ENVIRONMENTAL AND THERMAL PERFORMANCE OF LEGUMES AS BIOFACADE IN A TROPICAL CLIMATE

by

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TABLE OF CONTENTS PAGE

CHAPTER 3: RESEARCH METHODOLOGY

CHAPTER 4: RESULTS AND DISCUSSION

(PART 1: SELECTION OF PLANT)

CHAPTER 5: RESULTS AND DISCUSSION

(PART 2: CARBON SEQUESTRATION & LEAF AREA)

LIST OF TABLES

PAGE

LIST OF FIGURES

PAGE

LIST OF PLATES

PAGE

LIST OF ABBREVIATIONS AND SYMBOLS

ASHRAE	-American Society of Heating, Refrigerating & Air Conditioning Engineers
Atmospheric [CO_2]	-Atmospheric Carbon Dioxide
AT	-Ambient Temperature
CDIAC	-Carbon Dioxide Information Analysis Center
Cond	-Stomatal Conductance
DAQ	-Data Acquisition System
GnPR	-Green Plot Ratio
GBI	-Green Building Index
GPP	-Gross Primary Productivity
IST	-Indoor Surface Temperature
Inter [CO_2]	-Intercelullar Carbon Dioxide
LA	-Leaf Area
NPP	-Net Primary Productivity
OST	-Outdoor Surface Temperature
Photo	-Photosynthesis Assimilation Rate
PAR	-Photosynthetically Active Radiation
P. sativum	-*Pisum sativum*
P tetragonobulus	-*Psophocarpus tetragonobulus*
P. vulgaris	-*Phaseolus vulgaris*
ppm	-Parts per million
RH	-Relative Humidity
T_{Air}	-Air Temperature
T_{Leaf}	-Leaf Temperature
UBBL	-Uniform Building By-Laws
UHI	-Urban Heat Island
UNFCCC	-United Nations Framework Convention on Climate Change
V. unguiculata sesquipedalis	-*Vigna unguiculata sesquipedalis*
VGS	-Vertical Greenery System

PRESTASI TERMA DAN ALAM PERSEKITARAN MENGGUNAKAN TANAMAN KEKACANG SEBAGAI BIOFASAD DI IKLIM TROPIKA

ABSTRAK

Tesis ini merupakan suatu kajian mengenai Biofasad, pensekuesteran karbon dan potensinnya sebagai penurun suhu di dalam persekitaran bandar. Menurut teori kesan Rumah Kaca, punca peningkatan suhu daripada pemanasan global adalah daripada pengeluaran gas karbon dioksida secara berlebihan. Tanpa menafikan keperluan pembangunan di bandar, Biofasad adalah penyelesaian alternatif. Biofasad adalah pokok menjalar yang dibiarkan tumbuh pada dinding bangunan yang berfungsi sebagai agen utama penurunan suhu permukaan dalam dan luar bangunan, dan mengatasi masalah pemanasan global melalui penyimpanan gas karbon dioksida oleh tisu tumbuhan. Terdapat tiga objektif dalam kajian ini iaitu; mengenalpasti tumbuhan kekacang yang sesuai bagi digunakan dalam Biofasad yang beriklim tropika, mengukur kadar penyerapan pensekuesteran karbon oleh tumbuhan kekacang dalam konteks dinding Biofasad untuk ramalan perdagangan karbon, dan memahami kesan Biofasad dalam menurunankan haba permukaan bangunan. Kajian tumbuhan dan pensekuesteran karbon dijalankan selama 14 bulan dan dengan dua kali penanaman. Empat spesis tumbuhan kekacang yang menjalar telah dikenalpasti dan pensekuesteran karbon keempat-empat sepsis telah dibandingkan. Spesis kacang botor atau *Psophocarpus tetragonobulus* mempunyai kadar sekuesteran yang kedua tertinggi dan paling stabil, dan dipilih untuk eksperimen Prestasi Suhu Bangunan. Dengan keluasan dinding eksperimen 9.175 m^2, Biofasad dapat menyimpan sebanyak 0.935783 kg CO_{2-eq} m^{-2} Pembebasan Gas Rumah Kaca setiap tahun. Kajian terhadap Prestasi Suhu Bangunan telah dijalankan selama tiga hari bagi Kajian Asas, dan selama sebulan pada Skala Bangunan Sebenar. Pada Kajian Asas, kesan haba pada dinding timur di waktu petang (Jam 15:00 hingga 17:00) menunjukkan tumbuhan menjalar telah mengurangkan suhu dinding bangunan sebanyak 5.6 ^{o}C secara purata. Untuk analisis Skala Bangunan Sebenar, kesan haba dinding dalaman pada waktu siang menunjukkan Biofasad dapat menurunkan suhu permukaan dinding sebanyak 2 ^{o}C (purata). Pada waktu malam, Biofasad menghadapi kesukaran untuk mengeluarkan haba ke persekitaran luar bangunan berbanding dinding Biasa dengan perbezaan suhu sebanyak 0.8 ^{o}C (purata). Penemuan utama kajian ini ialah kaedah baru untuk menjangkakan perdagangan karbon melalui pensekuesteran karbon oleh daun pokok dalam konteks Biofasad untuk tempoh jangka masa panjang. Berdasarkan kajian konsep, kawasan permukaan bangunan Biofasad di Universiti Sains Malaysia (USM) dapat menurunkan sebanyak 46.28% daripada seluruh pengeluaran karbon dioksida di USM setiap tahun. Strategi untuk meningkatkan keberkesanan Biofacade termasuk meningkatkan ketebalan dedaun dan untuk menggalakkan pertumbuhan sehingga 100% liputan dinding oleh daun telah dicapai. Siraman automatik dan penggunaan kokopit pada akar tanah tumbuhan dapat mengekalkan kelembapan tanah seterusnya mengekalkan kesuburan rimbunan daun. Pada masa hadapan, kajian memerlukan tempoh masa yang lebih panjang dan pengkhususan ke atas spesis lain.

