THERMAL PERFORMANCE OF GREEN ROOF AT DHAKA CITY IN BANGLADESH

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To:

My Beloved Father, Mother

and

My Husband, Son and Daughter.

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ABSTRACT

Sustainability development is one of the main issues today around the world. Appropriate use of building design strategy of construction process contributes to reducing the consumption of building energy. Green roof can play a positive role to reduction of roof surface temperature and air temperature that can be translated into energy saving means. The aim of research is to investigate the thermal performance of the green roof and the changes that occurs in the indoor thermal environment with diurnal variation of the room during summer and winter season in subtropical Bangladesh and tropical Malaysia. This research was conducted through field measurement. The pilot study was conducted in Malaysia for two weeks before the main field study was done in Bangladesh for duration of one year. The main reason of the pilot study was to clarify the instrumentation. The pilot study results indicated that the green roof is more effective than bare roof in tropical climate. The pilot study suggested a good potential of similar green roof strategy for Bangladesh. To evaluate thermal performance of green roof in Bangladesh, some quantitative data analysis is necessary before large-scale implementation of green roof can be introduced. To meet these requirements, field measurements were carried out locally on selected buildings in Dhaka city. Three building were selected for field study, two buildings with green roof and another was a reinforce cement concrete (R.C.C.) bare roof. A set of thermal data loggers were installed to record the air temperature of indoor, outdoor and surface temperature. Data collection was carried out for duration of two months in winter and five months in summer. Thermal performance evaluation was done by comparative study between green roof and typical concrete bare roof. This research also evaluates U-value and RTTV calculation of different types of green roof and bare roof. The research found that green roof on contemporary building has better thermal performance and comfortable compare to bare roof in summer season. During winter, occasionally green roof reduces the indoor temperature to below comfort zone. It also noted that the thermal performance of green roof depends on the different type of design strategy. Constructed sunken, raised, exposed and organized pot plants green roofs can reduce indoor air temperature to 3.67°C, 1.22°C, 2.49°C and 6.8°C compare to outdoor air temperature. Green roofs also achieve a remarkable surface temperature reduction around 27.63°C. As part of an integrated system of green roof, denser plants can offer a better evaporative cooling impact to the micro-climate. This research suggests that the rooftop garden is one of the natural ecological solutions for reducing the effect of *Urban Heat Island (UHI).* This study concludes that the use of green roof on contemporary buildings of Bangladesh have significant impact on the overall indoor thermal performance. Thus, contemporary buildings should consider employing this sustainable green roof to achieve thermal comfort environment.

