Journal of Engineering and Applied Sciences 13 (Special Issue 3): 3183-3187, 2018
ISSN: 1816-949X

The Effect of Green Roof Configurations on Runoff Retention Performance

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Abstract: This study focused on the runoff retention performance within extensive green roof system with respect to different native plant species and configurations in Malaysia. A total of four green roofs were constructed with two configurations (with drainage and without drainage layers) and each test bed was planted with *Portulaca grandiflora* cultivars (sedum) and *Axonopus compressus* (cow grass), respectively. The runoff volume was measured volumetrically and water retention percentage was calculated for four monitored events at each green roof configurations. Results showed that sedum was the most effective native plant species in retaining runoff water. The green roof configuration with sedum planted in substrate and layers performed the best runoff retention efficiency in Malaysia.

Key words: Extensive green roof, native plant species, runoff retention performance, tropical climate, storm, drainage

INTRODUCTION

Rapid urbanization and industrialization processes especially in developing countries like Malaysia have significantly reduced the natural catchments in the last decades (Yusof and Johari, 2012). This situation is alarming as the urbanization level in Kuala Lumpur (Capital city of Malaysia) is expected to reach 83% in 2030 (United Nations, 2002). Increasing impervious areas as a consequence of streets, driveways and buildings constructions have affected the hydrological and environmental conditions of the existing catchment (Abdul, 2012). The direct hydrological impacts from urbanization process are including increased storm water runoff volume, decreased ground water recharge, changes of river morphology as well as enhancing soil erosions (Stone, 2004). The pollutant loadings that generated from anthropogenic activities are increased simultaneously with urban stormwater runoff and subsequently causing the aquatic environmental problems (Carter and Rasmussen, 2005). Furthermore, the uncertainties of rainfall due to climate change have affected the water security in the urban city (Ghahraman, 2013; Khordadi *et al*., 2015; Dariane, 2003).

Sustainable development in urban city is greatly needed for ensuring the livelihood of next generations. In the recent years, green roof is promoted as an effective measure for urban stormwater management as well as providing many environmental benefits (DID., 2001; Chow and Baker, 2016). The environmental benefits of green roofs are including electricity energy saving (Saadatian *et al*., 2013; Kamarulzaman *et al*., 2014) increase amenity and aesthetic values of building effective stormwater runoff control (Liptan, 2003; Kok *et al*., 2016; Musa *et al*., 2008; Kasmin *et al*., 2014; Chow *et al*., 2015) decrease urban air temperatures (Shaharuddin *et al*., 2011) improve urban air quality, enhanced removal of urban stormwater and air toxic pollutants, reduce noise pollution in urban environments and mitigation of urban heat island effects (GSA., 2011).

Designing green roof system requires multi disciplines knowledge in terms of plants biology, hydrology, engineering and architecture. Critical aspects of green roof design must be included such as total weight of green roof systems, technical design of green roof structures, suitability of planted vegetation and the rainfall condition at the regions. As the green roof technology is becoming more popular, more studies are needed as the green roof plant species respond differently to climate and rainfall conditions (Volder and Dvorak, 2014). It is also feasible to identify the

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differences in runoff retention performance related to the specific roof configuration. Thus, this study was aimed to determine the runoff retention performance of different configurations for extensive green roofs in Malaysia. Green roof system is a new concept of urban design and planning in Malaysia. More understandings and knowledge are required on the technical design aspects and suitable plant species that can endure the harsh environment of tropical climate. Therefore, there must be research conducted as the way to promote sustainable and livable urban cities in Malaysia.

MATERIALS AND METHODS

This study was carried out at the rooftop level of College of Engineering building in Universiti Tenaga Nasional (UNITEN). Four test beds which vary systematically in their configuration and plant species were established at the experimental site (Fig. 1). The dimension for each green roof test bed is 0.8 m (length)×0.5 m (width)×0.2 m (height) and lifted at height of 0.8 m from ground level. The selected plant species for this study are *Axonopus compressus* (cow grass) and *Portulaca grandflora* cultivars (sedum) as shown in Fig. 2. This vegetation types are the native plant species in Malaysia that can survive in extreme weather condition. The planted vegetation in each test bed was ensured to cover 100% of substrate surface by the end of growing season. To maintain species composition, any plants not planted that germinated in the test bed were removed by hand once or twice a month during the study period. The two designed configurations for green roof system are shown in Fig. 3 Green roof configuration is consists of vegetation, substrate, filter fabric and drainage layers while green roof configuration is consists of vegetation and substrate layers only. The depth of substrate for green roof configuration is 125 while 150 mm for green roof configuration. The physical characteristics of substrate that used in this study are summarized in Table 1. Two test beds with no vegetation (bare ground) were also prepared for green roof configuration as a control. Hydrological and atmospheric data such as rainfall and air temperature were collected from a weather station that installed at the study site. Stormwater runoff volumes from test beds were collected by using an infiltrated runoff harvesting tank. Water retention volume was calculated by subtracting the rainfall volume with runoff volume.