ENVIRONMENTAL AND THERMAL PERFORMANCE OF LEGUMES AS BIOFACADE IN A TROPICAL CLIMATE

ABSTRACT

This is a thesis on a study of Biofacade, its carbon sequestration and its thermal reduction potential in urban environment. It is known that the rise of temperature through global warming is caused from excessive emission of carbon dioxide. Without denying urban development, Biofacades are alternative solutions. A Biofacade of leguminous climbing plant that serves as an agent to reduce the building wall surface temperature and overcome global warming by the storage of carbon dioxide in the plant tissue through carbon sequestration was studied in this research. There are three objectives in this research; to determine the suitable leguminous plant for use in Biofacade in tropical climate, to measure the carbon sequestration by leguminous plants in a Biofacade context for carbon trading prediction and to examine the thermal reduction by leguminous plants attached to the external walls. The plant studies and the carbon sequestration study were conducted for 14 months and over two cycles of planting. Four leguminous climbing plants were identified and the carbon sequestration rates of each were compared. The plant species of winged bean or *Psophocarpus tetragonobulus* has the second highest but the most stable sequestration rate and was chosen for the Building Thermal Performance experiment. With an experimental wall area of 9.175 m^2, the Biofacade was stored as much as 0.935783 kg $CO_{2\text{-eq}}$ m^{-2} of Greenhouse gas emission annually. The study on the Building Thermal Performance was conducted for three days in Basic Study and for a month in Actual Building Scale. For Basic Study analyses, the thermal effects of the east wall in the evening (15:00 to 17:00 hours) showed that the climbing plant had significantly reduced the wall temperature by 5.6 ^{o}C on the average. For the Actual Building Scale analyses, the thermal effects of the internal wall in the day time period showed that the Biofacade had significantly reduced the wall temperature with a 2 ^{o}C (average) temperature difference. At night, the Biofacade had difficulties in emitting the heat back to the environment compared to a Typical wall with a 0.8 ^{o}C (average) temperature difference. The ultimate finding of this study is a new method of carbon trading prediction by carbon sequestration of leaves plant in the Biofacade context over a long time period. Based on the conception study, Biofacade on buildings in the Universiti Sains Malaysia (USM) could offset as much as 46.28% of USM's carbon dioxide emission annually. Strategies to improve on the effectiveness of the Biofacade include increasing the thickness of the foliage and to encourage growth until 100% wall coverage by the leaves is achieved. An automatic sprinkler and coco peat on the plants roots could retain soil humidity, thus, sustaining lush foliage. A longer study period and evaluation of more species for Biofacade study is potential avenue for future work.

CHAPTER 1 INTRODUCTION

1.1 Problem Statement

Global warming is primarily caused by increasing concentrations of greenhouse gas emissions produced by deforestation and carbon dioxide emissions (Miller, 2005). Deforestation is the process of clearing the trees, which absorb carbon dioxide through photosynthesis, faster than they grow back. Humans also add large amounts of carbon dioxide into the atmosphere by burning forests. In addition, many other activities increase the emission of carbon dioxide, such as power generation from power plants, and burning fossil fuel to propel cars and airplanes.

Since the Industrial Revolution in the seventeenth-century, the burning of fossil fuels has increased carbon dioxide emission in the atmosphere. According to Shakun et al. (2012), an increase of carbon dioxide concentration in the atmosphere causes an increase of the average global temperature. An indication of global warming is that ambient temperature is increasing everywhere, which has also altered the indoor environment of buildings. Consequently, humans tend to use more energy to cool buildings, especially in urban areas where hard surfaces are predominant. The outdoor temperature increases more when the air-conditioning is switched on; contributing to the Urban Heat Island (UHI) phenomenon (Priyadarsini, 2009). Either directly or indirectly due to the UHI effect, building masses absorb heat during the day and reemit after the sun sets, creating high temperature differences between urban and rural areas.

An international environmental treaty of the United Nations Framework Convention on Climate Change (UNFCCC) urged every individual country to take part in stabilizing the greenhouse gas concentrations in the atmosphere until an acceptable level of interference is reached. The Kyoto Protocol, under the UNFCCC, facilitates urgent action towards achieving 'stabilization' through three flexible mechanisms – Clean Development Mechanism (CDM), Joint Implementation (JI), and Emission Trading (ET) (Halvorssen, 2008). Of these mechanisms, CDM is the only mechanism that is relevant to Malaysia as it aims and promotes co-operative measures between industrialized (Annex I) and developing (non-Annex I) countries.

The CDM allows industrialized countries to buy Certified Emission Reduction (CERs) units from developing countries. CDM is expected to produce the carbon dioxide equivalent in emission reductions. Carbon Capture and Storage (CCS) was included in the CDM carbon offsetting scheme project in 2011, giving way for developing countries to access project finance and contribute to greenhouse gas emission reduction efforts (Global CCS Institute, 2012). By 2050, more than 3,400 of the CCS projects listed will be up and running, mostly involving Europe, North America and Australia (Global CCS Institute, 2012). Sequestration of carbon dioxide gas, as a way to earn carbon credits for financial pay-out, was first mentioned in the International Conference of Energy and Environment (ICEE) in 2009 by the Minister of Energy, Green Technology and Water (KeTTHA, 2012).