ABSTRAK

Kelestarian pembangunan adalah salah satu isu utama hari ini di seluruh dunia. Strategi reka bentuk bangunan yang bersesuian dalam proses pembinaan menyumbang untuk mengurangkan penggunaan tenaga bangunan. Bumbung hijau boleh memainkan peranan yang positif kepada pengurangan suhu permukaan bumbung dan suhu udara yang boleh diterjemahkan sebagai kaedah penjimatan tenaga. Tujuan kajian adalah untuk menyelidiki prestasi terma ada bumbung hijau dan perubahan yang berlaku dalam persekitaran tertutup dengan perubahan terma harian bilik semasa musim panas dan musim sejuk di subtropika Bangladesh dan tropika Malaysia. Kajian ini telah dijalankan melalui pengukuran lapangan. Kajian rintis telah dijalankan di Malaysia selama dua minggu sebelum kajian lapangan utama yang telah dilakukan di Bangladesh untuk tempoh satu tahun. Tujuan utama kajian rintis adalah untuk memperjelaskan instrumentasi. Hasil kajian rintis menunjukkan bahawa bumbung hijau adalah lebih berkesan daripada bumbung terdedah dalam iklim tropika. Kajian rintis telah mencadangkan potensi yang baik untuk strategi bumbung hijau yang serupa untuk Bangladesh. Untuk menilai prestasi terma bumbung hijau di Bangladesh, beberapa analisis data kuantitatif adalah perlu sebelum pelaksanaan berskala besar bumbung hijau boleh diperkenalkan. Bagi memenuhi keperluan ini, pengukuran lapangan telah dijalankan pada bangunan tempatan yang dipilih di bandar Dhaka. Tiga bangunan telah dipilih untuk kajian lapangan, dua bangunan dengan bumbung hijau dan satu lagi adalah bumbung kosong konkrit simen bertetulang (RCC). Satu set pencatat data haba telah dipasang untuk merekodkan suhu udara suhu dalaman, luaran dan permukaan. Pengumpulan data telah dijalankan untuk tempoh dua bulan di musim sejuk dan lima bulan di musim panas. Penilaian perbandingan prestasi terma telah dilakukan dengan kajian perbandingan antara bumbung hijau dan bumbung konkrit tipikal terdedah. Kajian ini juga menilai pengiraan nilai-U dan RTTV pada beberapa jenis bumbung hijau dan bumbung kosong. Kajian ini mendapati bahawa bumbung hijau di bangunan kontemporari mempunyai prestasi terma yang lebih baik dan selesa berbanding dengan bumbung terdedah di musim panas. Semasa musim sejuk, kadang-kadang bumbung hijau mengurangkan suhu dalaman di bawah zon keselesaan. Ia juga menunjukkan bahawa prestasi haba bumbung hijau bergantung kepada perbezaan jenis strategi reka bentuk. Pasu tumbuhan dibina tenggelam, dibangkitkan, terdedah dan disusun di bumbung hijau boleh mengurangkan suhu udara tertutup kepada 3.67°C, 1.22°C, 2.49°C dan 6.8°C berbanding dengan suhu udara luar. Bumbung hijau juga mencapai pengurangan suhu permukaan yang luar biasa di sekitar 27.63°C. Sebagai sebahagian daripada sistem bersepadu bumbung hijau, tumbuh-tumbuhan yang lebih padat boleh menawarkan penyejukan penyejatan yang lebih baik kesan kepada iklim mikro. Kajian ini menunjukkan bahawa taman atas bumbung adalah salah satu penyelesaian ekologi semulajadi untuk mengurangkan kesan *Urban Heat Island (UHI)*. Kajian ini merumuskan bahawa penggunaan bumbung hijau di bangunan kontemporari di Bangladesh mempunyai impak yang besar ke atas keseluruhan prestasi terma dalaman. Oleh itu, bangunan kontemporari harus mempertimbangkan untuk menggunakan bumbung hijau lestari bagi mencapai persekitaran keselesaan terma.

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LIST OF ABBREVIATIONS

ASHRAE	-	American Society of Heating, Refrigerating and Air Conditioning Engineers
BMD	-	Bangladesh Meteorological Department
BST	-	Bangladesh Standard Time
BUET	-	Bangladesh University of Engineering and Technology
CV	-	Comfort Vote
D.I	-	Discomfort Index
ET	-	Effective Temperature
GMT	-	Greenwich Mean Time
MRT		Mean Radiant Temperature
R.C.C.		Reinforce cement concrete
TTC	-	Thermal Time Constant
Tn		Neutral Temperature
Tm		Mean Temperature
UTM		Universiti Teknologi Malaysia
WHO		World Health Organization
OTTV		Overall Thermal Transfer Value
RTTV		Roof Thermal Transfer Value

LIST OF SYMBOLS

%	Percentage
°K	Degree Kelvin
Max	Maximum
Min	Minimum
ºC	Degree Centigrade
ºF	Degree Fahrenheit
Rh	Relative Humidity
T_d	Dry bulb temperature (^{0}C)
T_g	Globe Temperature
T_i	Indoor temperature (^{0}C)
T_n	Neutral Temperature
T_o	Outdoor temperature (^{0}C)
T_w	Wet bulb temperature (^{0}C)
T_{igr}	Indoor Temperature under green roof (^{0}C)
T_{ibr}	Indoor Temperature under bare roof (^{0}C)
$T_{igr1.5}$	Indoor Temperature under green roof at 1.5m height level (^{0}C)
T_{igr3}	Indoor Temperature under green roof at 3m height level (^{0}C)
T_{igrv}	Indoor Temperature under green roof with ventilation (^{0}C)
T_{igrwv}	Indoor Temperature under green roof without ventilation (^{0}C)
T_{cgr}	Ceiling Temperature under green roof (^{0}C)
T_{ss}	Soil surface temperature (^{0}C)
T_s	Soil temperature (^{0}C)
T_{gs}	Grass temperature (^{0}C)
T_{bp}	Bush Plants temperature (^{0}C)
T_{bk}	Brick Pavement temperature (^{0}C)
μ	Decrement Factor
Φ	The time-lag

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

Urbanization is the growth in the proportion of the population living in the urban area. The world has experienced unprecedented urban growth in the last and current centuries. In 1800, only 3 percent of the world population lived in urban areas. The world population began to increase substantially after 1900. the percentage of urban population increased 14 percent and 45 percent in 1900 and 2000 respectively. For the first time in history, more than half of the world population is living in urban areas in 2008 (Laski and Schellekens, 2007). It is also estimated that by 2030, up to 5 billion people will live in towns and cities (Wong, 2009).

