduction of an external building wall capable in reducing the energy for internal space cooling by 50 to 70 percent.

VGS comes in many forms and methods. The system is well accepted across Europe over the past few decades and applied to many types of buildings such as residentials, offices, gardens and even university buildings. Even in our neighbouring country Singapore for instance, VGS are widely used especially in in new constructions in tandem with the 2$^{nd}$ Green Building Masterplan (2009) aiming the national target of greening at least 80% of the buildings in Singapore by 2030. However, in the contrary besides of all the advantages of VGS the application of this kind of technology is still considered as new and scant in Malaysia. Therefore, the key question arises, “What are the determinant factors for VGS application a sustainable approach towards energy conservation in Malaysia especially in university buildings?’.

With respect to this matter, this study focuses on identifying the determinant factors of VGS application in Malaysian universities as a sustainable approach towards energy conservation for cooling purposes. By grouping the factors into particular categories, further analysis can be done to determine the most influential factors and further action measures can be taken to overcome them. Indirectly, the data gained from the study would be beneficial to the interest parties involved in sustainable university in order to make VGS projects a success towards energy conservation.

## 1.2 Problem Statement

In 2016, the Ministry of Higher Education (MoHE) announced to reduce the dependence of universities on government funding due to the global economic crisis (Amanat Tahun Baharu, 2016). Surely, this will lead to the reduction of government's allocation for the operational cost such as management purposes, utilities consumption and other subsidies enjoyed by the university. The situation put the university in a big dilemma where it must strive to reduce the cost of energy consumption but at the same time need to increase the rate of intakes whereby students can be considered as the clients and as the source of economic benefits as well.

Study conducted by Choong, Chong, Low, & Hakim, (2012) revealed that the energy consumption in both Universiti Teknologi Malaysia and International Islamic University Malaysia has led to more than ten million ringgit annually due to increment of students' population almost every year. The finding is parallel to Abu Bakar et al., (2013) regarding the annual electricity bill for Universiti Teknologi Malaysia in 2009 alone cost about RM18.99 million therefore, rising serious attention amongst the interest parties. Population and various activities held in the campus identified as the contributor for the high energy consumption by impacting the environment either directly or indirectly (Sohif Mat, Kamaruzzaman Sopian, Mazlin Mokhtar, Baharuddin Ali, Halimaton Saadiah Hashim, Abdul Khalim Abdul Rashid, Muhammad Fauzi Mohd Zain, 2009). These findings can be well understood by examining the statistic provided by the Ministry of Higher Education (MoHE), showing that there are more than 1 million people (students and staffs) as building users at any given time which include the public and private universities, colleges and polytechnics. There were only 20 public universities in 2006 and in 2011 alone, 40 private universities have been incorporated. The opportunity also taken by foreign universities to launch their campus locally due to rapid development of the education industry in Malaysia (Faizatul Akmar Abdul Nifa, Mohd Nasrun Mohd Nawi, Wan Nadzri Osman, 2015).

Balogun & Akhibi, (2015) conducted a study by auditing the building energy consumption in Covenant University, Nigeria and they found that 49 percent of the energy used in the academic building dedicated for space cooling. Similar study also done by Tang, (2012) in Curtin University Sarawak Campus obtained almost similar result where 50 percent of energy consumed went to the air-conditioning system for the whole campus buildings. Another interesting research done by Jamaludin et al., (2013) concluded that the average electricity usage of non-air-conditioned residential colleges in tropical regions ranging between 20 to 60 kWh/m2/year whereby lighting and fan usage are identified as two major M&E electricity consumers. Therefore, with all the evidence given, it is undoubtedly that energy usage for cooling purposes in university buildings is an important issue and should be addressed with serious attention.

VGS is specifically chosen as the focus in this study due to its multiple advantages especially regarding thermal performance and also its relation to sustainability. The main purpose of the system can be simplified as a “wall insulator” against the solar radiation from the sun which basically the main source of heat gains in buildings. The solar energy heating the side of a building will generate more powerful convection currents compared to a horizontal surface (Nigel Dunnet, 2013) yet, with the excellent plant properties against solar radiation, VGS helps buildings to be cooler and thus reducing the energy usage especially in term of cooling purposes.

