Recent Trends in Civil Engineering and Built Environment Vol. 4 No. 3 (2023) 439-446

RTCEBE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN :2773-5184

Green Roof Performance in Rainfall Runoff Reduction

Amelia Hathirah Amaram[1], Noor Aliza Ahmad[2]*,

[1]Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Senior Lecturer, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia

DOI: https://doi.org/10.30880/rtcebe.2023.04.03.047
Received 06 January 2022; Accepted 15 May 2023; Available online 31 December 2023

Abstract: The process of urbanization may result in a dramatic shift in land use from permeable to the impermeable surface. The new construction of buildings in emerging areas has been connected to urban flood events. The increasing stormwater runoff is a significant concern associated with urbanization. Malaysia's climate is regarded to be dry and hot all year. It is prone to floods and flash floods, particularly during cyclical monsoon cold surge events. Green roofs have the potential to reduce flooding risk by reducing water runoff. The aim of this study is to observe the performance of green roofs in reducing water runoff quantity and to study the effectiveness of green roofs in delaying water runoff. The result showed that green roofs manage to produce a lower average volume of water runoff the range of 0.440 L/m^2 to 0.464 L/m^2 of water runoff from 1.0 L of stormwater in both events. Green roof manages to delay an average of up to 15.3 minutes to release water runoff. Green roof also capable to retain stormwater runoff where it can retain in range of 53.6% to 56% of water runoff. Overall, green roof may become an alternative in reducing water runoff and for a better result, a detailed experiment should be conduct.

Keywords: Green Roof, Water Runoff Quantity, Water Runoff Management

1. Introduction

The growing urban population as a result of rural-urban migration has aided in the growth and expansion of cities. While the economic benefits of urbanization are apparent, the process of urbanization may result in a dramatic shift in land use from permeable to impermeable surface [1]. Apart from that, the new construction of buildings in emerging areas has been connected to urban flood events. Numerous experts contend that increasing stormwater runoff is a significant concern associated with urbanization. Thus, sustainable building design and construction have been vigorously advocated in a number of nations in order to reduce as many environmental concerns as possible, most notably those related to stormwater management. Sustainable or green buildings are constructed using eco-friendly technology. It is a component of Best Management Practices (BMPs) or Sustainable Urban Drainage Systems (SUDS), which are advocated in a large number of nations and locations across the globe. Malaysia's climate is regarded to be dry and hot all year, with significant rain at specified seasons.

**Corresponding author: aliza@uthm.edu.my*

Because of its geographical position and average annual rainfall of approximately 2000 mm, it is prone to floods and flash floods, particularly during cyclical monsoon cold surge events, which are marked by heavy rainfall from around November to February [3]. Green roofs have the potential to reduce flooding risk by reducing water runoff [2].

To overcome this problem, a study will be conduct to evaluate the ability of green roofs to meet stormwater management system criteria. Green roofs are classified as a component of stormwater management's site control component. As a site control component, it functions similarly to the perimeter swale, except that the green roof may catch precipitation before it reaches the ground, while the other components cannot. This system will delay the flow of water before it reaches the ground. As a result, it provides a lag period for existing drainage systems to transport ground surface runoff first. Green roofs may be utilized in conjunction with other SUDS or best management practices to improve the quantity of stormwater runoff. Hence, the aim of this study is to observe the performance of green roofs in reducing water runoff quantity and to study the effectiveness of green roofs in delaying water runoff.

This study is conducted to observe the performance of green roofs in water runoff. This study is focused on intensive green roofs and conventional roofs as control. It involved a physical model of green roof and conventional roof constructed at Kemaman, Terengganu. The experiment was conducted using artificial rainfall manually and compared with the conventional roof. Vegetation use was limited to Axonopus compressus or local name cow grass only. It is because cow grass is likewise simple to grow and has a high density in covering the surface of the substrate, which was topsoil in this research. Additionally, these species were selected because of their ease of maintenance. This green roof performance study in water quantity focused on parameters such as the volume of water runoff, the duration of water runoff, the time delay of water runoff and retention rate.

2. Materials and Methods

The methodology to investigate the performance of green roof in improving water quantity of water runoff. Two roof models, green roof model and the conventional roof model were constructed during the period of study. The experiment on both models was conducted to determine the response of the green roof model in reducing the volume of water runoff, duration of water runoff, the time delay of water runoff and retention rate. The experiment was conducted in three weeks to compare the performance of the green roof model in non-saturated soil and partly-saturated soil conditions. The experiment consists of two events, event 1 and event 2 using a 1.0-liter volume of water. Event 1 represents the non-saturated soil and event 2 represents as partly-saturated soil. The data was observed at a specific time (60 minutes). The volume of water runoff, retention rate and time for water runoff delay was investigated for both models in two events. The experiment was conducted manually on-site without any particular electronic automatic devices.

