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THERMAL PERFORMANCE OF ROOFTOP GREENERY SYSTEM AT THE TROPICAL CLIMATE OF MALAYSIA
A case study of a 10 storied building R.C.C flat rooftop at UTM, Johor Bahru, Malaysia

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ABSTRACT

In tropical countries rooftop greenery is more sympathetic to the prevailing climate and provides comfortable indoor environment. This paper analyses the above hypothesis on a 10 storied residential apartments in Universiti Teknologi Malaysia (UTM). The analysis of actual performance of the rooftop greenery can provide the information on effectiveness of its application on contemporary houses for tropical climate in Malaysia. Empirical studies have been performed an internal and external roof surface, where temperature and air temperature were measured for a period of three days in two phases. The first phase of measurement was carried out when the rooftop was empty. After the rooftop greenery was built then the second phase of measurement was conducted. Expected findings of the research are that the green rooftop will tend to experience lower surface temperature than the original exposed roof surface. So this research work will provide an introduction or preliminary guide line for thermally responsive architecture on the basis of thermal performance of the rooftop greenery system. Temperature is the main criteria of human comfort. To provide an indoor comfortable environment through the greening of the rooftop of the building is more appropriate in the tropical climate of Malaysia.

Keywords: Rooftop greenery system, thermal behavior.

INTRODUCTION

Sustainable design is the philosophy for designing the built environment to comply with the principles of economic, social and ecological sustainability. If we cannot sustain ourselves, and lest we forget, we have only ourselves to blame for our own problems and predicaments. Nature has supported us and has created its own balances through its own methods to deal with our excesses. There have been very visible signs which suggest that it is simply getting tired of being well, and good natured (Krishnan 2005). The intention of sustainable design is to eliminate negative environmental impacts completely through skillful and sensitive design. Sustainable designs impact the environment minimally and relate people with the natural environment. There are three major groups of problems for sustainability, which are population growth, depletion of resources and atmospheric pollution. CO_2 emissions are largely caused by energy use. We need to control CO_2 emissions, therefore can think about sustainability. This matter is closely linked to the problem of diminishing sources of energy. According to S.V. Szokolay (2008), this problem can be attacked from two directions: Reducing energy demands of buildings and substituting renewable sources of energy as far as possible.

Furthermore, the Malaysia energy centre estimates that CO_2 emissions per capita, increased by 45% between 1994-2005 (Mustapa issue 0021). However, more than 40% of the energy consumed can be reduced if energy efficiency is practiced and sustainable technologies are applied to buildings as in 2002, 44% of the total energy used in the residential sector in Malaysia was in the form of electricity (Zain-Ahmed 2008a). In the Malaysian residential housing sector, the housing stock is made up of terrace houses (61%), apartments (27%) and detached houses (12%). More than 70% of the detached houses are air-conditioned, while 62% of terrace houses and

36% of apartments are air-conditioned (Kubota, 2006). These air conditioners have been installed mainly in their master bedrooms (94%), other bedrooms (52%), living rooms (29%) and dining rooms (5%) (Kubota 2008). The current trends indicate that the bigger houses tend to be air conditioned, rather than the smaller houses and further suggest that the purchasing power of occupants is proportional to the nos. of installed air conditioners. Thus it is important to find passive cooling means that can reduce demand of air conditioning in this hot-humid tropical climate of Malaysia. The main purpose of this study is to determine passive cooling strategies for residential buildings in Malaysia. The purpose of the study is to examine the cooling effect of green roof as a passive cooling method in the high rise residential apartments in Malaysia. There are some limitations in this study, such as to get flat roof within university campus area and want to avoid shade by other structures. For these reasons, a 10 storied high flat roof is selected for the field study. 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. This paper presents the field measurements which compare the temperature cooling effect of green roof and original exposed roof. These findings lead to a discussion on the potential of indoor air temperature reduction by applying green roof. Green roof can reduce the effect of Urban Heat Island (UHI) and global warming in urban areas.

Aim and Objective

The aim is to improve the indoor environment for better quality of living and to reduce energy consumption. The objective of this research is therefore to explore the thermal performance of rooftop garden in the hot-humid tropical climate of Malaysia. Through such field measurements, it is desirable to find out the answers of the following questions:

1. How much reduction of roof surface temperature is caused by roof top garden?
2. What is the quantity of reduction of solar heat gain caused by rooftop garden?
3. Does the green roof change the urban heat island effect?