VGS is not something new in Malaysia. The application includes both residential and commercial premises. A study done by Abdul-Rahman, Wang, Rahim, Loo, & Miswan (2014), mentioned that VGS application in Malaysia can be dated as early as 1991 and 2009 for residential and commercial premises respectively. Basically, the purpose of installation tended to be more profit oriented whereby VGS will increase the aesthetics of the building therefore indirectly increasing the value of the property itself. However, despite of all the advantages especially in term of energy reduction in buildings, the application of VGS in Malaysia is still considered at a low pace. Furthermore, installation of VGS as an approach in reducing energy usage in buildings are commonly new (Farid et al., 2016).

The application of vertical greenery systems significantly advances United Nations Sustainable Development Goals (SDGs) 11, 12, and 13. By mitigating the urban heat island effect, reducing air pollution, and enhancing biodiversity, these systems contribute to SDG 11's aim of creating sustainable and inclusive cities. Moreover, through the use of sustainable materials, resource optimization, and waste reduction, vertical greenery systems promote responsible consumption and production practices, aligning with SDG 12's objectives. Additionally, these systems mitigate climate change by sequestering carbon dioxide, reducing energy consumption, and enhancing urban resilience to climate-related hazards, thus supporting SDG 13's goals of climate action and building resilient communities. Overall, vertical greenery systems offer integrated solutions that address urban sustainability challenges, making them instrumental in achieving multiple SDGs simultaneously (Johnston, 2016).

Positively, VGS have a very huge potentials as a sustainable approach in conserving energy especially for building cooling purposes. Yet still the application of the system can be considered as scarce in Malaysia especially in the local university. Therefore, by identifying all the determinant factors that encourage the application of VGS and categorized them into groups will enable us to find the key factor for the VGS application. Hence, proper action could be taken directly to the key factor in order to ensure the success of the VGS project as a means of energy conservation in buildings.

Searching the references regarding the determinant factors of VGS application is limited and there is no previous research which particularly discuss about the determinant factors VGS application in university. Hence, all the exploration, research and reference as made to the previous research regarding determinant and hindrance factors of application in some related field such as of green building, sustainable construction, green hotels and resorts, green building in Higher Learning Institutions (HEIs) and green roof as well.

Understanding the factors influencing people to accept or reject a particular technology is a complicated matter. In information and communication technology (ICT) studies, the Technology Acceptance Model (TAM) is notably considered as a successful enabling model referring to factors that affect new systems acceptance by users during development and implementation (Alrafi, 2007). There are three main constructs in TAM referred as perceived usefulness and perceived ease of use, behavioural intention and actual technology usage. The constructs of Perceived usefulness and perceived ease of use have a big influence of people's behavioural intention towards using the technology which also affected by the external variables as well. Adopting TAM into other field of studies especially construction has never been attempted by any scholars before. TAM could explain the reason why the development of VGS in Malaysia as in current state. TAM will also explain to us the actual acceptance of VGS in the country especially regarding the main players in the construction industry.

With respect to this matter, this study aims to test the TAM with relevant constructs modified to be suited with the construction elements referring to the acceptance and application of VGS as sustainable approach towards energy conservation for cooling purposes. Determinants of the application of VGS in Malaysia will be identified and then grouped into particular categories. These categories will be known as the external variables of TAM and further analysis can be done to determine the most influential factors for the VGS application. Indirectly, the data gained from the study would be beneficial to the interest parties in order to make VGS projects a success towards energy conservation.

## 1.3 Research Question

From the problem statement, three research questions emerged which are:

i) What are the groups for the determinant factors for the application of VGS?

ii) What are the relationships between the factors and the application of VGS?

iii) What is the structural model for the application of VGS towards energy conservation in higher learning institution?

