VEGETATION STRUCTURE AND CONFIGURATION FRAMEWORK FOR IMPROVING THERMAL ENVIRONMENT OF SINGLE-STOREY SEMI-DETACHED HOUSE IN TROPICAL CLIMATE

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by

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LIST OF SYMBOLS

˚C	Degree Celsius
%	Percentage
m/s	meter per second
CO_2	Carbon dioxide
CO	Carbon Monoxide
	Sunny
	Cloudly
	Partly Cloudy
	Drizzling rain
	Rain
	Rain with thunder

LIST OF ABBREVIATIONS

Avg.	Average
AV	Air Velocity
CS1	Case Study 1
CS2	Case Study 2
CO_2	Carbon dioxide
CH_4	Methane
CFCs	Chlorofluorocarbons
diff	Difference
DL1	Data Logger 1
DL2	Data Logger 2
ELO	Eastern Landscape Orientation
IPCC	Intergovernmental Panel on Climate Change
IIUM	International Islamic University Malaysia
ILAM	Institute of Landscape Architects Malaysia
ISO	International Organization for Standardization
JPBD	*Jabatan Perancang Bandar dan Desa*
LNLH	Less to No Landscape House
m/s	Meter Per Second
Max	Maximum
Min	Minimum
MLH	Mixed Landscape House
N_2O	Nitrous oxide
P_1- P_{13}	Parameter 1- Parameter 13
(R)	Correlation Coefficient

(R^2)	Coefficient of Determination
RH	Relative Humidity
RO	Research Objective
RQ	Research Question
S_1-S_7	Scale 1- Scale 7
SLH	Structured Landscape House
SSLH	Semi-Structured Landscape House
UHI	Urban Heat Island
UiTM	Universiti Teknologi MARA
UMK	Universiti Malaysia Kelantan
UPM	Universiti Putra Malaysia
USM	Universiti Sains Malaysia
Va	Air velocity
VC	Vegetation Configuration
VS	Vegetation Structure
VSC	Vegetation Structure and Configuration
WLO	Western Landscape Orientation

LIST OF APPENDICES

KERANGKA STRUKTUR DAN KONFIGURASI TUMBUHAN UNTUK MENAMBAHBAIK PERSEKITARAN RUMAH BERKEMBAR SETINGKAT DI IKLIM TROPIKA

ABSTRAK

Fenomena Pulau Haba Bandar (UHI) semakin membimbangkan di bandar-bandar tropika akibat urbanisasi pesat dan pengurangan kawasan bervegetasi. Di Malaysia, reka bentuk landskap kediaman sering mengabaikan kepentingan vegetasi dalam mengawal keselesaan terma, terutamanya bagi rumah berkembar setingkat di kawasan pinggir bandar. Walaupun vegetasi diketahui mempengaruhi mikroiklim, aplikasinya dari segi struktur dan konfigurasi dalam perumahan pinggir bandar masih kurang diterokai. Kajian ini bertujuan untuk membangunkan satu rangka kerja Struktur dan Konfigurasi Vegetasi (VSC) yang optimum bagi meningkatkan prestasi terma persekitaran kediaman. Dua kajian kes berasaskan lapangan telah dijalankan di Perak, Malaysia, menggunakan Delta OHM HD32.1 untuk pemantauan mikroiklim terma dan HD37AB1347 bagi penilaian kualiti udara dalaman. Hasil Kajian Kes Pertama menunjukkan bahawa vegetasi yang menghadap timur dengan struktur dan konfigurasi yang sesuai mampu mengurangkan pendedahan haba pada waktu petang serta menurunkan suhu dalaman. Kajian Kes Kedua pula mendapati rumah yang dikelilingi vegetasi padat dan tersusun mencatatkan keadaan terma yang jauh lebih sejuk berbanding rumah dengan vegetasi jarang atau tiada langsung. Satu kajian Delphi melibatkan 16 orang pakar telah dijalankan untuk mengesahkan 14 parameter utama VSC. Antara cadangan yang diperoleh termasuk liputan vegetasi sebanyak 40–60% daripada kawasan landskap, penempatan vegetasi sejauh 3–6meter dari dinding

menghadap barat bagi memberi teduhan dan pengudaraan yang berkesan, serta penggunaan kanopi bersaiz sederhana (7.1–11meter diameter). Daun lebat, spesies malar hijau berdaun lebar, dan susunan kanopi berlapis turut disarankan bagi meningkatkan kecekapan penyejukan. Rangka kerja VSC yang telah disahkan ini menyediakan panduan praktikal untuk integrasi vegetasi dalam reka bentuk kediaman, menyokong arkitek landskap, perancang bandar dan pemilik rumah dalam mewujudkan perumahan tropika yang selesa dari segi terma dan responsif terhadap alam sekitar.

VEGETATION STRUCTURE AND CONFIGURATION FRAMEWORK FOR IMPROVING THERMAL ENVIRONMENT OF SINGLE-STOREY SEMI-DETACHED HOUSE IN TROPICAL CLIMATE

