Measurement of the runoff coefficient of extensive greenroof

J Vystrčil[1], O Nespěšný[1], K Šuhajda[1], D Bečkovský[1] and P Selník[1]

[1] Faculty of Civil Engineering, Institute of Building Structures, Brno University of Technology, Veveří 331/95, 602 00 Brno, Czech Republic

E-mail: jan.vystrcil@vutbr.cz

Abstract. Describes the procedure of experimental measurement of the runoff coefficient C, both of individual layers and the entire composition extensive green roofs. Experimental measurements make it possible to determine the reference behaviour of runoff characteristics, namely runoff coefficient C, with emphasis on the simulation of the real behaviour of extensive green roofs. The aim is an elementary description of the structural and physical behaviour of extensive green roofs. For the needs of experimental measurement, the dimensional and shape limits of test specimens are described, the conditions for conditioning of individual specimens, the boundary conditions of execution and individual steps of the experiment. Then is specified the method of evaluation and subsequent verification of measured data. The result of the experimental measurement is the amount of drained water from the tested specimens of the extensive green roof at time t, which shows a nonlinear behaviour. From the set of measured data, it is then possible to predict the behaviour of extensive green roofs in real conditions and to determine the runoff coefficient C of the tested specimens. These data represent reference values for the subsequent design of sub-elements and structures of buildings.

1. Introduction

According to Scharf B, Kraus F, in publication Green roofs and Greenpass [1] The United Nations has identified climate change as the greatest threat to human life. Following these results there is an increasing emphasis on the sustainable development of urbanism, architecture and society as a whole. Frequently addressed topics following climate change are the management of drinking water and rainwater, the elimination of the formation of heat islands in urban areas [2], the impact of greenery on the quality of urban environments [3]. One of the important measures to reduce heat islands, partial retention of rainwater on the construction site and reduce the risk of flash floods in cities during torrential rains is to design a of green roofs on buildings.

One of the parameters of the green roof formation is the runoff coefficient *C*. It is a dimensionless quantity indicating the ratio of the runoff rainwater to the total precipitation for the observed period. This parameter fundamentally affects the following sub-elements of buildings, such as rainwater drainage elements, retention tanks, infiltration objects etc. Furthermore, it can fundamentally affect the price for rainwater wastewater discharged into the public sewerage network.

The currently valid standards in the Czech Republic use only simplified table values to calculate the amount of rainwater drained from the roofs. ČSN EN 12056-3 [4] states for the calculation of the amount of rainwater drained from the roof, the runoff coefficient $C = 1.0$, unless national and local regulations and practices provide otherwise. ČSN 75 6760 [5] states the runoff factor *C* for the same calculation, with a slope of the roof planes of up to 5%, according to the following division 1.:

Table 1. Selected values of runoff coefficient according to ČSN 75 6760 [5].

Type of drained surface type of surface treatment	Tilt of surface <1%	 1%-5%	 >5%
	Runoff coefficient of drained water C		
Roofs with a permeable top layer of thickness up to 100 mm	0.7	0.7	0.7
Roofs with a permeable top layer of thickness over 100 mm to 250 mm	0.4	0.4	0.5
Roofs with a permeable top layer of thickness up to 250 mm	0.3	0.3	0.3

However, the mentioned standards do not state under which conditions this coefficient was determined.

The German regulation FLL Green roof - Guidelines for the planning, construction and maintenance of Green roofs [6], uses the nomenclature according to DIN EN 12056-3, where it is used for the designation C_s for the runoff coefficient or the runoff reference value. In this case, it is clearly described that this is a peak coefficient. However, the values of the runoff coefficient C_s are given below, according to Tab. 1, also only depending on the layer thickness.

Table 2. Values of runoff coefficient according to FLL Green roof - Guidelines for the planning, construction and maintenance of Green roofs [6].

Roof pitch up to 5°		Roof pitched greater than 5°
For 50 cm layer thickness	$C_s = 0.1$	
For 25 – 50 cm layer thickness	$C_s = 0.2$	
For 15 – 25 cm layer thickness	$C_s = 0.3$	
For 10 – 15 cm layer thickness	$C_s = 0.4$	$C_s = 0.5$
For 6 – 10 cm layer thickness	$C_s = 0.5$	$C_s = 0.6$
For 4 – 6 cm layer thickness	$C_s = 0.6$	$C_s = 0.7$
For 2 – 4 cm layer thickness	$C_s = 0.7$	$C_s = 0.8$

There is determined an exact procedure for determining these runoff coefficients of individual thicknesses of the green roof composition. To obtain the runoff coefficient are first all layers fully water saturated. Furthermore, the specimens are evenly sprinkled with simulated rain at an intensity of 300 l / (s * ha) for 15 minutes. Individual specimens are tested in the unrooted vegetation state. The developed rooting of the vegetation further slows down the outflow of rainwater from the green roof composition. The measurement is therefore performed on the safe side in terms of possible supersaturation of adjacent parts of buildings.