The research questions focus exclusively on "what" questions mainly because he research is in an exploratory phase, aiming to identify and categorize the fundamental elements and relationships related to the application of VGS. Answering "what" questions helps to establish a comprehensive understanding of the determinant factors and their interactions before exploring into more complex inquiries. By focusing on "what" questions, the research aims to systematically uncover and organize the key components and relationships involved in the application of VGS towards energy conservation in buildings, setting the stage for deeper investigation in future studies.

## 1.4 Research Objective

The aim of the study is to promote the application of VGS by developing a framework process. It is hope that this framework will encourage the decision makers in applying the VGS comprehensively as a method to conserve the building energy usage through a sustainable approach. To fulfil the purpose of this investigation and provide responses to the posed research inquiries, the study's objectives are delineated as follows:

i) To identify the determinant factors for the application of VGS and categorizing them into group factor.

ii) To determine the relationship between the identified group for the application of VGS.

iii) To develop the structural model for the application of VGS towards energy conservation in building as a sustainable approach in higher learning institution.

## 1.5 Research Scope

The scope of this study only focuses on the VGS application towards a sustainable university in term of energy conservation. There are multiple factors that have led to the choice of VGS as the focal case study for achieving energy conservation and sustainability goals within a university context. Ultimately, universities have large number of buildings which facilitates various functions such as classrooms, halls, offices, restaurants, sports centres, libraries, labs, shops, clinics, hostels and others. All these facilities collectively highlight the significant amount of energy they consume, particularly for cooling purposes. This situation strongly underscores the appropriateness of elevating VGS to a central topic of discussion. Given its proven ability in energy conservation, incorporating VGS could substantially contribute to cost-effective energy utilization across these facilities. Hence, identifying these key determinant factors and groups associated with VGS application stands as a recommended approach for university management to ensure its effective implementation.

This study engaged five prominent research universities: Universiti Kebangsaan Malaysia (UKM), Universiti Malaya (UM), Universiti Putra Malaysia (UPM), Universiti Sains Malaysia (USM), and Universiti Teknologi Malaysia (UTM). These universities were chosen due to their distinct strengths across various dimensions, which they have actively evolved to enhance sustainability. These universities are among Malaysia's top institutions, recognized nationally and internationally for their academic excellence and research output. Their stature ensures rigorous academic standards in conducting research, contributing credibility and robustness to findings in the field of sustainability (Saadatian et al., 2009). These five selected public research universities represent some of Malaysia's oldest, most esteemed, and highest-ranking educational institutions (World University Rankings, 2023).

Over the years, these universities have demonstrated a longstanding commitment to sustainability through research, education, and community engagement. They have actively contributed to policy discussions and initiatives aimed at addressing environmental challenges and promoting sustainable development locally and globally (Kamarudin et al., 2021). For instance, UKM houses the Institut Alam Sekitar dan Pembangunan (LESTARI), UM operates the Spatial Environmental Governance for Sustainability Research initiative, UPM hosts the Sustainable Consumption Research Centre, USM has the Centre for Global Sustainability Studies, and UTM features a dedicated Sustainability Unit. This diversity ensures a comprehensive exploration of various aspects of sustainability, including environmental, economic, and social dimensions (Lee & Tan, 2020). While they share similarities in terms of importance, popularity, and administrative approaches, they also exhibit distinctive strengths in diverse aspects of sustainable university practices (Saadatian et al., 2009).

As leading research universities, UKM, UM, UPM, USM, and UTM have access to extensive resources, databases, and networks that are crucial for collecting comprehensive data on sustainability practices and impacts. This access facilitates thorough and nuanced analysis, providing valuable insights into effective strategies and challenges in achieving sustainability goals (Hashim et al., 2022). Findings from research conducted at these universities are likely to have significant policy and practical implications. Their influence extends beyond academia to governmental, non-governmental, and industry sectors, fostering a broader impact on sustainable practices and policies in Malaysia and beyond (Rahman & Othman, 2021). These universities offer rich collaborative opportunities due to their established networks and partnerships with other academic institutions, government agencies, and international organizations. Collaborative research efforts enhance the depth and breadth of sustainability studies, encouraging interdisciplinary approaches and innovative solutions (Ibrahim & Zainal, 2020).