The construction industry of Malaysia has been considered as the inspiration for the Green Building Index (GBI) to promote a sustainable built environment. GBI is a rating tool that provides a design reference guide for green development. Achieving the standards of the GBI will reduce the negative impact on the environment such as mititgate the Urban Heat Island effect. As plants grow they absorb greenhouse gases (KYOTO Protocol to reduce emissions of greenhouse gasses) from the atmosphere and store it in their tissues, acting as carbon sponges (Green over Grey, 2013).

All economic sectors, especially agriculture, have a high impact on climate change (Xiong et al., 2007). The crisis in agriculture raises the issue of food security. In the next two decades, to ensure the current food production, cultivation and producing on used land must double (Cakmak, 2002). Disruptive climate change also affects species and their habitats, with consequent changes to the natural ecosystems.

Since land is becoming increasingly expensive, the space allocated to grow agricultural crops is becoming more scarce. People start to grow their own crops because of the easy accessibility of the food source. There are three factors that determine the regions of the world in respect to access to food or food production (Ramankutty et al., 2008). First, the productive cropland constitutes an adequate amount. Next, the high crop yields are easily maintained if fertilizers, pesticides and irrigation are available. Lastly, food is easily purchased and imported from other regions. Populations are rising and so are the demands for food supply. Ramankutty et al. (2008) analysed the statement made by Lai (1989) who said that the global distribution of croplands would change in the twentieth-century when croplands would diminish from ~0.75 ha/person in 1900 to ~0.35 ha/person in 1990. It was estimated that the minimum area of cropland to provide an adequate diet was 0.5 ha/person.

There are many issues concerning food self-sufficiency. Having access to food for a healthy and active life is defined as food security (Groot et al., 1998). Moreover, about 50% more people have to be fed than currently predicted to fulfil the food demand (Lotze-Campen et al., 2006). Basically, people in towns (urban) used to import food from rural agriculture. Urban spaces are expensive, and, thus, planting an agricultural crop would not be effective. Loh and Bedi (2008) stated that RM1.4 billion was spent on importing vegetables into Malaysia, which has a population of 28 million, as it was not self-sufficient.

However, food plants can use minimal space, such as by attaching plant climbers to walls. This method, if implemented properly, can reduce the percentage of imports from overseas, as well as earn profit by exporting plentiful food crops. Although many innovations have been identified, this method of producing food plants is not currently popular in Malaysia.

The term Biofacade was first used by Sunakorn (2008) as “a combination between natural environment and built environment forming a biological building skin”. Many similar phrases or terms have been used in research, namely, the Vertical Garden (Blanc, 2008), Green Facades (Kohler, 2008), Bioshader (Ip et al., 2004), Living Wall (Dunnet and Kingsbury, 2008), Green Wall (Irwin, 2009) Vertical Greenery System (VGS) (Wong et al., 2010), and vine covered wall (Bass et al., 2001).

Selecting climbing plants for application as a Biofacade is a crucial part in the design phase. Climbing methods like adhesive roots usually cause fine line cracks, which widen over time leading to damage and failure of the building surfaces (Dunnet and Kingsbury, 2008). As Malaysia is a tropical country with plants growing all the time without hibernation as in a temperate country, it raises an important question, how far can the maintenance of a Biofacade contribute to achieving sustainable development?

1.2 Research Background

Facades overgrown with plants have long been applied since humans chose to settle down in permanent dwellings. The first reason for having facades overgrown with plants was for beautification in which most of the plants used were natural climbers that grasped anything in reach. Although initially allowed to grow freely it is possible that later when these plants managed to cover most of the external wall they were considered a nuisance, especially when the plant led to brick failure through cracks, which widened and penetrated the building surface.

After many years, facades overgrown with plants had a very specific purpose, which was to provide food from the production of grapes. According to Taraba (2012), the ivy and grapevine were the two climbing plants that dominated facade planting in Central Europe. Wine was made from grapes and was an essential part of their culture and daily lives. It was popular to plant grapes on the external wall due to the easy accessibility to pick the fruit. However, fungal diseases caused many not to continue with this practice. Only in suitable climatic regions and with the introduction of new technologies has this practice persisted.

During the Romantic Era at the end of the eighteenth-century, most of the dwellings and castles were again overgrown with plants and it became a trend, specifically, the growing of Boston Ivy (Taraba, 2012). Dunnet and Kingsbury (2008) stated that climbing plants on the building facade were often used for summer cooling for screening of the sides of domestic building like sheds and garages. During the Garden City Movement, at the beginning of the twentieth-century, climbing plants on the building facade were often linked to the Arts and Crafts Movement (Dunnet and Kingsbury, 2008). However, the trend did not last long, because people started to realize that facades overgrown with plants required regular care and trimming to prevent damage to their buildings.

Nowadays, facades overgrown with plants are developed more (1) to overcome the problems of building cracks caused by conventional green wall planting, (2) to increase the temperature reduction difference and carbon dioxide emission in the atmosphere, (3) as a noise control, (4) and for the aesthetic enhancement of buildings.