Fig. 1: Experimental green roof test beds at the rooftop level of college of engineering building, UNITEN

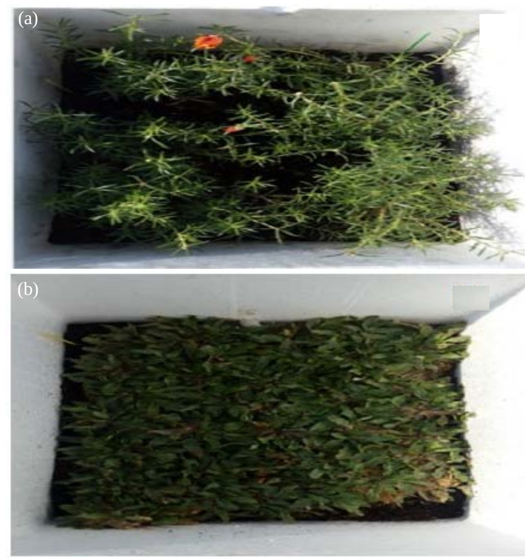

Fig. 2: Plant species for extensive green roofs; a) *Portulaca grandflora* cultivars (sedum) and b) *Axonopus compressus* (cow grass)

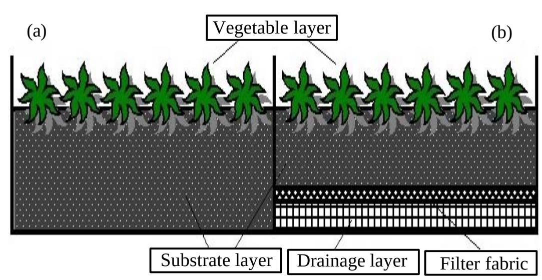

Fig. 3: Green roof configurations; a) Vegetation with substrate layer only and b) Vegetation with substrate, filter fabric and drainage layers

Table 1: Physical characteristics of green roof substrate

Parameters	Values
Organic content (%)	6.33000
Permeability of soil, k (mm/sec)	0.00075
Specific gravity (Gs)	1.70000
Density of soil (Full saturation) (Mg/m^3)	0.51900
Dry density of soil, pd (Mg/m^3)	0.09500
Void ratio, e = ((Gs×Pw)/Pd)-1	16.89500
Porosity, n = (e /(1+e))	0.94400
Water content (w)	0.14800
Maximum water holdingcapacity, Sr = (wGs)/e	0.01500
Air voids content, Av = (e-wGs)/1+e	33.53800
Particle density, Mw = Sr e Pw	0.25100

RESULTS AND DISCUSSION

Monitored storm events: The rainfall depth for monitored storm events was collected at the experimental site during the study period. A total of twelve storm events were recorded in the months of March, November and December at the study site as shown in Table 2. The highest rainfall amount is recorded for storm events on 23th November which has a total rainfall depth of 56 mm. On the other hand, storm event on 24th March recorded the lowest rainfall amount which is only 0.5 mm. The rainfall volume was calculated for each storm event at green roof test beds during the monitoring period and the results are summarized in Table 2.

Runoff retention performance analysis: The runoff volume collected from each storm event at every test bed was measured and compared with the rainfall volume. The runoff volume results for green roof configurations A and B are showed in Fig. 4 and 5, respectively. The amount of rainfall volumes for events 5 and 6 were relatively small and no runoff volumes were observed at both green roof test beds. No runoff volume was collected for event No. 3 at green roof configuration A due to technical problem of runoff harvesting tanks.

The runoff retention percentage for green roof with different configurations was analyzed and the results are presented in Table 3. The results showed that the green roof configuration A were able to retain most of the rainwater amounts with retention rate ranges from 80.4-84.7%. Meanwhile, the runoff retention percentages for green roof configuration B were varied from 3.23-77.81%. Apparently, the test beds that planted with sedum showed higher capability to retain the rain water compared to cow grass for both configurations during the study period. The mean retention percentage for sedum at configuration A and B is 84.3 and 55.5%, respectively. On the other hand, the mean retention percentage for cow grass at configurations A and B is 80.5 and 34.8%,

Table 2: Rainfall depths and volumes for each storm event at green roof test beds

Dates	Rainfall depth (mm)	Rainfall volume (L)
Green roof configuration (A)		
5 Mar.	9.3	3.72
10 Mar.	10.1	4.04
13 Mar.	19.0	7.60
20 Mar.	9.8	3.92
21 Mar.	1.4	0.56
24 Mar.	0.5	0.20
Green roof configuration (B)		
22 Nov.	8.0	1.13
23 Nov.	56.0	7.88
26 Nov.	8.0	1.13
28 Nov.	27.0	3.80
3 Dec.	1.0	0.14
4 Dec.	1.0	0.14

