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THE INNOVATION OF GREEN ROOF TO DADICATE THE BUILDING ENVIRONMENT IN HONG KONG

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Abstract

Hong Kong, as a highly developed city in Asia and it currently faces three major challenges, namely, urbanization growth, water scarcity, and climate change. The consequence of these threats puts more stress on the urban water cycle and increases metropolitan temperatures through urban heat island effects. Introducing green infrastructure through water sensitive urban design is one of the solutions to reduce the harmful impacts of urbanization while providing additional amenity and water quality benefits for communities and the environment. This paper describes the results of a current research project that is investigating the water quantity and thermal benefits of two different types of green roofs, namely, intensive and extensive. The study site consists of a series of small scale green roofs located at the Hong Kong Island. Laboratory and field investigations of rainfall and runoff confirm that green roofs can retain significant amounts of storm water and can also mitigate the peak flow and attenuate the time of concentration. The thermal benefits of green roofs have also been investigated through two scenarios of cold and warm days. The objective indicate that the thermal variation of the media is less than surrounding areas and on cold days the media's temperature is warmer than outside and on warm days it is cooler. Integrating green roofs into the built environments of Hong Kong could work as a climate change adaption tool that could yield significant thermal benefits.

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1. Introduction

Over recent decades, the hydrologic cycle of water has changed significantly due to continuous changes in the world from forest or other intrinsic vegetation to rural or urban environments. Hong Kong is one of the most urbanized cities in the world and seven million residents squeeze in this area. The growth rate of urbanization has led to changes of green spaces through introduction of large impervious areas, such as roofs, car parks, roads, highways, and paving (Berndtsson [1]). These alterations through growth of urbanization dramatically change the urban hydrological cycle. They also increase urban temperature which can lead to urban heat island effects (Skinner [2]).

2. Literature Review

Hong Kong located in the southern part of China and it currently faces three major challenges, namely, urbanization growth, water scarcity, and climate change. The consequence of these threats puts more stress on the urban water cycle and increases metropolitan temperatures through urban heat island effects. Introducing green infrastructure through water sensitive urban design (WSUD) is one of the possible solutions to mitigate the harmful impacts on urbanization. Also, it could provide additional amenity and water quality benefits for communities and the environment. Hong Kong Government Authorities plan to get rid of the water sensitive cities in the world and the water quantity is enough to support all Hong Kong residents to use. Also, Hong Kong Land Bureau also recommends the introduction of green roofs but research is required to develop this technology to be resilient in Hong Kong's harsh climate (Razzaghmanesh et al. [3]). This paper describes the results of a current research project that investigates the water quantity and the thermal benefits of two different types of green roofs, namely, intensive and extensive.

3. Methods

Hong Kong, as one of the most urbanized cities in the world and seven million residents squeeze in this area. The growth rate of urbanization has led to changes of green spaces through introduction of large impervious areas, such as roofs, car parks, roads, highways, and paving. The study site in this experiment consisted of a series of small scale green roofs located at the Hong Kong Island. In this study, four scaled green roofs were constructed, each with a single drainage point to measure the outflow and to collect water quality samples. The dimensions of the beds were 1.2m × 1.8m and two different media depths of 100mm and 300mm were considered for these tests. Two different substrates were used. The first was a media containing crushed brick, scoria, coir fiber, and composted organics. The second media included scoria-composted pine bark and hydro cell flakes.

In this study, the effect of green roofs on runoff quantity before and after planting was investigated. For this investigation, the rainfall patterns for Hong Kong was studied. The online meteorological data from Hong Kong weather station were used in this study. In addition, sample representative rainfall for Hong Kong was simulated in the laboratory to assess the effects of pre-planting of the beds and to understand the sole effect of growing media on the runoff water quantity from the systems. For each bed, three different rainfall intensities during the same time periods were simulated. The quantity of the runoff from each bed was then measured. Rainfall runoff hydrographs and retention capacities of the beds were calculated and presented graphically.

