UNIVERSITI PUTRA MALAYSIA

ASSESSMENT OF VEGETATION COOLING EFFECT THROUGH THE APPLICATION OF GREEN ROOFS IN TROPICAL CAMPUS ENVIRONMENT

ROOZBEH ARABI

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By

ROOZBEH ARABI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

February 2018

DEDICATION

I dedicate my thesis to my family and many friends. A special feeling of gratitude to my loving family who has never left my side. I also dedicate this thesis to my many friends who have supported me throughout the process. I will always appreciate all they have done

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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February 2018

Chairman : Mohd Fairuz Shahidan, PhD
Faculty : Design and Architecture

The high temperature is deteriorated mostly due to deficiency of green spaces particularly in tropical urban environment as a result of urbanization and population increase. Tropical University campuses and other educational contexts are not an exception. As a significant part of built-up areas, roofs include a noticeable percentage of the urban area and participate extremely to the higher air temperatures in a city. Rooftop greening is an effective way to reduce the air temperature especially in sprawling modern society and consequently ameliorate the UHI effect. But the thermal performance of tropical plants in green roofs is unknown. Consequently, this study investigated the thermal performance of tropical plants as the vegetative layer in green roofs at Universiti Putra Malaysia campus in terms of plant canopy density and coverage area percentage. The hot and cool spots in the study area were determined through satellite imagery, field measurement and simulation model. Out of seventy six successful tested plant species, nine plants were chosen through the field observation. Consequently, their Leaf area indices (LAI) were measured and compared using a canopy analyser 2000. *Pandanus pygmaeus* with LAI=7.545 was selected as a representative plant for extensive green roofs. *Mesua ferrea* tree was chosen as a representative plant for intensive green roofs with almost the same LAI value. Then, seven scenarios were designed for prediction of mean air temperature during the different daytimes in the study area using ENVI-met simulation model. In the basic scenario, existing conditions without using green roofs were analysed. Then, *Pandanus pygmaeus* was used with a coverage area of one-third, two-third and 100 % on the roofs. The same procedure was repeated for *Mesua ferrea* tree. After comparing the simulation data of different scenarios, finally, the research proved that: A: the rates of cooling effects vary at different altitudes inside the urban canopy layer. B: Extensive green roofs have the optimum cooling effect on the air layer where they are located. However, the vegetative layer of both intensive and extensive green roofs cools all the air layers located between the plant canopy and the ground surface. C: the pace of air temperature reduction from one-third coverage to two-third coverage is higher than two-third coverage to 100% coverage. D: green roofs have a negligible cooling effect in the early morning. E: the intensive green roofs had a greater cooling effect than the extensive ones. Intensive green roofs with 100% coverage area can reduce the mean air temperature up to 1.21 °C during the peak hours at the pedestrian level. However, the extensive ones mitigate the air temperature at this altitude about 0.89 °C. Also, the maximum temperature reduction occurs during peak hours when the air relative humidity reaches to its minimum level about 47 percent. It is hoped that, the outputs of this research can be implemented as an auxiliary guideline in choosing the types of vegetative layer and their coverage area in green roofs.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN KESAN PENYEJUKAN MENGGUNAKAN TANAMAN BUMBUNG HIJAU DI DALAM PERSEKITARAN DI KAMPUS TROPIKA

