THERMAL PERFORMANCE OF POTTED PLANTS IN MITIGATING INDOOR TEMPERATURE IN TROPICAL CLIMATE

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Special dedication to

my beloved wife Zalinna Kaliman,

a woman with great patience and kindness

and my lovely kids Aqil Aiman, Amir Farid, Anis Qistina and Azhad Iman

for filling my life with joy and happiness.

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which keep my spirit burning

in achieving my goals.

Love You All

May Allah bless us

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ABSTRACT

Reducing indoor heat gain from the roof into the building means reducing the cooling energy consumption of air conditioning system hence increase indoor comfort. Apart from its high initial installation cost, green roof is proven to be the best way in dealing with the issue of indoor heat gain in a building thus contributes in reducing urban heat island effect. Green roof also called eco-roof or vegetated roof is described as a roof that is planted with specific vegetation above a waterproofing membrane. A study in Malaysia suggested that potted plants as an alternative to more economic green roof and its potential in dealing with indoor heat gain needs further exploration. Potted plants are plants grown in containers or pots instead of planting them in the ground. This study investigated the potential of potted plants as an affordable alternative tool to green roof application in reducing indoor temperature in tropical climate regions. Four similar test cells equipped with data acquisition system were built. Each top of the cell is treated with four different design variables; potted plants, vegetated, non-vegetated 150mm depth soil layer and a bare top surface. Indoor peak heat value and lowest value were recorded and analyzed. At heat peak hour, potted plants managed to reduce a daily average of 8.7% indoor heat gain whereas vegetation cell only managed to reduce an average of 7.9% indoor heat gain. Potted plants were also found to reduce a daily average of 35.5% of total heat transfer amount compared to 28.5% in vegetated cell. Based on these results potted plants appear to offer an alternative strategy towards reducing indoor temperature. In conclusion, this study suggests that potted plants could provide an affordable way especially to urban population in their strategy to deal with the high energy consumption for cooling.

ABSTRAK

Mengurangkan haba dalaman dari bumbung ke dalam bangunan bermakna pengurangan tenaga melalui sistem penyaman udara sekaligus meningkatkan keselesaan dalaman. Selain daripada kos pendahuluan yang tinggi dalam pemasangannya, bumbung hijau terbukti sebagai cara terbaik dalam menangani isu haba dalaman bangunan serta menyumbang dalam mengurangkan kesan pulau haba di bandar. Bumbung hijau juga dipanggil *eco-roof* atau tanaman bumbung digambarkan sebagai bumbung yang ditanam dengan tumbuh-tumbuhan khusus di atas lapisan kalis air. Satu kajian di Malaysia, mencadangkan tanaman pasu sebagai alternatif kepada bumbung hijau yang lebih ekonomik dan potensinya dalam menangani isu haba dalaman perlukan kajian lebih mendalam. Tanaman pasu adalah tumbuhan yang ditanam di dalam bekas atau pasu, bukannya seperti lazimnya yang ditanam di dalam tanah. Kajian ini bertujuan untuk menilai potensi tanaman pasu sebagai alternatif kepada bumbung hijau dalam mengurangkan suhu dalam bangunan di kawasan iklim tropika. Empat sel ujian dilengkapi sistem perolehan data telah dibina. Permukaan atas setiap sel diletakkan empat pembolehubah reka bentuk yang berbeza; tanaman pasu, tumbuh-tumbuhan, 150mm lapisan tanah tanpa tumbuhan dan permukaan atas yang terdedah. Nilai suhu puncak dan nilai suhu terendah dalaman direkod dan dianalisis. Ketika suhu puncak, tanaman pasu mengurangkan purata harian suhu dalaman sebanyak 8.7% berbanding 7.9%. oleh sel dilitupi tumbuh-tumbuhan. Tanaman pasu juga dapat mengurangkan purata jumlah pemindahan suhu harian sebanyak 35.5% berbanding 28.5% dalam sel dilitupi tumbuh-tumbuhan. Berdasarkan keputusan ini tanaman pasu mampu menawarkan satu alternatif kepada strategi mengurangkan suhu dalaman bangunan. Sebagai kesimpulan, kajian ini mencadangkan bahawa tanaman pasu mampu menyumbang terutamanya kepada penduduk bandar sebagai satu strategi mengurangkan peningkatan penggunaan tenaga untuk penyejukan.