Scope

Green landscape or gardening will be a component of the building. For understand the thermal performance of rooftop greenery of buildings in urban areas and to promote it in contemporary buildings as a thermal comfort strategy for modern design.

LITERATURE REVIEW

Researcher	**Methodology**	**Findings**
Onmura et al (2001)	Field measurement on a planted roof in Japan	The surface temperature decrease of around 30–60°C was observed on site
Onmura et al (2001)	Wind tunnel experiment and a numerical calculation	Evaporative cooling effect of the green roof was also confirmed
Niachou et al (2001)	Field measurement of surface and air temperature on a planted roof and complemented by a mathematical approach	Thermal properties of green roofs and energy savings were examined
Elean Palomo Del Barrio (1998	Mathematical analysis	Thermal behavior of green roofs
Wong, (2006	Field measurement	Green roofs act as insulation devices rather than cooling the roofs
Ekaterini Eumorfopoulou (1998)	Calculation to examine the thermal behavior of planted roof	Green roofs can contribute to the thermal performance of buildings but it cannot replace the insulation layer
Onmura (1994 and 2001)	Field measurement on thermal protection techniques of green roof	Reduction in the local air temperature near canopy, thus reducing (4–5°C)the incoming heat flux into the building
Del Barrio (1998) and Good (1990)	Prediction	Worth mentioning on the works of thermal performance of green roofs
Dominguez (1998); Lozano (1990); Eumorfopoulou and Aravantinos (2003); Takakura (2000) et al; Capelli et al (1998)	Implementation of green roof in the buildings	Thermal behavior and effectiveness of vegetation covers with different average absorption for solar radiation and diffusive properties

Researcher	Methodology	Findings
Niachou et al (2001),	Field investigation on green roof and mathematical approach	Both indoor and outdoor thermal properties are considered for thermal performance of green roof.
Hoyano (1988 and 1994)	Experimental study	Effect of rooftop lawn planting on thermal environment and also described for climatologically uses of plants for solar control and the effects on the thermal environment
Rakesh, 2005	Mathematical formulation	Green roof have a cooling potential
Wong (2002).	Field measurement	Thermal benefits of roof top garden

All these researchers support the cooling potential of the green roof through experiment conducted with various parameters. However, there is uncertainty on the usefulness of green roof in cooling and maintaining comfortable temperature throughout day and night in the hot-humid tropical climate of Malaysia. This paper presents the field measurements which compare the temperature cooling effect of green roof and original exposed roof surface. These findings lead to a discussion on the potential of indoor air temperature reduction by applying green roof.

METHODOLOGY

The field measurement was carried out on the rooftop of a high-rise 10 storied residential building in Malaysia. The field measurement was not influenced by any shadows or reflected solar radiation since there were no high-rise buildings around it. The extensive type of rooftop garden is organized by 50 nos. of pot plants to cover the rooftop surface. Plants are arranged densely, the layout of the rooftop garden shows in figure 1. Pot plants are used for this research because it is easy to maintain, cost effective to construct, easy for drainage of rain water from rooftop and has lesser effect on the roof surface. Since cost of construction of the actual green roof construction cost is higher then the pot plants green roof, pot plants green roof is constructed for this study.

The field measurements were done in two phases. The first phase of measurement was carried out when the roof top was empty, during 26th to 29th November, 2008. After the rooftop garden was built, then the second phase of the experiment was conducted, during 30th November to 2nd December, 2008. This time period was taken to get data on rainy and sunny days. In this phase, the field measurements were carried out on two roof tops of the same type, one was bare roof and another was pot planted greenery roof. This was done to compare the direct effect of green roof and bare roof within the same condition of the outdoor ambient environment.

The physical measurements were carried out using the temperature and humidity and surface temperature data loggers. The temperature and the relative humidity for both internal and external data were recorded at 15 minutes interval. The data was averaged for every hour to obtain the hourly values. The positions and the measured variables of the data loggers are described in table 1. The building was fully occupied by residents and no mechanical cooling was used during the field measurements period. The instruments used in field measurements are summarized as follow.

1. Dickson Data Logger
2. Infra red ray gun data logger

Air temperature & Humidity sensor logger

Bare roof top before Greenery | Construction of Greenery | Dense Greenery on rooftop

Figure 1. Bare roof top and roof top greenery

Figure 2: Internal view of experimental room and entry of the room

Table 1. Description of data logger positions installed at roof top of the tested apartment in Univerviti Teknologi Malaysia and measured variables.