The above-mentioned methods for determining the runoff coefficient *C* of green roof formations were insufficient by the research team in view of the ever-increasing amount of building materials and construction solutions. Furthermore, these current values very often do not provide a sufficiently accurate description of the real behaviour of the green roof composition. However, this is essential for the design of related parts of buildings such as the mentioned sewer networks, storage and retention tanks and infiltration facilities. For these reasons, a methodology for testing and determining the runoff coefficient *C* of individual technical layers and entire green roof composition was determined. That will describe the behaviour of green roof assemblies with a high emphasis on simulation of real behaviour.

2. Methodology

The purpose of the measurement is to determine the reference behaviour of the runoff characteristics, namely the runoff coefficient *C*. The aim is to obtain the basic structural and physical behaviour, which can be further used in common construction practice. Either individual technical layers or the entire composition from the waterproofing layer to the contact surface with the weather are measured. In the case of extensive green roofs, it is a layer of drought-loving plants in the form of a vegetation carpet, in the case of an intensive or semi-intensive roof, it is a surface formed by an intensive substrate.

2.1. Conditioning of test specimens

2.1.1. Conditioning of technical layers. First, the measured components or the composition are sprinkled 27 mm in 15 minutes per 1 m^2. They are then removed and left in bulk for natural drying, the required moisture content of the specimen to be measured being 20 ± 3%.

2.1.2. Substrate conditioning. First, the measured components or the composition are sprayed with 27 mm in 15 minutes per 1 m^2. They are then removed and left in bulk for natural drying, the required moisture content of the specimen to be measured being 25 ± 5%.

2.1.3. Conditioning of vegetation for measurement purposes. For the extensive variant, always using surface vegetation (vegetation carpet according to type) - Before the measurement, the carpet must be stored for at least 48 hours in the installed figure/position. For measuring purposes semi-intensive and intensive green roofs, it is not used vegetation.

2.2. Custom measurement

2.2.1. Slopes for measuring layers. The value of the proven drainage coefficient must correspond to the slope of the designed green roof or differ by a maximum of 3 ° (inclusive) for roofs with a slope of up to 12 °. In other cases, it may differ by a maximum of 6 ° (inclusive). (Measurements are made for flat roofs on a slope of 1 and 5 °. In the case of a sloping roof, measurements are made on a slope of 10 and 20 °).

2.2.2. Test conditions. The reference precipitation is evenly distributed precipitation over time and area with a total volume of 27 mm/m^2 over 15 minutes at constant intensity. The reference precipitation must irrigate the whole area at a temperature of 18 to 22 ° C, at normal atmospheric pressure, a constant relative humidity of 45-60% and no wind up to 0,2 m/s. The permissible measurement deviation is 3%.

2.3. Test specimens
The tested composition is realized on a reference square area of 1.4 to 2.3 m^2 in the entire composition of green roof at the measured slope. The outflow from the outlet line in the length of 1.2 to 1.5 m is continuously monitored by measuring the mass of the drained water in the interval of 5 seconds for 2 hours from the beginning of the sprinkling of the specimen by reference precipitation.

2.4. Boundary conditions for measuring partial layers of green roofs.
Differences for measuring separate layers of a composition. All the above apply with the addition of: Separate technical layers are loaded with a load of 80 kg/m^2 for extensive aggregate roofs of the 4-8 mm fraction, 150 kg/m^2 for semi-intensive and intensive variants of the 4-8 mm fraction.

2.5. Determination of runoff coefficient
The measured data according to the issue showed the need to distinguish between the peak runoff coefficient C_{peak} and the reference runoff coefficient C. The reference runoff coefficient C is determined by equation (1):

$$C = \frac{(C_{1200}+C_{1500}+C_{1800})}{3} \tag{1}$$

Where C is the reference runoff coefficient, C_{1200}, C_{1500} and C_{1800} are the partial runoff coefficients at 1200, 1500 and 1800 second tracking.

