Lab-based study to analyse the influence of parameters on the water retention capacity of green roofs

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Abstract
This paper presents a laboratory-based analysis of green roofs water retention capacity. The testing facility includes the rainfall simulator "RS-TUHH", two green roof models and the measuring equipment. The first series of tests was carried out with three rain events and three roof slopes. Test results show that the thicker the substrate the higher the retention. However, the longer the duration of the rainfall the smaller the influence of this parameter. This is confirmed by the value of the discharge coefficient "C" calculated with the FLL-procedure. The green roof can retain the rainwater until its saturation, then no further retention takes place. The variation of the roof slope between 2 % and 6 % does not show significant effects.

Keywords
Green roofs modelling, rainfall simulation, laboratory tests

INTRODUCTION

In urban areas, storm water is mainly collected and conveyed to sewer systems or to local waterbodies. However, during extreme events, which might become more frequent due to climate change (IPCC 2014), the capacity of these systems can be exceeded and flooding can occur. SUDS (Sustainable Drainage Systems) are found to have an effective potential to reduce the hydraulic stress on traditional drainage systems (Stovin et al., 2013). During recent years, several German cities developed their own strategies to mitigate the possible effects of climate change. As an example, the city of Hamburg announced in April 2014 its "Green roof strategy" (www.hamburg.de/gruendach). To quantify the effects of these adaptation strategies the implementation of numerical models is required. In these models the drainage systems are parametrised and future scenarios are calculated. Although the water retention capacity of green roofs has been investigated over the last three decades, there is still a need for improving understanding of the influence of the single parameters as well as the correlation amongst them (Lamera et al., 2014). The objective of this and further investigations is to provide this understanding based on laboratory tests. Test results will be compared to those of real green roofs and used to calibrate and optimise numerical models e.g. the enhanced hydrological model "KalypsoHydrology" to simulate SUDS (Hellmers et al., 2015).

MATERIALS AND METHODS

For the preparation of the testing facility three main work steps includes:

- development and construction of a rainfall simulator "RS-TUHH" (Palmaricciotti et al., 2014);
- development and construction of two support structures for green roof models; and

- development of an experimental matrix

Rainfall simulator "RS-TUHH"

The rainfall simulator (see Figure 1) consists of three elements: an aluminium structure, a pressure and distribution control module and an irrigation system. The "RS-TUHH" has a testing area of 6 m² and can reproduce rainfall with intensities between 3 and 300 mm/h.

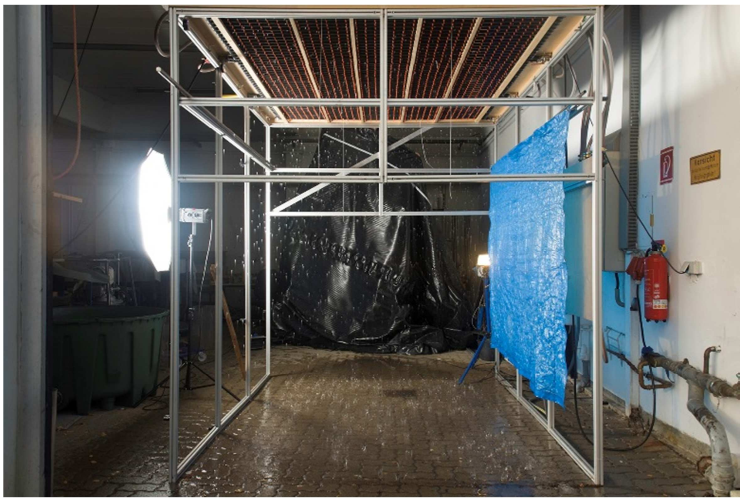


Figure 1. The rainfall simulator "RS-TUHH"

Green roof models

Two support structures of 3 x 1 m² were built to allow the simultaneous testing of two (reference or comparison) models. Prerequisites of these structures were possibility of movement and adjustment of the inclination. The support structures are made out of steel square pipes. The four corners of the structures were equipped with wheels enabling the front side of the structure to rotate. To allow the adjustment of the inclination, two telescopic tubes were installed on the backside of the structures. To allocate the green roof models two wooden trays covered by a polyethylene sheet were built. The lower side of the tray is opened through a punched sheet which leads the outflow into a collector that conveys the water to the outlet. The two models are presented in Figure 2.