Oleh

ROOZBEH ARABI

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Pengerusi : Mohd Fairuz Shahidan, PhD
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Suhu yang semakin meningkat tinggi disebabkan kekurangan kawasan hijau di dalam persekitaran bandar tropika. Selain itu, kawasan hijau di persekitaran bandar tropika semakin berkurangan disebabkan oleh pertambahan penduduk dan kepesatan pembangunan bandar. Keadaan ini tidak terkecuali bagi kawasan persekitaran tropika di kampus-kampus Universiti dan kawasan yang berkaitan dengan pendidikan. Kepentingan keadaan ini mempunyai kaitan rapat dengan kawasan binaan seperti bumbung bangunan yang mempunyai peratusan yang tinggi menyebabkan suhu udara lebih tinggi di kawasan bandar. Penghijauan di atas bumbung bangunan adalah satu cara yang berkesan untuk menyeimbangkan bahang udara terutamanya dalam memperbaiki kehidupan masyarakat moden dan seterusnya menyeimbangkan kesan kepulauan haba bandar. Walau bagaimanapun, prestasi terma tumbuhan tropika di bumbung hijau masih belum mendapat perhatian . Oleh itu, kajian ini mengkaji prestasi terma tumbuhan tropika sebagai lapisan tumbuhan bagi bumbung hijau di kampus Universiti Putra Malaysia berdasarkan kepadatan tumbuhan kanopi (canopy density) dan peratusan kawasan litupan. Penentuan titik panas dan sejuk bagi kajian ini ditentukan melalui imej satelit, pengukuran lapangan dan model simulasi. Daripada tujuh puluh enam spesies tumbuhan yang berjaya diuji, sembilan tumbuhan dipilih melalui pemerhatian lapangan. Oleh itu, indeks kelebaran daun tumbuhan (*LAI*) diukur dan dibandingkan menggunakan penganalisis kanopi 2000 (*canopy analyser 2000*). *Pandanus pygmaeus* dengan LAI = 7.5 dipilih sebagai mewakili tumbuhan untuk bumbung hijau yang luas. Pokok *Mesua ferrea* pula dipilih bagi mewakili tumbuhan untuk bumbung hijau intensif dengan nilai *LAI* yang hampir sama. Kemudian, tujuh senario telah direka untuk menentukan min suhu udara pada waktu siang yang berbeza di kawasan kajian model simulasi *ENVI-met*. Dalam senario asas, keadaan yang sedia ada tanpa menggunakan bumbung hijau dianalisis. Setelah itu, *Pandanus pygmaeus* ditanam dengan keluasan meliputi 33, 66 dan seratus peratus pada bumbung. Prosedur yang sama diulangi untuk pokok

Mesua ferrea. Setelah membandingkan data simulasi, akhirnya, penyelidikan membuktikan bahawa: A: kadar kesan penyejukan berbeza-beza pada tahap ketinggian yang berlainan dalam lapisan kanopi bandar (*urban canopy layer*). B: Bumbung hijau yang luas mempunyai kesan penyejukan yang optimum pada lapisan udara di semua tempat yang telah ditetapkan. Walau bagaimanapun, lapisan tumbuhan kedua-dua bumbung hijau intensif dan ekstensif dapat menyejukkan kesemua lapisan udara yang terletak di antara tanaman kanopi dan permukaan tanah. C: kadar pengurangan bahang suhu udara dari liputan 33% hingga 66% adalah lebih tinggi daripada liputan 66% hingga 100%. D: bumbung hijau tidak mempunyai kesan penyejukan yang ketara di awal pagi. E: bumbung hijau intensif mempunyai kesan penyejukan yang lebih besar berbanding bumbung hijau ekstensif. Bumbung hijau intensif dengan kawasan liputan 100% boleh mengurangkan bahang suhu udara minimum sehingga 1.21°C pada waktu puncak di kawasan aras pejalan kaki. Walau bagaimanapun, bumbung hijau ekstensif mengurangkan bahang suhu udara pada aras ini kira-kira 0.89°C. Tambahan daripada itu, suhu udara menurun secara maksimum di mana ianya berlaku pada waktu puncak apabila kelembapan relatif udara mencapai tahap minimum. Secara keseluruhan, dapatan hasil penyelidikan ini dapat digunakan sebagai garis panduan tambahan dalam memilih jenis spesies tumbuhan dan liputan kawasan bumbung hijau bagi membantu menangani masalah kesan kepulauan haba di kawasan tropika.