2.1 Roof physical model

There was a vegetated model and a non-vegetated model (control). The effective size of both models was 1.0 × 1.0 m. The total surface area was 0.1 m^2. The slope for vegetated and non-vegetated model was 5°. The depth of a non-vegetated model was 50 mm, while the depth of a vegetation model was 200 mm, comprising 80 mm of vegetated layer design. A 25mm PVC pipe was attached at the low end of the vegetated roof to direct water runoff or simulated runoff for the purpose of quantifying the runoff collection.

2.2 Green roof model layer

The vegetation layer (Cow grass) with soil growth medium (topsoil), filtration layer (geotextile), drainage layer and protection layer (geotextile) utilized in this investigation are shown in Figure 1.

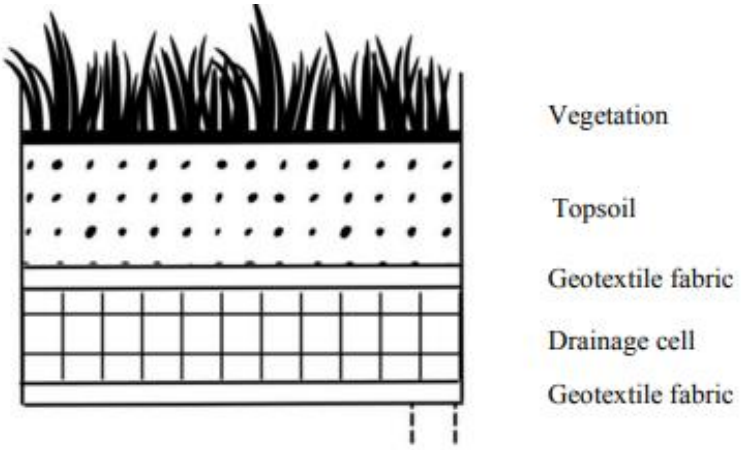

Figure 1. A layer of green roof model

2.3 Vegetation composition

The selected plant was selected with the objective of emulating SUDS methods in stormwater management, particularly in the water quantity aspect, in this research. Cow Grass, Axonopus compressus, has a great tolerance for both non-saturated soil and partly-saturated soil conditions. Cow Grass is likewise simple to grow and has a high density in covering the surface of the substrate, which was topsoil in this research. Additionally, these species were selected because of their ease of maintenance.

2.4 Site testing

The green roof model and traditional roof were subjected to the volume of water runoff, duration of water runoff, the time delay of water runoff and retention rate testing during and after an artificial rainfall event. Additionally, total water runoff was calculated for both models throughout the specified time range. The volume of water runoff, duration of water runoff, the time delay of water runoff and retention rate were determined manually on-site, without the use of any specific electronic instrument. The experiment was conducted in three weeks in order to get for average where the data were recorded in two days for each week to compare between non-saturated soil and partly-saturated soil conditions. The partly-saturated soil condition is conducted a day after non-saturated soil condition.

Figure 2. Green roof and Conventional roof model setup

2.4 Data collection

A month following the formation of vegetation, data on outflow water samples were recorded. This is because the vegetation had established a healthy growth and distribution pattern on the testbeds area's substrate. These data were gathered in order to fulfill the study's purpose.

i. Water runoff quantity - The performance of the green roof system in reducing the volume of water runoff was observed in two events in three weeks which are event 1 and event 2 with 1 liter of artificial rainfall.
ii. Duration of water runoff - The duration of water runoff is recorded when the water runoff stops to release using a stopwatch.
iii. Time delaying of water runoff - The time delaying is recorded when the water runoff starts to release from the green roof and conventional roof using a stopwatch.
iv. Retention rate - Runoff retention rates from the green roof and conventional roof in this study were calculated as in Equation 1.

$$\mathrm{RR} = \left(\frac{RV-V}{RV}\right) Eq.1$$

Where,

RR = Retention Rate (%)

RV = Rainfall Volume (L)

V = Runoff Volume (L)

3. Results and Discussion

Based on the manual experiment, four parameters observed includes the total of water runoff, duration of water runoff and time delay of water runoff. The retention rate is also calculated using the formula in Equation 1.