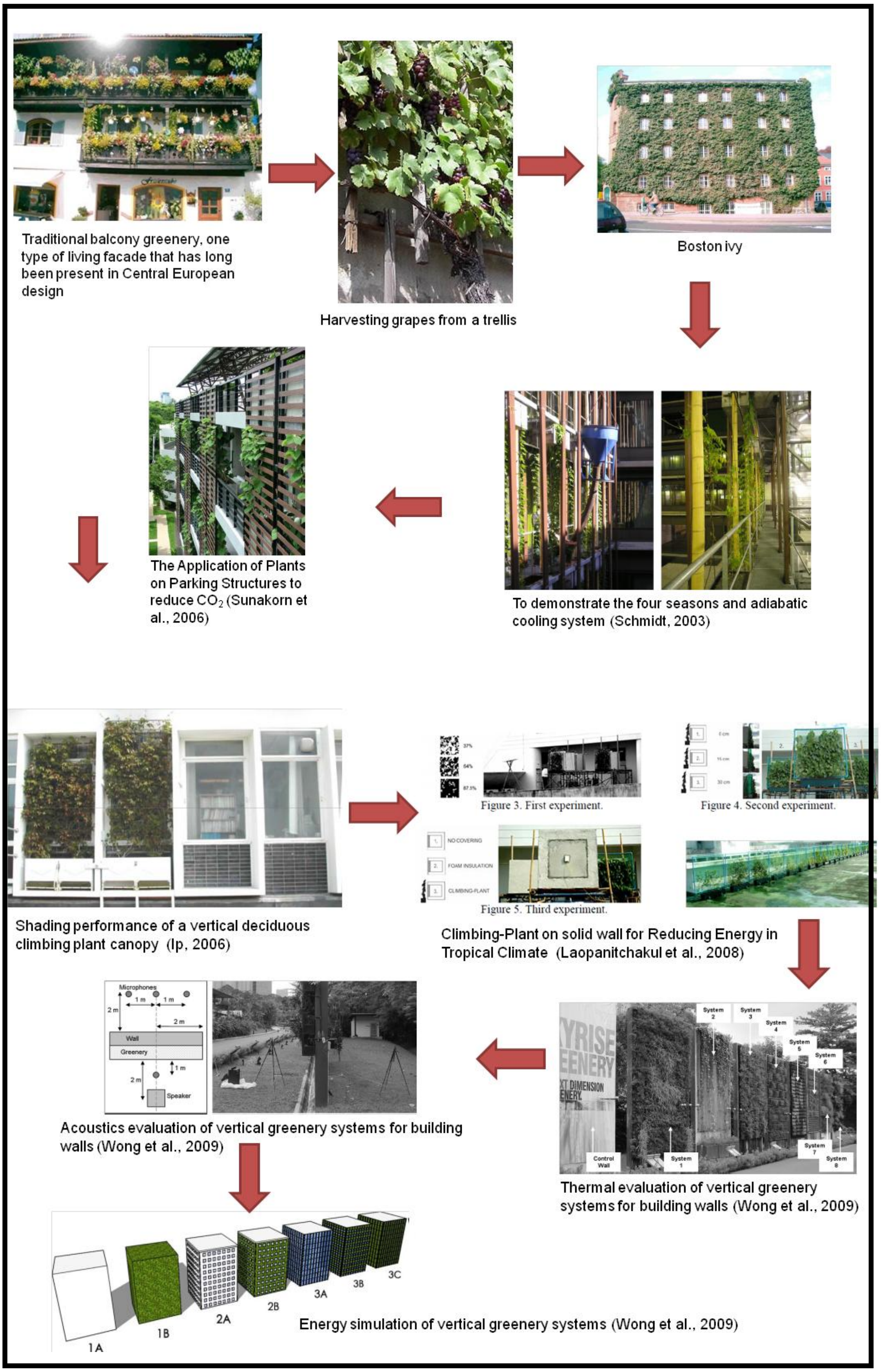

Figure 1.1: History and research development of facade greening, the external building.

According to Schmidt (2003), some researchers demonstrated the function of climber plants for an adiabatic cooling system. Some even developed it specifically for industrial purposes. Likewise, Sunakorn et al. (2006) also experimented with the application of plants in an urban setting to reduce carbon dioxide emission. The same goes for Ip et al., (2004), who investigated the shading performance of a vertical deciduous climbing plant canopy. For the tropical climate facades, Wong et al., (2010) analysed eight different vertical greenery systems, and identified the preferred design for reducing the thermal impact on the wall and reducing the acoustic impact for human benefit (Figure 1.1).

Biofacade application on building in Malaysia is designing basically to fulfil the aesthetic value for marketing purpose. It is rarely design based on scientific studies such as to reduce the carbon dioxide in the atmosphere for world carbon trade. To obtain world carbon trade, a practical field of scientific studies is needed. Practical scientific studies offer a measurable investment for long term projects. The Clean Development Mechanism (CDM) project is renowned for its reduction of greenhouse gas emissions, through financial and technology investment opportunities in various ways.

For example, Norway, the fifth largest oil exporter in the world, gives USD100 million to Africa for forests planting on behalf of them for carbon trade (Menne et al., 2011). Biofacades are seen as a way to earn carbon credits without sacrificing horizontal land, as a plantation can be grown vertically. Moreover, climbing plants grown on a building facade are mentioned in the GBI rating system as a point-earning initiative. The study experimented on the ability of Biofacades to reduce the thermal effect on buildings. By achieving points, the building is likely to be more environmentally friendly than those that do not address the issue (GBI, 2011).