The partial runoff coefficients C_i are determined by equation (2):

$$C_i = \frac{Q_{d\mathrm{rained}}}{Q_{\mathrm{rained}}} \tag{2}$$

Where C_i represents the partial runoff coefficient at the observed time t, $Q_{drained}$ represents the value of the effluent from the specimen at the relevant time t and Q_{rained} represents the sum of the simulated precipitation per test specimen at time t.

The peak runoff coefficient C_{peak} is determined by equation (3):

$$C_{\mathrm{peak}} = \frac{Q_{900}}{Q_{\mathrm{rained}}} \tag{3}$$

Where C_{peak} represents the peak runoff coefficient at 900 s from the start of sprinkling the specimen, Q_{drained} represents the value of the effluent from the specimen at 900 s and Q_{rained} represents the total sum of the simulated rain on test specimen.

2.6. Testing equipment

For the purpose of measuring runoff parameters and subsequent determination of runoff coefficient C, the research team created a test bench, which allows easy mounting of test specimens, their easy inclination to the appropriate inclination and is equipped with fittings with measuring and reading devices, ensuring simple operation and export of measured data. The test bench is shown at Figure 1.

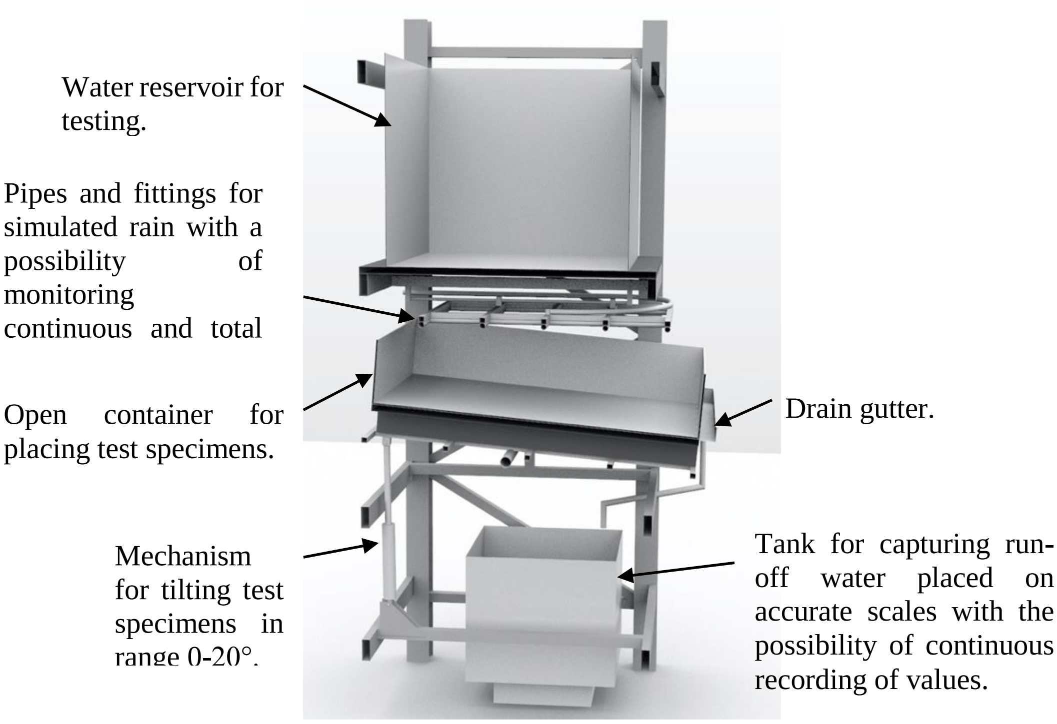

Figure 1. Section of axonometry 3D model test bench.

3. Results of testing

The result of measuring the runoff parameters according to the methodology described above is a graph of the course of runoff of rainwater over time with uniform sprinkling of specimens by simulated rain. Based on these data, the stated runoff coefficients are determined. An example of the measurement output is evident from Figure 2, when a specimen of one composition of an extensive green roof was measured at two different tilts.