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I certify that a Thesis Examination Committee has met on 19 February 2018 to conduct the final examination of Roozbeh Arabi on his thesis entitled "Assessment of Vegetation Cooling Effect Through Application of Green Roofs in Tropical Campus Environment" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
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- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
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Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

AOI	Area of Interest
CAM	CRASSULACEAN acid metabolism
CBD	Central Business District
CFD	Computational Fluid Dynamics
CSO	Combined Sewage Overflow
CV	Coefficient of Variation
DANCED	Danish International Assistant
DBT	Dry Bulb Temperature
DN	Digital Number
EPA	Environmental Protection Agency
EST	Effective Sky Temperature
ET	Evapotranspiration
ETM	Enhanced Thematic Mapper
Et_o	Reference Evapotranspiration
KBTU	Kilo British Thermal Units
K_C	Crop Coefficient
LAD	Leaf Area Density
LAI	Leaf Area Index
LSE	Land Surface Emissivity
LST	Land Surface Temperature
LULC	Land Use Land Cover
L_λ	Spectral Radiance
MACRES	Agensi Remote Sensing Malaysia
Mf	*Mesua ferrea*
MJ	Mega Joules
MMD	Malaysian Meteorological Department:

MPS	Meters per Second
MRT	Mean Radiant Temperature
NDVI	Normalized Difference Vegetation Index
NFU	National Formosa University
NIR	near-infrared
NLR	Normal Lapse Rate
OAQ	Outdoor Air Quality
OSS	Open Source Software
PET	psychologically equivalent temperature
Pp	Pandaus pygmeus
R & R	Repeatability and Reliability
RSD	Relative Standard Deviation
SRI	Solar Reflectance Index
T_B	Brightness Temperature
TIR	Thermal Infra-Red
TM	Thematic Mapper
TRY	Test Reference Year
UCL	Urban Canopy Layer
UHI	Urban Heat Island
ULST	Urban Land Surface Temperature
UTM	University Teknologi Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Fifteen percent of the global inhabitants lived in cities in the end of the nineteenth century. Nowadays, around 50% of the people in the world live in urban districts that is more than 2% of the whole earth's land (Mirzaei et al., 2010). The growth in urban population has caused urban sprawl, particularly in developing countries. High concentration of buildings truly initiates many environmental problems: disturbs the thermal comfort conditions, amplifies the mortality and morbidity of the population, intensifies the air pollution problems and is usually correlated with the increase in urban temperatures which is named Urban Heat Island (UHI) (Kardinal Jusuf, Wong, Hagen, Anggoro, & Hong, 2007). According to statistics, electricity consumption from air conditioning increases 6% for every 1°C of outdoor temperature rise in UHI phenomenon, which is a significant amount of consumption and amplifies the energy demand of urban areas (Liu et al., 2012; Santamouris, 2014). The climate of a city influences the ways in which, its outdoor spaces are used. Especially public spaces intended for use by pedestrians and cyclists, such as parks, squares, residential and shopping streets, and foot- and cycle-paths will be used and enjoyed more frequently when they have a comfortable and healthy climate. Because of an anticipated increase in the global temperature and intensified UHI phenomenon, the climate is expected to be more inconvenient in the tropic regions (Kleerekoper et al., 2012; Tso, 1996)

To offset the UHI effect, important mitigation strategies in the architecture field have been proposed and developed; the most significant ones are high albedo materials and greenery systems. But, the key factor in controlling the surface temperature is the greenery system, even more than low-albedo or non-reflective surfaces (Goward et al., 1985; Lin et al., 2008; Liu et al., 2012; Nichol, 1996b; Salata et al., 2015; Weng et al., 2004; Wong et al., 2005).

The high temperature in the UHI effect is deteriorated mostly because of the deficiency of green regions in the urban environment (Susca et al., 2011; Wong, Chen, et al., 2003)

Temperature of dry, dark surfaces in none-vegetated areas can get to 88°C during the day, while the temperature of vegetated surfaces with humid soil under the same conditions may reach just 18°C (Gartland, 2011). In spite of this fact, the green spaces in the urban context are slowly diminishing as a result of urbanization and population increase (Saito et al., 1991).