ABSTRACT

Urban Heat Island (UHI) effects are intensifying in tropical cities due to rapid urbanization and the diminishing presence of vegetation. In Malaysia, residential landscapes often lack climate-responsive design, particularly in single-storey semi-detached housing. Although vegetation plays a key role in regulating microclimates, its structural application in suburban residential settings remains underexplored. This research aims to develop an optimal Vegetation Structure and Configuration (VSC) framework to enhance thermal performance in such environments. Two field-based case studies were conducted in Perak, Malaysia, utilizing Delta OHM HD32.1 for thermal microclimate monitoring and HD37AB1347 for indoor air quality assessment. Findings from Case Study One indicated that eastern-facing vegetation, when properly structured and configured, significantly reduced afternoon heat exposure, lowering indoor air temperatures. Case Study Two demonstrated that houses surrounded by dense and systematically arranged vegetation exhibited notably cooler thermal conditions than those with sparse or no vegetation. A Delphi study involving 16 experts validated 14 key VSC parameters. Recommendations include 40–60% vegetation coverage of the landscape area, strategic placement of vegetation 3–6 meters from west-facing walls, and the use of medium-sized canopies (7.1–11 meters in diameter) to provide effective shading and ventilation. Dense foliage, broadleaf evergreen species, and multi-layered canopy arrangements were also found to enhance cooling efficiency. The validated VSC

framework developed in this study provides practical guidelines for integrating vegetation into residential design, supporting landscape architects, urban planners, and homeowners in creating thermally comfortable and sustainable housing in tropical climates.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Rapid urbanisation has significantly changed global settlement patterns, with more than half of the world's population currently living in urban areas. Karakounos et al., (2018) indicated that more than 3.4 billion people, approximately 50% of the world's population live in urban areas, with that number predicted to rise to 5 billion (60% of the world's population) by 2030. This figure is projected to increase to 68% by the year 2050, according to the United Nations and supported by Rhee and colleagues in 2023. Malaysia mirrors this trend, where rural to urban migration and rapid development have increased the demand for housing and infrastructure (Ismail, 2010). Between 1999 to 2007, Malaysia's urbanised areas expanded at an average rate of 13.63% annually (Tan et al., 2009), and the national population reached 33.4 million in 2023, with 91.1% comprising citizens (Department of Statistics Malaysia, 2023).

This growth has led to significant land-use change, converting natural green landscapes into built environments dominated by impervious materials such as asphalt, concrete, and built structures. This transformation has intensified the Urban Heat Island (UHI) effect, a phenomenon where urban areas exhibit higher temperatures than their rural counterparts due to reduced greenery and increased surface heat retention (Gómez-Navarro et al., 2021). As noted by Kamarulzaman et al. (2016) the increase in urban air temperatures is strongly linked to dense infrastructure, excessive paved surfaces, human activities, and the loss of vegetated areas. In many urban developments, particularly housing projects, vegetation is either minimal or replaced entirely with hardscapes.

As mentioned by Shakun (2012) and Basher (2018), high-density building development generally neglects vegetation requirements. Many trees and softscapes are substituted with concrete pavements, buildings, and street fixtures during housing development (Gómez-Navarro et al., 2021). In Malaysia’s tropical climate, where high solar radiation and humidity persist year-round, the UHI effect is particularly severe. This contributes to declining thermal comfort levels, especially in densely built low-rise residential areas (Thani et al., 2013; Ramakreshnan et al., 2018).

More critically, UHI not only affects outdoor conditions but also contributes to the degradation of residential thermal environments, that impact occupant comfort and energy consumption. Residential areas, especially low-rise houses, with limited vertical insulation and exposed facades, are highly susceptible to solar heat gain. The lack of vegetation exacerbates this, resulting in elevated indoor temperatures, poor ventilation, and discomfort for residents.

In response to these challenges, vegetation has emerged as a widely recognised method to passively regulate thermal environments. Through mechanisms such as shading, evapotranspiration, and the regulation of airflow (Fu et al., 2022), vegetation can help reduce localised heat and improve thermal conditions both indoors and outdoors (Wong et al., 2007; Oliveira et al., 2011). Yu et al.(2018) noted that urban vegetation is among the most universally applied approaches to climate moderation. However, much of the existing research has examined vegetation benefits at a generalised or large-scale level, without addressing the effectiveness of specific vegetation arrangements or configurations, especially in small-scale residential settings.

This study responds to that gap by investigating targeted vegetation design strategies at the micro (household) level. In particular, it examines how different arrangements of Vegetation Structure and Configuration (VSC) such as orientation, canopy size, leaf density, and spatial layout affect thermal performance in single-storey semi-detached houses, a common suburban housing type in Malaysia. These houses are functionally popular due to their affordability and available garden space, but their low-rise design, with three exposed facades, makes them especially vulnerable to solar heat gain. Despite this, most studies in Malaysia have focused on terrace houses, apartments, or green infrastructure on a broader urban scale, with limited attention to how structured planting can enhance thermal comfort in this specific context (Abu Bakar, 2017; Misni, 2012; Yunos, 2012).

To address this gap, the study introduces the concept of Vegetation Structure and Configuration (VSC)**,** which refers to the detailed arrangement of vegetation in terms of height, canopy width, foliage density, leaf type, spatial distance from the building, layering (e.g., ground, mid, and upper canopy), and orientation relative to solar exposure**.** Unlike general greenery, the VSC approach investigates which specific combinations of these parameters, such as dense trees on western facades, layered planting structures, or strategic vegetation coverage inside yards are most effective at modulating indoor air temperature, humidity, and airflow.

The deliberate focus on single-storey semi-detached houses is both practical and relevant. These houses offer practical landscape areas that are suitable for vegetation interventions, yet their thermal vulnerability due to low-rise construction and open exposures remains largely under-addressed. By exploring and validating different VSC parameters through field-based thermal measurements and expert consultation using the Delphi method, this study aims to develop a practical framework. The goal is to inform climate-responsive design solutions that support sustainable, comfortable housing, specifically for the tropical urban context. This framework will serve as a guide for architects, landscape professionals, urban planners, and homeowners seeking to address thermal discomfort through informed vegetation strategies.

