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Thermal Performance and Temperature Mitigation towards Application of Green Roof in Tropical Climate

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Many studies have been conducted to ascertain the implementation of green roofs provides many advantages including extended roof life, increase of water run off quality and mitigation of urban heat island effect. Green roofs also have a carbon reducing benefits as they have the capacity to sequester carbon dioxide (CO_2) in different part such as plant biomass and substrate. However, the lack of experimental data for tropical climate makes it difficult to evaluate eventually the suitability of green roofs as a heat mitigation and carbon emission reduction strategy in Malaysia. To explore the thermal performance of green roof, field measurement was carried out in Heriot-watt university the Malaysia's first purpose – built green campus in Putrajaya.
The study measured solar radiation, outdoor and surface air temperature to determine the thermal performance of the green roof growing media (soil). Moreover, the empirical tests were compared between bare roof and two different soil thicknesses green roof (12 cm and 28 cm) to find out the effectiveness of green roof on heat transfer and carbon emission reduction with regard to surface and ambient air temperature and relative humidity. The temperature and relative humidity sensors were installed from 1m above the green roof surface to green roof layers.
The results showed that green roof influenced on surface and ambient air temperature reduction significantly where the ambient air temperature above green roof (12 and 28 cm depth) was between 1-2 ^{0}C lower than that for the bare roof. As a result, the findings showed that vegetation was more effective in reducing indoor air temperature where the more thickness was applied in the green roof. Thus, the study strongly suggests that green roofs are beneficial to moderate the air temperature in hot and humid climate.

1. Introduction

Today's, buildings consume a significant amount of energy in order to provide comfortable indoor environment. However, high amount of energy consumption especially in the developing countries causes such environmental issues like global warming or air and water pollutions. Therefore, the high levels of pollution in urban areas affect the human activities, and increasing in the amount of asphalted areas instead to green areas inducement the difference in temperature in urban area in compare with surrounding areas. The air temperatures even high during the night time in summer (Tereshchenko et al., 2001). This phenomenon has been explore by many researchers through past years (Hasanean, 2001) and they demonstrate that higher temperature gain the demand for cooling systems (Santamouris et al., 2001). As a result, many studies have been conducted in order to achieve sustainable environment without compromising occupant's satisfaction within built environment.
As an effective energy efficiency strategy, green roof is considered as a successful practice to attain sustainable development recently. The green roof is an applicable practice that not only provides environmental recuperation and occupant's thermal comfort but also mitigates energy consumption of buildings. Meanwhile, Results of Whittinghill et al. (2014) study ascertain the potential of green roofs and ornamental landscapes to sequester carbon by comparing the carbon content of nine in ground and three green roof landscape systems. This experiment suggests that by increasing the substrate layer the ability of green roofs for carbon sequestration would improve.
Within urban areas, green spaces have an essential role as a temperature reduction and the temperature gap between rural and urban areas may decrease by 0.8 °C (Rosenzweig et al., 2006). There are many other

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advantages on implementation of green roof such as noise reduction, increase of water run off quality. With regard to human interaction, green roofs provide recreational opportunities, add aesthetical values and improve the urban quality.

Green roofs also decrease the ambient air temperature during daytime and night time saves energy due to the enhancement of shading. For instance, a green roof have improve the surface temperature in Australia which was recorded by 90 °C previously because of several green roof variable such as foliage shading, soil thermal resistance, evapotranspiration, and so forth. (Williams et al., 2010). Therefore, the works of Wong et al. (2003) were the most relevant here. They determined how a green roof could influence the exterior surface temperature during the summer and winter and their temperature variation domain is lower inverse temperature fluctuation of typical flat roof. Although there are many studies ascertained the impact of green roofs on building energy performance, noise reduction, and increase of water run off quality many aspects are still not well understood, hence more studies on this subject are necessary. For instance, quantifying the impact of green roofs on indoor air temperature has not yet been examined with detailed models and under Malaysia climate condition.