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LIST OF ABBREVIATIONS/SYMBOLS

ASHRAE	-	American Society of Temperatureing, Refrigerating and Air conditioning Engineers
dB	-	decibel
CO_2	-	Carbon Dioxide
DAAC	-	Distributed Active Archive Center
EPA	-	Environmental Protection Agency
HVAC	-	Heating, Ventilation and Air-Conditioning
IAQ	-	Indoor Air Quality
IPCC	-	Intergovernmental Panel on Climate Change
MODIS	-	Moderate Resolution Imaging Spectroradiometer
NOx	-	Nitrogen Oxide
ORNL	-	Oak Ridge National Laboratory
SO_2	-	Sulphur Dioxide
UAP	-	Urban Air Pollution
UNEP	-	United Nations Environment Program
UTM	-	University Technology of Malaysia
UHI	-	Urban Temperature Island
VOC	-	Volatile Organic Compound
WHO	-	World Health Organization
%	-	Percentage
°C	-	Degree of Celsius
°F	-	Degree of Fahrenheit
UTS	-	University of Technology Sydney
UV	-	Ultra Violet
LAI	-	Leaf Area Index
T_i	-	Indoor air temperature

T_s	-	Indoor surface temperature
T_{iA}	-	Indoor air temperature in Cell A
T_{iB}	-	Indoor air temperature in Cell B
T_{iC}	-	Indoor air temperature in Cell C
T_{iD}	-	Indoor air temperature in Cell D
T_{sA}	-	Indoor surface temperature in Cell A
T_{sB}	-	Indoor surface temperature in Cell B
T_{sC}	-	Indoor surface temperature in Cell C
T_{sD}	-	Indoor surface temperature in Cell D
T_a	-	Ambient temperature

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CHAPTER 1

INTRODUCTION

1.0 Background

World Health Organization (WHO) predicted the urban population to grow approximately 1.5% per year, between 2025 to 2030. Cities populations have different intake styles than in rural areas (Jyoti K. Parikh *et al.*, 1991). They consume more food and energy than urban rural population. They contribute to the cities environment pollution affecting the city's population health and quality of life. Urbanization definitely increases the human lifestyle quality, technology, diversity of people, and social opportunities. But on the other hand it brings the environmental crisis. If no effort is made to adapt the increase in cities population, urbanization will bring more harm to cities life such as limited open spaces, increased pollution, traffic congestion and decreasing resources. As urbanization demands new spaces, vegetation and open spaces had to be sacrificed to make ways for new building, roads, parking lots and other accommodations.

Major modification of the land-surface through urbanization and other business activities, has been confirmed to impact regional and probably global meteorology, and thus locally-measured heat range information (McKitrick and Michaels, 2004). Surfaces that were once permeable and moist become impermeable and dry. As a result urban surface temperature and overall ambient air temperature arise due to the significant number of non-reflective, water-resistant surfaces in buildings, roofs and paving materials that absorb more of the sun's rays during the daytime thus contributes to high temperature differences between cities and rural areas (Santamouris, 2001). In particular, components such as concrete, stone and asphalt tend to absorb and trap heat at the surface (Landsberg, 1981; Oke, 1982) and a lack of vegetation reduces heat lost due to evapotranspiration. According to Andrew S. Goudie, (1997), cities are warmer than rural areas between 0.6 to 1.3°C due to the combination of increase energy consumption and differences in albedo (the rate at which an object can reflect solar radiation).

Urban Heat Island (UHI) is a main threat to cities population directly caused by urbanization. It is a phenomenon to describe higher surrounding cities air temperature as compared to surrounding rural temperatures. McKitrick and Michaels (2004) described urban heat island as “a phenomenon whereby the concentration of structures and waste heat from human activity (most notably air conditioners and internal combustion engines) results in a slightly warmer envelope of air over urbanized areas when compared to surrounding rural areas”. The UHI mainly depends on the modification of energy balance in cities areas which is due to several factors: urban canyons (Landsberg, 1981), thermal properties of the building materials, substitution of green areas with impervious surfaces that limit evapo-transpiration (Takebayashi and Moriyama, 2007), and decrease in urban albedo (Akbari and Konopacki, 2005). Urban heat island has resulted in higher energy demand for cooling homes and buildings. In order to maintain comfort levels in building structures due to the arising temperature, more cooling energy is needed. Oke’s heat island parametric model shows that higher population increases density and air temperature in cities. Oke, (1987) demonstrated that population and Urban Heat Island (UHI) intensity are directly related and lead to higher energy consumption for air conditioning buildings.

