Effects of slopes on the stormwater attenuation performance in extensive green roof

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Abstract. This study is aimed to determine the effects of slope on stormwater retention and peak flow attenuation performances in extensive green roof in Malaysia. One green roof test bed with dimensions of 2.0 m (length) x 1 m (width) x 0.2 m (height) was constructed in Universiti Tenaga Nasional. The substrate layer was fixed as 130 mm depth and placed on top of the filter fabric and drainage layers. The green roof test bed was planted with Portulaca Grandiflora (sedum species) as the native plant in Malaysia. Different slopes (0 º, 2 º, 5 º and 7 º) of green roof test bed were tested in this study for its stormwater retention and peak flow attenuation performances. The results show that stormwater retention percentages are ranged from 56.9% to 52.3%. The stormwater retention percentages are decreased as slope increased in this study. Flat slope showed the longest observed time of peak flow while the 7 º slope has the shortest observed time of peak flow. This finding suggests that slope has a significant impact to the stormwater retention and peak flow attenuation performances in extensive green roof.

1. Introduction

The urbanization process is taking place rapidly in the recent decades and the urban city population growth is expected to reach 85% by 2030 [1]. The impervious surfaces such as street, building and roof have changed the hydrological processes in the natural catchment which cause the increased of runoff volume, decreased evapotranspiration and ground water recharges, as well as enhancing river channel erosion [2,3,4,5]. As the impervious surfaces are increasing, more frequent flash floods will be happening in urban city. Rooftop and road systems commonly account for 80% of all the impervious surfaces in the urban area [6]. Rooftop runoff poses a greater threat to water quantity in urban catchment than rural catchment as the runoff can enter the receiving water bodies more rapidly due to the greater connectivity of roofs to gutters and drainages.

Green roof have been introduced as a sustainable stormwater management technology to control the urban stormwater runoff. Green roofs have been widely implemented in many temperate countries like European countries, USA and Canada. Numerous studies had proved that green roofs can effectively reduce the peak flow and extend the delay of stormwater runoff [7,8,9,10,11,12,13,14,15,16]. The runoff can be delayed between 10 min [13,17,18] to 4 hours [19] from the green roofs if compared to conventional roofs of which the runoff is nearly instantaneous. Carter and Rasmussen [20] observed 57% of peak flow in a vegetated roof was delayed up to 10 minutes as compared with that from a conventional roof. Liu [7] found that runoff from the green roof was reduced to 0.5 mm/h when the initial rainfall was 2.8 mm/h. Meanwhile, Moran et al. [9] in North Carolina, USA found 57% to 87% reduction in flow rates from a green roof. Fassman-Beck et al. [21] monitored four green roofs (depth 5-15 cm) in New Zealand and observed 73% to 89% of peak flow reduction compared to control roofs. Alfredo et al. [22] also found 22% to 70% reduction in peak discharges from green roofs compared to the control roof.

Though green roofs is widely implemented in many developed countries, climatic variations between the temperate and tropical regions have hindered the direct transferal of roof designs, substrate specifications, and plant species. Therefore, it is important to carry out local study on the green roof system with regards to its suitable plant species, substrate composition and roof designs [23]. Choosing native plants in green roof systems will provide many benefits such as better adaption to local condition, require less watering, low maintenance, increase biodiversity as well as more aesthetically pleasing than non-native plant. The roof design is also very important for tropical countries like Malaysia as it subjected to short and frequent high intensity storm events. The research related to the green roof systems is still lacking in Malaysia. Therefore, this study is carried out to determine the effects of slope on stormwater retention and peak flow attenuation performances in extensive green roof in Malaysia.

2. Methodology

2.1. Setup of experimental green roof

This experiment was conducted at the civil engineering laboratory in Universiti Tenaga Nasional (UNITEN). The dimension of green roof test bed is 2.0 m length x 1 m width x 0.2 m height, and installed at a height of 1m above the ground level. Figure 1 shows the experimental green roof test beds that established in this study.

Fig. 1. Experimental green roof test beds that established in this study.

The typical potting soil was chosen in this study for investigating its stormwater retention performance and attenuation of peak flow. The choice of this substrate type was based on its availability and popularity as common horticultural substrate used by the local landscaping industry. The substrate layer was fixed as 130 mm depth and placed on top of the filter fabric and drainage layers (Fig. 1). The green roof test bed was planted with Portulaca Grandiflora (sedum) as shown in Fig. 1. All surface areas inside the green roof test bed were ensured that 100% covered by the respective plant. Different slopes (0 º, 2 º, 5 º and 7 º) of green roof test bed were tested in this study for its stormwater retention and peak flow attenuation performances.

2.2. Data collection and analysis

An artificial rainfall simulator was installed at 0.5 m height above the green roof test bed. The simulated rainfall was set to run for 5 minutes duration and time was recorded after the rainfall initiated. A total of 400 liter of simulated rainfall volume was poured onto the green roof test bed during the experiment. Once the first runoff is observed, time was recorded for each experiment. The stormwater runoff that discharged from drainage layer within the green roof test beds was drained out by using a PVC pipe. A runoff harvesting tank was placed under the green roof test beds and connected to the PVC pipe in order to collect the runoff from green roofs. The water volume in the runoff harvesting tank was measured and time of each measurement was collected simultaneously during the simulated rainfall period. The measured runoff volume and time were converted to runoff flow rate in order to plot the hydrograph for each experiment.

Fig. 2. Simulated rainfall (a) and measurement of flow rate (b) during the experiment.

