

Paper title

Comparison of laboratory and in-field water storage properties of different green roofs and gravel roof

Abstract

Green roofs gain importance in urban water management. Thanks to their water storage ability they can be applied to avoid pluvial flooding. In planning processes water capacity of green roofs ascertained in laboratory tests is taken as basis for calculations. A research project shall clarify, if laboratory results for water capacity of green roofs comply with field tests and if gravel roofings could be an alternative to green roofs in that concern.

Five green roofs (constructions heights from 7 to 30cm) and one gravel roofing have been tested. The vegetation layer comprises of four structure materials (limestone, basalt, brick and claylit) mixed with silica sand and organic components.

In a first step the water capacity was ascertained according to Austrian Standard Institute for all vegetation layers. In a field test the named materials have been used to construct test fields. Every test field has been equipped with two soil humidity sensors. The sensors have been installed 1 cm under the surface and one 1 cm above the bottom of the vegetation layers. The test period chosen (26.7. to 9.8.2011) include three rainfall events (4.8.: 5.8mm; 7.8. to 8.8.: 11.3mm; 28.7.: 20.5mm).

In general the maximum water capacity in the field tests of vegetation layers differs significantly from the laboratory results. An average rainfall event in Vienna may be stored within every tested green roof. The field test showed, that thin green roofs are not able to store rainfalls from 20mm or more. The results for the „alternative“ gravel roof show clearly that also concerning the water storage it is no option compared to green roofs.

The prolonged investigation will support the implementation green roofs and allow realistic calculation of their water storage capacity.

Authors' Biographies



Bernhard Scharf, born 1974 in Salzburg, studied Landscape architecture and Landscape planning at the University of Natural Resources and Life Sciences Vienna. He wrote his master thesis at the Institute of Soil Bioengineering and Landscape Construction (IBLB) about flowering turf, a drought and load resistant alternative to grass lawns. Since 2006 he is employed as Scientist at the IBLB. His research focus is laid upon vegetation technology especially building integrated greening.



Ulrike Pitha, born 1976 in Moedling/Austria, studied Landscape architecture and Landscape planning at the University of Natural Resources and Life Sciences Vienna. She wrote her master thesis at the Institute of Soil Bioengineering and Landscape Construction (IBLB) about Gravel paths in historical gardens and her PhD thesis about wheelchair use in urban parks. Since 2006 she is leader of the vegetation technology research group of the IBLB.



Vera Enzi, born 1984 in Villach/Austria, studied Landscape architecture and Landscape planning at the University of Natural Resources and Life Sciences Vienna. She wrote her master thesis at the Institute of Soil Bioengineering and Landscape Construction (IBLB) about Facade greenings – Innovations and Chances. Since 2010 she is employed as researcher in the field of the vegetation technology at the IBLB. Her international and national Projects focus at the field of façade- and roof greening, dealing with microclimate and vegetation development as well as related building physics of green technologies. She is also managing the Austrian and European Green Roof Association (VfB and EFB).

Background

Industrial Context

The growth of cities and the increase of individual mobility are unabated. Accordingly the proportion of sealed impermeable surface rises. Simultaneously extreme weather conditions increase in number. This effect of climate change and the high degree of sealed and impermeable surfaces cumulate in Europe's metropolis.

The sewer systems in the old European cities have been planned and built under different meteorological framework conditions, which have changed significantly. In case of today's heavy rain events frequently sewers are overburdened causing urban flooding and damage to private and public property.

Municipalities have taken measures to counteract harm to their inhabitants and property. These measures vary throughout Europe. Some municipalities enlarge their sewer system as immediate action, construction giant main sewers for retention (e.g. Vienna). Other municipalities collect wastewater charges based on the proportion of sealed surfaces of a real estate, where the presence of green roofs is accounted to minder the charge.

SCHADE (2000) indicated that green roofs are able to store rainfall and delay runoff significantly. LIESECKE (2000) published a long-term research of the water storage capacity of different construction types of green roofs.

But still the pointed application of green roofs as measure to counteract deficiencies of the sewer system and prevent pluvial flooding is not yet known. City planners have not encountered green roofs as highly appropriate measure of urban water management. The green roof branch could experience a major growth if this awareness can be created.