In the future, the threat of global warming may enhance the hazard potential of the urban heat island. According to Intergovernmental Panel on Climate Change (IPCC, 2001), in over the period of 1990–2100, the worldwide averaged near-surface air temperature is expected to raise by 1.4 to 5.8°C, given a range of climate sensitivities and greenhouse gas emissions to changes in radiative forcing. Especially important are shifts in minimum average temperature, cloud cover and wind speed. Global warming has the potential to considerably change the intensity (e.g., size and duration) and raise the spatial extent of heat islands in urban environments. As temperature heats up, the frequency with which UHI conditions occur could grow. Researchers expected that the durations of heat waves are projected to increase in the future (Rosenzweig and Solecki, 2001).

Urban heat island is one of the major issues affecting in the city's quality of life. The generally raised temperatures in the city center prove to be a very unsustainable factor, resulting higher energy consume for cooling building, thus risking the life of cities population. As rapid increase in population expected in the near future, it is essential to realize the threats it will bring. Setting up and applying heat island mitigation strategies is the only way in reducing energy consumption towards improving the quality of city's life.

Malaysia is experiencing similar climate of hot humid temperature throughout the year. The typical Kuala Lumpur climate has the characteristics of very small in monthly temperature, highest temperature of the hottest month (February/March) is 32-33°C and the coolest month is December with 31°C. The lowest temperature is 23-24°C (Dasimah, B. O., 2009). As a tropical climate country, Malaysia, especially urban cities do experience high temperature environment due to the urban heat island effect. Observations on the heat urban increase as to rural areas had been done by a few researchers (Sham, 1973; Zainab, 1980; Shaharuddin, 1997; Shaharuddin *et al*., 2006; Sin and Chan, 2004; Ilham, 2006). According to Sham (1973) between 1975 and 1990 the commercial centers in Kuala Lumpur and the Klang urban areas recorded several degrees warmer than the surrounding region. Consequently, Elsayed (2009) found that there is an increase of 1.5°C in the intensity of the UHI of the city from 4.0°C in 1985 to 5.5°C in 2004 and relates that the population density contributes to the increase in the intensity of the urban heat island of the city of Kuala Lumpur. Most cities experienced maximum and minimum heat, and this will go on along with the rapid urbanization (Shaharuddin *et al*., 2006). It affects the urban population, especially in terms of comfort (Shaharuddin *et al*., 1997). Increase urban population, decrease number of vegetation, transportation and air conditioning in Malaysia contributes to the heat release thus create discomfort to the population (Siti Zakiah, 2004).

A biologically related solution to reduce urban heat is through vegetation (Voogt, J., 2004). Plants and open land scenery usually constitutes majority of rural area. Cooler surface temperature in rural area is contributed by the effects of trees sun shading. The so-called evapotranspiration process also contributes to reduce the surrounding air temperature (Santamouris, 2001). It is a process which plants dissipating normal heat by releasing water to the nearby air (Santamouris, 2001). In comparison urban areas are recognized by dry, resistant areas, such as conventional rooftops, pathways, streets, and parking lots. As places develop, nature has to be given up, more plants are lost, and more areas are turned into paving, streets and structures. Surfaces once permeable and full with shade from the plants and ground cover were replaced with impermeable surfaces, which hold no moisture to keep urban areas cool. Furthermore it absorb heat, releasing less water, which plays a role in raised surface area and air temperature.

A vegetated green roof, also called a vegetated roof, green roof, garden roof, eco-roof, or planted roof, among other terms, is a system above a waterproofed structure that supports the long-term growth of plants (Meyer, M., 2010). They have been used for winter time insulating material and summer cooling. Researches on the warm qualities of vegetated roof proved that the vegetated roofs application contribute to the building thermal protection by blocking solar radiations (Theodosiou, 2003; Wong *et al*., 2003; Niachou *et al*., 2001; Eumorfopoulou and Aravantinos, 1998; Palomo Del Barrio, 1998). The roofs also decrease urban heat islands effects, thus improving the environment (Wong *et al*., 2003).

In tropical cities, urban pressure on street trees is immense, although they are still relatively green (Emmanuel, R., 2009). Cooling strategy through urban greening in the tropics continue to be practical and most popular ways due to its high humidity, abundance of water availability and combined with year-round warm weather. Since green roofs originated from Europe, most researchers were only focused on European countries especially Germany as government officials tout sustainability initiatives, and that could be the reason green roof application is more popular compared to other regions. Therefore, there is a need to shift the focus of the research to tropical climate countries since green roofs play a major significant role in heat mitigation and reducing the storm water runoff, especially in urban areas.