The temperature will be decreased in addition to saving the energy on account of the green constructions by which the microclimate would be controlled as well. Furthermore, the green constructions are capable of enhancing the visual scenery, creating an ecological environment for better biodiversity. They also abate the rainwater runoff, the air pollution, and the noise. What is more, the buildings will be protected and the pressure associated with the urban life could be minimized by the green constructions while providing the horticultural therapy (Getter et al., 2006). The greenery system can be employed in the ground level areas or on the buildings' rooftops or in the vertical surfaces. Buildings receive twice as much solar radiation from rooftops than from vertical surfaces. However, the role of roofs in creating the UHI effect and increasing the outdoor air temperature is very critical. Many researches have proven that roof surfaces are a main factor in the thermal balance of a city (Akbari et al., 2003; Arnfield, 1982; Bansal et al., 1992; Kłysik et al., 1999; Susca et al., 2011). Roofs include a noticeable percentage of the urban area and participate extremely in the higher air temperatures in a city. They include almost 20 to 25% of the urban surface (Akbari et al., 2003; Susca et al., 2011) and the conventional roof materials tend to heat up in the sun to temperatures of 50–90°C. By heating roof materials, some problems are created for the buildings below them and surrounding landscape such as: deteriorating the UHI effect, uprising indoor temperature, increasing energy demand for cooling, reduced indoor thermal comfort, more expenditure on utility bills, rapid corrosion of the roof materials, more deterioration on the cooling systems, increasing the rate of emissions in the power plants and sending more roof materials waste sent to landfill (Gartland, 2011). Thus, rooftop greening is an effective way to reduce temperatures (Hui, 2009; Santamouris, 2012). This subject has been extensively reviewed. The greenery systems mitigate the UHI side effects especially the outdoor air temperature through two processes ((Akbari & Rose, 2001, 18; Emmanuel, 2005a, 1600; Huang et al., 1990; Rosenfeld et al., 1995, 256; Santamouris, Papanikolaou, et al., 2001, 214; Shahidan, 2011, 168; Shashua-Bar et al., 2000, 227; Solecki et al., 2005, 39). Firstly, the plants shade the buildings and protect them against the sun radiation. As a result the building below them will be cooler (Shahidan et al., 2012). Secondly, Plants absorb water through their roots and release it into the air in the form of vapour through their leaves. Consequently, the air temperature would be lower within and downwind of the well-vegetated regions because of this process named evapotranspiration. This outdoor cooling effect is equivalent to five typical air conditioners (Che-Ani et al., 2009; Santamouris & Asimakopoulos, 2001a).

The reports in the experimental measurements show that the UHI mitigation produced by different coverings differs extensively as a result of vegetation and weather differences and simulation models have not yet been employed enough to simulate the cooling effects accurately (Takakura et al., 2000). While policy efforts exist and the desires of investors lead towards greening, more research efforts are essential. Legislators, policy makers at all the urban scales and investors require decision support tools which are able to evaluate the effect of greening in the urban context to make precise and determined decisions regarding the environmental issues (Srivanit et al., 2013). Therefore, this research focuses on the existing simulator instrument to assess the effectiveness of alternative mitigation strategies in terms of green roofs on local climate alteration in the study location.

1.2 Problem Statement

There is a quotation from Wendell Berry in a paper published by (Eagan et al., 1992) which describes the current situation of colleges and adds more importance to the issue. "Find a college, if you can, that does not damage the world or its future. Where would they have gone? How many institutions have attempted to minimize the damage that they do to the world that their graduates will inherit? The answers are clearly not many. "In the previous section, the potential of the green roofs in decreasing the outdoor air temperature was recognized in the urban context. Therefore, in this section, the topic of colleges is specifically addressed.

Universities and colleges are microcosms of the society's systems to feed and house the people, administer programs and conduct research; therefore their operations have many of the same opportunities and consequences for the environment as offices, restaurants, homes and hotels. Universities partially as a function of their sizes do indeed cause significant environmental effects (Creighton, 1998). Therefore, university and educational campus complexes can be regarded as a ''city'' on a smaller scale as a result of their population size, large coverage, and different complex activities, which may impose serious effects on the environment (Srivanit et al., 2013; Sun et al., 2012; Wong, Jusuf, et al., 2007) . In spite of some interests in the environmental programs, there is a lack of environmental attempts in main related areas too (Creighton, 1998). Educational institutions have had a lot of conflicts in terms of environmental sustainability in recent years. Many university campuses may have a general support for sustainability of the environment. However, it is challenging for the educational managers and leaders to apply comprehensive green policies on the campuses efficiently. Therefore, sustainability of campus has become a serious concern for university planners and policy makers as they have realized the effects of university operations and activities on the environment (Alshuwaikhat et al., 2008; Geng et al., 2012; Koester et al., 2006). Beside the environmental sustainability, another critical challenge which modern societies are facing is the need to achieve energy sustainability, decrease the air pollution and mitigate the UHI effect. Buildings roughly cause 40% of the total energy consumption globally (Laustsen, 2008). Implementation of energy- efficient approaches in the educational campuses can improve the energy conservation significantly (Aman et al., 2011). If universities and colleges promote their environmental efficiency effectively the overall effect could be enormous (Rappaport, 2008).