The stormwater retention percentage of green roof is generally calculated by dividing the difference between rainfall and runoff depths with the total rainfall depth as shown in Equation 1.

$$Retention\ (\%) = \frac{Rainfall\ (mm) - Runoff\ (mm)}{Rainfall\ (mm)} x\ 100\% \qquad \text{Equation 1}$$

The curve number (CN) is calculated for every green roof test bed by using Equation (2):

$$CN = \frac{25400}{254 + S} \qquad \text{Equation 2}$$

Where, S = rainwater retention in soil (mm)

The hydrograph for each experiment with respect to different slope values (0 º, 2 º, 5 º and 7 º) was plotted in order to determine the peak flow rate and time to peak flow.

3. Results and discussions

The effects of slope on the stormwater retention performance and delay of peak flow have been investigated during a 3 month study in Universiti Tenaga Nasional. The stormwater retention percentage is calculated for every storm event monitored in each green roof configuration. The stormwater retention percentages are ranged from 56.9% to 52.3%. The highest stormwater retention percentage is observed at the 2 º slope (56.9%) while the least at the 7 º slope (52.3%). It is observed that stormwater retention percentages are decreased as slope increased in this study. The cumulative runoff depths for green roof test beds with different slope values are presented in Fig. 3. The curve number was also calculated for each green roof slope in the study. The curve numbers for 0 º, 2 º, 5 º and 7 º slopes are 81.7, 81.8, 82.0 and 82.9, respectively. The curve number started to show significant different at the 7 º slope. All of these curve numbers are lower than a conventional roof curve number of 98. Using these curve numbers in the equation CN= 25,400/(254 + S) and solving for potential retention (S) we find that S ranges from 52.3 mm to 56.9 mm. These findings are greater than that reported by Carter and Rasmussen [20] who found a curve number of 86 (S=40.5 mm) for a green roof with <2% slope and 7.62 cm of substrate. This may be due to difference in substrate depth, antecedent substrate moisture status and rainfall pattern [24]. The hydrographs for every green roof configurations are shown in Fig. 4. Great variations were observed for the time of peak flow in green roof with respect to different slopes. Flat slope (0 º) showed the longest observed time of peak flow. Meanwhile, the 7 º slope exhibited 45% faster than the observed time of peak flow in flat slope. The magnitude of peak flow for 7 º slope is 1.75 time greater that the peak flow in flat slope. This finding suggests that slope has a significant impact to the attenuation of peak flow in extensive green roof.

Table 1. Water retention percentage, curve number and observed times of runoff

Slope (º)	Water retention percentage (%)	Curve number	Observed time	
			First runoff	Peak flow
0	56.9	81.7	11 min 5 s	23 min 5 s
2	56.4	81.8	9 min 23 s	19 min 23 s
5	55.9	82.0	7 min 46 s	15 min 46 s
7	52.3	82.9	4 min 37s	12 min 37 s

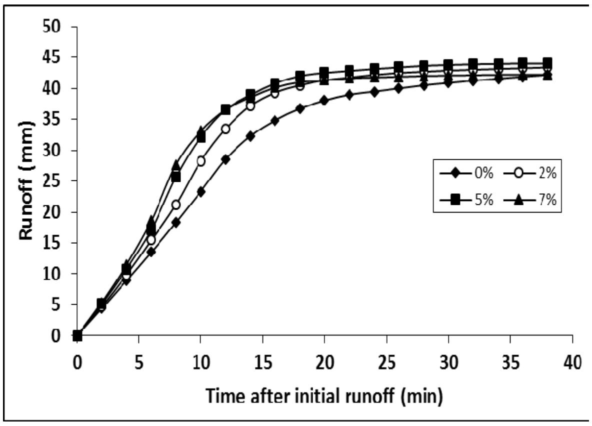

Fig. 3. Cumulative runoff depths for green roof test beds with different slope values

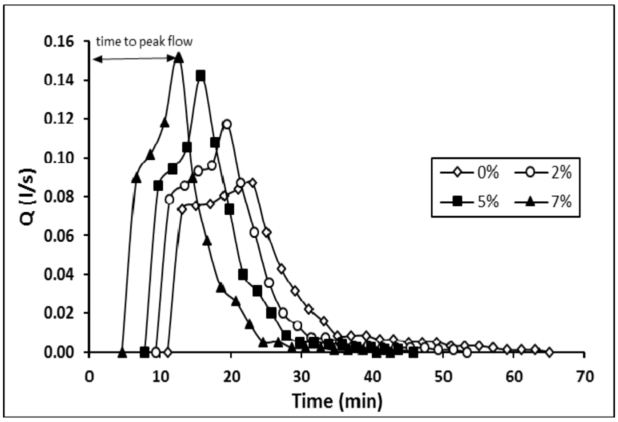

Fig. 4. Hydrographs for green roof test beds with different slope values

4. Conclusions

This study has investigated the effects of slope on the stormwater retention performance and delay time of peak flow in extensive green roofs. The results showed that green roofs with 0 º and 7 º slopes exhibited the highest and lowest stormwater retention percentages which recorded 56.9% and 52.3%, respectively. Flat slope showed the longest observed time of peak flow while the 7 º slope has the shortest observed time of peak flow. The magnitude of peak flow for 7 º slope is 1.75 time greater than the peak flow in flat slope. This finding suggests that slope has a significant impact to the stormwater retention and peak flow attenuation performances in extensive green roof.

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