The research aim is to investigate which leguminous plants of Malaysia can absorb the highest amount of carbon dioxide over an extended period to act as a carbon sink. Likewise, to determine quantitatively how significant are these facades with plants attached to the external walls in terms of thermal reduction inside a room.

1.3 Research Question

From prior reviews, it is understood that carbon emissions are perceived as the leading cause of global warming. Urban Heat Islands result in more stagnant wind and make the urban environment even warmer. As such, plants have been considered as one of the ways to sequester the carbon from the atmosphere and hold it in leaves and soil for a very long time. Plants also help in giving natural shade to the building. Plants with fruit have demonstrated the potential of supplying food and medicine for the future or even for commercial investment. Moreover, it saves space while still accommodating an agricultural crop.

However, since the effectiveness of this strategy is totally dependent on the type of plant, it is only practical for use in a tropical climate since these investigations were conducted in Malaysia. Therefore, the following questions were formulated as the first methodological steps.

Research Questions:

i. Which legume plants possess the highest photosynthesis rate?
ii. Do Biofacades affect the ecosystem?
iii. What percentage of the wall is covered by leaves?
iv. How much carbon dioxide do plants absorb in a year?
v. Are all the legume plants investigated resilient to the Biofacade concept?
vi. What was the temperature reduction when a Biofacade was applied?

1.4 Research Aim and Objectives

Based on the problem statement and research background, this study aims to determine the suitable leguminous plant for use in Biofacade in tropical climate. From the leguminous species plant study, the researcher measure and identify the carbon sequestration of plants and the implications in terms of temperature and the built environment.

i. To determine the suitable leguminous plant for use in Biofacade in tropical climate.
ii. To measure the carbon sequestration by leguminous plants in a Biofacade context for carbon trading prediction.
iii. To examine the thermal reduction by leguminous plants attached to the external walls.

1.5 Research Approach and Methods

To achieve the objective and answer the research questions, this study was conducted using quantitative research, generally employing scientific methods. It includes a collection of empirical data, experimental control and manipulation of variables.

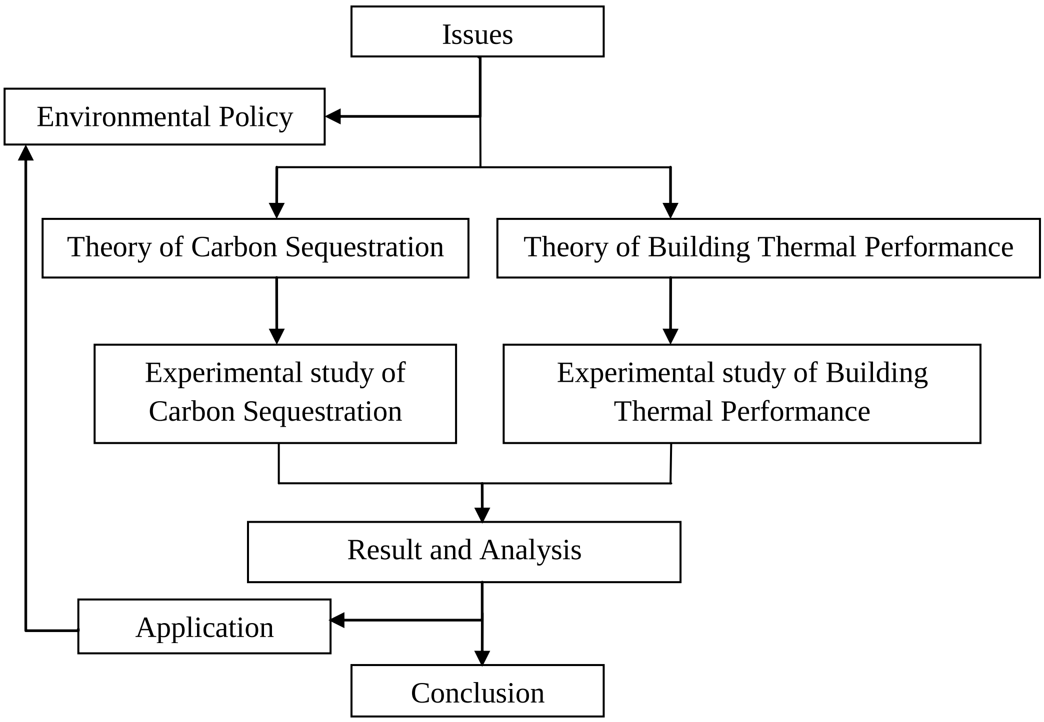

Figure 1.2: Research Framework

Firstly, the Environmental policy of the Kyoto Protocol was reviewed. The theory of carbon dioxide and building thermal performance is discussed in the literature review. Before the study starts with experimental work, initial studies regarding the selection of plants was conducted. Initial studies are important to identify the most efficient legume plant for application in the experiment. The plants were be grown in an open environment to record the growth of the plants, which it is postulated could grow faster in an urban space, in parallel with higher carbon dioxide concentration.

The carbon sequestration and building thermal was analysed for both experiments in a different chapter.

Based on the results and analysis, the researcher was able to establish whether it reflects the environmental policy by application. In the foreseeable future, the use of plants as a carbon neutralizer in an urban setting will become one of the key design considerations in modern building development. Therefore, it is crucial to determine the effects and consequences of biological facades. The study ends with a discussion and future works concerning the use of Biofacades.