1.2 Problem Statement

Urban Heat Island (UHI) is an escalating environmental issue in cities globally, including those in tropical regions such as Malaysia. As urbanisation increases, natural vegetated areas are rapidly being replaced by impervious surfaces like concrete, asphalt, and rooftops. These materials absorb and retain heat, contributing to higher urban temperatures compared to nearby rural areas. In Malaysia, studies have shown that urban surface temperatures can be 6 to 8°C higher than in surrounding rural zones (Ramakreshnan et al., 2018). This intensifies urban thermal stress, impacts energy consumption, and reduces environmental comfort.

The UHI effect directly contributes to the deterioration of the thermal environment, which refers to the measurable climatic conditions such as air temperature, surface temperature, humidity, wind flow, and solar radiation that exist around and within buildings. It differs from thermal comfort, which is a subjective human perception of comfort within those conditions. When the thermal environment becomes more extreme, especially in residential areas, it can result in discomfort, higher cooling demand, and poor indoor livability. However, while UHI is widely studied at the city scale, its specific impacts on the thermal environment of low-rise residential housing have received limited attention.

Vegetation is a well-established strategy for improving the thermal environment through shading, evapotranspiration, and airflow enhancement. Researchers such as Kong et al. (2017) highlight its ability to alleviate UHI-induced heat stress. Aboelata and Sodoudi (2020) found that urban scenarios with 100 percent grass or 70% grass plus 30% trees can reduce surface temperatures by 6.4K and 9.2K respectively. Misni (2012) emphasised that a blend of tall trees and low ground covers is especially effective in Malaysia's humid climate. Other studies by Davis et al. (2016); Fan et al. (2015); Yu and Yu (2018) affirm that vegetation height, volume, density, and configuration all influence land surface temperatures and heat mitigation potential.

Despite these findings, existing urban greening strategies are often broad and non-specific, lacking guidance on which vegetation parameters such as height, density, foliage type, spacing, and orientation is most effective in residential settings. Furthermore, most research is conducted at macro or public-space scales and does not consider the microclimatic effects of vegetation in private residential lots, especially in Malaysia's tropical climate. Empirical studies that measure the actual thermal impact of vegetation in single-storey houses are especially lacking (Akram Rosheidat, 2014; Mohd Yunos and Md Saring, 2012).

This is significant because single-storey semi-detached houses represent a common and increasingly valuable housing type in Malaysia's suburbs. These houses are typically low-rise with three exposed facades, making them especially vulnerable to direct solar heat gain. According to the Valuation and Property Services Department, (Ministry of Finance, 2024), although semi-detached houses made up 7.7% of all residential transactions, they showed the highest price growth rate at 4.1% surpassing terraced, detached, and high-rise houses. This trend reflects rising market interest and long-term investment potential. Yet, despite their thermal vulnerability and popularity, targeted studies exploring how to improve thermal performance in this housing type remain absent.

This research seeks to address that gap by developing a Vegetation Structure and Configuration (VSC) framework specifically tailored to single-storey semi-detached houses in Malaysia's tropical climate. The study will analyse thirteen key vegetation parameters, which are categorised into two main groups; *vegetation structure*, encompassing leaf density, leaf dimensions, leaf colour, canopy size, vegetation shape, and vegetation height; and *vegetation configuration*, comprising orientation, distance to the building, vegetation type, layering, diversity, shading, and area. These parameters will be evaluated for their impact on indoor and outdoor air temperatures. The field measurements will focus on specific vegetation arrangements such as differing planting orientations (east vs. west), vegetation densities, and structured versus mixed layouts to determine which combinations offer the greatest thermal benefit in a real residential context.

Field measurements will be complemented by expert consultation using the Delphi method, with optimal VSC defined through expert judgement and consensus obtained across two Delphi rounds. By integrating empirical data and expert perspectives, this research offers an approach focused on performance and climate responsiveness in residential landscape design. The resulting VSC framework will fill a critical gap in sustainable housing strategies, helping architects, urban planners, and homeowners to optimise vegetation for better thermal environments and improved thermal comfort in tropical residential communities.

1.3 Research Questions

The literature study revealed that the Vegetation Structure and Configuration (VSC) approach has the potential to solve environmental issues while also lowering building thermal performance. As a result, the following research questions are formulated:

RQ1: What effects does vegetation in different landscape orientations have on the outdoor and indoor thermal environment of single-storey semi-detached houses?

RQ2: How do the different VSC parameters affect thermal environment of single-storey semi-detached houses?

RQ3: What is the optimal VSC framework for enhancing the thermal environment of single-storey semi-detached houses in the tropical climate of Malaysia?

1.4 Research Aim and Objectives

The aim of this research is to investigate the potential of Vegetation Structure and Configuration (VSC) around single-storey semi-detached houses to improve the thermal performance of buildings. To achieve the research, aim and answer the research question, several objectives were developed:

RO1 To determine the effects of vegetation in different landscape orientations on outdoor and indoor thermal environment of single-storey semi-detached houses.

RO2 To investigate how variations in Vegetation Structure and Configuration (VSC) parameters affect thermal environment in single-storey semi-detached houses.

RO3 To develop an optimal Vegetation Structure and Configuration (VSC) framework specifically for enhancing the thermal environment of single-storey semi-detached houses in the tropical climate of Malaysia.

