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Green Roofs as Best Management Practices for Heat Reduction and Stormwater Flow Mitigation

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Abstract: Green roofs or vegetated roofs have many benefits for the environment. As on-site detention storage can also it can improve runoff water quality as well as reduce stormwater flow. This paper analyses the difference between two surfaces and the effect of green roof on stormwater flow. An experimental green roof plot was created on a main building where a Portable Automatic Weather Station (MAWS) weather station was already set-up on the green roof since February 2006. Nearby concrete layer was selected as a control site which is equipped with Thermometer-Stevenson Screen. Hourly data were plotted on graph paper. The formula developed by Rongfu was used to estimate the total rainfall retained by the green roof. The result showed that the green roof can reduce ambient air temperature up to 1.6°C. By using the 9.8 mm total rainfall as the threshold for the green roof to permit outflow from the main inlets, the total volume of rainfall retained by the green roof catchment was calculated at about 52,632 m^3. This large amount of rainfall means that the green roof could reduce the stormwater as well as peak flow at the drainage in heavy rainfall events. This technique can be a good option to reduce ambient air temperature and flashflood in tropical urban areas like Kuala Lumpur.

Key words: Green roof · Concrete top · Best Management Practices · Stormwater

INTRODUCTION

In an urban area, a high percentage of the precipitation is converted into runoff from an urban surface. The most primarily impervious elements in cities are roof tops and pavements [1]. The total runoff is sometimes referred to as stormwater or urban runoff and can be gauged in volumes and rates of flow based on individual storm events. Apart from the impact of flooding, urban stormwater has also been recognised as a major pollutant (especially in terms of sediment loads) to the receiving urban streams [2]. The quality and quantity of urban runoff depends on the nature of urban surfaces and the activities within them [3]. To address the problems of stormwater retention method and roof cooling effect while genrating other environmental benefits, researchers have developed a programme to encourage the use of green roofs in urban areas [4, 5].

Extensive green, or vegetated roofs are usually made-up of soil layer of < 15 cm depth and covered by vegetation. Typically, a designed green roof has complex structures which include filter membrane, drainage layer, support panel, thermal insulation and vapor control layer [6]. The importance of green roof can be seen from its benefits such as increasing roof life period, providing retention of stormwater or reducing urban rainfall runoff [4, 7, 8], reducing maximum air temperature in order to mitigate urban heat island effect and reducing the energy costs for cooling or heating of buildings [4, 9-14]. Apart from that, green roofs can be a useful technique for air quality improvement in the cities, increased acoustic insulation, improved urban aesthetics, community green space [2] and habitat for wildlife in urban area [15, 16, 17]. The objectives of this article are two-folds: (1) to analyze the temperature differences between green roof and concrete tops and (2) to analyze the effect that green roofs can have on stormwater runoff volume during heavy rainfall events.

MATERIALS AND METHODS

The Study Area: One flat concrete top of the Universiti Kebangsaan Malaysia (UKM) main building was chosen to install Thermometer-Stevenson Screen for monitoring

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hourly temperature and relative humidity of the concrete surface. The area was about 61.44 m^2 and roughly a rectangular in shape. The site was located at about 50 m above the ground whereby underneath of the site was a lecture hall and lobby area. An open space with a few trees was located on the west side of this area. Meanwhile, lecturers' rooms (main building of the faculty) were located on the south side of the concrete top. The block B wing was joined with the main faculty building by a corridor on the east side of the concrete top. For measuring temperature on green roof, one experimental plot was created on the top of the main passage way from the faculty of Social Sciences and Humanities building to the students' activities complex (PUSANIKA). Generally, this extensive green roof was made-up of about 15 cm depth of soil layer, lightweight in nature and covered mainly by the grass species of *Axonopus compressus* or known locally as *rumput sundal* and *Desmodium triflorum* or *rumput barek sisek putin*. The area was approximately 645 m^2 and located about 50 m from the ground level. The site had 51 m long drain located along the north side of the area. The diameter of the drain was 0.5 m with a depth of 0.5 m. There were 31 rainfall outlets along the drain.

Data Collection: Temperature and relative humidity were recorded at both sites from 15th February to 20th March 2006. Climatic data for the green roof area were detected and recorded by sensors of Portable Automatic Weather Station (MAWS), which is operated by solar panel. All these climatic data were stored in data logger and then transferred to computer for processing and analysing.

Temperature and relative humidity at the concrete top were measured by thermometer and hairhygrograph, respectively. These instruments were operated by clock drum and placed inside the Stevenson screen at about 1.5 m above the concrete surface. Chart paper was placed around the clock drum to detect the temperature and relative humidity for a week and a new chart paper will would be placed to record the data for the following week. Meanwhile, infiltration rainfall data were collected after rain from the 31 rainfall outlets.

Data Analysis: The formula developed by Rongfu [18] was used to calculate the total rainfall volume. In order to find rainfall depth (mm), rainfall volume must be calculated first (measured in m^3/s, cumecs) as well as the total area of the catchment (green roof measured in km^2). Apart from that, various types of vegetation must be identified, especially grass that can be found on the green roof.