Sl no.	Position and Description	Measured variable
1	Rooftop surface under the green shade and without green shade	Rooftop surface temperature
2	Soil surface of the pot plants under the green	Soil surface temperature
3	Indoor ceiling surface of the test room	Indoor ceiling surface temperature
4	Indoor space of the test room 1.5m from floor level	Indoor air temperature and relative humidity
5	Outdoor environment 2m above the rooftop surface	Outdoor air temperature and relative humidity

Comfort Zone for Malaysia

The analytical method of evaluating the comfort zone for Malaysia have been studied by several authors (Rajeh 1988; Jones 1993), using the concept of the "Neutrality Temperature". This study uses the neutrality temperature as a base to determine the thermal performance of the rooftop greenery system in the topical climate of Malaysia. In various studies, neutrality temperature is defined as the temperature that gives a thermal experience that is neither warm nor cool, which is a state of "neutral" or "comfortable". It is the mid point of the comfort zone, as an average value for many experimental subjects. According to Auliciems, A. and S. Szokolay (1997), with the range of the comfort zone taken as 5°C, thermal comfort temperatures extend approximately about 2.5°C above and below the neutral temperature. According to Szokolay comfort formula, the neutral temperature needed to maintain at 26°C. The upper and lower limits of the temperature of the comfort zone would then be 28.5°C and 23.5 °C respectively. In this research the comfort environment that is evaluated according to comfort zone, is 23.5°C to 28.5°C.

Construction and Maintenance Policy of the Rooftop Greenery

In tropical climate, during most of the months of the year, rainfall occurs on a daily basis on average. February is the only dry month in the whole year. For this reason the rooftop garden do not need daily maintenance and watering. From nature, the plants get enough water, air and sunlight for their growth. So nature gives all the necessary prosperity to maintain the plants. Pots plants are densely arranged on rooftops, shown in figure 3. There are three to five, 12.5mm holes in the bottom of the pots, through which the pot plants drain the extra water to the roof. The flat concrete roof slab has one inch slope from the middle of the slab to the end of the slab for rainwater drainage. The mouth of the water drainage pipes, which are 100mm diameter, is covered with steel nets (figure 3) to prevent rubbish entering into the pipes. Some brick or stone cheeps were placed over the net as a protection for the net. For better growth, the plants require fertilizer every six months. The lift room and the water tank are placed side by side on one side of the roof. One main staircase continued upon the roof for access to the rooftop for maintenance.

RESULT AND ANALYSIS

Comparison of External Surface Temperature

The thermal performance of roof top greenery and bare roof was compared to identify the ability of the green roof in reducing indoor air temperature of the high-rise building and the surrounding environmental effects on micro climate of the ambient environment. The result is analyzed by comparing the internal and external surface temperature, ambient air temperature and relative humidity. The surface temperature is a major indicator for determining the

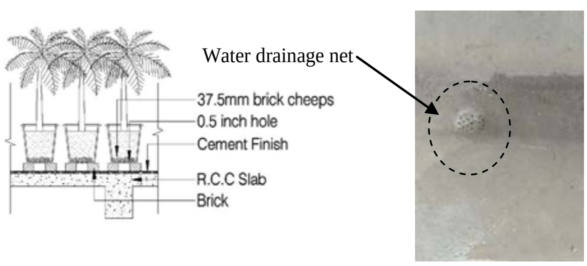

Figure 3. Section of pot plants arrangement (Left) and net on water drainage pipe (Right)