To address how green infrastructure such as green roofs can impact on urban temperatures, the thermal effects of green roof beds were investigated. Measurements included temperatures in the green roof media and also the surrounding air temperatures which were monitored in two stages. In the first stage, the thermometers were installed at the same depths (10mm, 50mm, and 100mm) in all beds. Then in the next stage, for each bed separately the media temperature was studied. Firstly, the shallow system temperatures were measured at depths of 30mm, 50mm, and 100mm, then in the deeper systems the thermal behaviour was monitored for two scenarios at depths of 5mm, 10mm, and 15mm and then at 100mm, 200mm, and 300mm (Figure 1).

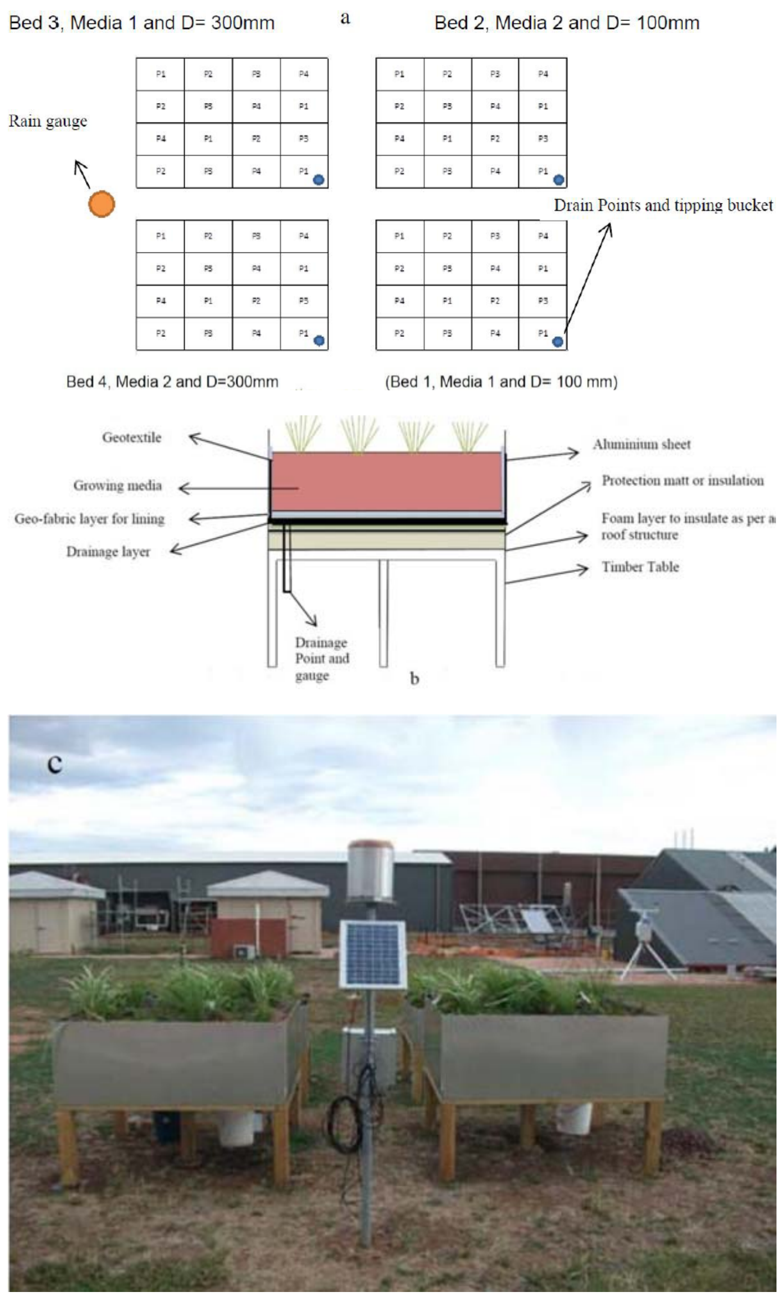


Figure 1. Green roof bed layouts (a), Green roofs built up profile (b), and Green roof beds (c).