The participants in this research encompassed a diverse group, including the top management team, academic staff, and non-academic staff. Among the non-academic participants were energy managers or facility managers, operating within the maintenance unit or commonly known as the facilities unit of the university. Additionally, support staff from sustainability centres were also included in the study. The selection of these individuals was predicated on their extensive knowledge and experience in the realm of green and sustainable university practices. This expertise rendered them capable of providing invaluable insights and inputs for investigating the impact of determinant factors on the application of VGS, particularly its capabilities in fostering energy conservation as an enduring approach within the university context.

## 1.6 Research Significance

The aim of this research is to provide valuable knowledge and information that can serve as references for parties or organizations engaged in the field of sustainable development. In addition, this research may; -

i) Responding to the environmental problems and energy issues in buildings especially in Malaysia.
ii) Contribute substantially to the country particularly to the building sector in order to reduce the cost energy consumption and minimising energy wastage through sustainable approach.
iii) The information acquired from this study could prove advantageous for stakeholders in the realm of sustainable construction. This knowledge would

contribute to the achievement of successful VGS projects aimed at enhancing energy conservation.

iv) Participate in raising awareness about the environmental effects and energy usage associated with VGS among both building occupants and the general public.

## 1.7 Chapters Outline

This study is divided into six chapters. Below is the brief outline of each chapter:

**Chapter One** provides an encompassing overview of the study. This chapter commences with an introduction and proceeds to delve into the problem statement, research inquiries, research aims, research boundaries, research importance, research methodology, and an outline of the subsequent chapters.

**Chapter Two** discuss the energy demand in Malaysia and then the Malaysian climate condition itself. The discussion proceeds on with the introduction to passive cooling strategies and then concluded with the concept of determinant factors.

**Chapter Three** discuss a comprehensive exploration of the research design and methodology that has been selected for this study, aimed at successfully attaining each specified objective.

**Chapter Four** Chapter Four discuss a thorough examination of the results obtained through data collection, which contributes to achieving both the primary and secondary objectives

**Chapter Five** provides findings and discussions related to the two research objectives.

**Chapter Six** Chapter Six comprises the concluding remarks, highlights the contributions of the research, and provides recommendations for potential future research endeavours.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter of the research work provides an extensive literature review on energy demand in Malaysia, closely examining its correlation with the country's climate conditions. The chapter progresses to introduce passive cooling strategies, highlighting their role in explaining the complicated connection between solar radiation and the plants within vertical greeneries. Within this context, the comprehensive capabilities of VGS in energy conservation are thoroughly explored. Furthermore, the chapter explores into the concept of determinant factors, specifically in the context of applying VGS in university settings. This study underscores the potential of VGS as a sustainable approach for enhancing energy conservation within educational institutions.

## 2.2 Energy Demand in Malaysia

Energy demand is a crucial indicator of a country's economic growth and development. In the context of Malaysia, as a rapidly developing nation, the energy demand has been consistently increasing over the years. Malaysia's energy mix comprises a combination of fossil fuels, renewable sources, and nuclear energy. As of recent data, the major contributors to Malaysia's energy generation are natural gas, coal, and petroleum. Natural gas accounts for a substantial portion of the energy mix due to its availability and relatively cleaner combustion. Coal and petroleum also play significant roles, mainly in electricity generation and transportation sectors (Ariffin et al., 2021).

Malaysia's energy mix comprises a diverse range of sources, including fossil fuels, renewable energy, and nuclear power. As of recent data, most of the energy demand is met through fossil fuels, particularly oil and natural gas. The Energy Commission of Malaysia reports that natural gas accounted for about 42.1% of the total primary energy supply in 2020, followed by oil at 35.5% and coal at 18.9%. Renewable energy sources, such as hydroelectricity, solar, and biomass, contribute a smaller portion, but the government has been focusing on increasing their share to enhance sustainability and reduce dependency on fossil fuels (Suruhanjaya Tenaga, 2020).