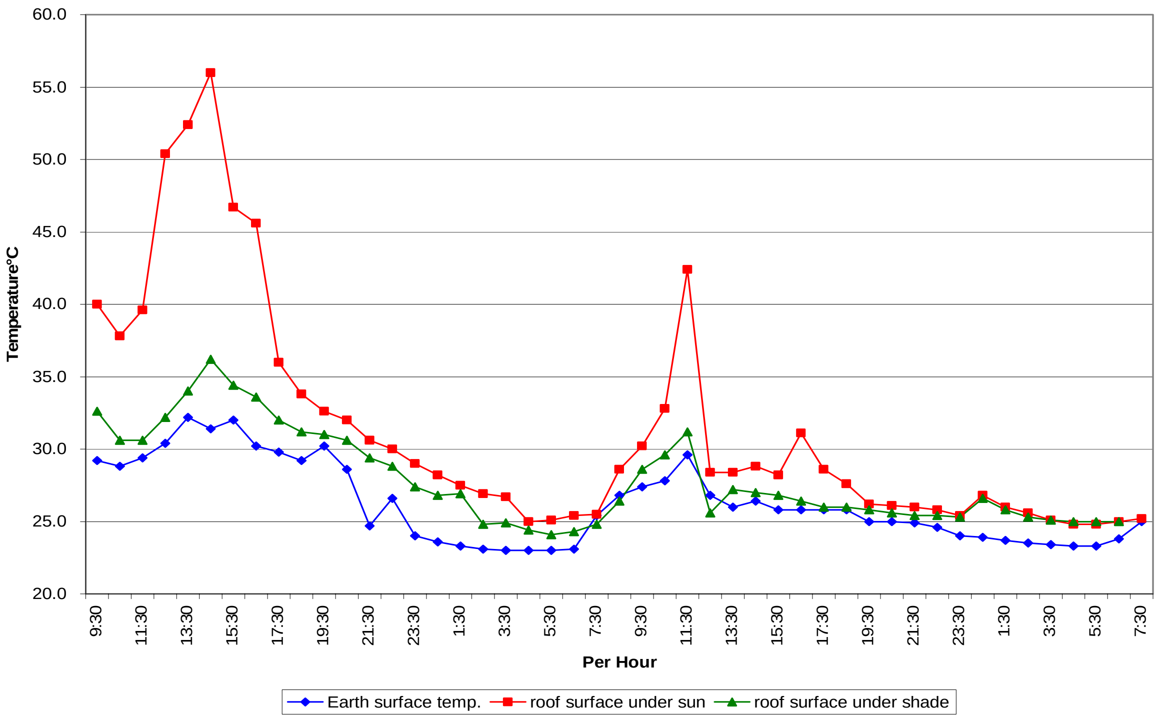

Figure 4. Profile of soil surface, bare roof top and roof top with greenery temperature

thermal performance of the building. The surface temperature comparison is presented in figure 4. Surface temperatures on exposed bare roof top were much higher than green roof. The rooftop surface maximum temperature was decreased by around 11.2°C to 19.8°C in field experiment. The maximum surface temperature of the bare rooftop (BRs) was 56.0°C; the rooftop surface with greenery (GRs) was 36.2°C. The maximum temperature of potted soil surface (Es) under plants shade was 32.2°C. hence, from the data, it can derive the following relationship between the three types of roof surfaces: BRs> GRs> Es.

During sunny days, the highest surface temperature difference between potted soil surface and bare roof hard surface is recorded to be 24°C. Higher surface temperature of the bare roof indicates that high levels of solar radiation is absorbed by the concrete bare roof during daytime and is emitted as long-wave radiation at night.

The surface temperature fluctuation is attributable to the thermal protection of the rooftop greenery system which the rooftop surface. Shaded soil surface temperature under the plants is lower than shaded concrete surface temperature because the dark black colored concrete roof absorbed more solar energy. So shade is essential for the concrete rooftop.

The systems effectiveness would be increased if the concrete surface is fully covered with proper densely arranged pot plants in tropical climate of Malaysia.

During rainy days when soil surface is wet, the thermal performance of rooftop greenery with higher moisture performs better than bare roof. From the graph profile (figure 4) of shaded concrete roof surface and wet soil surface temperature difference is very minimal during most of the day time after rainfall.

The results show that the rooftop greenery performed well during the period when the pot plants soil surface was wet. The maximum difference of temperature between bare roof surface and wet soil surface is 22°C. During most days, surface temperatures of the green roof stayed within low temperature range. It was caused by evaporation of wet soil and shade of densely arranged pot plants. The evaporative cooling effect of the green roof was also confirmed by this phenomenon.

The Comparison of the internal ceiling Surface Temperature

The thermal benefit of the green roof reduces the surface temperature of the ceiling and prevents the solar heat transfer into the indoor environment and improves the thermal performance of the building.

From the graph profile (figure 5), green roof reduces the ceiling surface temperature by a maximum of 3.0°C and on average 1.7°C, in comparison to bare roof.