The daily rainfall (in mm) was converted into daily estimated flow (in m^3/s or cumecs) by using a formula proposed by Rongfu [6]:

$$R_d = (R_v \times 24 \times 60 \times 60 \times 1000)/A \times 1000^2 = (86.4 \times R_v)/A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(i)}$$

or

$$Rv = (R_d.A)/86.4$$

Where,

R_d = Rainfall depth (mm)
R_v = Rainfall volume (m^3/s, cumecs)
A = Catchment area (km^2)

The conversion was to make possible the study of the retention storage of water in the green roof catchment.

RESULTS AND DISCUSSION

In general, both surfaces have different value of hourly mean temperature, i.e. 28.8°C for the concrete top and 27.5°C for the green roof with the difference of approximately 1.3°C (Figure 1). Both surfaces displayed almost similar hourly trends with the temperatures of the concrete top always higher than those of the green roof, except for a few hours after midday. However, the temperature differences between both surfaces reached its maximum value of ± 3.0°C around 0800-1000 hr. Perhaps, the release of latent heat from the green roof reached its maximum during this time of the day, thus accidentally caused the lowest temperatures to prevail at the green roof. On the other hand, during the same time, the concrete top began to absorb heat, hence the marked temperature increase.

The negative temperature differences between both surfaces during the evening could be due to the slowing down of the photosynthesis process which used up energy from the sun, CO_2 from the atmosphere and H_2O from the soil. Besides, evapotranspiration process was perhaps at its minimum, leaving excessive heat stored in the soil. This increased the heat storage in the green roof significantly as high temperatures prevailed during the evening over this surface. Another possible explanation is that soil moisture could delay the release of latent heat at the green roof as compared to the concrete top. Hence, the surface maintained its high temperatures for a few hours in the evening.

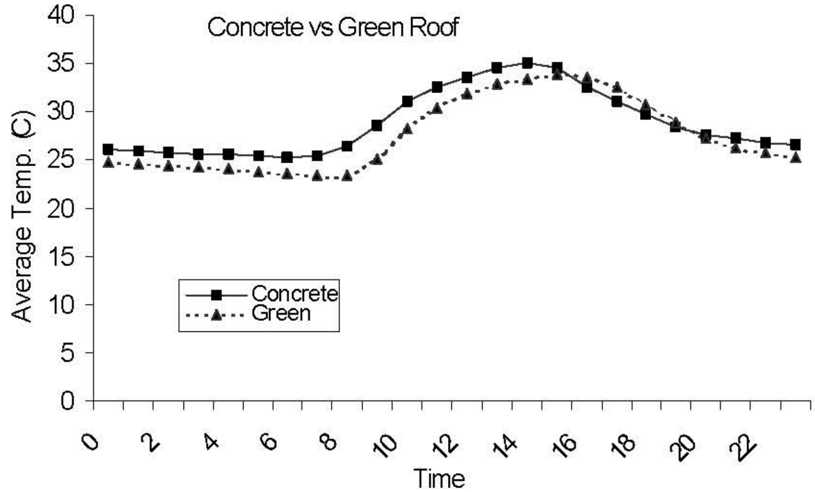

Fig. 1: Average hourly temperature between two surfaces (15 Feb - 20 March 2006)

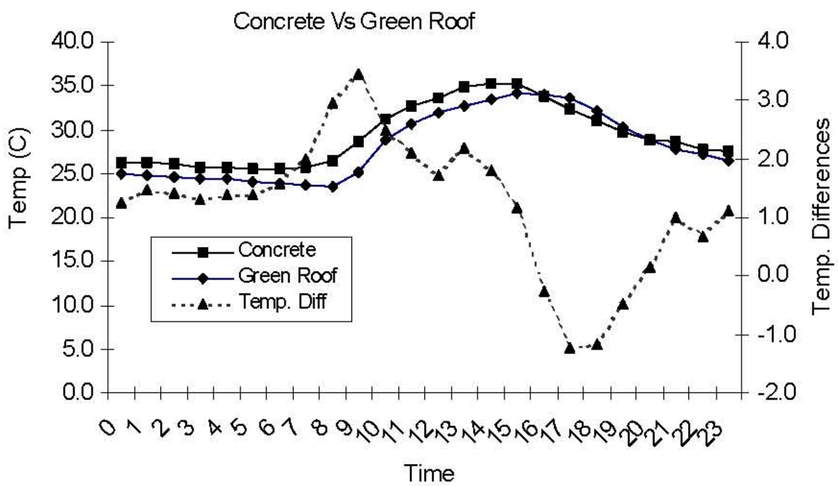

Fig. 2: Average hourly temperature in non-rainy period (15 Feb - 20 March 2006)