The energy demand in Malaysia has been steadily rising over the years due to factors like population growth, urbanization, and industrial expansion. The Economic Planning Unit's National Energy Balance report highlights that Malaysia's total final energy consumption increased from 60,928 GWh in 2010 to 77,646 GWh in 2019, signifying a significant growth rate. Despite its growing energy demand, Malaysia faces several challenges in its energy sector. One significant concern is the over-reliance on fossil fuels, which poses risks in terms of energy security, price volatility, and environmental sustainability. The Institute for Energy Economics and Financial Analysis (IEEFA) emphasizes the importance of diversifying the energy mix to mitigate these risks. Additionally, environmental concerns related to carbon emissions and climate change have prompted the government to adopt cleaner and more sustainable energy solutions.

To address these challenges, Malaysia has implemented various policy initiatives and transition strategies. The Malaysian Energy Commission introduced the Energy Efficiency and Conservation Act (EECA) in 2019 to promote energy efficiency across sectors (Suruhanjaya Tenaga, 2020). The government has also set ambitious targets for renewable energy capacity, aiming to achieve 20% renewable energy in the energy mix by 2025 under the Malaysian Sustainable Energy Development Authority (SEDA).

Higher learning institutions play a pivotal role in shaping the future by educating and influencing the next generation. With this influential position comes a responsibility to lead by example, particularly in matters concerning sustainability, including energy consumption. Energy consumption in higher learning institutions has gained significant attention due to its environmental and economic implications.

Research conducted by the Ministry of Higher Education Malaysia (MOHE) highlights the increasing energy demand in these institutions, driven by expanding campuses, advanced technologies, and an influx of students (Ministry of Higher Education Malaysia (MoHE), 2021). This surge in energy consumption aligns with global trends, as higher learning institutions worldwide continue to expand and embrace technological advancements.

The increase in energy consumption brings forth challenges related to sustainability and cost management. A study by Anthony Jnr. (2021), emphasizes that Malaysian universities face hurdles in maintaining a balance between providing optimal learning environments and conserving energy. As institutions strive to create conducive spaces for education and research, energy-intensive facilities like laboratories, lecture halls, and research centres contribute significantly to overall energy consumption.

Addressing the energy challenge in higher learning institutions requires a multi-faceted approach. One potential solution lies in the adoption of energy-efficient technologies and practices. The Green Technology Master Plan (GTMP) by the Ministry of Environment and Water Malaysia (MEW) provides a roadmap for integrating sustainable practices in various sectors, including education (KeTTHA, 2017). Institutions can leverage the GTMP framework to implement energy-efficient technologies, such as smart lighting, efficient cooling systems, and renewable energy sources.

Several Malaysian universities have already embarked on initiatives to reduce energy consumption and promote sustainability. Universiti Putra Malaysia (UPM), for instance, established the UPM Solar Park to harness solar energy for its campus operations (UPM, n.d.). Additionally, Universiti Sains Malaysia (USM) introduced energy-saving measures, including optimizing air conditioning systems and promoting energy conservation awareness among students and staff (USM, n.d.).

Therefore, it is evident that the increasing energy consumption in universities is a matter of significant concern. The rising campus population poses a continuous dilemma for universities, balancing the need for energy conservation (cost-cutting) with the growing energy demands of the campus community. Thus, a more sustainable approach is necessary, and the utilization of VGS presents itself as one viable option. This is due to its proven ability in energy conservation while also holding substantial potential for sustainability.