1.6 Research Scope and Limitations

The research presents the legume plants of Malaysia that can absorb the highest amount of carbon dioxide through their leaves. Legume plants were chosen as the main study due to the practicality of obtaining fruits for edible purposes and herbs for medication. Legumes are unique to investigate because of their commercial value, especially the fruit pods and tuberous roots. Generally, fruit pods are consumed as edible products and tuberous roots as alternative sources of fermentation carbohydrates, which contain energy.

The most appropriate tropical legume plants were narrowed down in the research such as specific aspects like twining and tendril climbing methods. A height of three metres is the minimum requirement. The requirement for the chosen plant includes durability and ability to grow well even under hot sun. It must be drought resistant. Moreover, the plant chosen should also have a commercial value that is beneficial to the household users. This is important to decrease import from trade and increase the exports if there is any residue of crop plantation.

Carbon dioxide in the atmosphere is sunk (carbon sink) by the leaves, which act as a reservoir to clean the air. Carbon sequestration is a term used in this thesis to represent this system. This thesis investigates the highest carbon sequestration in the context of legumes. The research investigation was conducted in an urban area in which the high population density contributes to the high carbon dioxide captured in the atmosphere. Thus, the results and analysis were influenced considerably by the area chosen. This thesis also presents the significance of the colour of the leaves and the relationship to the plant's carbon sequestration rate.

Research development on facade greening by plants all over the world has shown that the heat in buildings (indoor temperature) and nearby (Urban Heat Island) were reduced by growing plants next to or on top of buildings. Many designs of facade greening with plants have had different effects on the temperature reduction. There are two systems of facade greening: Carrier System and Support System (Chiang and Tan, 2009). The Carrier System receives shade from the leaf arrangement and soil or growth media on the wall. The Support System only receives shade from the leaf arrangement, where the soil or growth media were put on the bottom. This thesis focuses on the Support System, which excluded research on soil type.

1.7 Research Significance

The research is important because of the need to determine the temperature reduction when planting the vegetation on external walls. The problems of green walls, either directly or indirectly, were identified on site. The findings are useful to educate developers and clients on Biofacade applications in Malaysia and determine the effectiveness for future solutions.

It is also for future documentation of the carbon sequestration from specific plants. The data obtained in this study are useful to estimate the carbon trading emissions in response to meet the obligations specified by the Kyoto Protocol. This knowledge is useful for architects, researchers and manufactures, and helps increase the public awareness concerning the ecological system of the Biofacade.

This study also emphasizes the solution to space problems for agricultural crops in urban settings. As the land in urban areas is more expensive, Biofacades provide an advantage for consumers to optimize the usage of every vertical inch of their premises. Furthermore, the aesthetics of the building are enhanced and added value is given to commercial buildings with the planting of a Biofacade.

1.8 Thesis outline

The chapter summaries of the thesis are as follows:

Chapter 1 introduces the research development of the facade's greening. Issues such as temperature rise due to global warming and food insecurity due to high population density are elaborated upon. Population growth and human longevity also compound the space limitations, especially in urban areas. Research Questions and Research Objectives are introduced in this chapter before developing the Research Approach and Methods.

Next, **Chapter 2** investigates the main concept and strategies of Biofacades. This chapter also discusses the methods and innovations for facade greening from previous research. The preliminary investigation of the potential of climbing plants is critically explained at this point, leading to the result of plant selection in Chapter 3. The potential usage of green walls in Malaysia is reviewed in the final part of this chapter.

Chapter 3 continues with the Research Methodology and Site Description, which were modified and selected based on the literature review; thus, it consists of three approaches. The reasons as to why and what type of plant was selected are explained in this chapter together with plant care management. The final part of this chapter explains how the data are analysed, as presented in Chapter 4. The chapter provides limitations on the research and narrows down the selection of plants.

Chapter 4 starts with the selection of plants for Biofacade application. Several climbing plants are analysed for possibilities and the best four species are identified. In the first growth of five months, four species are identified and the characteristics, especially concerning the resilience of the plants to grow on the evening side of the building, fruiting pattern, flowering, plant height possibilities, and their benefits towards human life are determined. In the second growth, where only one species is planted, the investigations continue over a longer period of nine months. Pests, diseases and overcoming the problems are also explained in this chapter. The final part of this chapter elaborates on the resilience and use of legumes in Biofacades.

Chapter 5 contains Carbon Sequestration and Leaf Area study for the prediction of carbon dioxide storage in the Biofacade. This helps clarify the significance of the study, which is in parallel with the obligations of the Kyoto Protocol and Green Building Index (GBI). The final part of this chapter presents the annual prediction of carbon sequestration by Biofacade application.

The temperature reduction for energy saving is also discussed in **Chapter 6**, which corresponds to the requirements of the Green Building Index (GBI). The building thermal performance are analysed for wall surface. Three cases including pilot study are analysed in this chapter.

Chapter 7 summarizes the overall findings and provides guidelines and design recommendations for ideal implementation in future works. The chapter also reviews the Research Questions and Objectives, and whether they fulfil the research intentions as stated in Chapter 1.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

This chapter includes the concept of carbon dioxide, previous research concerning the approaches to reducing building thermal performance, and the potential of façade greening using edible climbing plants. It also includes discussion concerning global warming and the Kyoto Protocol obligations that Malaysia has agreed to participate in. Next, the chapter introduces Biofacade application in Malaysia. The study explores the Biofacade potential in a tropical climate, availability and reliability of research tools, and significance of the study from previous research. The results of these different studies led to a structured investigation of Biofacades with plant selection as the initial study. The research gap is discussed at the end of this chapter.