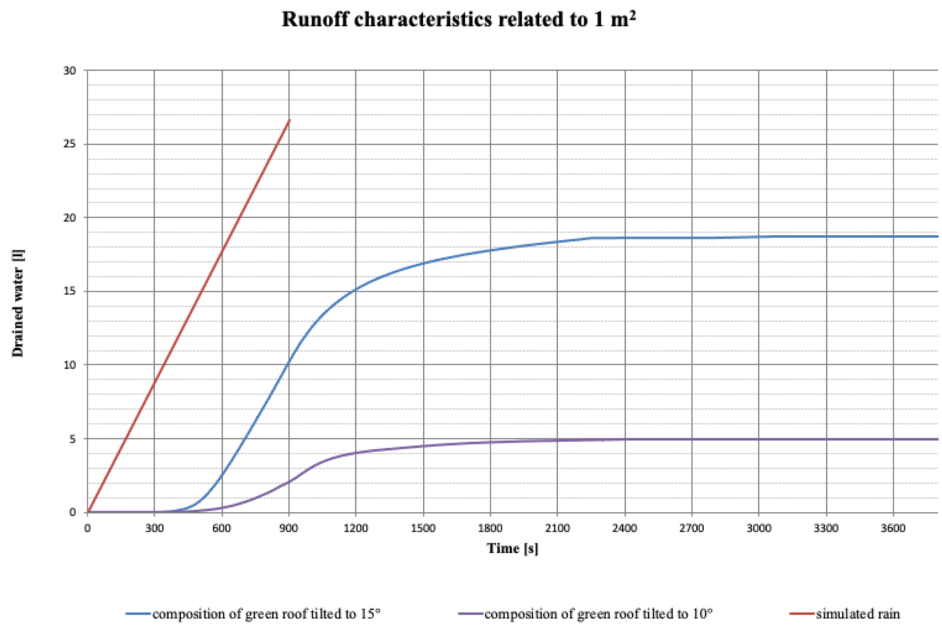

Figure 2. Comparison of runoff characteristics of the specimen green roof cladding in two different tilts.

A comparison of the course of selected materials for hydroaccumulation layers in the same slope is evident from Figure 3.

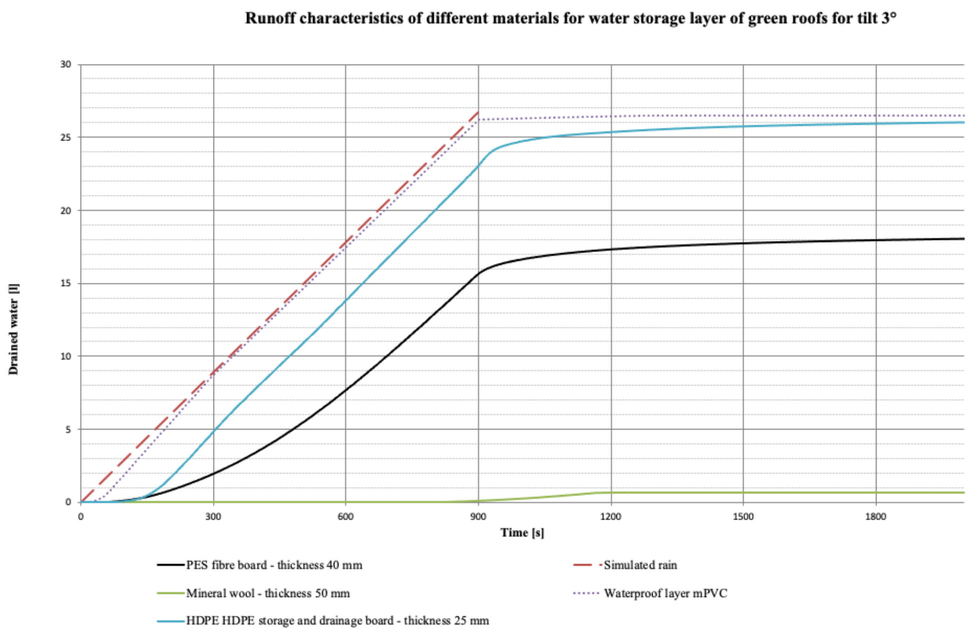

Figure 3. Comparison of runoff characteristics of different materials for water reservoir layer in tilt 3°.

4. Conclusion

The main output of the measurement is the determined reference coefficient of runoff C. Other secondary outputs are the peak runoff coefficient Cpeak and a graph of the course of rainwater runoff during the composition. Thanks to these outputs, it is possible to very quickly compare individual materials or entire compositions of green roofs for a suitable individual design of the green roof structure not only with regard to the type of technical layers, but also according to the conditions of the locality. It also provides more accurate data for the design of related parts of buildings such as retention, accumulation and infiltration facilities, etc. The average runoff coefficient C has a major impact on the calculation of the price for the discharge of rainwater into sewers. The precise determination of the individual compositions of green roofs can therefore have a significant effect on the cost of operating a building during its overall life cycle.

5. References

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