Green educational campuses have sustainability strategies to improve the implementation of greening facilities and green buildings, such as green street grids (by planting all the existing footpath locations with vegetation), planting vegetation in unused locations and changing the paving blocks with planted surfaces. These greening strategies can promote the quality of outdoor and indoor environments ,improve the campus population's hygiene and ameliorate the UHI side effects (Srivanit et al., 2013). However, providing the accessible intact ground space in the campus environment is almost impossible and very expensive, it is quite difficult to implement large-scale UHI mitigation strategies on the ground surfaces. Concurrently, construction decreases the ratio of the spaces devoted to vegetation or other mitigation infra-structures as a result of the new buildings sprawl (Mathieu et al., 2007; Santamouris, 2012; Smith et al., 2011). Unfortunately, the high amount of impervious surfaces (Ferguson, 1998) and the high land prices make the creation of green areas in campuses very expensive if not impossible. There is a huge amount of unused roof area (about 40–50% of the impermeable surfaces on campuses (Dunnett et al., 2004; Mentens et al., 2006). Concurrently, the roofs create a perfect area to implement the UHI mitigation strategies regarding the relevant limited cost while these strategies are important for the micro-climate change. Although the potential energy contribution of green roofs is a relatively well-investigated area, the existing data on the possible UHI mitigation potential of green roofs on the campuses is relatively limited (Cameron et al., 2012) and researches that quantify the possible effects of different greenery schemes on the campus environment are lacking particularly for addressing some of the more important design parameters such as types (what?), and amounts (how much?) of greenery to be used (Sun et al., 2012). In this regard, more case studies are needed as little data exists concerning the quantification of various green roof strategies that affect the outdoor air temperature and UHI effect; particularly on the educational campuses where a few experimental studies have been performed in terms of field measurements and simulation strategies. Further research is necessary in order to efficiently guide the design and planning of urban green space, and specifically to investigate the importance of the abundance, distribution and type of greening (Bowler et al., 2010). Therefore, this study investigates the potential effect of green roofs in terms of different plant canopy densities and planting area on the outdoor air temperature on an educational campus in Malaysia.

1.3 Research Questions

The main research question is:
How does the plant density and total planting area of the green roofs as an Urban Heat Island (UHI) mitigation strategy mitigate the outdoor air temperature in the engineering faculty of Univeristi Putra Malaysia (UPM)as a tropical educational campus? Sub-research questions are:

1. Where are the hot and cool spots and how much is the overall area of the roofs in the engineering faculty of UPM?
2. Which plant species has the highest canopy density in the selected collection of the plants proper for the extensive green roofs as an UHI mitigation strategy?

3. How much does the outdoor air temperature in different levels differ after modification of the overall green roofs' planting area and the plant canopy density in green roofs in the engineering faculty of UPM?
4. Which one of the simulated scenarios has the optimum cooling effect and why?

1.4 Research Aim and Objectives

The goal of this research is to investigate the optimal cooling effect potential of green roofs as an UHI mitigation strategy influenced by the plant canopy density and planting area on outdoor air temperature in the engineering faculty of UPM as an educational campus in the tropics. To obtain this goal, the following objectives have been considered:

1. To identify the existing cool and hot spots and determine the overall roofs area in the engineering faculty of UPM.
2. To evaluate nine plant species adopted to tropical climate and suitable for extensive green roofs and determine the most dense one for the highest environmental impact in green roofs in the engineering faculty of UPM.
3. To investigate the changes occurring in different air layers after modification of the plant canopy density and greenery coverage area in the campus environment and compare them with the current condition.
4. To determine the optimum cooling effect of green roofs as an UHI mitigation strategy in the tropical campus environment in terms of plant type and coverage area and compare it with the current condition.