Problem

Planning processes are commonly based on standards, guidelines and directives. Until now only a few standards concerning green roofs (e.g. ASI L1131, 2010) and some green roof guidelines (e.g. FLL, 2008) exist in Europe. These standards provide benchmarks concerning water capacity of vegetation base layer materials of different green roof types etc. In Austria, as typically for most European nations, the water capacity is ascertained according to a national standard (ASI B2606-1, 2009).

The presented research investigates whether the laboratory test results can be taken as basis for planning processes. A comparison of laboratory and field results should establish clarity.

Additionally this research shall demonstrate the difference between green roofs and gravel roofs concerning their water storage performance.

Learning Objectives:

- Can standard laboratory water capacity measurement methods serve as basis for water storage performance of green roofs, urban water management and urban water planning?

- Are gravel roofs an appropriate alternative to green roofs concerning water retention?
- How differ green roof construction types in their water storage performance?

Approach

By means of selected green roof constructions and materials the laboratory test results for water capacity and field water storage performance should be compared. A gravel roof should be investigated similarly to allow a comparison to the green roofs.

Analysis

Materials

Five green roofs and one gravel roofing have been chosen for the investigation. Table 1 provides detailed information about the green roof test variants A, B, C, D, E and the gravel roof test variant F.

Table 1: Detailed description of the different test variants.

variant	height [cm]	material
A	7	limestone gravel, perlite, soil, compost
		protection layer
B	7	clayey mineral substrate, compost
		filter fleece
	5	clayey mineral substrate
C		protection layer
	7	recycling brick, silica sand, compost
		filter fleece
D	5	recycling brick
		protection layer
	15	recycling brick, silica sand, compost
E		filter fleece
	15	basalt, lava, compost, perlite
		protection layer
F	15	perlite
	8	lime stone gravel (light grey)
		protection layer

The test variants have been built on a roof in Vienna. Each test variant has a size of 4 m².

Method laboratory test

The water capacity of each vegetation base layer material and the gravel has been ascertained according to Austrian Standard B 2606-1 Surfaces for sports areas – Lawns (2009). The standard defines the test procedure as follows:

- The test material has to be filled in a Proctor-cylinder (150 mm diameter, 125 mm height) at a water content of $w = 0.12$ to 0.13 .
- The materials have to be compacted by 12 Proctor-hammer strokes (weight 4.5 kg, falling height 450 mm).
- The cylinder's base plate has to be replaced by a filter plate.
- The whole cylinder is put into a water basin with a water level of 10 to 30 mm above the material surface for four hours.
- After four hours of undisturbed water drainage the net mass of the test material is ascertained.
- The test material is dried at $105\text{ }^{\circ}\text{C}$ until the end of weight loss.
- The mass of the dried material is ascertained.
- The test has to be repeated three times.
- The difference of the net mass to the dried mass is ascertained for every recurrence.
- The arithmetic average of the mass differences of all recurrences represents the water capacity of the tested material.

Method field test

Each 4 m^2 sized test field is equipped with two soil humidity sensors (Decagon Echo² 5TM). The sensors are installed 1 cm under the surface and one 1 cm above the bottom of the vegetation base layers.

The following figure 1 shows the position of the sensors within the test variants.

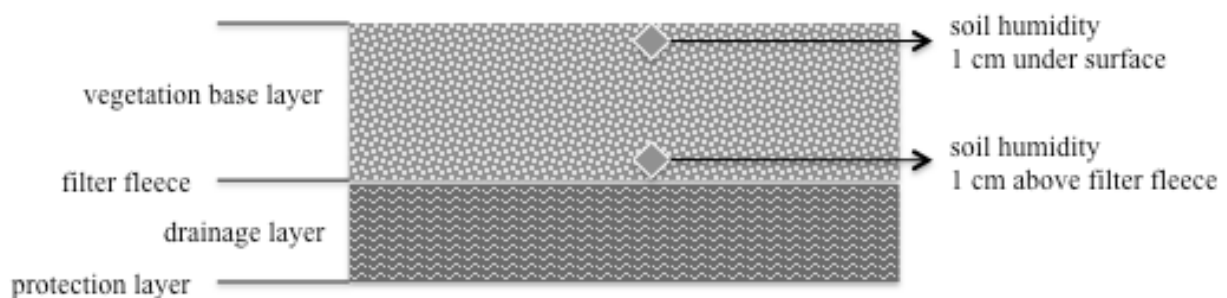


Figure 1: Measurement setup showing the position of the sensors.