1.2 Problem Statement

Reducing indoor heat gain from the roof means reducing the cooling energy consumption of air-conditioning system and increase indoor comfort. Apart from its high upfront installation cost (Carter, T., and Keeler, A., 2008), vegetated roofs proven to be the best way in dealing with issue of indoor heat gain in a building thus contributes in reducing urban heat island effect. Combating the urban heat island effect will be unsuccessful without the total involvement of urban population. Therefore possible affordable ways in reducing indoor heat gain need to be explored and Asmat Ismail *et al*., (2010) proved that placing potted plants on top of a roof contributed in reducing indoor temperature. As the study by Asmat Ismail *et al*., (2010) only made comparison between potted plants and the bare roof, how will potted plants perform compared to vegetated roof?

1.3 Research Gap

By comparing potted plants with a bare roof of a single room, Asmat Ismail *et al.* (2010) experimented and proved that by placing potted plants on top of a flat roof contributed in reducing the indoor air temperatures with an average indoor temperature dropped between 0.21 and 1.73°C. Limited study conducted on the benefits of potted plants toward creating indoor comfort had raise a question of how good is potted plants compared to vegetated roof in term of its thermal performance. Therefore this study seeks to quantify the thermal performance between potted plants and vegetated roof in reducing indoor air temperature.

1.4 Research Aims

The aim of this research is to explore the potential contribution of potted plants in heat mitigation of indoor temperature of a building instead of vegetated roof in designing green roof application, especially in Malaysia climate.

1.5 Research Objectives

To achieve the aim of the research, the following objectives are formulated:

i. To investigate the thermal performance of four types of top cell treatment; potted plants, vegetated roof, non-vegetated and bare roof in reducing indoor air and surface temperature.
ii. To compare and evaluate the thermal performance of potted plants and vegetated roof in reducing indoor air and surface temperature.

1.6 Significance of Study

This study promotes the affordable green living strategy instead of vegetated roof application especially to urban populations with limited building space on ways in mitigating indoor air temperature. The study will verify the thermal performance of potted plants in comparison to high upfront cost of vegetated roof. It will educate and create the awareness to building owners of the benefits having potted plants as an alternative approach to vegetated roof in reducing indoor temperature thus reducing the cooling energy consumption of air-conditioning system and increase indoor comfort. Moreover the strategy is in line with the five main objectives of The National Green Technology Policy unveiled by the Prime Minister in 2009. The study fulfils the fifth objective of The National Green Technology Policy which says “Enhancing public education and awareness on Green Technology and encouraging its widespread use”. The study will also serve as a future reference for researchers on the subject of green living. And importantly, this study will educate designers, architects, building developers and contractors in fulfilling their responsibility to the community in creating a green living environment.

1.7 Scope of Research

The context of the research will focus on Malaysia warm and humid climate. The research aim is to investigate the thermal performance of four types of top treatment; potted plants, vegetated roof, non-vegetated and bare roof in mitigating indoor air and surface temperature. Two measured parameters; indoor air temperature and indoor surface temperature were involved in the research as these parameters with determine the indoor temperature reduced, indoor temperature loss and the total amount of indoor temperature involved. Four similar test cells measuring 1m x 1m x 1m were used to place the four different top treatments. All data from each cell were measured simultaneously at the same time period and same days. Due to the time constraint the conducted experiment did not take into consideration of any specific day, month or even specific places.

1.8 Research Limitation

Time was the critical factors limiting the duration of the experiment. Started with building up the four units of experimental models to the setting up the completed model on site situated at the highest point above sea level in Universiti Teknologi Malaysia. Due to time constraint and economical reasons plywood was used as the main structure of the test cell. All test cells were made out of the same material and size to reduce the influence of material properties to the result. The slab on top of each cell too were made of plywood instead of concrete slab. Four concrete slabs on top of the test cells to be built at the highest point above sea level in Universiti Teknologi Malaysia will definitely need detail planning and management especially in terms of construction duration, transportation and logistics.

Again time constraint was the main reason in deciding to choose *Ipomoea pes-caprae* as the same plants were used by Asmat Ismail *et al.,* (2010) in investigating the effect of potted plants in reducing indoor temperature of a room. With the same reason both experiments did not take into consideration of any special date or specific event such as the regional hottest or coldest month, wettest or driest month and event hottest or coolest places. Experiment 1 was conducted from 7th to 12th March while Experiment 2 from 17th to 22nd June 2011. Therefore the results will only reveal the effects of the different top treatment to indoor temperature.