2.2 Main concept of Carbon Dioxide

2.2.1 Carbon dioxide principle

Carbon dioxide is a gas that exists in the atmosphere. It is circulated through the surface and the atmosphere of the Earth by the carbon cycle. Carbon dioxide is a natural temperature control system in the atmosphere (Miller, 2005). If the carbon cycle removes much of the carbon dioxide such as sequestration by plants, the atmosphere will be cooler. If the cycle happens quickly within the space such as deforestation, the atmosphere will get warmer. Even slight changes in the carbon cycle can affect the climate and ecosystem. Carbon dioxide, water and light are needed by plants and are used in photosynthesis to produce carbohydrates and process oxygen (Rosenberg, 1983).

Carbon is needed, as it is a source of protein, carbohydrates, and other organic compounds necessary for life. When too much carbon is burned, it causes global warming. Dead plants release carbon dioxide but not at a threatening level unless it is burned. As long as the carbons are stored in plants and the soil, in the form of fossil fuel, such as coal or oil, the atmosphere is secure. Carbon is not released to the atmosphere as carbon dioxide for recycling until it is extracted, burned, or until long geological process exposes these deposits to air (Miller, 2005).

Plants act as the intermediary in maintaining the atmosphere's carbon neutrality. Pearcy and Bjorkman (1983) quoted Gates, who mentioned that oil, gas and coal are estimated to contain nearly 4,130 x 10^9 metric tons of carbon of the world's remaining recoverable resources. He added that the atmospheric carbon dioxide concentration would increase by a factor of four if the total oil, gas, and coal were burned and half remained airborne. According to Pearcy and Bjorkman (1983), on average, plant growth increases by about 0.9% when 0.1% of carbon dioxide concentration is increased in a laboratory test. Thus, there is a probability for plants to grow faster in urban spaces where the carbon dioxide can act as a plant fertilizer.

The cumulative effects of carbon dioxide on yield and plant growth have a significant correlation (Pearcy and Bjorkman, 1983). Two plants were observed, one grown in a "normal" atmosphere and the other in a "high" carbon dioxide atmosphere. "Normal" was approximately 340 ppm carbon dioxide while "High" was estimated at 600 ppm carbon dioxide. In these experiments, there is evidence that some small seeds placed on the soil surface germinate faster in high carbon dioxide. Once the shoot emerges, it responds to high carbon dioxide by initiating and expanding each leaf faster, achieving a larger leaf area. However, this effect is not seen in all species. In summary, some, but not all kinds of plants grown in high carbon dioxide will reach the end of the seedling stage sooner and with a larger leaf area.

No effect was observed on the leaf protein content, on a leaf weight basis, of the *Nerium oleander* plants at 660 ppm carbon dioxide, compared to those at 330 ppm (Pearcy and Bjorkman, 1983). However, a significant increase on a leaf area basis was noted. On a different experiment for *Atriplex triangularis,* lower leaf protein contents were observed in plants at 660 ppm carbon dioxide concentration compared to the ones at 330 ppm in both leaf weight and leaf area basis. In summary, the carbon dioxide concentration effect as a plant fertilizer is varied according to the different kinds of plant. The experiment regarding atmospheric carbon dioxide should be done in urban areas, where higher temperature phenomenon exists due to higher atmosphere carbon content from the power plants, cars and buildings.

2.2.2 Carbon Emission and Store

Human activities affect the carbon cycle in two ways, through deforestation and the burning of fossil fuels (Miller, 2005). The flux of carbon to the atmosphere is uncertain and difficult to quantify (De Fries et al., 2002). Thus, estimation of carbon fluxes from deforestation are always estimated based on various methods of calculation. With net global carbon dioxide emissions between 1.1-3.6 Pg C/year, Crutzen and Andrea (1990), in his analysis, estimates that deforestation from tropical forests might have contributed 20% to 60% of the greenhouse warming caused by carbon dioxide emissions from fossil fuel burning for the years 1940 - 1980. Houghton et al., (2005) estimated that deforestation released carbon dioxide emission of 1-2 Pg C/ year (15% - 35% of yearly fossil fuel emissions) during the 1990s.

Carbon dioxide emissions are increasing annually. Based on 2008 emissions, Malaysia was ranked in the top 27 for annual carbon dioxide emissions with 208,267 in thousands of metric tons, comprising 0.69% of the global total (Millenium Development Goals Indicators, 2011). The data were collected by the Carbon Dioxide Information Analysis Center (CDIAC) for the United Nations. The amount was estimated based on the burning of fossil fuels. Carbon prices are normally quoted in Euros per ton of carbon dioxide or its equivalent. Other greenhouse gasses, such as nitrogen dioxide, ozone, water vapour and methane, are traded but using carbon dioxide equivalent unit for global warming potential.

Plants and soil act as a reservoir to store the carbon. As the plant grows, the carbon stored in plants is different according to the species (Chazdon, 1986), its location or altitude (Korner, 1987), and the water content in the plants (Lawlor, 2002). Thus, the increase of stored carbon in plants can be controlled. However, leaf longevity within plant categories is reduced with the higher carbon gain in plants (Kikuzawa, 1999).