The measurement setup allows determining the water storage performance of the test variants. A climate station next to the test fields measures the precipitation as most relevant parameter for the analyses.

Investigation period and precipitation

The soil humidity and climate data of the test variants is recorded since February 2011. For the analyses in this paper a period in summer 2011 from July 26th to August 9th has been chosen. This period covers three rainfall events of different intensities and durations (also see fig.2.):

- Date 4.8.2011; precipitation 5.8 mm; duration 6.5 h
- Date 7.8. to 8.8.2011; precipitation 11.3 mm; duration 24 h
- Date 28.7.2011; precipitation 20.5 mm (thereof 10.3 mm within 50 min); duration 7.5 h

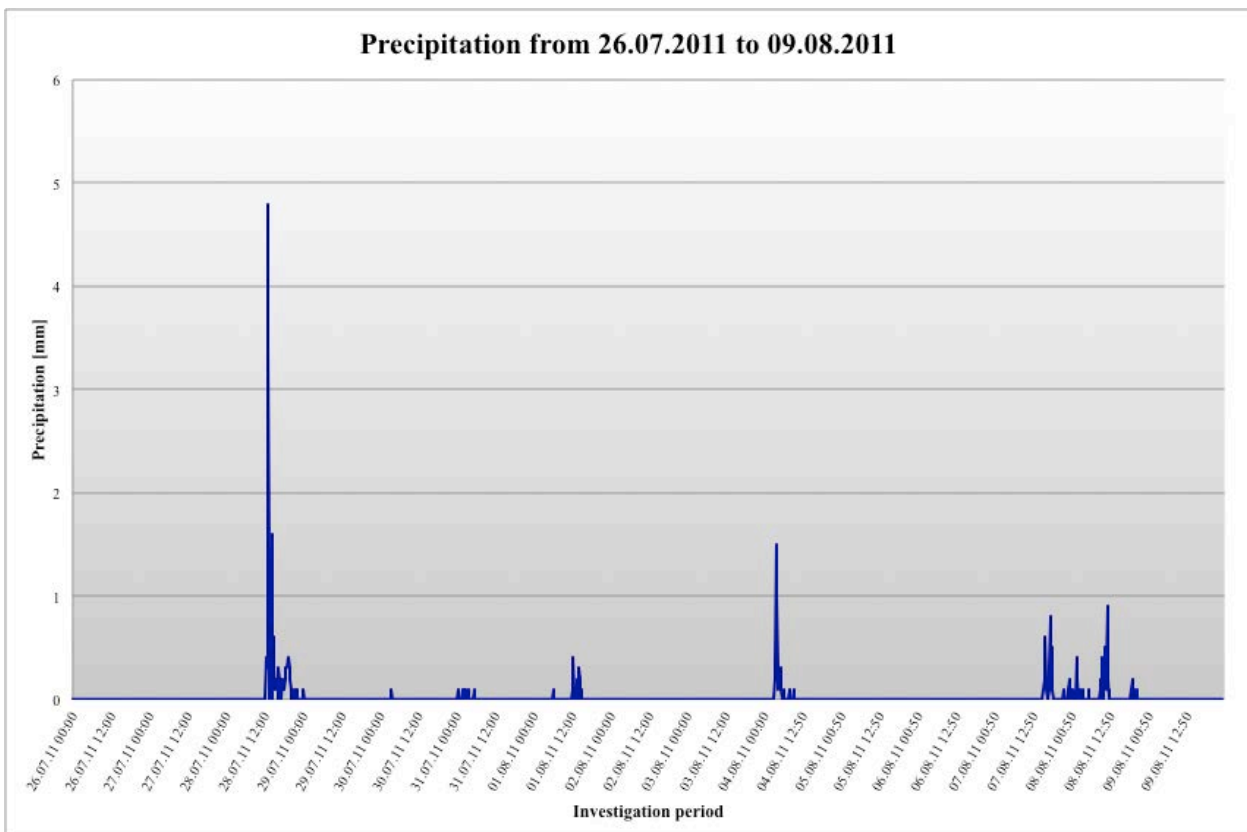


Figure 2: Precipitation in investigation period measured at the test sites with a R M Young rain gauge.