The current study aims to evaluate the heat transfer through different roof types including extensive green roof by two different thickness and bare roof by using experimental study. In order to achieve this aim, experimental and empirical tests were conducted and the actual behaviour of green roof construction towards heat reduction in comparison with standard common roofs was identified. The specific objective was to explore the substrate thickness effects the improvement and heat transfer of vegetation roof in tropical climate of Malaysia.

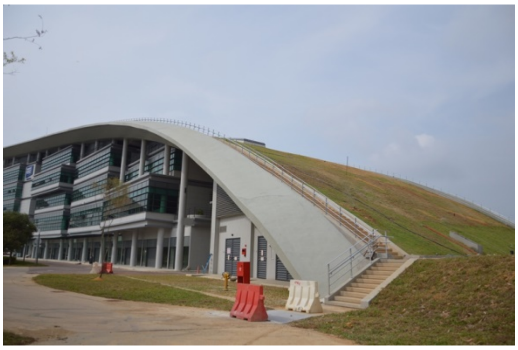

Figure 1: Heriot-watt University in Putrajaya.

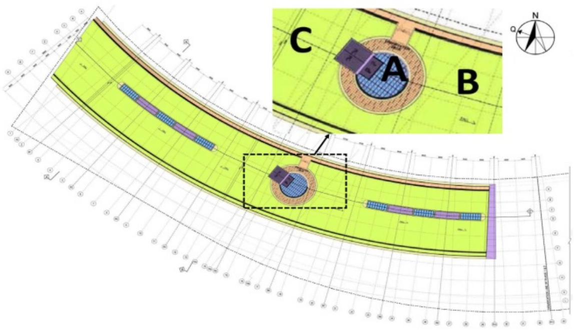

Figure 2: Layout of the rooftop garden

Figure 3: Soil temperature and RH sensors.

Figure 4: Surface temperature and RH sensors.

2. Methodology

The field measurement was carried out on the rooftop of the Heriot-watt University City campus which is the first purpose-built green campus in Putrajaya city (Figure 1). The building latitude is 2.8 °N and longitude is 101.6 °E. In this study, a bare roof as a reference and two types of green roof (with different thickness on their growing media) were measured, and the effects of garden roof with different soil deep were comparing with that typical flat roof. The roof top garden is an extensive one, which covers with grass as well as side pavement for accessing by visitors. Figure 2 shows the layout of the green roof and measuring points. The measurement were done from 1st April to 15th April 2016, a total of 15 d and the average of data used for analysis process. The rooftop of the building was divided into three areas represented by A, B and C. For every measuring point on the vegetation roof two sets of thermocouples were placed in two different depths to capture the soil temperature and soil moisture and reading were recorded every 10 min interval. Meanwhile one set of thermocouple was also placed in contact with the bare roof at zone A to record the hard surface temperature and moisture as well (see Figures 3 and 4). In the same time the ambient air temperature and relative humidity were measured at different heights above two different vegetation roof and bare roof respectively. The types and positions of sensors are mentioned in Table 1.

Table 1: Environmental sensors and installation position on the case study site

Area	Sensor	Measured environmental parameter and position
A	Air temperature sensor	Air temperature at 30,60 and 100 cm above the roof surface
	Relative humidity sensor	Relative humidity at 30,60 and 100 cm above the roof surface
	Surface temperature sensor	Concrete surface temperature
	Surface moisture sensor	Concrete surface moisture
B	Air temperature sensor	Air temperature at 30,60 and 100 cm above the roof surface
	Relative humidity sensor	Relative humidity at 30,60 and 100 cm above the roof surface
	Soil temperature sensor	Soil temperature at 28 cm depth
	Soil moisture sensor	Soil moisture at 28 cm depth
C	Air temperature sensor	Air temperature at 30,60 and 100 cm above the roof surface
	Relative humidity sensor	Relative humidity at 30,60 and 100 cm above the roof surface
	Soil temperature sensor	Soil temperature at 12 cm depth
	Soil moisture sensor	Soil moisture at 12 cm depth
Weather station	Air temperature sensor	Air temperature above the experimental area
	Relative humidity sensor	Relative humidity above the experimental area
	Pyranometer	Intensity of solar radiation
	Anemometer	Wind speed and wind direction above the experimental area