Biosequestration or carbon sequestration is a process of removing carbon from the air through a biological process, such as croplands (Smith, 2004). The carbon is kept in the leaves and soil as a reservoir. Global warming is caused by greenhouse gasses with carbon dioxide as the main cause (Hansen, 1990). Thus, growing more plants keeps the atmosphere from warming. As the plant grows, the carbon inside the plant tends to slow its release of the carbon from the decayed plant material (Houghton et al., 2005). The carbon held inside the dead-plants would still hold the carbon unless they are burned-down, which would have an immediate impact on greenhouse warming caused by carbon dioxide (Crutzen, 1990).

2.2.3 Carbon Emission Trading and Kyoto Protocol Obligations: Adoption in Malaysia

Kyoto Protocol sets quantified and commitments for limiting or reducing greenhouse gas emission. The Kyoto Protocol came into force in 2005. Developed countries including Malaysia agreed to reduce the overall emission by 5.2% from the levels in 1990 by the end of year 2012 (Department of the Environment Transport and the Regions, 2000). To reflect the programme, under the plans for a Low Carbon Cities Framework and Assessment System, Malaysia targeted to reduce carbon dioxide emissions by 40% by 2020 (Azril, 2011). The United States is the only industrialized nation under Annex I that has not ratified the treaty, and is therefore not bound by it.

Kyoto Protocol has three flexible mechanism; The Clean Development Mechanism (CDM), Joint Implementation (JI), and International Emissions Trading (IET). Among mechanism, only CDM aims at promoting co-operative measure between industrialized (Annex I) and developing (non-Annex I) countries. As a non-Annex I, CDM is the only mechanism under Kyoto Protocol that relevant to Malaysia. The

Clean Development Mechanism (CDM) has become an alternative nowadays for new development and established under Article 12 Kyoto Protocol, for example, renewable energies like wind, hydro, solar, rain, tides, waves, geothermal heat, modern biomass and biofuels. Carbon capture and storage (under biomass) related to this thesis.

Carbon is becoming the world's biggest commodity market, and it becoming the world's biggest overall market. If carbon sequestration in plants is used to meet the carbon emission reduction according to the Kyoto Protocol obligations, the system in plant carbon must be measureable and verifiable, including to yearly commitment period. Carbon projects have become increasingly important since the introduction of emission trading under Phase I of the Kyoto Protocol in 2005.

2.2.4 Field Measurement Methods and Research Instruments for Carbon Dioxide Performance in Plants

Research in Thailand was conducted on the growing of plants on the parking structure of Kasetsart University to observe and compare the carbon dioxide level of a parking structure with and without climbing plants attached (Sunakorn et al., 2006). She explored vertical planting as a solution to the shortage of space, as high rise building given more surface area to absorb carbon dioxide. Five tropical climbing plant species were tested using a carbon dioxide sensor data logger in a sealed glass chamber. The five species selected were *Artabotrys hexapetaluks (L. F) Bhandari, Argyreia nervosa (Burm. F) Bojer, Congea tomentosa Roxb. Solandra grandiflora Sw.* and *Beaumontia grandiflora Wallich,* which are commonly used in landscape design architecture. The plant selection was selected based on local varieties, vine strength, maintenance level and aesthetic value of leaves or flowers.

Every climbing plant had two samples with the same size and approximately equal leaf size area for the carbon dioxide capture experiment (Sunakorn et al., 2006). A plant was evenly positioned in a glass chamber measuring 600 mm x 600 mm x 1000 mm. A carbon dioxide source in the form of an incense stick with the same length and width was put in each glass chamber. A carbon dioxide sensor was set inside the glass chamber and recorded the levels of carbon dioxide for each minute, which was repeated twice for each plant from 09:00 until 12:00 hours. The carbon dioxide content of an empty glass chamber with a lit incense stick (source of carbon dioxide) was also recorded as a control experiment.

The top three best performing species in carbon dioxide capture were then planted using a full-scale planting box with a vertical lattice at the north and south facades of a test building (Sunakorn et al., 2006). Observations indicated that growing plants on different orientations does not affect the growth rate. The species with the best performance in order are *Congea tormentosa, Artabotrays hexapetalus,* and *Solandra grandiflora*. Plants with larger leaves absorbed better than the ones with smaller leaf areas.

Growth coverage and visual aesthetic quality were observed on the four months and only one species was selected for final growth (Sunakorn et al., 2006). Photo documentation was taken every week for growth rate observations. The photos used a black and white negative technique to differentiate between leaf cover and background wall for growth comparison. The investigations were conducted in a completed parking building in an urban environment for a 12-month period.

Observations for carbon dioxide capture in an urban environment were conducted for nine hours from 10:00 until 19:00 hours on weekends based on the operating hours of the parking structures (Sunakorn et al., 2006). Other parking structures without climbing plants were selected with similar behaviour as additional observation studies. The parking structures compared included an underground shopping centre parking with ventilation, ground level theatre parking, ground level airport parking, and hospital parking structure near to Kasetsart University. To sum up, the carbon level in the heavy traffic contributed considerably to the carbon dioxide emission into the atmosphere. In comparison, a higher level of carbon dioxide was released from the parking structure of the shopping centre, followed by the airport and the theatre.

The hospital parking structure near to Kasetsart University was considered most suitable for carbon dioxide observation as a comparison to Kasetsart University multi-levelled parking structure (Sunakorn et al., 2006). The objective of this observation was to evaluate and further understand the level of carbon dioxide in the atmosphere through the day and night time. A carbon dioxide and wind velocity sensor with data logger was installed for a week-long continuous measurement at five minute intervals.

Observations showed that at both parking structures, the carbon dioxide level rose from 00:00 until 05:00 hours where there was absolutely no traffic and the wind was