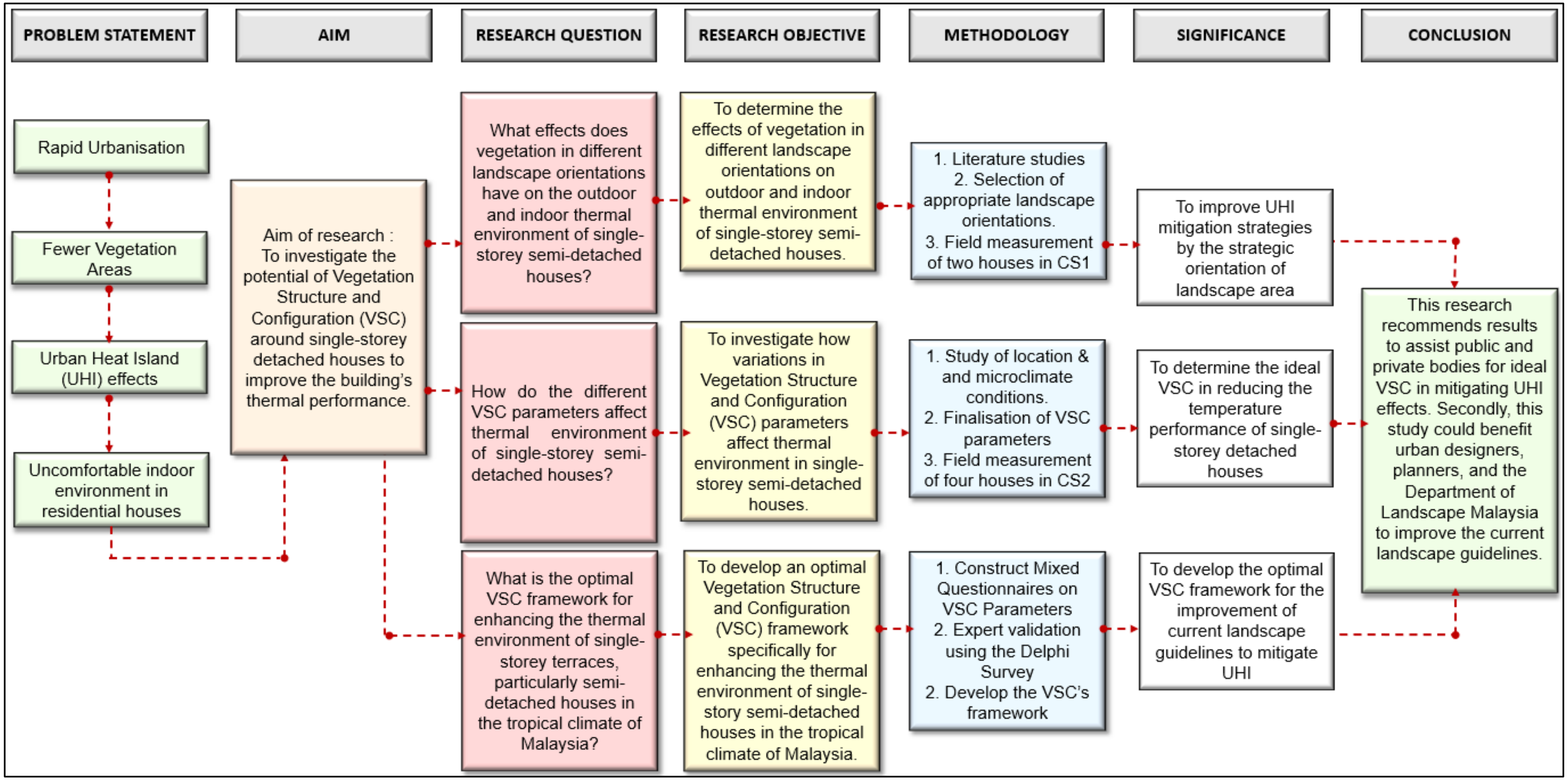

Figure 1.1 Research Framework

1.5 Research Scope

This study investigates the influence of Vegetation Structure and Configuration (VSC) on the thermal environment of single-storey semi-detached houses in Malaysia's tropical climate, with a focus on both indoor and outdoor microclimatic parameters. The scope is defined by the study's three objectives, each addressing a specific component of the VSC framework: landscape orientation, vegetation characteristics, and expert validation. The research was conducted in Bandar Seri Iskandar, located in the Perak Tengah District of Perak, a region selected primarily due to its significant exposure to rising temperatures and rapid urbanization. According to Muhamad (2018) in Astro Awani news, the Malaysian Meteorological Department reported peak temperatures of 37 to 38°C in Perak, Kedah, and Perlis. Furthermore, Think City Geospatial Analyst (2021) identified Ipoh, Perak as having the largest recorded temperature increase among five major Malaysian cities, a rise of 6.75°C over 21 years, attributed to urban development and ecological transformation. These climatic trends render the region ideal for evaluating vegetation's role in mitigating thermal stress in residential environments.

From an urban planning perspective, Bandar Seri Iskandar offers a suitable setting due to its standardized residential designs and landscape features representative of Malaysian suburban development. The focus on single-storey semi-detached houses is due to their architectural vulnerability where three exposed facades and low-rise forms create high solar exposure, and their practicality for implementing landscaping strategies, as they typically include moderate garden spaces suitable for vegetation planting. According to statistics from the Perak Tengah District local authority, four regions in Seri Iskandar were recognized as containing semi-detached housing types:

Puncak Iskandar, Taman Gemilang, Taman Iskandar Perdana, and Taman Iskandar Bestari. The study focused on Taman Iskandar Bestari and Taman Iskandar Perdana, established between 2006 and 2009, due to the maturity of their vegetation and the appropriateness of their landscape elements, despite Puncak Iskandar and Taman Gemilang being newer townships. These neighbourhoods provided stable and well-established vegetation environments essential for meaningful field observations.