4. Results

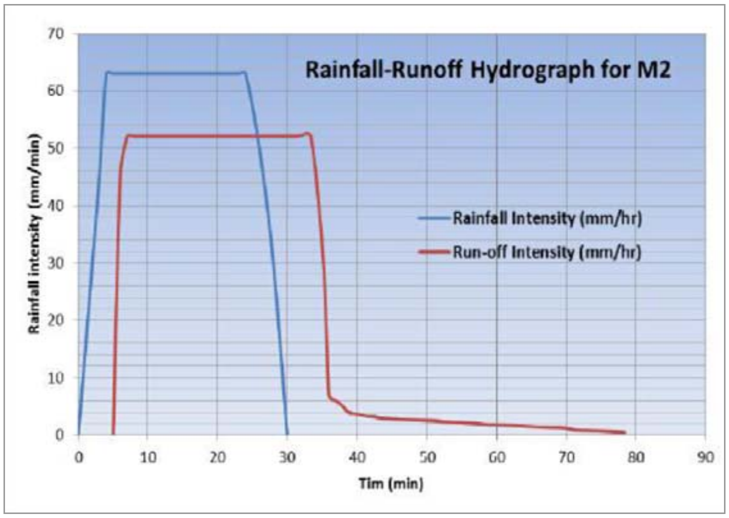
4.1. Water quantity

One of the important strategies in sustainable urban drainage systems (SUDS) and water sensitive urban design (WSUD) systems is runoff source control (Alsup et al. [4]; Palla et al. [5]; Voyde et al. [6]). Installing green roofs is viewed as a best management practice (BMP) to attenuate peak runoff flows in urban areas. Therefore, one of the most important objectives in green roof studies is determining how green roofs can affect storm water quantity. This requires an understanding of the hydrology of green roofs. For these reasons, laboratory tests were conducted to measure the quantity of runoff from the green roof beds that did not include any planted vegetation. Table 1 outlines the results of these tests. The results show that water retention capacity of the beds after running the test three times was decreased. This might be due to short rest times between the tests and the presence of existing moisture in the beds or because of lack of plants in the systems. However, two typical outflow hydrographs of rainfall and runoff for the laboratory scale green roofs showed that there were not significant differences between the rainfall and runoff peaks and start time of the green roof. Then, the green roof beds were planted and moved to the study site.

Table 1. Results of laboratory scale rainfall and runoff simulation

System's Name	Depth (mm)	Green roof area (m^2)	Run time (min)	Rainfall intensity (mm/hr)	Time of concentration (min)	Inflow	Outflow	Media volume	ADWP	Retention capacity (%)
Media 1-Intensive	300	1.8	40	40	28	41.14	26.25	540	7	36.20
Media 1-Extensive	100	1.8	30	40	20	30.86	15.75	180	7	48.96
Media 2-Intensive	300	1.8	70	40	60	72.00	33.5	540	7	53.47
Media 2-Extensive	100	1.8	40	40	25	41.14	21.4	180	1	47.99
Media 1-Intensive	300	1.8	30	63	12	48.60	45.1	540	1	7.20
Media 1-Extensive	100	1.8	30	63	6	48.60	47.5	180	1	2.26
Media 2-Intensive	300	1.8	30	63	17	48.60	41.35	540	1	14.92
Media 2-Extensive	100	1.8	30	63	5	48.60	48	180	1	1.23
Media 1-Intensive	300	1.8	15	87	8.6	33.56	30	540	1	10.60
Media 1-Extensive	100	1.8	15	87	5	33.56	32.3	180	1	3.75
Media 2-Intensive	300	1.8	15	87	13.5	33.56	33	540	1	1.66
Media 2-Extensive	100	1.8	15	87	1.5	33.56	33	180	1	1.66

A rain gauge and runoff tipping counters were installed in the systems and these were connected to a programmed data logger (Figure 2 and Figure 3). It was possible to record data after each rainfall and to retrieve them through remote access. Table 2 outlines the results of the retention capacity calculations for May 2012 as an example month.