1.9 Research Framework

The research started with selecting a topic and then narrowing it down to identifying the current issues arise regarding the topic. Evaluating research problem is the critical part. References were made from previous studies through literature reviews and resulted in deciding the research problem, research gap, research question and the research methodology. As the research aim is to investigate the effect of four types of top treatment; potted plants, vegetated roof, non-vegetated and bare roof to indoor temperature of the cells, two design parameters were measured simultaneously, indoor air and indoor surface temperature. Experiment 1 acted as a pilot test to ensure the results consistencies and therefore contributed in verifying the validity and reliability of the test cells and its experimental equipments for the goodness of the Experiment 2. The flow of the research is shown in Figure 1.1

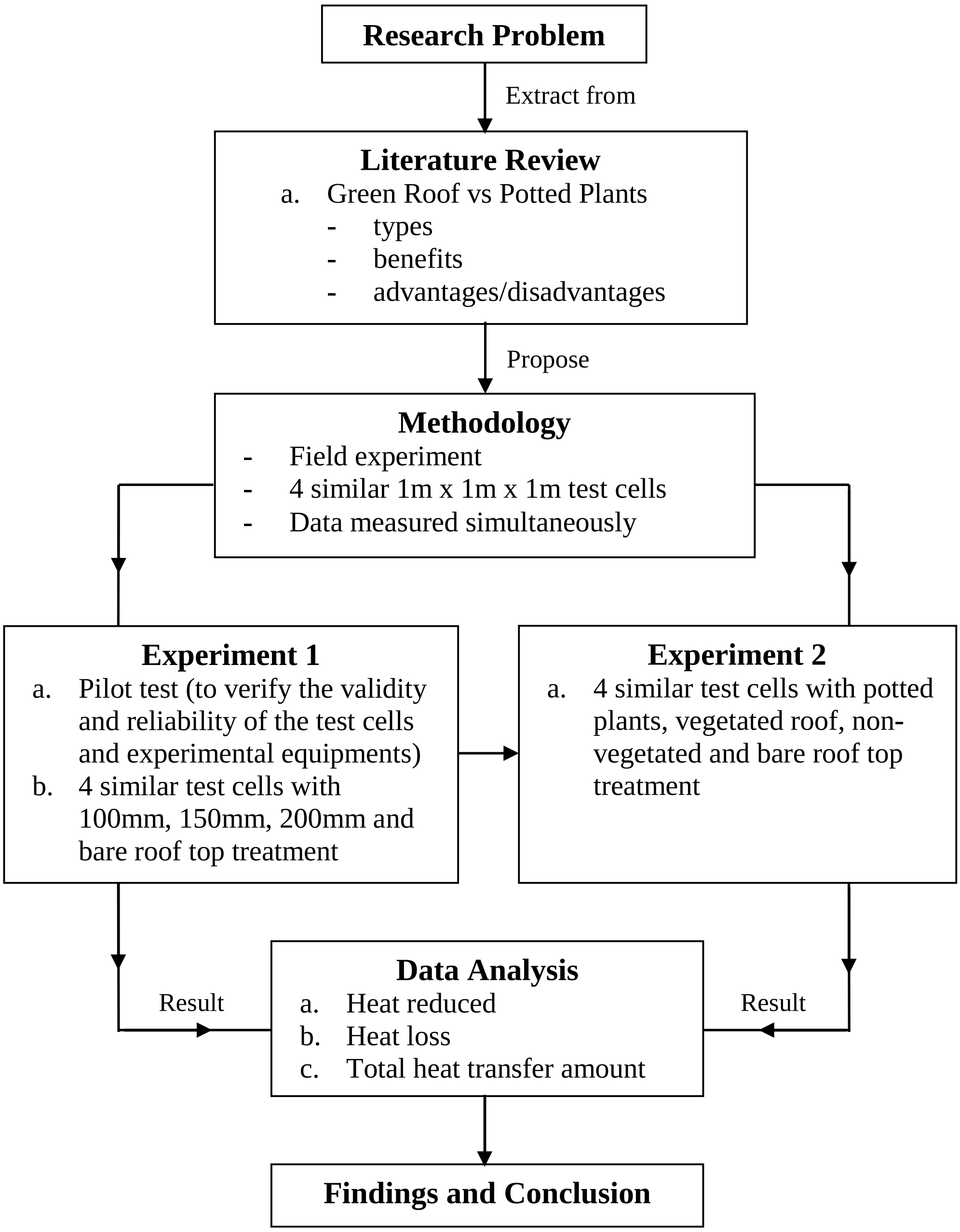

Figure 1.1: Research Flow Chart

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