3. Data analysis

The aim of this study was to conduct a comparison between typical flat roof, extensive green roof with 12 cm soil thickness and extensive green roof with 28 cm soil depth for investigating the thermal performance of different types of roof as well as their ability to reduce the CO_2 emission. According to the field measurement results, the temperature range of the green roof with deeper soil thickness varies from 27.4 to 34.5 °C. Besides, there is a similar fluctuation of the temperatures of the lower soil depth green roof from 29.1 to 35.2 °C. Meanwhile, the highest temperatures are ranging between 24.9 to 60.7 °C and are captured from hard roof. Therefore, compared with two types of vegetated roof, considerably higher temperature was absorbed at the bare roof for the whole day.

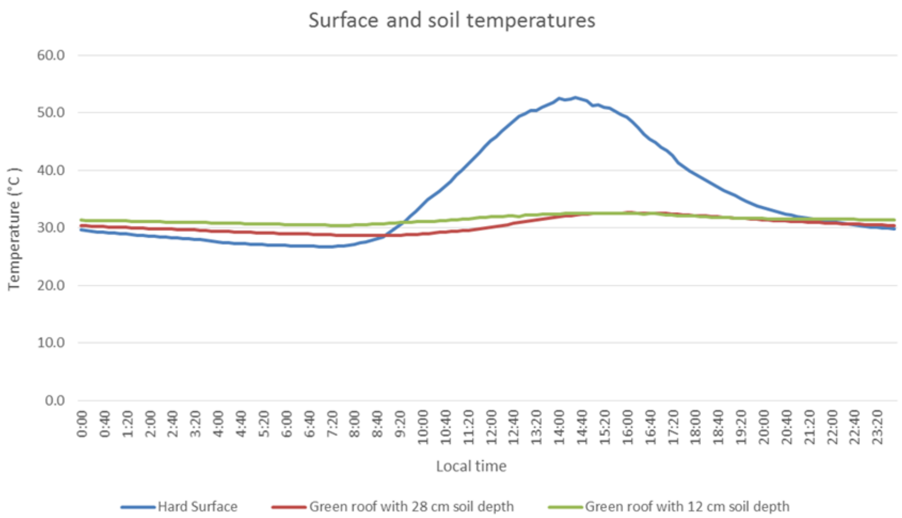

Figure 5: Surface and soil temperatures

Figure 5 shows these differences and illustrates the impact of roofing covered by vegetation on heat transfer through the roof. The comparison between the extensive green roofs with two different soil thicknesses ascertainment that preparation vegetated roof with growing medium which is more profound has significantly reduced the heat gain into the building (Figure 6). For the roof with typical flat surface, the heat transfer was subjected to fluctuation at different time of the day and, it is worth to mention that the heat gain during the daytime via roof surface will be inverse heat lost at night. Compared with bare roof, it is obvious that heat absorption were much lower with the presence of soil layer over a typical day. Meanwhile, some temperature differences can still be observed under different types of soil thickness. It was observed that temperature was lower at the thicker soil green roof over a typical day in comparison with the 12 cm soil layer.