Table 3: Runoff retention percentage for green roof configuration A and B

Events	Grass	Sedum
Green roof configuration (A)		
1	80.4	83.9
2	80.7	84.7
3	N/A	N/A
4	80.4	84.2
Mean	80.5	84.3
Green roof configuration (B)		
1	11.22	42.29
2	72.10	77.81
3	3.23	28.09
4	52.65	73.70
Mean	34.8	55.5

N/A: Data Not Available

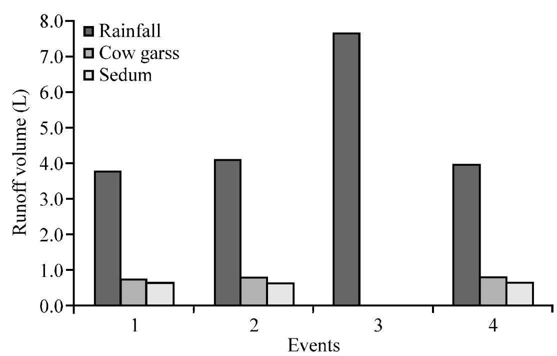

Fig. 4: Rainfall and runoff volumes for 4 monitored storm events in green roof Configuration B

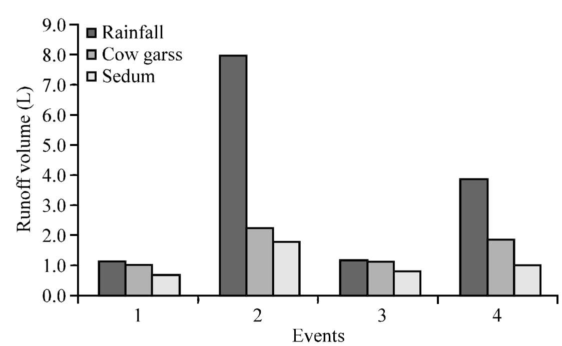

Fig. 5: Rainfall and runoff volumes for 4 monitored storm events in green roof Configuration B

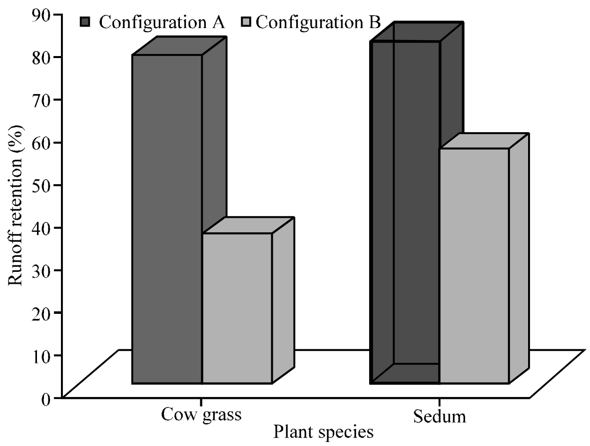

Fig. 6: Average runoff retention percentage for green roof configuration A and B

respectively. It was shown that vegetation had a great influence on the runoff retention performance. The monoculture of sedum in green roof test bed with drainage layer is more effective at reducing the water runoff by averagely retaining 84.3% of runoff water. In contrast, the average percentage of runoff water retained by sedum planted in test bed without drainage layer was less capable to retain the rainwater which only performed 55.5% of retention rate. Overall, the test bed of sedum planted in substrate with filter fabric and drainage layers was the most effective green roof design at retaining water runoff. The results also suggested that the retention rate of green roofs was depended on types of plant species and availability of drainage system (Fig. 6).

CONCLUSION

The results in this study have shown the runoff retention performance of two green roof configurations in Malaysia. Based on the findings in this study, it is proved that green roof with drainage layer performed better in retaining runoff water in Malaysia. The monoculture of *Portulaca grandiflora* cultivars (sedum) has proved that it has higher rainwater runoff retention efficiency compared to cow grass within the extensive green roofs. Overall, the test bed of sedum planted in substrate with filter fabric and drainage layers was the most effective design at retaining rainwater runoff.

RECOMMENDATIONS

Further research on other types of substrates and plant species is necessary in order to find the ultimate substrate and plant species that have the best hydrological performance for extensive green roofs in tropical country.

ACKNOWLEDGEMENTS

The researchers would like to thank Ministry of Higher Education, Malaysia (MOE) for providing the research grant (Vot No. 20140130FRGS) and Universiti Tenaga Nasional (UNITEN) for supporting this research.

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