Figure 2. Green roof models

For the first series of experiments, two green roof models with the same characteristics: protection mat, drainage board and filter fleece but different substrate thickness (8 cm and 6 cm) were installed. The substrate is a mixture of expanded shale, expanded clay, lava, pumice, crushed brick, porlith and green waste compost (Optigreen, 2011).

Experimental matrix

For the scope of the tests, the FLL procedure (FLL Guidelines 2008) was taken into account, in particular the section to determine the discharge coefficient “C”. The setting of the tests was then extended to a 3 x 3 experimental matrix (see Table 1) by defining three precipitation series (P) and three roof slopes (S). From the statistically generated “KOSTRA”-table (www.dwd.de), the chosen rainfall intensities correspond to return periods between 100 and 200 years for 15, 30 and 60 minutes respectively. Roof slopes of 2, 4 and 6 % were selected as a second input parameter.

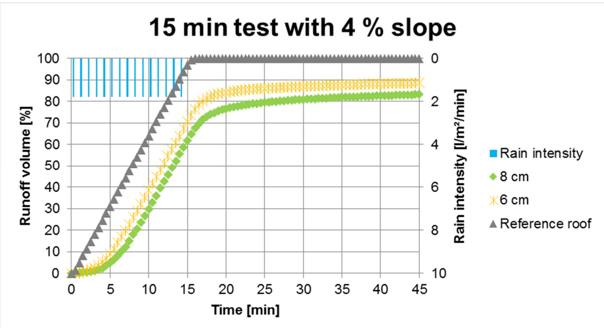
Table 1. Experimental matrix

	P15	P30	P60
S2	T1 (I, II, III)	T2 (I, II, III)	T3 (I, II, III)
S4	T4 (I, II, III)	T5 (I, II, III)	T6 (I, II, III)
S6	T7 (I, II, III)	T8 (I, II, III)	T9 (I, II, III)
	~ 1,8 l/m²/min	~ 1,2 l/m²/min	~ 0,8 l/m²/min

According to the FLL-procedure each experiment is carried out 24 hour after full saturation. All experiments reported in this work respected this rule. Since all experiments were carried out within 6 weeks, where weather conditions in Hamburg did not suffer important variations, it is assumed that the soil moisture at the beginning of each experiment was constant. After completing the first test series, a further investigation was carried out by irrigating the green roof models with different rain intensities but for the same duration.

RESULTS AND DISCUSSION

The interpretation of the test results provides a good basis for the assessment of the influence of substrate thickness, rainfall intensity and roof slope on the retention capacity of the selected green roof type. Plotting the results the following conclusions can be deduced. The model with the thicker substrate layer can retain more water (see Figure 3 left). However, the longer the rain event the smaller the influence of this parameter (comparison Figure 3 left with Figure 5 left).



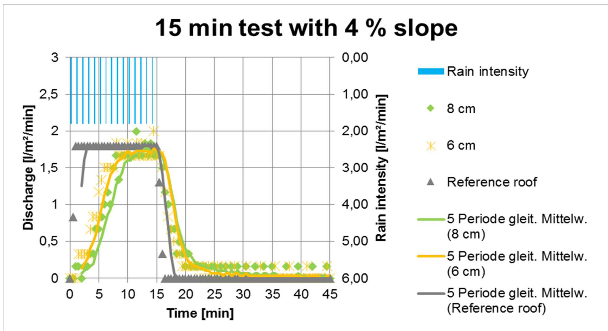


Figure 3: Runoff volume (left) and discharge (right) of the models by 15 min and 4% slope

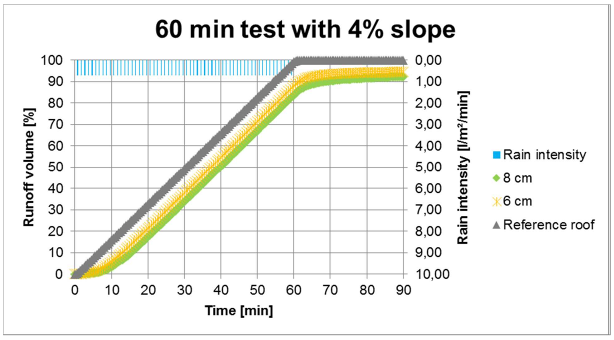
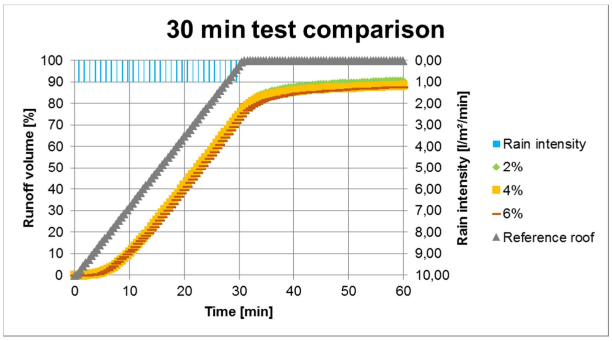