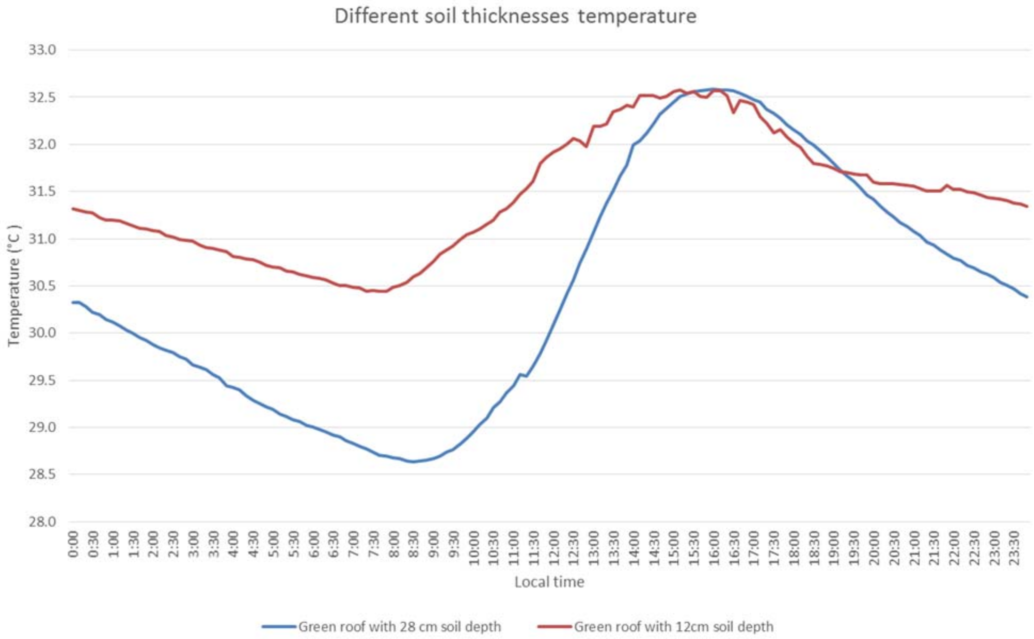

Figure 6: Different soil thicknesses temperature

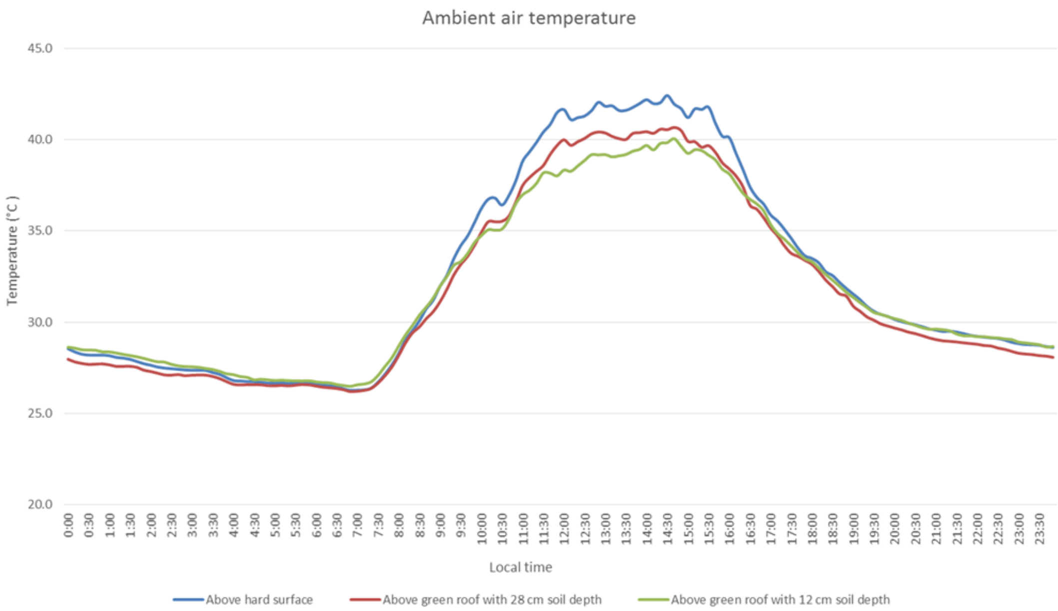

Figure 7: Ambient air temperature.