## 2.3 Malaysian Climate Condition

Malaysia, situated in Southeast Asia, is characterized by its tropical climate, lush landscapes, and diverse ecosystems. The country's climate plays a pivotal role in shaping its environment, economy, and societal activities. Malaysia's climate can be classified under the Köppen climate classification as predominantly equatorial (Aw), with variations across different regions. The country experiences two monsoon seasons – the Southwest Monsoon (May to September) and the Northeast Monsoon (November to March). The monsoons bring significant rainfall, impacting various sectors such as agriculture, water resources, and infrastructure development.

According to the Malaysian Meteorological Department (MetMalaysia), Malaysia's climate is characterized by high temperatures and humidity throughout the year due to its proximity to the equator. These climatic conditions significantly influence daily life, affecting activities ranging from outdoor work to tourism (KEMENTERIAN SUMBER ASLI, n.d.).

Rainfall patterns in Malaysia are influenced by its geographical features, including mountain ranges, coastlines, and proximity to the ocean. The Western Coast experiences higher rainfall during the Southwest Monsoon, while the Eastern Coast receives more precipitation during the Northeast Monsoon. This variation has implications for regional agriculture, hydroelectric power generation, and flood management. Temperature trends in Malaysia show slight variations over the years. The Global Climate Risk Index 2021 ranked Malaysia as one of the countries most affected by climate change, indicating increased vulnerability to extreme weather events. The rise in temperature poses risks to health, agriculture, and biodiversity, necessitating adaptive measures to mitigate potential impacts (*Global Climate Risk Index, 2021*, 2023).

Temperature trends in Malaysia show slight variations over the years. The Global Climate Risk Index 2021 ranked Malaysia as one of the countries most affected by climate change, indicating increased vulnerability to extreme weather events. The rise in temperature poses risks to health, agriculture, and biodiversity, necessitating adaptive measures to mitigate potential impacts (*Global Climate Risk Index, 2021*, 2023).

Malaysia's climate is marked by tropical characteristics, including distinct monsoon seasons and high temperatures throughout the year. However, the changing climate landscape due to global warming presents challenges to the nation's environment, economy, and societal well-being. By considering the insights from various sources and credible citations, it becomes evident that effective climate change mitigation and adaptation measures are imperative for Malaysia to navigate the complex climate realities and secure a sustainable future.

## 2.4 Introduction to Passive Cooling Strategies

Passive cooling technique is the approach used to cool buildings without any machine tools being used. It is also known as a set of natural processes and indoor temperature reduction techniques, as opposed to the use of 'active' mechanical equipment. In other words, passive cooling refers to systems or design elements that are used to cool the buildings without any power consumption. Prieto et al., (2018) divided passive cooling into two main categories which are Heat Avoidance Strategies (HAS) and Heat Dissipation System (HDS). HAS basically refers to what so called as ‘pure passive strategies’ which related to the design and materials applied for the completion of building. HDS on the other hand, referring to the application of minor mechanical equipment such as fans and pumps that would lead to better performance for the passive system.

Other solutions for passive cooling systems include planting next to the building surface to shield the building skin, such as climbing ivy or creeping plants, from excessive heat conduction into the interior.

Roof and wall sprays are another type of passive cooling system that is simple and easy to handle. A roof spraying system can lower the roof surface temperature from 55-70$^{o}$C to 27-29$^{o}$C, while a wall spray can lower the indoor air temperature by up to 3$^{o}$C. Providing an air gap and radiant barrier under the roof also has significant cooling potential. These strategies can block downward radiation from the sun by up to 97% (Pérez et al., 2011). For advance passive cooling techniques, green roofs and cool roofs are the best options, which can significantly reduce or eliminate the peak outside and inside air temperatures of buildings and reduce the surface temperature by up to 21ºC in summer (Pérez et al., 2011).

### 2.4.1 Building Façade for Thermal Behaviour Process

The building's outer surface directly receives solar radiation in the form of short waves (SR), which are emitted from the sun and transmitted through the earth's atmosphere (Susorova et al., 2013). A significant portion of the absorbed energy falls within the 300-3000 nm range of short wave solar radiation. Roughly 2% of this energy is either reflected back (reflection) or transmitted through (transmission). For example, leaves absorb energy from the ground via long wave infrared radiation (Ottelé, 2011).