The truth is that almost half of the world population lives in the tropics. Figure 1.1 shows the rate of urbanization in the tropical areas. According to Gupta (2002), the urban population of the developing countries increase rapidly from 286 million to 1,515 million between 1950 and 1990 and the figure will reach up to 4 billion by 2025, with almost all developing countries within tropics and subtropics (Wong, 2009). Therefore, significant attention should be paid to sustainable urbanization in the tropics and subtropics areas of the world to achieve sustainability. For this reason, the area of field study of this research was selected for tropical Malaysia and subtropical country Bangladesh.

Figure 1.1 Dense Dhaka city skylines during day (top) and night skyline view (bottom)

At the turn of the 19th to 20th century many Asian countries have experienced high economic growth accompanied by rapid urbanization. Due to rapid urbanization there has been a tremendous population growth in cities. This growth affect people's aesthetic sense and it influence the architecture of the world (kubuta, 2006). However, architectural design has paid very little attention to the local extreme climatic conditions in the region. At the same time many 'green' thoughts that all growth and development is undesirable, but other recognize that some development must occur for future. We need to done our future development with consciousness of sustainability. It is the only one way to save our world from global warming from the view point of rapid urbanization. Architect, town planer, designer, landscape designer have a great influence for sustainable development. There are three major groups of problem for sustainability such as population growth, depletion of resource and atmospheric pollution. Energy is the common denominator of items depletion of resource and atmospheric pollution. CO_2 emissions are largely caused by energy use, thus the best measure of CO_2 emissions, therefore sustainability, is energy demand. This is closely linked to the problem of diminishing sources of energy. According to S.V. Szokolay, 2008 the problem can attack from two directions: Reduce energy demands of buildings and Substitute renewable sources of energy as far as possible. Increase in CO_2 from human activity over the past 20 years. Most of the rest is due to land-use change, in particular deforestation. High concentration of buildings actually triggers many environmental issues, such as 'Urban Heat Island' (UHI) effect and climate change. The UHI effect is aggravated mainly due to the loss of green areas in the urban environment. Green vegetation strategically placed around roofs and around the building surface can be considered as a complement of urban greens for environmental sustainability. This is the main issue to start this research on green applications of buildings, is actually an ecological solution to the dense concrete jungle in Malaysia as a pilot study and Bangladesh as a long time field study. Both selected country is under tropical climate. The green roof will be one of the best solutions against deforestation of urban areas. Without a doubt these cost of a green roof application on building lot less than if climate change continues its trend.

The roof is the main element of the building that has much exposure to the sun and therefore gains solar radiation. The impact of solar radiation affects the thermal behavior of roof more than any other part of the house especially in tropical countries (Mallick, 1993). In Bangladesh, most of the roofs are exposed to direct solar radiation, and which elevates the indoor temperature above the local indoor comfort level (24ºC to 32ºC by Mallick, 1993) in summer seasons (Abul Mukim Mridha, 2002). Mechanical cooling is a very expensive (per unit 3.5 taka) option. In such a context, developing passive means of the solar control is important for comfortable living and higher productivity during hot seasons of the year. In Bangladesh, contemporary buildings are designed by architects according owner's demands which are based on low investment and use of local materials. These reinforced concrete roof building are very common but uncomfortable for living at night (Rumana 2008).

Urban growth resulted in tremendous increase of energy consumption of building. The building thermal comfort can be realized through building envelope design related to sustainable eco-building design concepts. The design concept aim is to reduce the heat gain and minimize the cooling load for the mechanical air-conditioning, it is one of the primary focuses in the building energy policy now a days. In terms of energy used, the distribution of the critical hours has considerable importance particularly during the summer months when the consumption of energy (electricity) is expected to increase. The hours between 10am and 5pm the energy consumption is at its peak (figure 1.2; Sabbir Ahmed 1995).