3.1 Total of water runoff

Figure 3 presented an average of total water runoff and shows that green roofs mitigate more water runoff compared to the conventional roof in event 1 and event 2 where the average total water runoff for a green roof is 0.44 L/m^2 and 0.464 L/m^2 and the average total water runoff for the conventional roof is 0.680 L/m^2 and 0.658 L/m^2. It shows that a green roof produces lower water runoff compared to a conventional roof. This proved that a green roof performs well in reducing the total water runoff. Green roofs allow stormwater to be retained for a longer duration. This is because, stormwater is held in soil medium and subsequently transferred to the plant layer of the green roof, which typically contributes to volume reduction as compared to a conventional roof. Additionally, according to [4], green roof vegetation enables evapotranspiration (ET), which may assist in reducing runoff volumes in comparison to a conventional roof. Figure 3 also illustrates the average total water runoff in event 1 and event 2. It shows that the green roof in event 1 which is in non-saturated soil condition can reduce more water runoff compared to the green roof in partly-saturated soil condition (event 2). This result proves that green roof performs well in non-saturated soil condition compared to partly-saturated soil condition. This is because wetter substrate conditions reduce water storage capacity, resulting in an increase in total runoff.

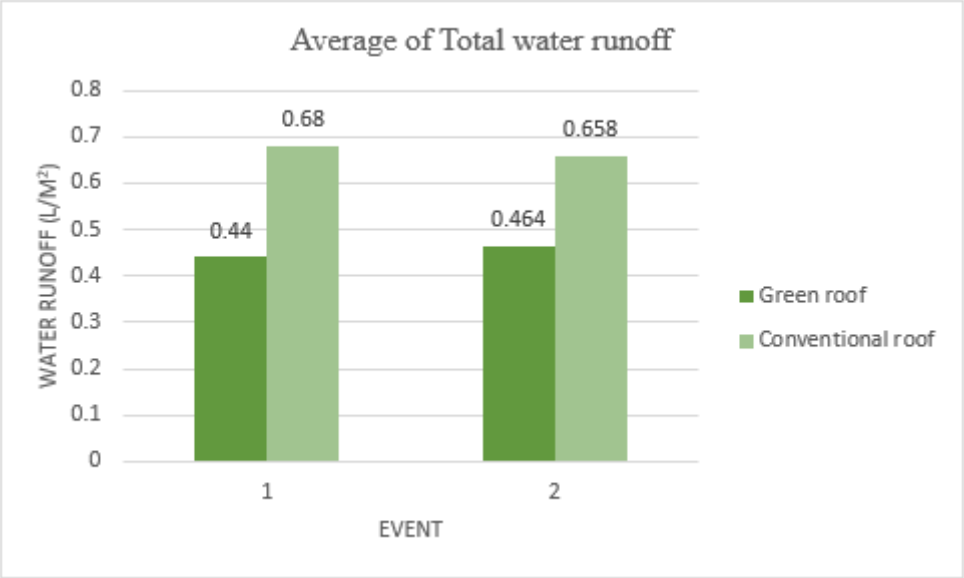

Figure 3. Average of total water runoff in non-saturated soil and partly saturated soil condition

3.2 Duration of water runoff

Figure 4 illustrate the comparison of the average duration of water runoff for green roof and conventional roof in event 1 and event 2. Based on Figure 4.8, the average duration of water runoff for a green roof is longer than conventional roof where the green roof recorded 45 minutes and 42 minutes in event 1 and event 2 respectively while the conventional roof recorded 21 minutes and 23 minutes in event 1 and event 2 respectively. This shows that the green roof took a longer time of water runoff compared to the conventional roof. This is because the stormwater in the green roof has to go through multiple layers and resulting in a longer duration to release. This proves that a green roof manages to reduce flooding risk by increasing the duration of water runoff compared to the conventional roof (Fang, 2010). Figure 4 also shows the comparison of average duration between non-saturated soil and partly-saturated soil condition. Based on the data collected, it can observe that the green roof took a longer duration of water runoff in both non-saturated soil and partly-saturated soil condition compared to conventional roofs.