Radiation that's absorbed by the building's facade can either be released outward through convection (C) into the surrounding atmosphere, or it can be conducted (Q) into the building's interior. However, according to Susorova et al., (2013), the energy might be retained within the wall material (S). On sunny days, much of the radiation absorbed transforms into sensible heat (infrared light) by materials like concrete, bituminous substances, or masonry (Ottelé, 2011). Hence, cultivating plants on the exterior wall's surface to intercept this radiation could diminish the warming of solid surfaces especially in the open space areas with no shadings.

Equation (1) below stating the bare wall (bw) energy balance:

$$SR_{bw} + LR_{bw} + C_{bw} = Q_{bw} + S_{bw} \quad (1)$$

Nonetheless, there exists an extra element affecting the radiative exchange of the vegetated wall (XR) situated between the surface of the facade and the layer of leaves from the climbing plant. Equation (2) indicating the vegetated wall energy balance (vw):

$$SR_{vw} + LR_{vw} + XR + C_{vw} = Q_{vw} + S_{vw} \quad (2)$$

Plants undergo evaporation during both daytime and nighttime due to the bidirectional exchange of energy through convection (Ottelé, 2011). When leaves are warmer than their surroundings, they transfer energy to the air, whereas if leaves are cooler, they absorb energy from the air (Ottelé, 2011). As pointed out by Susorova et al. (2013), a thermal lag occurs once heat is absorbed from the exterior into the wall; the extent of this lag relies on the wall's heat capacity. Depending on factors such as wall thickness, density, and heat capacity, a brick wall can retain heat for up to 6 hours. Figure 2.1 visually represents the energy equilibrium of a vegetated façade.

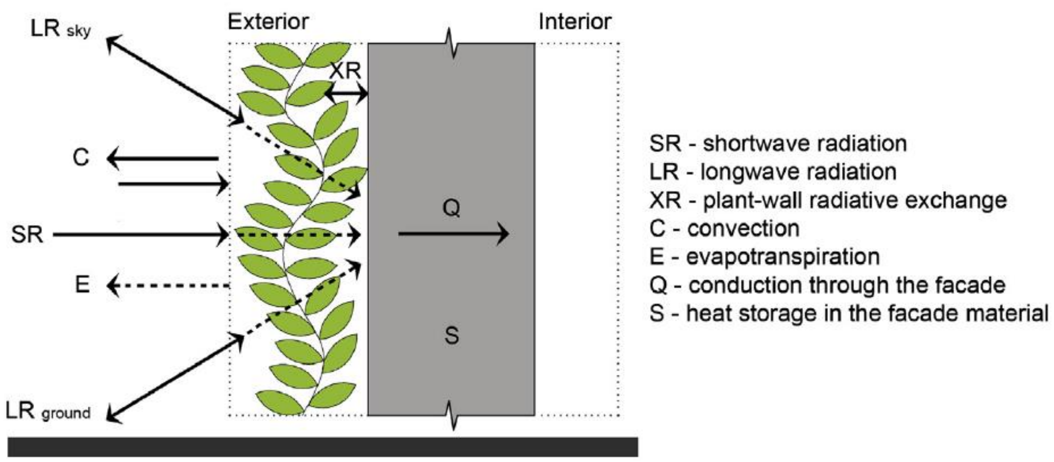


Figure 2.1: Energy balance of vegetated façade (Susorova et al., 2013)

From 100 percent of the sunlight energy that falls on the external building wall into a climbing plant, 5-30% is reflected, 5-20% is used for photosynthesis, 10-50% is transformed into heat, 20-40% is used for evapotranspiration and 5-30% is passed through the wall's leaves. The energy balance of the leaves was derived by transpiration as 30%, 18% by reflection, 30% by absorption, 18% by transmission and 4% by photosynthesis (Ottelé, 2011). Figure 2.2 illustrates the schematisation of the plant energy balance of vegetation translated at building level for green façade.