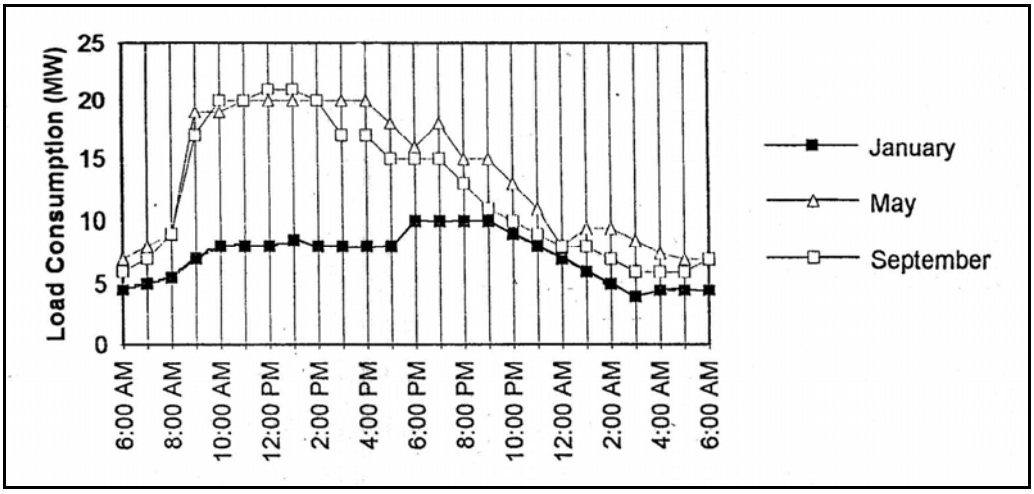

Figure 1.2 Variation in energy consumption at different time of the year in Dhaka city.(Source: Sabbir Ahmed 1995)

The most significant environmental challenge of today is global climate change, food security, excessive fossil fuel dependency and growing energy demands. All major challenges of the 21st century and some of the greatest problem are facing humanity. In this context, urban design, and the fundamental principles of how to shape our cities, has only recently started to feature in the greenhouse debates. Previously, most of the debates were circled around ideas about active faced technology for 'eco-buildings' and purely technologically driven solutions.

This research investigates the effectiveness of green roof application technique for residential building in hot-humid tropical climate of Johor in Malaysia as pilot study and hot warm-humid tropical climate of Dhaka in Bangladesh. The physical measurements for both countries were carried out using air temperature, humidity data loggers and surface temperature data loggers. Internal and external air temperature and relative humidity were measured for evaluate the thermal performance of green roof application on building. There is uncertainty on the usefulness of green roof application for cooling and maintaining comfort temperature throughout day and night in hot-humid tropical climate of Malaysia and warm-humid tropical climate of Bangladesh. This study started to justify the evaluation of passive cooling potential of indoor air temperature reduction by applying green roof compare to bare roof. This research finding can provide further improvements, advancement of knowledge and appropriate sustainable design strategy of green roof technology within tropical and subtropical cities in the world.

1.2 Statement of the Problem

Among, the major problems of Malaysian residential development are the overheating of roof spaces caused by inappropriate selection of roofing systems and materials. For buildings in equatorial regions with warm and humid climate such as Malaysia, the roof has been said to be a major Source of heat gain. Solar protection of the roof remains one of the main concerns in the thermal design of buildings in the region. (W. Puangsombut et al., 2007: Francois et al., 2004: Olgyay, 1992. Koenigsberger et al., 1980). Due to its geographical location, Malaysia receives the sun directly overhead most of the day throughout the year. Therefore, major heat gain of Malaysian houses comes from the roof. Once the heat gets into the roof space, the hot air heats up the internal structures and surfaces, and the heat is then retained for most of the night. The excessive heat gained from the sun will be radiated from the roof space to the occupants in the house through long wave radiation (Koenigsberger et al., 1980). According to previous studies, around 87% of heat transfer from the roof to occupant is through radiation process. Whereby on around 13% of heat is transferred through conduction and convection (Cowan, 1973). It is also recommended that reflective insulation can be used to replace mass insulation materials due to higher thermal performance (Allen, 2008). Since most of the cities in this tropical region have hot-humid climate whole year around, it is particularly important to develop passive cooling in order to reduce energy demand caused by the growing use of air-conditioners. However, there is uncertainty on the usefulness of green roof in cooling and maintaining comfortable temperature throughout the day and during the night in the hot-humid tropical climate of Malaysia. Temperature is the main criteria of human comfort. To solve this indoor comfort environmental problem green roof tends to experience lower temperature than the original exposed roof to provide an indoor comfortable environment. So this research work will provide an introduction or preliminary guide line for thermally responsive architecture on the basis of thermal performance of the green roof in Malaysia.