1.5 Research Methodology

1.5.1 Satellite images

Universiti Putra Malaysia (UPM)'s environment, especially the greenery system distribution and the building density was investigated through the satellite images. The satellite image of Serdang was zoomed into the campus level. The thermal satellite image and UPM's map were analysed to identify the ''cool'' and ''hot'' spots at the Faculty of Engineering in UPM.

1.5.2 Field measurement

The key instruments in this research were HOBO temperature and Relative Humidity data loggers (accuracy ± 5%, operating range -20 to +70 °C) and canopy analyser 2000. The HOBO data loggers were organized at an interval of every 10 minutes. Based on the study of satellite images and a mobile survey, the whole campus was divided into four groups regarding their different building and greenery distribution conditions. The first group was the dense and uninterrupted greenery system in the swamp part (south-eastern part of the Engineering faculty).The second group was the sparse greenery areas, the third group, the built-up areas without greenery while the fourth group was the central manmade lake.

The LAI-2000 calculated Leaf Area Index (LAI) and other canopy structure attributes from radiation measurements made with a "fish-eye" optical sensor (148° field of view).

1.5.3 Computer simulation

ENVI-Met is a three dimensional microclimatic model designed in order to simulate the air-plant-surface interactions. A base model was constructed based on the building information and electronic map provided by Faculty of Engineering in UPM. In addition to the current condition, six scenarios were designed; covering a. 33% b. 66 % c.100 % of conventional roofs with greenery system including the selected plant species with highest Leaf Area Index. Two types of plants were applied: A shrub as a representative for extensive green roofs and a tree as a representative for intensive green roofs. Subsequently, the fluctuations of outdoor air temperature in different scenarios from the current condition were calculated and analysed.

1.6 Significance of the Study

First and foremost, the micro-climate of an educational campus in Malaysia will be evaluated in this study. The outcome of this research will provide a helpful resource for using green roofs in this campus and even other campuses and open spaces of the educational institutions in the tropics. The results of this study can be used as a guide for architects and landscape designers to design cooler outdoor spaces particularly in development of campuses in tropical climates by using green roofs. Secondly, the cooling effects of different leaf area indices of vegetative surfaces were examined and compared in this research and was presented in detail. Consequently, the outcome of this part helps the architects and landscape designers to make better decisions when trying to propose a plant species for green roofs on campuses. Most of the studies in this area have examined the effect of one special leaf area index on outdoor air temperature and almost all of them presupposed the ground-level vegetation like grass. But in this study, the comparison has been made between two different leaf area indices of local plants in higher-level vegetation (green roofs).

Third, different quantities of existing roofs' area in a tropical campus environment were covered by green roofs in a simulation program; their effects on outdoor air temperature were examined in different levels. Therefore, the cooling effects of different areas will be available for landscape designers and architects in detail and they are able to monitor the effectiveness of the overall area and consequently propose an optimum overall area of green roofs based on employers' demands. Technically, there are a few studies which have compared the effect of different overall area of vegetation on outdoor air temperature and in the case of green roofs, it is very rare.

Finally, the microclimatic tool of ENVI-MET was used for evaluating the interaction between green roofs and the climate in UPM. By using this software, this research is able to consider all the parameters in the micro-climate but will focus on the outdoor air temperature. In other words, this program is not a one-dimensional program and consequently the results are not biased.

1.7 Scope and limitation of the study

This research will address the impact of extensive and intensive green roofs as an UHI mitigation strategy on mitigating the outdoor air temperature in the Faculty of Engineering of UPM. The analyses conducted in three parts and limitations are listed according to the individual investigations as follows:

1- In the field measurement, the quantity of data loggers was restricted. As the area of targeted location was more than 27 hectares, positioning the data loggers needed more accuracy in order to collect the data which was representative of different outdoor landscape environments. Thus, 10 significant location points with different outdoor landscape characteristics were observed and selected in order to represent the current condition of Engineering Faculty.

2- ENVI-met simulations were limited to six proposed scenarios because of the hardware and time constraints. Therefore, the researcher attempted to select the most appropriate scenarios in order to conduct this research.