Figure 5: Runoff volume (left) and discharge (right) of the models by 60 min and 4% slope

The green roofs can retain the rainfall until saturation is reached. From that moment on there is no more retention, independently from the layer thickness (see Figure 3 right and Figure 5 right). The trend of the discharge curves is similar for the three slopes (see Figure 4).

Figure 6 shows the runoff volume and the discharge of the model with 6 cm substrate. For this test, the models were irrigated for 35 minutes with 0.5, 1.0, 1.5 and 2.0 l/m²/min respectively. Both charts show that between 0.5 and 1.0 l/m²/min there is an important difference in the response of the green roof in terms of retention and delay of peak flow. This difference tends to decrease by increasing



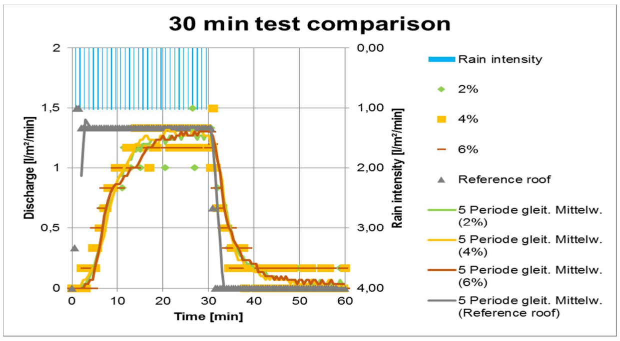
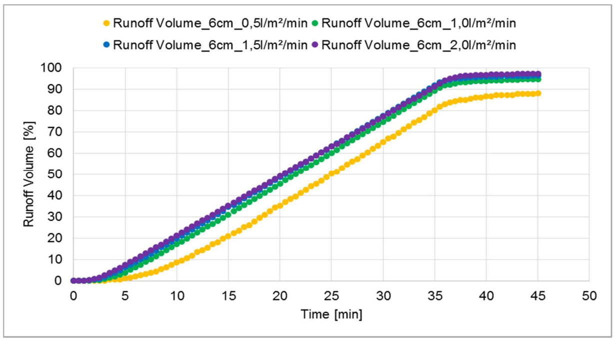


Figure 4: Test comparison: runoff volume (left) and discharge (right) of the models by 30 min duration and slope between 2 and 6%

rain intensities. The peak flow delay between 1.0 and 1.5 l/m²/min is nearly the same and decreases marginally for the 2.0 l/m²/min.



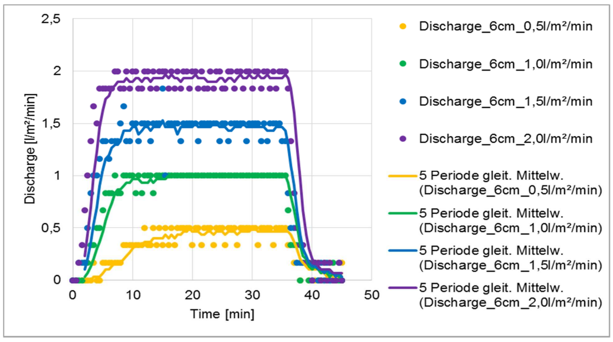


Figure 6: Runoff volume (left) and discharge (right) of the models by 35 min duration and intensities varying between 0.5 and 2.0 l/m²/min

The discharge coefficient "C" (FLL procedure) is always smaller for the thicker substrate and it increases for longer rainfall durations.

CONCLUSION AND OUTLOOK

Knowledge and experiences achieved during the conduction of the tests indicate that physical simulations have high potential for delivering key parameters and correlations to be used to optimise numerical models. Additionally, the gained experience should help optimising the measurement methods and improve the experimental procedure.

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