In Bangladesh the temperature difference between rural and urban area is 4ºC to 5ºC (Mallick, 1993) because of the amount of hard surface along with the high outdoor temperature. Traditional houses are based on low investment and high maintenance and the general construction materials are mud, bamboo, thatch wood C.I.(Corrugated Iron) sheets etc. These houses are extensively protected from effects of solar radiation by trees, open surroundings allowing easy cross ventilation, which produce its own microclimate, often include good solution of climatic comfort problems. For technological limitations and the always-overriding considerations of safety, some of these solutions must be considered ingenious (Koenigsberger et al, 1973). But in cities due to heavy concentration of the surrounding built environment this is not always successfully achieved. From previous study by Rumana and Hamdan,(2007a) on thermal performance of Bangladesh traditional house, state that double layer traditional roof section is the most effective design elements to control the indoor comfortable environment. Another research by Rumana and Hamdan,(2010) on comparative analysis of thermal performance study of contemporary house and traditional house also state that the indoor environment of traditional house is more comfortable than contemporary house. This research also indicates single layer R.C.C flat roof is very uncomfortable design element of a building (Rumana and Hamdan, 2008). It is essential to solve this problem need to redesign the contemporary building flat roof to achieve indoor comfortable environment. This is the main issue to start this research on thermal performance evaluation of green roof as an indoor thermal comfortable strategy and solution for the contemporary r.c.c flat roof buildings in Bangladesh.

The comparisons of heat transfer and energy consumption through case study building's roofs and walls envelope are essential to analyze to justify the thermal performance of different types of green roofs more accurately. This research also wants to find out the U-value of green roofs compare to bare roof and the envelope thermal performance standard which is known as Overall Thermal Transfer Value (OTTV). The target of this OTTV calculation to assist architect and professional person to comply with the building envelope thermal performance standard prescribed in building development.

The OTTV standard applied only to air-conditioned non-residential building since 1979. The OTTV requirement does not apply to non air-conditioned buildings such as residential buildings that are designed to be naturally ventilated. However, as it is became increasingly common for residential buildings to be air conditioned. There is a need to regulate the design the design of their envelopes. So that heat gains into the interior spaces and hence air conditioning energy consumption can be minimized. According to climatic change in Dhaka the outdoor temperature over 40°C during peak hours of summer day time (BMD). The use of A.C. in the top floor under bare roof of any contemporary residential building in Dhaka is essential to achieve thermal comfort (Rumana and Hamdan, 2008) environment and which is very costly for residents, for this reason the house rent of top floor is lower than any other floor level of the building. However, for Bangladesh it is essential to developing a comprehensive energy code to cover air conditioning for the design and planning of energy-efficient residential building. OTTV is one aspect of energy conservation of the sustainable building.

1.3 Research Questions

In this applied research through field measurements, it is desirable to find out the answers of the following questions:

1. What is the performance of green roof for indoor comfort environment of contemporary building in Malaysia?

2. How green roof plays a vital role with diurnal variation of ambient environment in Dhaka, Bangladesh?
3. How is the thermal performance of green roof in contemporary building in Dhaka city during summer and winter season?
4. What are the resultants U-Value of green roofs?
5. How much heat is the flow reduction percentage between green roofs and bare roof?
6. How much energy cost can be reduced using green roof through OTTV and RTTV calculation?