The scope for Research Objective 1 assessed how solar exposure in different orientations interacts with surrounding vegetation to affect thermal conditions. This was addressed through Case Study 1 (CS1), which involved two single-storey semi-detached houses situated on intermediate lots in Taman Iskandar Perdana. Although architecturally identical, the houses differed in the orientation of their landscaped areas; one facing east (Eastern Landscape Orientation, ELO), the other west (Western Landscape Orientation, WLO). Field measurements focused on key microclimatic parameters such as air temperature (ºC), relative humidity (%), and air velocity (m/s). These parameters are central to understanding thermal environments and energy performance and are directly aligned with the study's three research objectives. Each parameter was monitored using calibrated thermal microclimate sensors (Delta OHM HD32.1) and indoor air quality loggers (HD37AB1347) to record real-time microclimatic data, enabling the assessment of how vegetation orientation relative to solar exposure impacts thermal conditions.

Research Objective 2 explores how different VSC configurations influence the thermal environment. Case Study 2 (CS2) involved four semi-detached houses on corner lots in Taman Iskandar Bestari, each with broader landscaping areas and distinct vegetation patterns. These were labelled into four types based on on-site vegetation analysis, the Structured Landscape House (SLH), which featured dense, multi-layered, and consistently arranged vegetation; the Semi-Structured Landscape House (SSLH), with moderate vegetation density and semi-organized layout; the Mixed Landscape House (MLH), which included inconsistent vegetation arrangements and varied canopy sizes; and the Less to No Landscape House (LNLH), which had minimal or no vegetation.

The VSC field measurement analysis is based on 13 parameters, including (P_1)vegetation orientation / placement, (P_2)vegetation distance to wall, (P_3)vegetation type, (P_4)vegetation layer, (P_5)vegetation diversity, (P_6)vegetation shading, (P_7)vegetation area, (P_8)leaf density, (P_9)leaf dimensions, (P_{10})leaf colour, (P_{11})canopy size, (P_{12})vegetation shape and, (P_{13})vegetation height. Microclimatic parameters (air temperature, relative humidity, and air velocity) were again monitored over at least seven consecutive days for each house. This scope enabled empirical comparison across different vegetation configurations in real residential settings.

For Research Objective 3, the study employed the Delphi method to validate the empirical findings and develop a practical VSC framework. A panel of sixteen experts from landscape architecture, urban planning, environmental sciences, and arboriculture participated in a structured two-round consultation. The scope of this phase focused on achieving consensus on the significant and ranking of 13 pre-identified VSC parameters, translating them into a practical VSC framework for thermally efficient residential design. Round 1 gathered open-ended input and preliminary rankings, while Round 2 used structured questionnaires to reach consensus on the significance of each VSC parameter. The panel was selected based on professional qualifications, research experience, and familiarity with tropical vegetation design. Together, these scopes integrate empirical fieldwork with expert validation, forming a multi-layered approach to understanding and optimizing vegetation's role in residential thermal regulation in tropical climates.

The difference in the number of houses between CS1 and CS2 was shaped by both practical and methodological considerations. In CS1, only four rows of semi-detached houses exist in Taman Iskandar Perdana, and many houses had undergone significant modifications, such as structural extensions or conversion of landscaping areas into fully cemented spaces, which disqualified them from the study. Only two houses met the vegetation and orientation criteria, one oriented east and the other west. This pairing was sufficient for Research Objective 1, which focused on directional landscape influence rather than vegetation variation. In contrast, CS2 in Taman Iskandar Bestari required houses with distinguishable VSC profiles to address Research Objective 2. While suitable corner-lot houses were also limited, the final four were obtained through a snowball sampling technique, whereby homeowner referrals facilitated access to additional participants. Though the numerical difference may appear uneven, both case studies were methodologically adequate to meet their respective objectives, offering valid empirical insights under real-world constraints.

1.6 Research Limitations

The fieldwork was done in the middle of the wet season August-December 2018. According to Misni (2012), this period is appropriate to ensure the surrounding vegetations are at the maximum impact of green and lush landscapes. During the dry season, because of rare rainfall and slightly higher air temperatures, the surrounding vegetation is less fertile. Due to equipment constrains, on-site data collection was conducted in three sessions in August 2018 for CS1 and in October and November 2018 for CS2. The field measurements were taken sequentially for each house over a period of three days for CS1 and over a period of seven days for each house in CS2. However, this did not have a major impact on the results as the studies were carried out in consistently similar weather patterns. There were some issues and limitations in conducting this study, which are listed below:

i) Permission, time and accessibility to the premises were required to conduct the field research implementation on a residential house.

ii) Continuous supervision is needed to keep on-site instruments safe during measurements. Exposure to variable weather might impact data collecting and the possibility of technical problems such as low batteries.

iii) There were minor data inconsistencies during field measurements due to a battery problem. The thermal microclimate data logger required a full lithium battery (Type C) to record data from time to time.

iv) Restricted availability of sensors, such as the solar radiation probe, which in turn led to the study relying on nearby weather station data.

v) Lack of equipment and personnel to collect data for each residence simultaneously. Therefore, the equipment had to be used in rotation for one week for each house.

vi) Data was collected for 7 days for each residence. Due to technical issues with certain house instruments, only 5 days of data were analysed to standardise the data for each house.