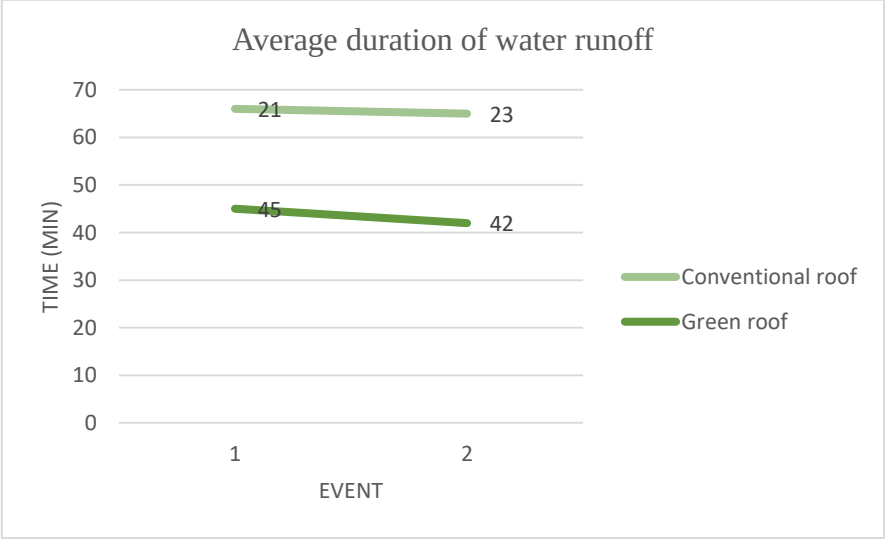

Figure 4. Average duration of water runoff in non-saturated and partly-saturated soil condition

3.3 Time delay of water runoff

Figure 5 illustrates the average time delay of water runoff. It shows that the green roof recorded a longer average time delay of water runoff compared to the conventional roof in both events were 15.3 minutes and 11 minutes in event 1 and event 2 respectively. This is because the stormwater in the green roof has to go through multiple layers before runoff and resulting in a delay of time to runoff compared to a conventional roof. This delay is most likely due to the infiltration process through the green roof layer [5]. This finding found that a green roof has the ability to delay the stormwater runoff. Figure 5 also shows that the green roof in non-saturated soil condition average delay of time is higher compared to the partly-saturated soil condition where in non-saturated soil condition average time delay is 15.3 minutes while in partly-saturated soil condition is 11 minutes. The difference time delay for non-saturated soil conditions and partly-saturated soil conditions is 4.3 minutes. It is found that green roofs perform effectively in non-saturated soil conditions compared to partly-saturated soil conditions.

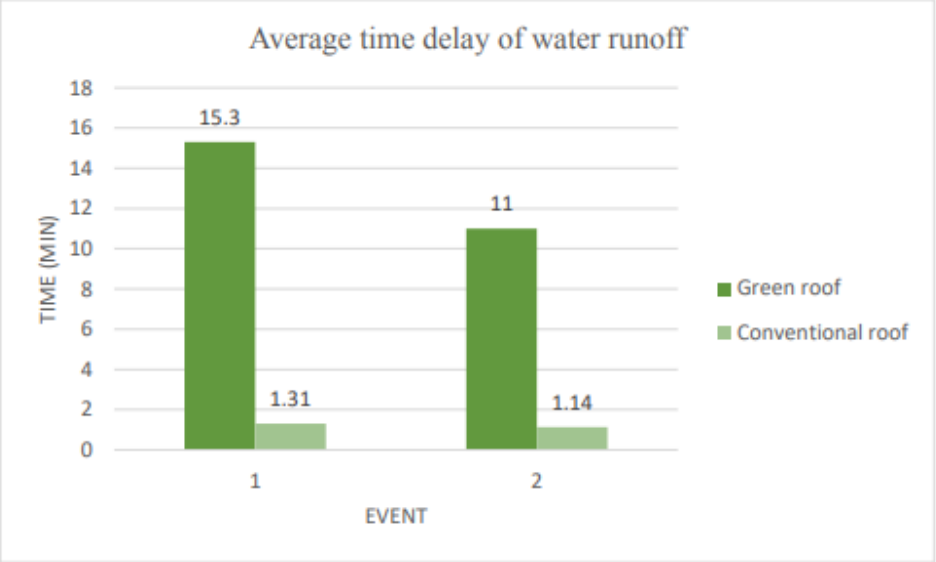

Figure 5. Average time delay of water runoff

3.4 Retention rate

Figure 6 show the data recorded for the average retention rate of green roof and conventional roof. The average of retention rate for green roof is higher than conventional roof where the green roof recorded 53.6% and 56% while the conventional roof recorded 32% and 34%. This proved that a green roof is capable to retain stormwater runoff and manage to reduce flood risk. This is because the layer of the green roof influences the retention rate through the water absorption by the green roof and distributes the water runoff slowly through the release of the excess water that is in the substrate pores. In Figure 6 also can observe that green in in non-saturated soil condition perform well compared to the partly-saturated soil condition where the average of retention rate for green roof in non-saturated soil condition recorded 56% which is higher compared to average retention in conventional roof (53.6%).