The Comparison of the Internal and External Air Temperature

The thermal performance of the green roof evaluation in reducing the indoor air temperature of the building is extended over the validation of cooling energy potential. Effect on indoor air temperature is also shown in figure 6. It is found that the average indoor air temperature is reduced by 2.4°C with roof during sunshine hours. However the reduction of air temperature follows a pattern. A maximum reduction of temperature is observed during peak heating period of 1:30 pm to 3:30 pm and minimum reduction occurs during in off sunshine period. The amount of solar heat energy entering into the indoors through green roof in comparison with the bare roof is decreased by more than 3 times (figure 6). The temperature fluctuation with the outdoors, is less with green roof in comparison to bare roof at night.

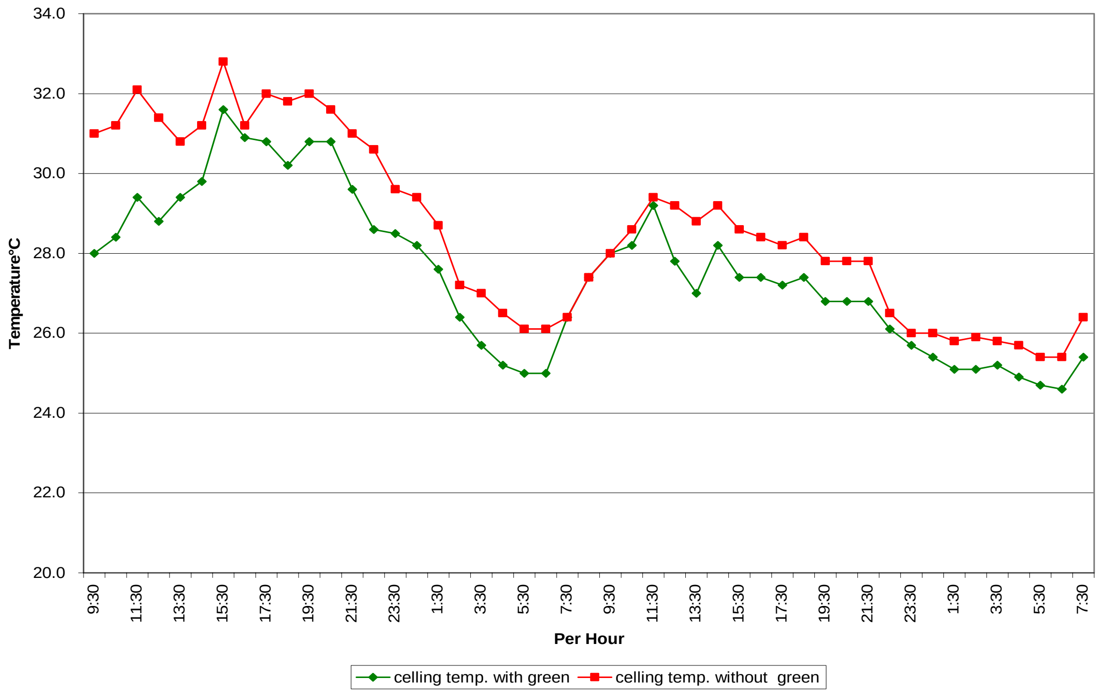

Figure 5. Profile of green roof ceiling surface temperature and bare roof ceiling surface temperature