1.7 Research Approach and Methodology

This research requires three phases, as depicted in Figure 1.2, to accomplish its aim and objectives. The research phase is described in detail below:

1) The ***First Phase*** of the research begins with **Desktop Study** of relevant topic to determine the issues, research objectives, scope, methodology, research hypothesis, as well as the research gaps. Journal articles, theses, books, and other published sources are used to obtain information for the empirical study conducted. The house selection criteria and measurement parameters for field research were determined based on the information gathered. Two appropriate case study areas for field research were chosen, namely case study 1 (CS1) and case study 2 (CS2). In addition, the meteorological and VSC parameters necessary for field measurement study are also determined.

2) The ***Second Phase*** of the research involves **Field Measurement Study** on a particular case study to attain the research aim and objectives *(Objective 1 and 2)*. Meteorological data gathered by field instruments, observation, and measurements of VSC parameters are the most crucial data obtained during this phase. In addition, two units of thermal microclimate monitoring instruments with data loggers (Delta OHM; HD32.1) and one unit of indoor air quality monitoring instruments (HD37AB1347) were installed around and within the houses, respectively *(refer subsection 3.4.3 for detail)*. To ensure the accuracy and comparability of the data, similar instrument placements were assigned to each house. Due to instrument limitations, data collection for each case study was undertaken consecutively after each cycle was completed, beginning with three

days for each house in CS1 and continuing with seven days for each house in CS2. To assure the safety of the data, all details and data acquired in the instrument's software were promptly downloaded to the researcher's desktop and tabled prior to analysis once the field research was completed. This process is repeated for each house. Detailed measurements of the structure and configuration of the vegetation surrounding for each house in both case studies are also documented and plotted in the landscape layout plan.

3) The ***Third Phase*** of this research involves **Delphi Study** method, meticulous data collection from experts to develop the Vegetation Structure and Configuration (VSC) framework *(Objective 3).* This structured communication technique, originally developed as a systematic forecasting method, relies on a panel of experts to reach consensus on complex issues. The process begins with expert selection based on pre-established criteria, ensuring the panel's qualifications, experience, and knowledge. The experts are then contacted to invite their participation, with a proposed number of 10 to 15 experts. The survey is conducted in two rounds, with the first round involving open-ended questions to gather a comprehensive list of factors relevant to vegetation structure and configuration. The second round involves experts rating the importance of identified factors, promoting a more informed judgment process. The Delphi method's effectiveness in consolidating expert knowledge and achieving consensus in complex research areas is demonstrated by its iterative rounds and structured communication.

Following the three phases of the research methodology, a crucial step involves the analysis of the data. During this process, the researcher verifies that the research objectives have been reached before making conclusions and proposing recommendations for future research in the final chapter of the thesis. The field measurement data obtained from both case study houses were analysed as daily readings and subsequently averaged for each house. Correlation analysis was conducted to provide a more accurate evaluation of the associations between the identified parameters. The data was subsequently shown in tables and graphs. The summary of the research methodology phase is illustrated in Figure 1.2.

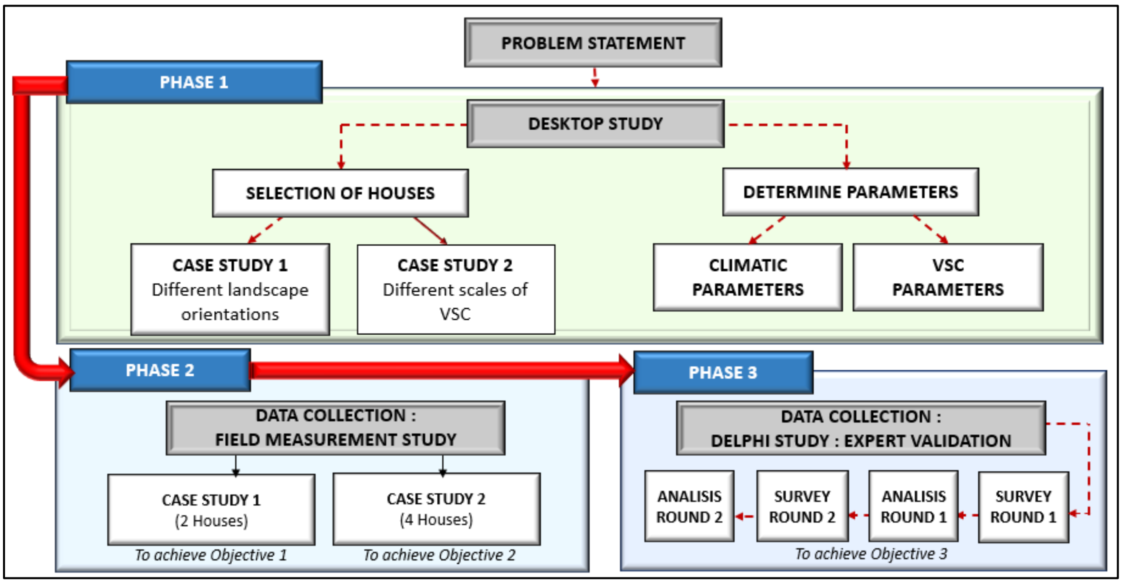

Figure 1.2: Summary of Research Methodology

1.8 Significance of Research

In recent decades, researchers have been increasingly interested in the ability of vegetation to minimize global thermal performance in microclimates. Although some studies have been conducted in tropical climates, relatively limited research, especially in residential areas, has been done in the Malaysian context. This research will be the first study to develop a Vegetation Structure and Configuration (VSC) framework in the tropical climate of Malaysia, with a focus on single-storey Semi-Detached houses.

The findings of this research would become a novelty for the body of knowledge in which it offers a greater understanding of the VSC to public and private bodies for adequate vegetation selection around their outdoor landscape. Secondly, this study could benefit urban designers, planners, and the Department of Landscape Malaysia to improve the current landscape guideline to generate more comfortable urban thermal performance in Malaysia and other similar climate contexts. Finally, the results of the research can be applied to enhance existing passive cooling techniques as well as to add value to the existing knowledge body in related fields.