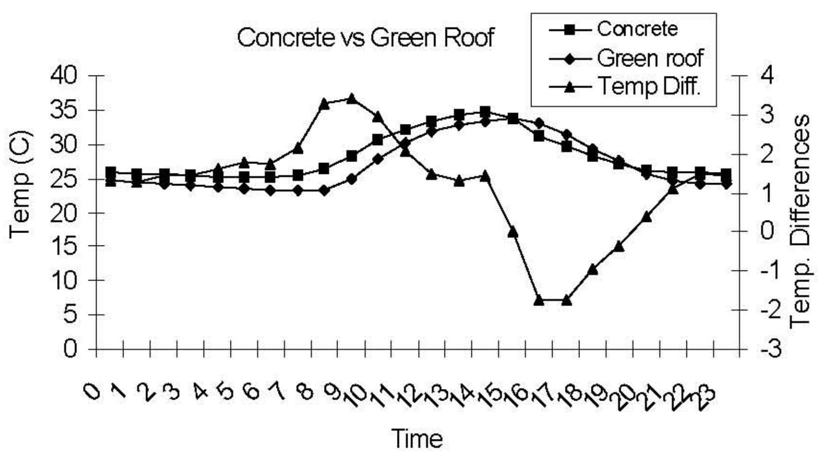

Fig. 3: Average hourly temperature in rainy period (15 Feb - 20 March 2006)

Basically, there were no significant pattern changes between rainy and non-rainy periods (Figure 2 and 3). However, based on hourly variation, the highest peak was revealed at 09:00 hr, whereby the temperature difference reached almost 3.5°C.

It is no exaggeration to say that from the results of the study a green roof with several cm thicknesses of soil layers and covered by grass is capable of reducing ambient air as well as indoor temperatures. Understandably, when a green roof is installed on a flat top building such as the one studied, there is a layer of soil and vegetation that does several things for the buildings. First, the soil and vegetation protect the water proofing membrane of the roof from UV radiation, mechanical damage and harsh weather conditions. This will extend the life span of the roof, which resulted in low maintenance and replacement costs over time.

Second, the soil layer in a green roof may also provide a range of thermal insulation, which may result in reduced energy consumption and initial equipment size [19]. A standard or concrete roofing system has a surface which absorbs heat from the sun during the day and radiates it back to space at night as latent heat. The otherwise large fluctuations in temperature often cause damage to roofing membrane and increase the energy consumption of the cooling equipment. Hence, the green roof's soil and vegetation layers play their role in reducing thermal transferring across roof system.

Based on the 11 March 2006 data reading, it was observed that the total rainfall of 9.8 mm was the threshold for the green roof to permit outflow from the main inlets. This is because there was no antecedent rainfall within 48 hours. This means that the rainfall value of more than 9.8 mm will permit outflow as the soil infiltration capacity is maximum at that figure.

By using formula (i), the estimated flow (rainfall volume in m^3 or cumecs) on 11th March 2006 (total rainfall = 9.8 mm) may be calculated as follows:

$$Rv = (R_d.A)/86.4 = (9.8 \times 6.45 \times 10^{-4})/86.4 = 7.31 \text{ m}^3.$$

The duration of rainfall at the event was 2 hours or 2 x 60 x60 = 7,200 second. Thus, the total volume of rainfall that has been retained by the green roof catchment is = total rainfall volume = 7.31 x 7,200 = 52,632 m^3.

In this study, a large amount of flow has been retained by the green roof catchment area due to the infiltration and seepage processes. As such it would be a good management practice to reduce the stormwater as well as the peak flow at the drainage in heavy rainfall events.

CONCLUSION

In conclusion, the effect of green roof in temperature reduction as compared with concrete top is quite clear. In general, green roof can lower the ambient air temperature as high as 1.5°C throughout a day and slightly pronounced during non-rainy day (1.6°C) as compared to rainy day (< 1.5°C). In addition, the effects of green roof on temperature reduction can be further studied by identifying soil types and soil layers, thickness of the soil, soil moisture content, type of vegetation and heat loss gain.

In terms of stormwater retention, it was shown that the green roof or eco-roof method could reduce peak flow and its magnitude as well as improving the water quality through soil infiltration and seepage process. Even though this study did not monitor the detail outflow, it showed that the rainfall volume of less than 9.8 mm was totally intercepted by the soil layer. Therefore, with the green roof area of about 645 m^2 and the soil depth of about 15 cm, the total rainfall of 8.9 mm is considered as a threshold value at which the green roof can store rain water. However, the significance of extensive green roofs to reduce ambient air temperature and retain the stormwater runoff is much dependent on the type and characteristics of the vegetation, soil structure and thickness and management of the area. It is also important to carry out the study for a longer period in order to obtain more meaningful results [20].

This preliminary study implies that to a certain extent an extensive green roof method is a good management practice for reducing ambient air temperature and stormwater discharge. Therefore, there is a need for the authorities such as the planning department of the Kuala Lumpur Cityhall to impose a regulation to all developers in the government and private sectors to include an extensive green roof technique in their housing projects. This is to ensure that the benefit of extensive green roofs, particularly in reducing ambient air temperature and stormwater discharge in urban areas can be realised in the near future. Furthermore, the retained and filtered water from the green roofs can be used for other external household chores, such as car washing, plant watering and drain cleaning, that would contribute to the reduction of the household water bill.

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