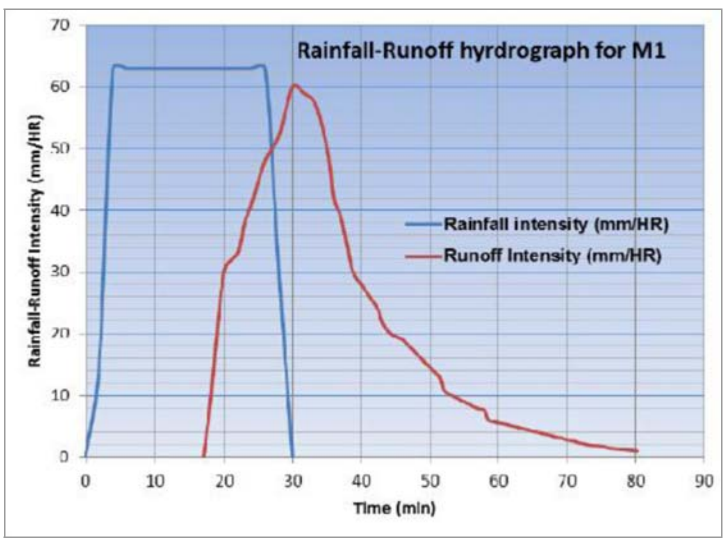


Figure 2. Typical rainfall-runoff hydrographs of the green roof beds in the laboratory.

Figure 3. Green roof beds: (a) rain gauge and data logger; (b) outflow runoff tipping counter.

The results showed that water retention capacity of the beds after planting and during rainfall events was very high and also that plants have an important role to increase the retention capacity. Furthermore, two typical rainfall and runoff hydrographs are shown in Figure 4. Results show that there are significant differences between rainfall and runoff peaks and the start time of green roof runoff (Table 2).