3- Another limitation was the lack of equipment to measure wind speed, wind direction, temperature and humidity through installing a temporary weather station at Faculty of Engineering (lack of access to financial resources and lack of facilities at the university). Therefore, the researcher took the permission from the authorities to use the facilities in UPM's climatic station. Since the wind flow is a mesoscale climatic parameter, the station data was used in the case of wind flow due to the proximity of the climatic station to the Faculty of Engineering in UPM,

4- The other limitation was the lack of access to the standard solar shield so that the researcher was forced to make it and did a comparison study between the handmade solar shield and the standard one

5- The researcher accessed to the canopy analyser with an excessive delay and this led to prolongation of the research process.

6- For green roofs surveys in Kuala Lumpur, the researcher was unable to obtain the entry permission to the rooftops of the private buildings; therefore, the researcher had to conduct the survey on the buildings that were open to the public.

7- To validate the instruments which were used in the study, the researcher was forced to measure twice in the weather station. Consequently, the reinstallation process of the devices took nearly two months.

8- The lack of access to high- speed computers that led to longer time of simulation process; the simulations were conducted by two laptops non-stop and the process took more than two months.

1.8 Research Framework

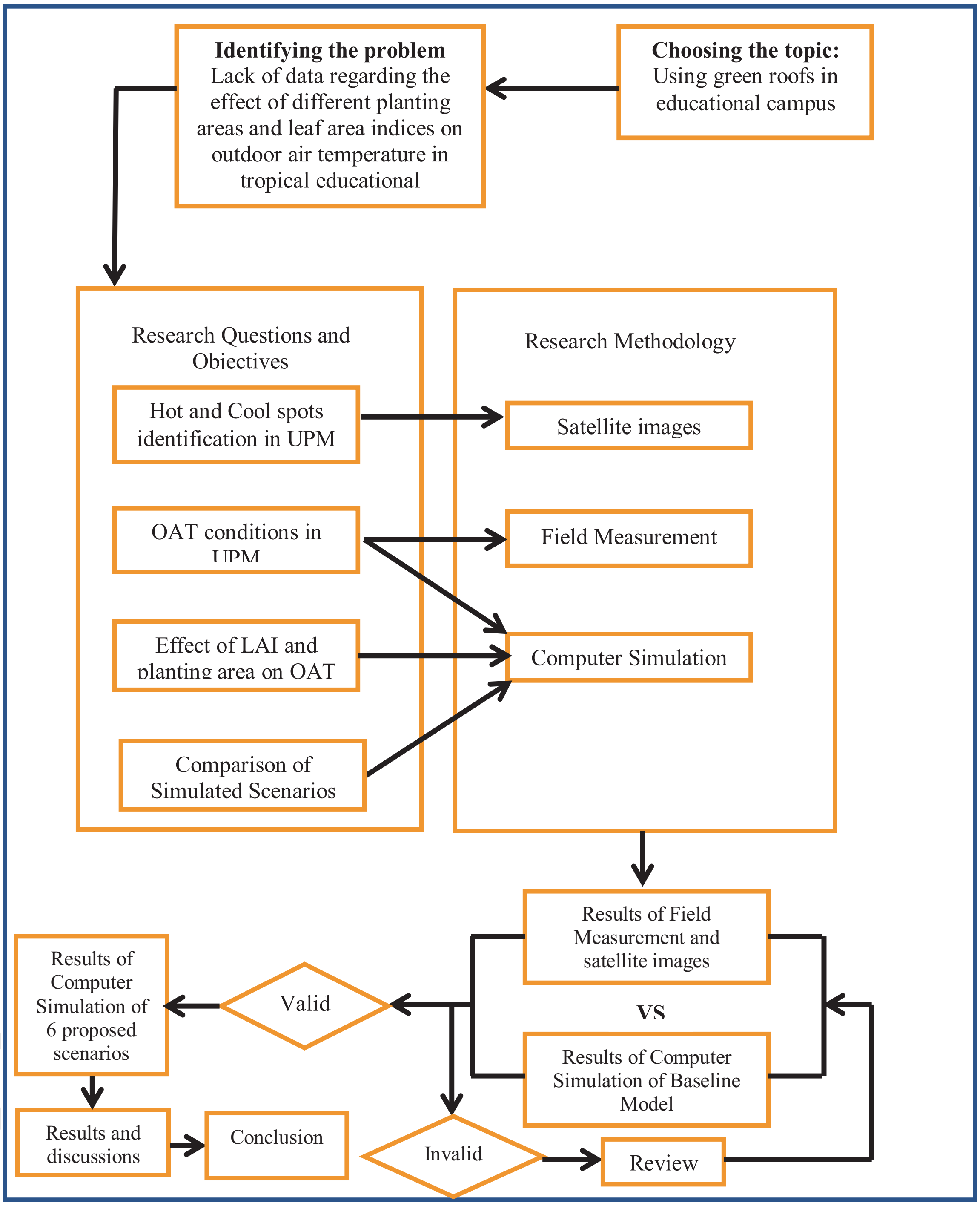

Diagram 1 : The Conceptual Framework of the thesis

1.9 Structure of Thesis

This study includes five chapters. Chapter One provided a brief introduction of the study including the background and the research problem, the research questions, the aim and objectives, research methodologies, the scope and limitations, and significance of the research. Chapter Two presents the most significant findings in the literature related to the urban heat island, greening policies of educational campuses, the microclimatic condition in outdoor spaces particularly in the tropics, considerations for the plant selection in green roofs and outdoor air temperature and its assessment methods. This chapter also introduces the Serdang climate and the relevant simulation tools with a detailed