1.9 Outline of Thesis Structure

This research is organized into 7 chapters, which are summarised below. Figure 1.3 illustrates the overall thesis structure.

The overall study is mentioned in ***Chapter One.*** This chapter begins with the research background accompanied by a discussion of the problem statement, research questions, research objectives, scope and limitations, research approach and methodology, significance of the research, and the outline of the entire thesis structure is also illustrated.

Chapter Two presents a literature review of previous studies carried out on the thermal performance of surrounding vegetation, starting with the interpretation of the thesis title. Preliminary studies on the Malaysian climate and types of residential buildings are also presented in this chapter. Climate parameters, their relationship with thermal performance, and the heat transfer principle are also discussed. The next discussion will focus on the impacts of vegetation on microclimate change, beginning with the fundamental definition, VSC recognition, and so on. This chapter also explains the problems identified in the problem statement in more detail. A summary of the research gap is also discussed at the end of this chapter.

Chapter Three justifies the research methods and approaches used in this thesis. In this chapter, a site description, and the reasons for selecting the case study houses are critically explained. The research instruments used, and their approach are then discussed. Information about the different analytical approaches to data analysis and data collection during field research is also explained.

Chapter Four presents the overall results and discussion of Case Study 1 (CS1) to address the **First Objective**. Two single-storey semi-detached houses of the same age were examined in the tropical area of Bandar Seri Iskandar, Perak. These buildings were of similar design and construction but differed relatively in the orientation of the landscaping areas and in the vegetation structure and configuration.

Chapter Five examines the effect of different Vegetation Structure and Configuration (VSC) capacities in Case Study 2(CS2) to attain the **Second Objective.** The overall outcome and discussion of four houses that represent typical modern buildings and landscape design for medium-sized single-storey semi-detached houses in Malaysia were reviewed. The size of the landscape areas is larger in CS2 compared to CS1. However, the surrounding vegetation varied substantially, ranging from no landscape to sparse to heavily landscaped vegetation. These case study buildings were chosen to examine the impact of different VSC capacities on the outdoor and indoor air temperatures, relative humidity and air velocity of houses.

Chapter Six presents the findings of the expert validation process for the predetermined Vegetation Structure and Configuration (VSC) framework, aiming to achieve the **Third objective.** To construct this framework, a group of selected experts from various disciplines such as landscape architecture, arboriculture and environmental science were identified. These experts were tasked with answering mixed questionnaires developed in the 2-round of the Delphi study to evaluate and refine the significance vegetation parameters to develop the VSC framework.

Chapter Seven summarises and discusses the overall research findings. This chapter also provides the conclusion, recommendations, research contributions, and suggestions for future research. In addition, this closing chapter also reviews the research's hypotheses, questions and research objectives to ensure that they fulfil the research aim.

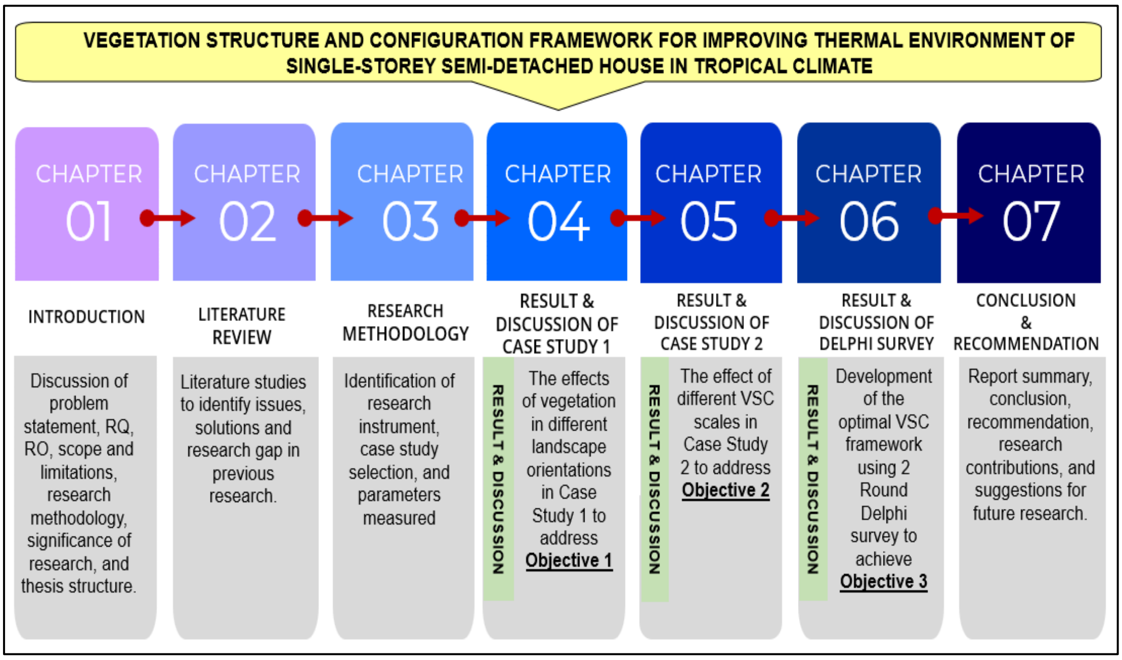

Figure 1.3: The overall thesis structure

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In urban environments, particularly in tropical regions, vegetation plays an essential role in regulating the thermal environment. Intensive urban vegetation planting is a highly prevalent practice (Ding et al., 2023; Yu and Yu, 2018; Wang et al., 2016). The presence of vegetation in cities serves as a natural cooling mechanism. Greater vegetative cover has a more pronounced cooling impact in urban areas (Dion, 2024; Fu et al., 2022; Kamarulzaman and Ismail, 2024). In the context of the residential environment, the optimizing of the Vegetation Structure and Configuration (VSC) is crucial for houses with peripheral green areas, such as single-storey semi-detached houses, one of the good alternatives to balance the heat of their surroundings. As discussed by Yuan and Ng (2012), well designed and arranged vegetation can serve as a natural barrier against high temperatures, decrease direct solar radiation, and improve passive cooling methods, therefore enhancing the thermal comfort of both indoor and outdoor environments.