1.4 Research Gap

Some previous study was done on thermal performance of traditional Malaysian houses. Previous all studies have shown that in Malaysian houses, roof has a huge impact on the thermal performance of the whole building (Badrul et al., 2006; Nor, 2005). Solar protection of the roof is the main concerns to all researchers (W. Puangsombut et al., 2007: Francois et al., 2004: Olgyay, 1992. Koenigsberger et al., 1980; Cowan, 1973). According to Peng Chen (2002), the thermal radiation of roof largely depends on the composition materials. According to Allen, (2008) inappropriate roofing materials will cause overheating of roof and therefore excessive heat will be radiated to the occupants. Unfortunately, there is a general lack of concern on the importance of the effect of roofing materials and sustainable design to achieve human comfort level in local residential buildings. This is the main issue of the problem of inappropriate roof design and materials. Therefore, a pilot study is aimed to collect local thermal data at Johor Bharu in Malaysia for verify all instrument before start the main research field study in Bangladesh and understand the thermal performance effect of green roof technology for residential buildings in Malaysia.

Very few studies were done about thermal performance and thermal comfort of indoor environment in respect to Dhaka city in Bangladesh. Rumana and Hamdan (2008) already had done another research on thermal performance of traditional house at Dhaka city and their findings state that Bangladesh traditional house is comfortable for both summer and winter season. According to Rumana and Hamdan (2008) study on thermal performance of contemporary house in the city of Dhaka research findings state that contemporary house is uncomfortable during day and night. The comparative study between the thermal performance of contemporary house and traditional house at dense Dhaka city in Bangladesh, also found that the traditional house is more comfortable than contemporary house (Rumana and Hamdan, 2010) The thermal performance of the operable roof insulation with special reference to Dhaka done by Abul Mukim Muzzammel Haque Mridha, (2002) and recommended that operable roof insulation at 450mm and 300mm height above the roof confirms that roof insulation at relatively higher height performance better than lower height. The factors for thermal comfort in residential high rise in Dhaka city research result suggested that the roof of the top floor be rendered heat-resistant by using any suitable means (Bijon, 2002). Previously some attempts were made to improve roof insulation. A study by Imamuddin et al (1993) and others using hollow blocks plastered over concrete roof has found differences of about 4-5ºC between the ceiling surfaces of such an insulated slab as compared to a standard concrete slab for flat roofs. The difference was more for inclined roofs. The difference in room temperature was however less, a maximum of 2 ºC. But the study is incomplete, as it did not record temperature data for 24 hours. Another study was conducted by F.H. Mallick (1993) by using earthen pots laid over concrete roof. The room temperature of insulated roof was found to be 2.5-3.4ºC lower in comparison without insulated roof at around 3pm. It is evident from both experiments that using fixed insulation on the roof top, day time temperature can be reduced to a lower level but these methods reduce the potential of radiant cooling as in both cases the indoor temperature is higher than the outdoor.

All of these above studies suggest some means (operable roof, hollow blocks) or insulation for modern contemporary building’s roof in Bangladesh but which are not user friendly. There is no specific research done to study the thermal performance of green roof on contemporary building in Bangladesh. However, the green roof with natural landscape on roof top appears to have solved the thermal environmental sustainability of the contemporary buildings. Therefore, this research attempts to focus on the indoor thermal performance of the green roof at contemporary buildings in respect to the impact of warm humid tropical climate of Bangladesh.

1.5 Research Aim and Objective

The aim of research is to investigate the thermal performance of the green roof and the changes that occurs in the indoor thermal environment with diurnal variation of the room during summer and winter season in subtropical Bangladesh and tropical Malaysia. To investigate the thermal performance of different type of green roofs compare to bare roof at Dhaka city with the following objectives:

1. To evaluate the indoor thermal performance of green roof for top floor of contemporary residential buildings in Malaysia as pilot study and Bangladesh as main research case study.
2. To compare indoor environmental change occurs with the effect of different type of green roof and bare roof.
3. What is the thermal performance of green roof in contemporary buildings of Dhaka city during summer and winter seasons?
4. To evaluate the U-value and RTTV of different types of green roof and bare roof.
5. To evaluate the RTTV of different types of green roof and bare roof.

1.6 Scope and Limitations

1. Green Roof landscape is a component of contemporary buildings. It is important understand the thermal performance of green roof in urban areas and to promote it in contemporary buildings as a thermal comfort strategy for modern contemporary building design. This research will lead to a discussion on the potential of indoor air temperature reduction by applying green roof

and reducing energy consumption for sustainable comfortable and healthy life.