For every experimental zone, ambient air temperatures were measured at 3 different height, and the average of them calculated. Then the results are shown in Figure 7. According to the Figure 7 the high temperatures recorded from the closer distance to the surface in all experimental zones. The solar reflection was the main cause that the ambient air temperature above the hard surface is critically become obvious than vegetated roof during the day time and these differences were observed lower during the night. For mean ambient air temperatures measured above the different green roof and bare roof, sensors recorded 36.1 ^{0}C on top of the hard surface, 35.1 ^{0}C above the green roof with 28 cm soil thickness and 34.9 ^{0}C over the green roof with 12 cm depth during daytime and occurred around 28 ^{0}C at night for all the experimental areas.
However, the ambient air temperature could be higher during drought time when the sensors captured the lowest amounts of soil moisture in two different vegetated roofs. According to (Ondoño et al., 2016) higher water storage capacity of deeper substrate layer determine better performance of green roofs for carbon sequestration. The findings from this study also revealed a better moisture performance from green roof with 28 cm substrate layer in compare with 12 cm soil depth green roof. Based on this findings which shown in Figure 8, roofs with 28 cm depth would remain wet last longer and help to reduce carbon emission due to thicker substrates.

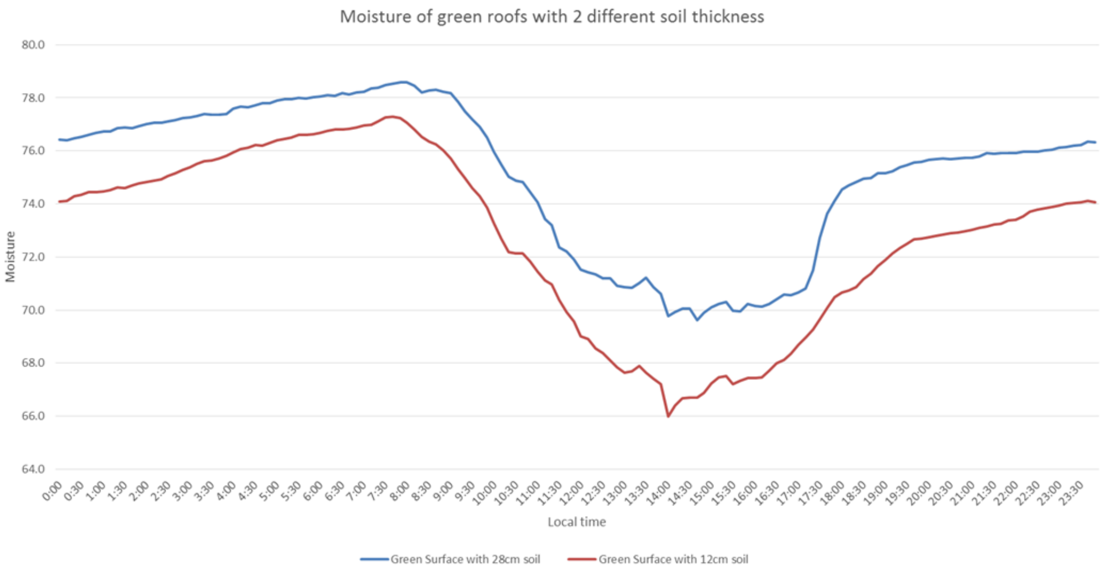

Figure 8: Moisture content of green roofs with 2 different soil thickness

4. Conclusion

The heat transfers from two vegetated roofs with different substrate thickness (12 cm and 28 cm) were studied over 2 weeks' experimental period and compared to a typical flat roof. The extensive green roofs provide lower surface temperature caused by the presents of soil layer, and therefore less heat is transfer through the roof. It is believed that thicker substrate improve the thermal performance of rooftop greenery as well as the capacity of green roof to sequester carbon.
However, during the drought periods, the peak soil temperature captured at 35.2 ^{0}C in compare with up to 60.7 ^{0}C during the time on the bare roof. Soil moisture observe through the experiment time indicate better performance of thicker soil for promoting the cooling effect of green roof. Besides, wet soil helps to boost soil capacity in CO_2 sequestration.
The results from ambient air temperature indicate that it could reach 46.2 ^{0}C above the 12 cm depth soil green roof, 47.3 ^{0}C on top of the 28 cm substrate thickness and captured at 49.2 ^{0}C above the hard surface. Among the field measurement in this study, it is found that vegetated roof with soil thickness of 28 cm, covered by grass performs best and giving the highest reduction of heat transmission. Overall, the results of this study are being continued to other parameters which could describe more environmental benefits.

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