description of the ENVI-met tool for simulating climatic condition in micro scale targeted campus areas. Chapter Three describes three methodologies of gathering observational data from UPM, the field measurement and computer simulation used in this study. The results of the campus study, field measurement and computer simulation using ENVI-met will be presented and analysed in Chapter Four. The results presented in chapter Four will be comprehensively discussed in Chapter Five in order to highlight the findings of this study and make interpretation based on the comparison of different scenarios. This chapter also will culminate this study by summarizing its findings and making conclusion and recommendations for further studies.

1.10 Conceptual Framework

Greening is a useful mitigation strategy that helps cooling the air and providing shade.Conceptual framework of the research on the relationship between the canopy density of vegetation in green roofs, the overall planting area and the air temperature in different levels was illustrated in Diagram 2. There were two independent variables in this study, one of which was the canopy density of the vegetative layer in green roofs and the second independent variable was the overall planting area of green roofs. The air temperature in different levels was the dependent variable and the effect of independent variables on the mean air temperature was determined. Other variables such as solar radiation, relative humidity, wind velocity and surface temperature were effective too. Nevertheless, in this comparative study, they were kept constant in order to determine the role of LAI and overall area of green roofs on the mean outdoor air temperature in different air levels.

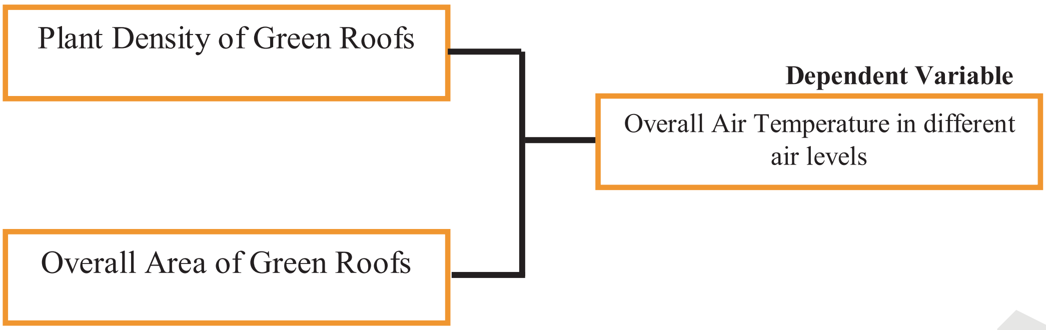

Diagram 2 : Conceptual Framework - The Relationship between Leaf Area Index, overall area of green roofs and outdoor air temperature in different air layers

1.11 Summary

This chapter highlights the need of this research to assess the cooling effect of green roofs as a temperature mitigation strategy in an educational campus of Malaysia country. Focus was given to UPM in Serdang city with the intention of further understanding the current scenario that relates to the study, literature supporting the research scope and theories reviewed in Chapter Two.

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