2. There are some limitations in this study. The pilot study in Malaysia was on flat concrete roof within university campus area and need to avoid shade by other structures. For these reasons, a 10 storied high flat roof is selected to develop potted plants green roof for the field measurement. The pot plants green roof was organized with 50 numbers of pot plants. All pot plants were hired from the landscape maintenance department of Universiti Teknologi Malaysia for only two weeks. The rooftop access permission was granted only two weeks for security purpose. For this scenario, the pilot study measurement in Malaysia was done in 2008 only for a short period.
3. There are some limitations in case 2 building during field investigation. The building access permission was granted only one week from 7am to 11 pm for security purpose.
4. Data logger’s battery duration is only for one year. For this reason when the machine is switched off then the data collection need to be stopped.
5. Due to the limitations of the thermal data logger quantity, the field measurements and data collection were possible only in two building at a time.
6. Wind flow also can have an effect on thermal performances of building but it is not considered in this experiment. Highest wind speed occurs in April 2.9 m/s and lowest in November 1.3 m/s in Dhaka city. There are other parameters affecting the indoor thermal comfort, for e.g. air velocity, clothing, sky conditions and metabolic heat production, which are not considered within this research work.
7. The indoor thermal comfort environment aspect was mainly dealt based on air and surface temperature difference under green roof and bare roof.
8. Above these opportunities and constraints, research on the thermal performance of the green roof with reference in Malaysia (pilot study) and dense Dhaka city in Bangladesh (main study) were carried out and described in the following chapters.

1.7 Significance of the Research

The significance of the research depends on the understanding of the thermal performance of green roof on contemporary building in the context of urban areas. Analyzing the cooling potential of green roof application on building to maintain indoor environmental sustainability, reducing energy consumption by maintaining lower indoor temperature, reducing Urban Heat Island (UHI) effect by large scale application of green roof in dense Dhaka city, Global warming, human well being, healthy and wealthy life of urban residents.

This research further establishes a number of casual relationships between the green roof design components with various micro-climatic factors. Hence by adopting the appropriate design strategy, modern contemporary buildings can be effectively designed towards sustainable urban environments.

This research study helps to develop the sustainable natural green landscape application process on buildings and green roof design guidelines for the modern building designers. The micro-climatic study of the green roof compare to bare roof conducted at dense Dhaka city, indicate the difference that exists within the larger context of the urban micro-climate.

1.8 Research Position

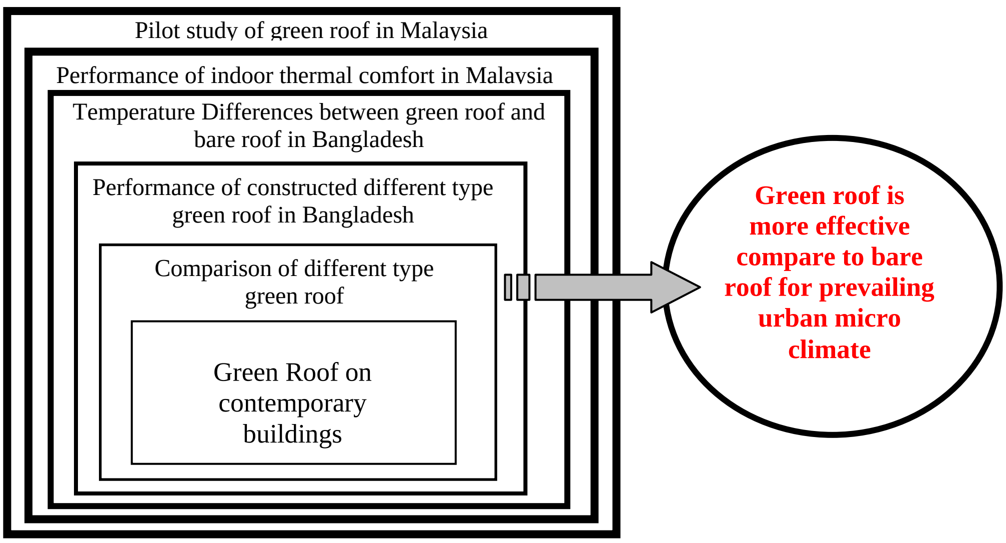

Figure 1.3 Diagram of research position.