Figure 6. Average retention rate

The findings support the strong opinion that green roofs have a better capacity to hold runoff under non-saturated soil conditions than partly-saturated soil conditions [6]. According to [7], the capacity of a green roof to retain runoff is dependent on the moisture content of the substrate prior to a rainfall event, which is regulated during the non-saturated soil condition by the plant evapotranspiration process.

4. Conclusion

From this study, it was found that a green roof has the ability to reduce water runoff compared to a conventional roof. Based on the data recorded in this study, green roofs manage to produce a lower average volume of water runoff a the range of 0.440 L/m^2 to 0.464 L/m^2 of water runoff from 1.0 L of stormwater compared to the conventional roof where it produces a range between 0.658 L/m^2 to 0.680 L/m^2 of water runoff in both events. Thus, it is proven that a green roof performs well in reducing water runoff compared to a conventional roof. In addition, the performance of green roofs in delaying water runoff was also examined. The study shows that green roofs manage to delay a longer time compared to conventional roofs. The green roof manages to delay up to 17 minutes to release water runoff compared to a conventional roof that only delays up to 1.45 minutes. This is because the water in the green roof has to go through multiple layers before runoff and resulting in a delay of time to runoff compared to a conventional roof. This delay is most likely due to the infiltration process through the green roof layer. Besides, the study also proved that a green roof is capable to retain stormwater runoff and manage to reduce flood risk. From the experiment conducted, the green roof can retain in range of 53.6% to 56% of water runoff in the green roof while conventional roof only retains in range of 29% to 36.5% of water runoff. This is because the layer of the green roof influences the retention rate through the water absorption by the green roof and distributes the water runoff slowly through the release of the excess water that is in the substrate pores. The recommendations that may be considered is by improving the layer of green roofs such as substrate layer and vegetation layer. For the substrate layer, the thickness of the substrate layer also gives an effect to the performance of green roofs in reducing water runoff. Besides, the selection of plant also needs to consider as different types of plants gives different impact on water reduction. In addition, the age of vegetation also needs to focus as the green roof will perform well in the early planting process. Lastly, in this study, the experiment was conducted manually without using any electronic devices or simulation. It is suggested to conduct a proper experiment using electronic devices or simulations to get a better result in water runoff reduction for the green roof.

Acknowledgement

The author would like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for its support. The author would also like to thank everyone for contributing to the completion of this project.

References

[1] H. Song, T. Qin, J. Wang, and T. H. F. Wong, "Characteristics of stormwater quality in Singapore catchments in 9 different types of land use," *Water (Switzerland)*, vol. 11, no. 5, pp. 1–10, 2019, doi: 10.3390/w11051089.

[2] B. Gregoire and J. Clausen, "Effect of a modular extensive green roof on stormwater runoff and water quality," *Ecol. Eng.*, vol. 37, pp. 963–969, Jun. 2011, doi: 10.1016/j.ecoleng.2011.02.004.

[3] K. M. Town, "Flood Risk Assessment on Selected Critical Infrastructure in Flood Risk Assessment on Selected Critical Infrastructure in Kota Marudu Town , Sabah , Malaysia," no. April, 2017, doi: 10.1051/matecconf/201710304019.

[4] M. Shafique, R. Kim, and K. Kyung-Ho, "Green roof for stormwater management in a highly urbanized area: The case of Seoul, Korea," *Sustain.*, vol. 10, no. 3, pp. 1–14, 2018, doi: 10.3390/su10030584.

[5] M. Carbone, G. Garofalo, G. Nigro, and P. Piro, "A conceptual model for predicting hydraulic behaviour of a green roof," *Procedia Eng.*, vol. 70, pp. 266–274, 2014, doi: 10.1016/j.proeng.2014.02.030.

[6] J. C. Berndtsson, "Green roof performance towards management of runoff water quantity and quality : A review," *Ecol. Eng.*, vol. 36, no. 4, pp. 351–360, 2010, doi: 10.1016/j.ecoleng.2009.12.014.

[7] C. Berretta, S. Poe, and V. Stovin, "Moisture content behaviour in extensive green roofs during dry periods: The influence of vegetation and substrate characteristics," 2014.