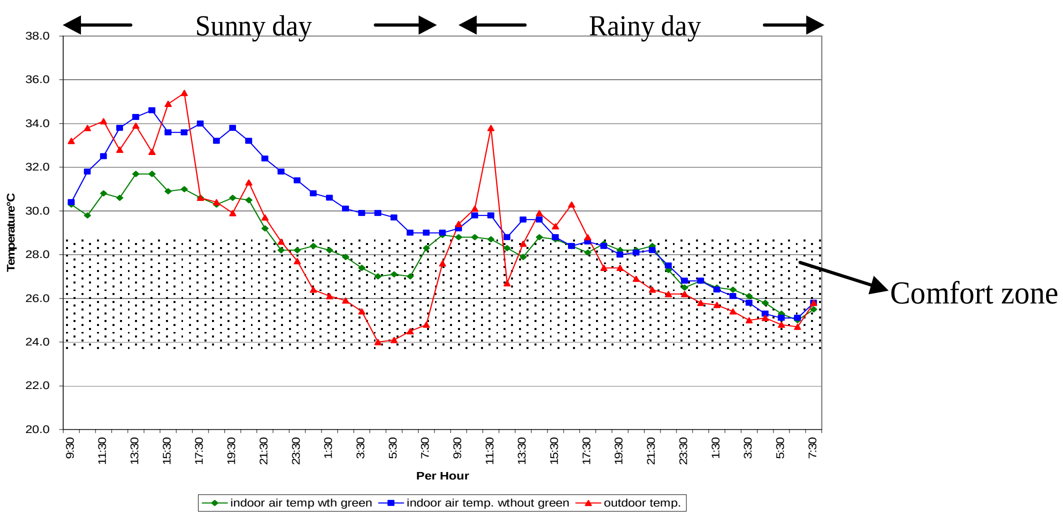

Figure 6. Profile of outdoor, with green roof indoor and without green roof indoor temperature

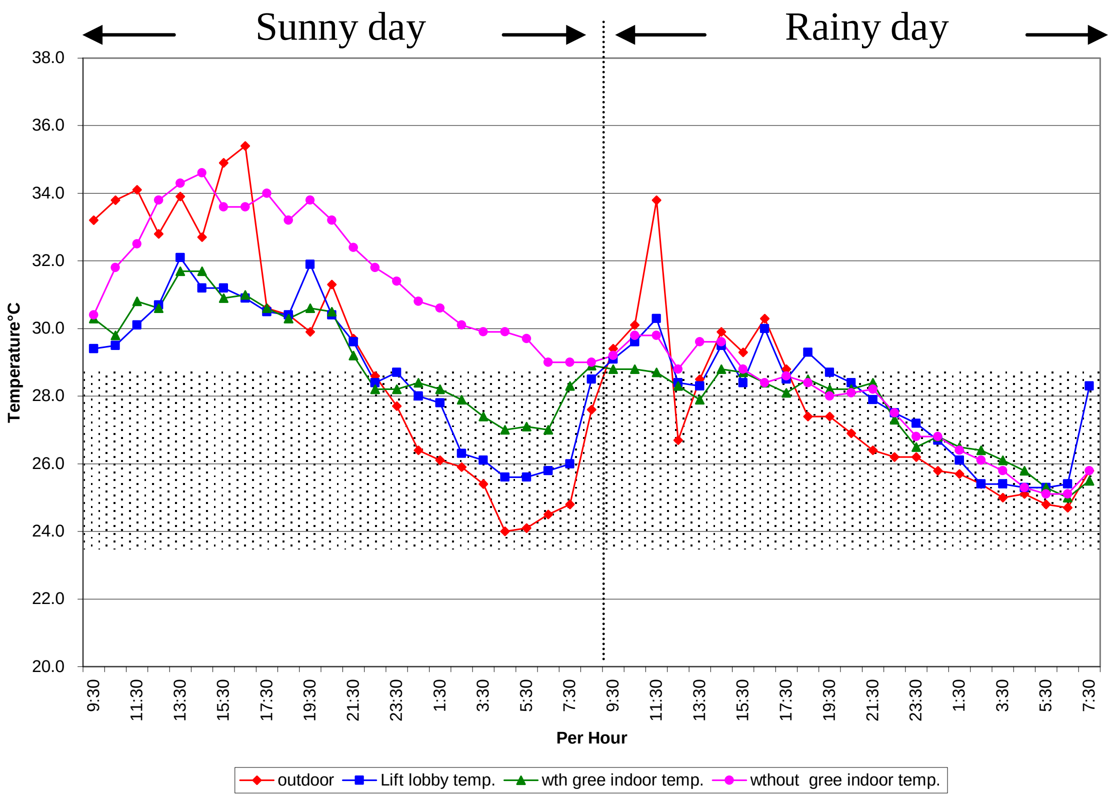

Figure 7. Profile of outdoor, lift lobby, with green roof indoor and without green roof indoor temperature