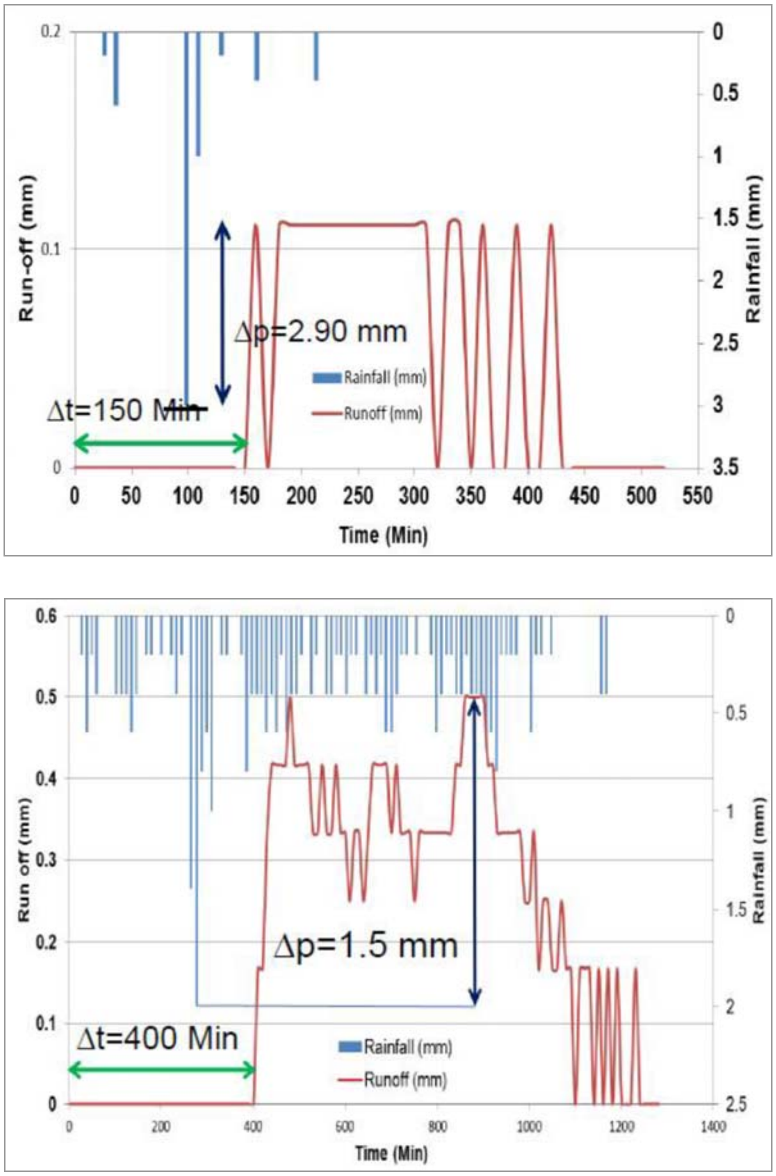


Figure 4. Rainfall-runoff data and typical hydrographs.

Table 2. Rainfall and runoff simulation of green roofs

System's Name	Depth (mm)	GR Area (m^2)	Date	Rainfall depth (mm)	Inflow	Outflow	Media volume	ADWP	Retention capacity (%)
Media 1-Intensive	300	1.8	02.05.2012	16.8	30.24	8	540	1	73.54
Media 1-Extensive	100	1.8	02.05.2012	16.8	30.24	7.5	180	1	75.20
Media 2-Intensive	300	1.8	02.05.2012	16.8	30.24	10	540	1	66.93
Media 2-Extensive	100	1.8	02.05.2012	16.8	30.24	7	180	1	76.85
Media 1-Intensive	300	1.8	11.05.2012	3	5.40	0	540	4	100.00
Media 1-Extensive	100	1.8	11.05.2012	3	5.40	0	180	4	100.00
Media 2-Intensive	300	1.8	11.05.2012	3	5.40	0	540	4	100.00
Media 2-Extensive	100	1.8	11.05.2012	3	5.40	0	180	4	100.00
Media 1-Intensive	300	1.8	25.05.2012	10	18.00	7.5	540	6	58.33
Media 1-Extensive	100	1.8	25.05.2012	10	18.00	10	180	6	44.44
Media 2-Intensive	300	1.8	25.05.2012	10	18.00	8.5	540	6	52.78
Media 2-Extensive	100	1.8	25.05.2012	10	18.00	8	180	6	55.56

4.2. Thermal investigation

There are different approaches for studying UHI (urban heat island) such as multi-scale phenomena, observation, and simulation approaches (Mirzae and Haghighat [7]). In this study, field observation was used to understand the thermal effects of green roofs on UHI and also heating and cooling effects in cold and warm day scenarios. The results show that green roof can be 2-5 degrees cooler during day times depending on the media type and depth. They can also be 2.5 to 5.5 degrees warmer than ambient temperatures during night times (Figure 5 and Figure 6). Also, generally, during day times, green roof beds were cooler than ambient temperatures and the heat flux direction was vertical from the surface to the soil but in the night time this flux was in the reverse direction.

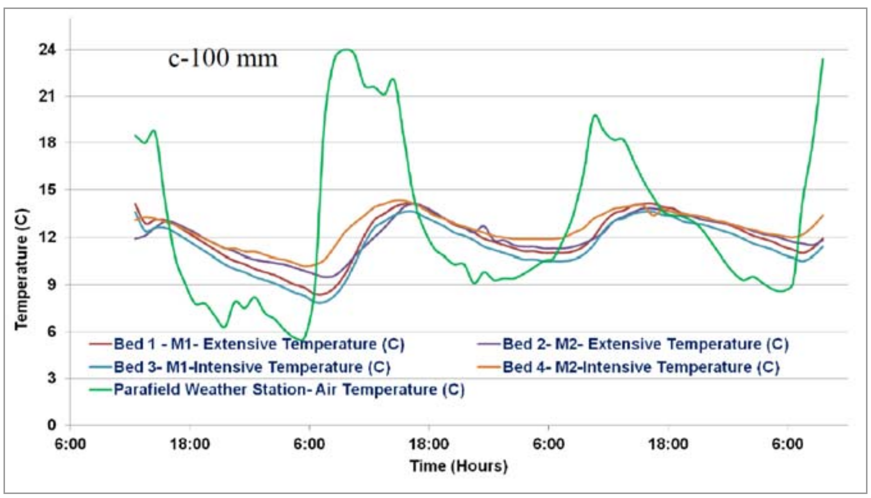


Figure 5. Observed temperature at different depths in bed 1.