1.9 Thesis Structure

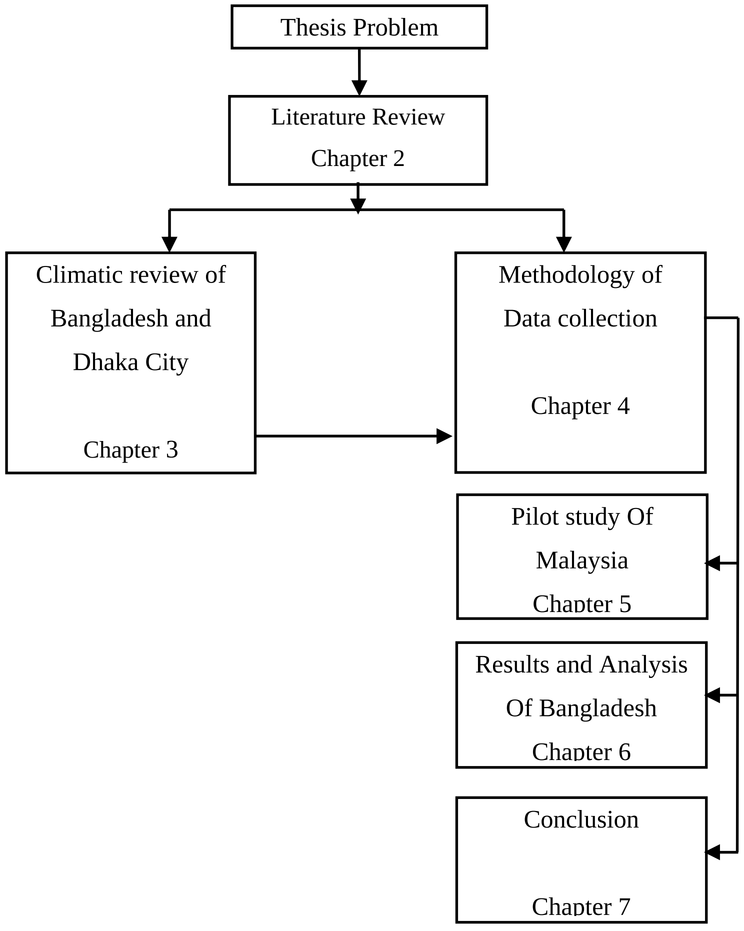

Figure 1.4 The flow of research process and thesis structure.

The thesis is organized into seven chapters as summarized below.

Chapter one introduces the main issue of this research. This chapter also introduces the statement of the problem, objectives of the study, scope and limitation of the study and significance of the research. The research gap, research questions and research hypothesis and the overall thesis structure are also presented in this chapter.

Chapter two introduces the literature review on green roof and other research work on green roof. Green roof technology and application system and benefit of green roof are also discussed in detail.

Chapter three presents the classification of climate and climatic region of Bangladesh. This chapter vastly explains the urban climatic elements such as temperature, rain fall, humidity, wind speed etc. the chapter also introduces the historical background of the Dhaka City. The previous study of climate, climatic comfort, indoor comfort, summer comfort zone, outdoor comfort, summer comfort zone will also be explained. Environmental criteria and comfort vote are also described in this chapter.

Chapter four introduces the methodology of this research. It describes the objective of the methodology and description of the selected contemporary building in Malaysia and Bangladesh. Instrumentation, installation of thermal data logger (Hobo) and placement of logger and methodology of data collection are also mentioned here.

Chapter five presents the results of pilot study in Malaysia. Pilot study evaluates the indoor environment comparison between under green roof and bare roof. It describes the temperature difference of outdoor and indoor with diurnal variation. Different type of surface temperature comparison, indoor air temperature with ventilation and without ventilation and pilot study data are also explained here.

Chapter six presents the results and analysis of Bangladesh. It describes the temperature difference of outdoor and indoor with the change of seasons and also with diurnal variation. Temperature difference between Bangladesh Meteorological Department and field study data are also explained here.

Chapter seven presents the overall review of the thesis objectives and research questions, followed by the concluding remarks of the major findings of the experiment; presents the guideline developed for green roof and it suggests further works to complement the thesis findings.

1.10 Conclusion

What has been discussed in this chapter is a brief introduction of the subjects that might be necessary for the understanding of this research. It included, a brief about the hypothesis and objective of the study, background information on Bangladesh and Malaysia, the context regarding contemporary buildings, research scope and limitation past investigations on thermal comfort of contemporary building etc. Finally a brief discussion on the research structure for this study has also been included in this chapter.

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