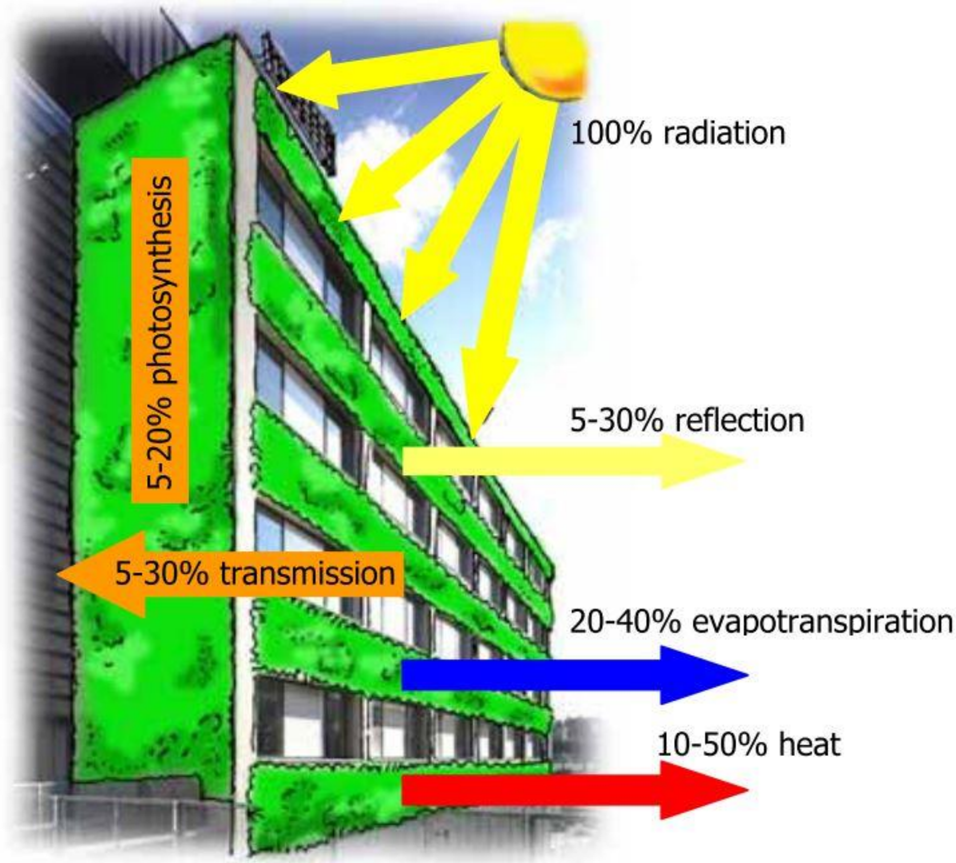


Figure 2.2: Plant energy balance schematisation (Ottelé, 2011)

## 2.5 Introduction to Vertical Greenery System

### 2.5.1 History of Vertical Greenery System

The history of Vertical Greenery System (VGS) or also named as Green Wall may start as early as the Babylonians through what is known as The Hanging Gardens of Babylon. It is maybe the earliest evidence recorded associating plants in buildings. Adding to the myth, the gardens were described as a huge mountain constructed from mud bricks comprising series of tiered gardens constructed in an ascended manner supported by the lush of greeneries consisting of trees, shrubs and vines as illustrated in Figure 2.3. Some researchers may describe it was more roof gardens rather than green walls but the usage of vines surely explain that there will be creepers on the wall building suiting the description of green walls itself (*Going Vertical: The History of Green Walls*, n.d.).

Figure 2.3: Artist's impression of the Hanging Gardens of Babylon
(https://dinromerohistory.wordpress.com)

The application of VGS can be found through various civilization around the world with the primary means to cover their buildings for various reasons mainly by using climbers. For example, in Europe VGS are used for the beauty purposes and some of them are used as crop harvesting purposes such as grape cultivation for the