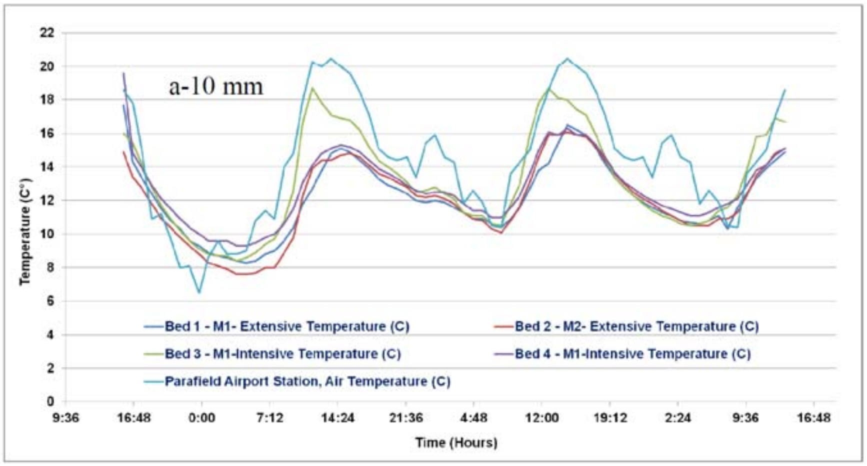


Figure 6. Observed temperature at different depths in bed 4.

5. Discussion

As Berndtsson [1] discussed, the most significant difference between the runoff hydrographs from conventional roofs and green roofs are the peak flows and the time to the start of runoff. The time of peak flow events in conventional roofs is sooner than the corresponding times in green roofs. Also, in green roofs, the times of concentration to the downpipe are greater than the corresponding times in conventional roofs. This delay of peak flow and long travel time are the main benefits of green roofs (Stovin [8]). The runoff retention volume of the green roofs in this project was 69% on average and was 100% in warm seasons. Palla et al. [5] reported a 42% to 80% retention volume with an average retention volume of 52% and a peak flow reduction of 83%. Voyde et al. [6] studied the hydrology of a green roof under sub-tropical conditions in Sydney, Australia. They found that for a green roof in the sub area of Sydney there was 66% retention of rainfall over a one year period. They concluded that green roofs can significantly reduce runoff and especially the maximum runoff. Their results showed that in some individual events, green roofs could retain an average of 82% of the rainfall and can reduce up to 93% of the peak flow (Van Roon [9]). In this study, the average retention was 67% and this can mitigate 85% of the runoff peak. The results of this study showed that if green roofs are integrated into the built environments of Hong Kong, they can bring benefits in terms of heat island effects and storm water management.

Different scenarios of thermal behaviour of green roofs were investigated. Under the same environmental conditions, it was shown that intensive or deeper green roof systems are cooler during day and are warmer at night compared to extensive green roofs. The heat flux direction was generally from the top to the bottom layers during the days and was in the reverse direction at night. Furthermore, the results show that the thermal distribution is quite stable at deeper layers of the growing media but it fluctuated more in the upper layers of the substrates.

6. Conclusion

In this research, results of the current research on introducing green roofs into urban and built environments of Hong Kong has been discussed. The results confirm that green roofs could act as one of the main possible options for achieving the WSUD objectives outlined in Hong Kong and make Hong Kong as one of the most water sensitive cities in the world. The thermal variation of the media is less than surrounding areas and on cold days the media's temperature is warmer than outside and on warm days it is cooler. Integrating green roofs into the built environments of Hong Kong could work as a climate change adaption tool that could yield significant thermal benefits. However, developing resilient green roofs could also be an effective climate change adaptation tool to mitigate urban heat island effects and to reduce urban temperature. Therefore, upgrade the green roof to contribute for human need is necessary. Also, the water quantity and thermal benefits could be a good method to be used in the world.

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