Furthermore, Yu et al., (2023) have established that controlling the landscape configuration is a widely acknowledged approach to mitigate the UHI issues. Several mitigation strategies have examined the influence of landscape configuration patterns, ratios of evergreen to deciduous tree arrangements, and vegetation structure in jointly managing thermal settings. Xiao and Yuizono (2022) examine the adaptability of landscape design in Hokuriku, Japan, revealing that the tree configuration ratio serves as a vital greening metric that influences thermal comfort both diurnally and nocturnally.

Implementing urban greening measures, especially in residential areas, is the simplest and most cost-effective approach to decrease the air temperature in the surrounding. Effective landscape design can minimize the quantity of sunlight that accesses a building, therefore ensuring optimal temperatures for both indoor and outdoor environments (Kamarulzaman et al., 2016).

2.2 Definition of Vegetation Structure and Configuration (VSC) and Thermal Environment

According to the Oxford Advanced Learner's Dictionary (2024), vegetation is defined as the collective plant life in a particular area or environment. Kamarulzaman et al. (2023) further emphasized that vegetation encompasses all forms of plant life such as trees, shrubs, grasses, and lawns, which are naturally present or intentionally introduced within a landscape. Misni (2012) highlighted that vegetation exists as plant communities, rather than in isolation, with species interacting within the same area to create distinct ecological effects. In the context of this study, Vegetation Structure and Configuration (VSC) refers to the systematic arrangement, density, and physical characteristics of plant life within a given space, particularly around buildings. It comprises two key components: Vegetation Structure (VS), which includes vertical characteristics such as canopy size, height, and leaf density, and Vegetation Configuration (VC), which describes the spatial layout, distribution, orientation, and density of the vegetation relative to the built environment.

The Vegetation Structure (VS) pertains to the stratification of plant height and foliage that determines the capacity for shading and cooling (Misni, 2012). Trees with wide canopies and dense foliage, for instance, are effective in blocking solar radiation and reducing surface temperatures, thereby minimizing heat transfer to buildings (Shashua-Bar et al., 2011; Tan et al., 2013). Vegetation Configuration (VC), on the other hand, addresses how vegetation is arranged in space around structures, including aspects such as directional placement and spatial spacing. Strategically oriented vegetation, especially on the east and west facades can significantly mitigate morning and afternoon heat gain, improving the thermal conditions within buildings (Akbari et al., 2001; Lin Yola, 2018).

Importantly, the relevance of VSC becomes increasingly critical when considering the rising global temperatures and the intensifying Urban Heat Island (UHI) phenomenon. Fu et al. (2022) forecast that the global mean temperature could increase by up to 5.5°C by the end of the 21st century, a trajectory that severely threatens thermal stability in urban environments. In line with this, Lin Yola (2018) warned that continued climate change will lead not only to energy crises but also to catastrophic environmental consequences. Rising temperatures are already contributing to more frequent and intense extreme weather events, including heatwaves, droughts, and severe tropical storms (Aleksandrowicz et al., 2017; (Mazdiyasni et al., 2017). The UHI effect amplifies these risks by trapping heat in urban areas due to the prevalence of heat-retaining materials and the reduction of vegetation (Rizvi et al., 2019). (Gómez-Navarro et al., 2021) define UHI as the occurrence of higher air temperatures in urban areas compared to their rural surroundings, caused by impervious surfaces replacing natural landscapes. This reduction in vegetated cover limits latent heat fluxes and reduces evaporative cooling, worsening local air temperature and thermal discomfort.

Therefore, incorporating VSC is a critical passive cooling strategy in urban design. Vegetation reduces surface and air temperatures through shading, evapotranspiration, and reflection of solar radiation. These processes contribute to cooler microclimates and help counteract UHI intensification, thereby improving human thermal comfort in densely developed environments (Yong, 2016; Abdi et al., 2020). Additionally, vegetation can modify wind flows and enhance natural ventilation, further reducing the need for mechanical cooling systems in tropical climates (Hami et al., 2019). In this context, the thermal environment refers to the collective climatic conditions—air temperature, humidity, solar radiation, and airflow—that influence human comfort around and within buildings (Ashtiani et al., 2014). In tropical regions, where high temperatures and humidity are constant challenges, managing this thermal environment through VSC is essential not only for indoor comfort but also for promoting sustainable, climate-adaptive urban living.

It is important to note that the term "Vegetation Structure and Configuration (VSC)" as used in this study is originated by the author. While many previous studies have examined either vegetation structure or configuration independently, there has been limited integration of the two as a unified concept. This research introduces the combined terminology of VSC to holistically capture the physical characteristics and spatial arrangement of vegetation in a single framework. The integration is intentional and strategic, allowing for a more comprehensive analysis aligned with the study's objectives, which aim to assess how both structural and configurational elements of vegetation influence thermal environments. The novel use of this combined term