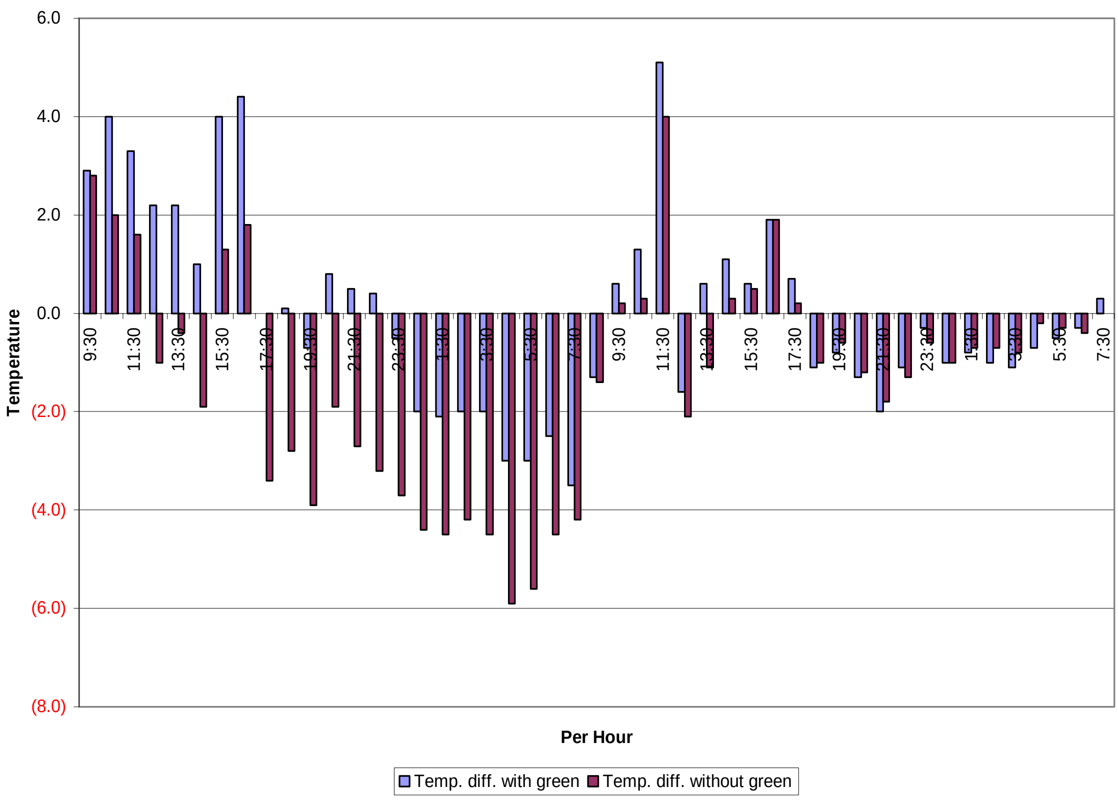

Figure 8. Profile of outdoor, with green roof indoor and without green roof indoor temperature

Effect on the microclimate of the building is shown in figure 6. Daily average indoor air temperature is 33.0°C with bare roof. This is reduced by 3.0°C with green roof, thereby reducing the average indoor air temperature to 30.0°C.

With diurnal variation, the indoor air temperature is reduced by green roof. Specifically, it can be seen from figure 8 that the maximum temperature difference between indoors and outdoors is 4.4°C with green roof during day time. Bare roof reduces the indoor air temperature by only 2.8°C from the outdoor temperature. While proper ventilation is provided into the indoor then the indoor air temperature is more dropped 1.5°C from general indoor temperature with green roof (figure 7). Roof top greenery plays a vital role in thermal protection which may reduce the thermal load applied to buildings.

CONCLUSION

The results confirm that roof top greenery contributes thermal benefit to both micro climates of indoor environment and the surrounding outdoor ambient environment of the building. It contributes to reduced energy consumption for cooling load, mitigates the UHI effect in urban environment and also reduces the effect of global warming by controlling the CO_2 level. In this study, heat transfer from outdoors to indoors through the bare roof was greater in comparison to the green roof. Actually, the thermal benefits are caused by the proper shade and dense arrangement of potted plants. Green roof can also reduce the average indoor air temperature more than the bare roof. Green roof can reduce the indoor air temperature 4°C to 5°C during day time. This phenomenon causes the formation of Urban Heat Island (UHI) effect in surrounding areas. Moreover, green roof surface shows lower surface temperature than the bare roof surface because greenery plays a vital role to in reducing the surface temperature through direct shading of the exposed bare roof surface. Greenery helps to cool the ambient air temperature through the consumption of solar energy for transpiration and photosynthesis of the plants. With rapid growth of urbanization, the UHI effect is aggravated mainly due to the demolishment of the greenery in the urban environment. However, rooftop greenery system is a natural ecological solution for reducing the effect of UHI and improving air quality by reducing CO_2 emissions. The roof top covering greenery system is easy to construct, maintain and replaceable pot plants for thermal protection. It provides a very effective solution for the contemporary buildings in tropical Malaysia. In the current age, people are increasingly becoming concerned with energy efficiency and an effective nature responsive eco system. Roof top greenery design adverse economic and social concerns as well as environmental aspects of sustainability. Green roof as a means for passive cooling alongside its related thermal benefits is essential for architectural design strategy in the hot-humid tropical climate of Malaysia.

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REFERENCE

Hoyano, A. (1983) Climatological uses of plants for solar control and the efforts on the thermal environmental of a building, *Energy and Buildings,* **11**, 29–36.

Hoyano, A., He, J., Horiguchi, T. and Wang, G. (1994) Experimental study on heat budget for foliage layer on lawn planting. Part 1. Effect of rooftop lawn planting on thermal environment, Journal of *Architecture Planning and Environmental Engineering*, Transactions of AIJ, **462**, 31–39.

Niachou, A. (2001) Analysis of the green roof thermal properties and investigation of its energy performance, *Energy and Buildings,* **33**, 719–729.

Anand Krishnan, (Dec.2005-Dec.2006) *Journal of the architects regional council Asia.*

Barrio Elean Palomo Del (1998) Analysis of the green roofs cooling potential in buildings, *Energy and Buildings,* **27**, 179–193.

Eumorfopoulou, E. and Aravantinos, D. (2003) The contribution of a planted roof to the thermal protection of buildings in Greece, *Energy and Buildings,* **27**, 29–36.

Del Barrio, E.P. (1998) Analysis of the green roofs cooling potential in buildings, *Energy and Buildings,* **27**, 179–193.

Eumorfopoulou Ekaterini (1998) The contribution of a planted roof to the thermal protection of buildings in Greece, *Energy and Buildings,* **27**, 29–36.

Green Roofs For Healthy Cities Website *http://www.peck.ca/grhcc/about.htm*, printed 11/13/01.

Dominguez, J. and Lozano, A. (1998) Green roof systems, Comput. *Mech. Publication*, **1**, 615–624.

Kubuta, T. and Ahmed, S. (2005) questionary survey on behaiviour for natural ventilation and electricity consumption in terraced houses, a case study of Johor Bharu City, Conference APSA, Penang, Malaysia.

Kuhn, Monica, "Roof Greening" *http://www.interlog.com/~rooftop/greening.html*, printed 11/12/01.

Liu, Karen (2001) "A Progress Report on the Environmental Benefits and Energy Efficiency of Green Roofs," *The Green Roof Infrastructure Monitor*, **Vol. 3, No. 2**, 14.

Cappelli, M., Cianfrini, C. and Corcicone, M. (1998) Effects of vegetation roof on indoor temperatures, *Heat Environment*, **16 (2),** 85–90.

Mustapa, S.I., Yusop, Y. Mitigating the adverse impact of climate change through sustainable use of energy, *Energy Smart*, **21**. Malaysia Energy Center.

Szokolay, S.V. (2008) *Huminity and Technology*, Proceeding 9^{th} Senvar + 2^{nd} Isesee.

Onmura, S. (2001) Study on evaporative cooling effect of roof lawn gardens. *Energy and Buildings*, **33**, 653–666.

Onmura, S., Matsumoto, M. and Hokoi S. (1994) A study on evaporative cooling effect by roof lawn garden, *Proceedings of the European conference on energy performance and indoor climate in buildings*, 634–639.

Onmura, S., Matsumoto, M. and Hokoi, S. (2001) Study on evaporative cooling effect of roof lawn gardens, *Energy and Buildings*, **33**, 653–666.

Takakura, T., Kitade, S. and Goto, E. (2001) Cooling effect of greenery cover over a building, *Energy and Buildings*, **31**, 1–6.

Good, W. (1990) Factors in planted roof design, *Constructions Specification*, **43 (11),** 132.

Wong Nyuk Hien (2003) “Investigation of thermal benefits of roof top garden in the tropical environment”, *Building and Environment*, **38**, **issue 2,** 261–270.

Wong Nyuk Hien (2007) “Study of thermal performance of extensive roof top greenery system in the tropical climate”, *Building and Environment*, **42, issue 1**, 25–54.

Zain-Ahmed, A. (2008a) Intrigating sustainable energy in building: Case study of Malaysia. FAU conference Copenhagen Business School. Denmark. 14-15 May.