Results of the laboratory test

The following table shows the results of the laboratory test of the water capacity of all test variants:

Table 2: Water capacity of the test materials and calculated water storage potential of the constructed test sites.

Test variant	A	B	C	D	E	F
Water capacity laboratory test result [%]	35,57	35,25	51,5	51,5	41,3	12
Calculated water storage [mm/m ²]	24,899	24,675	36,05	77,25	61,95	9,6
Height of vegetation base layer [cm]	7	7	7	15	15	8

According to the height of the respective vegetation base layer of each test variant the water storage potential has been calculated using the laboratory test results. Test variants A and B show the lowest water storage. Test variant C provides the highest water storage potential of the extensive green roofs. Expectably, the two reduced intensive green roofs have best results concerning water storage. Gravel (test variant F) can store only 9.6 mm of water per m².

Results of the field test

The following figures illustrate the actual water storage performance of the test variants in the field.

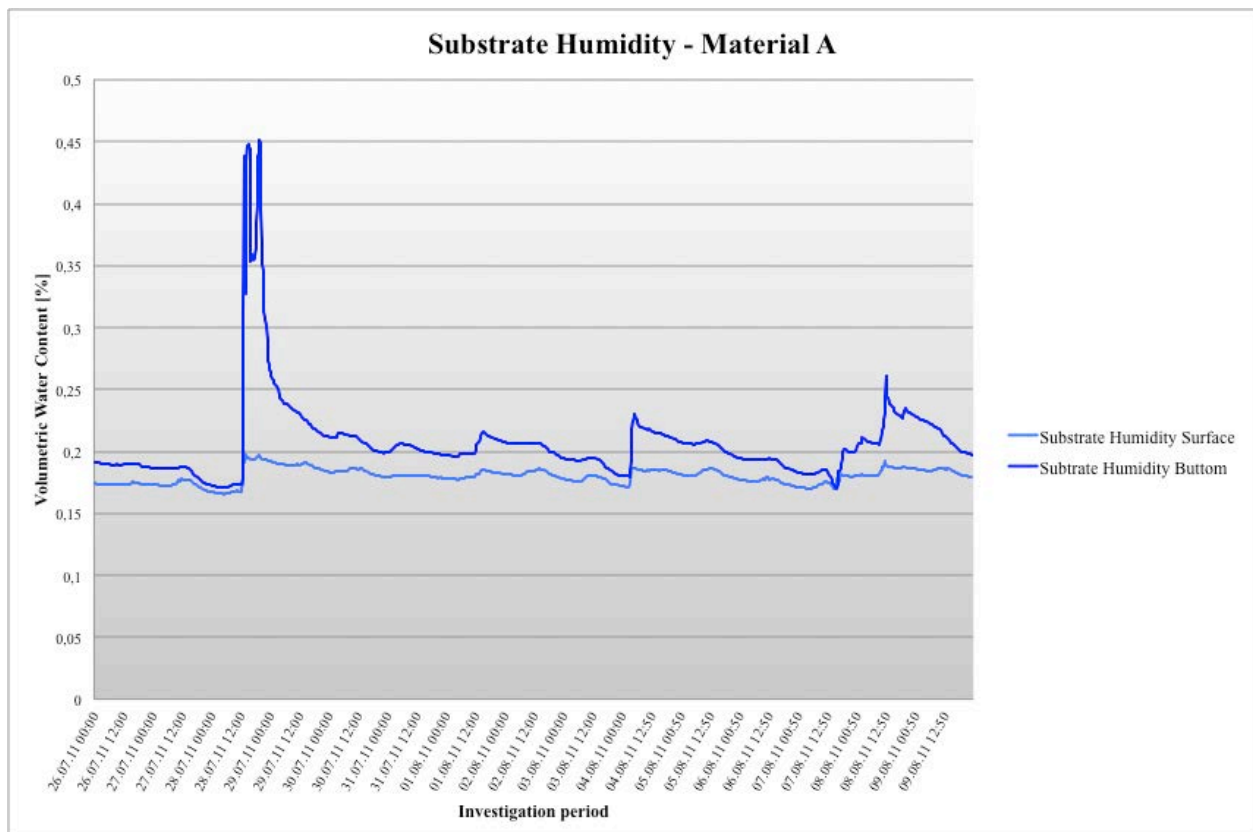


Figure 3: Soil humidity regime of test variant A over the investigation period from 26th of July to 9th of August 2011.

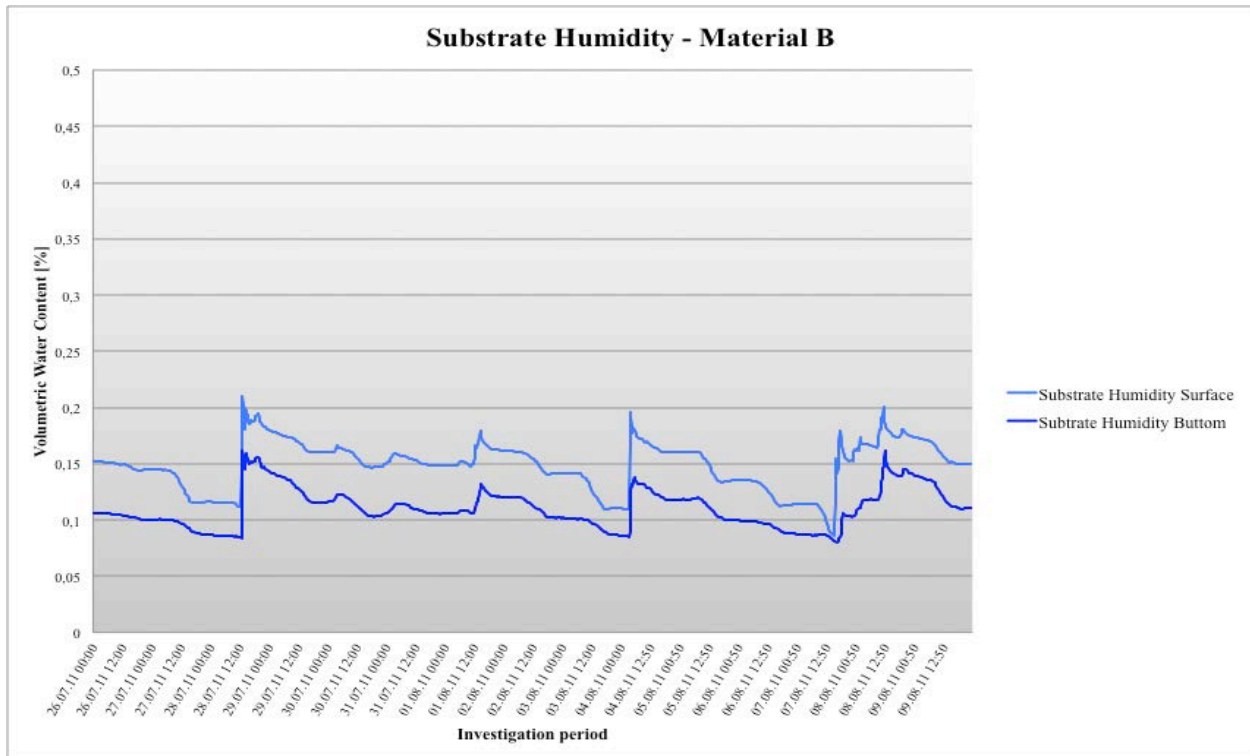


Figure 4: Soil humidity regime of test variant B over the investigation period from 26th of July to 9th of August 2011.

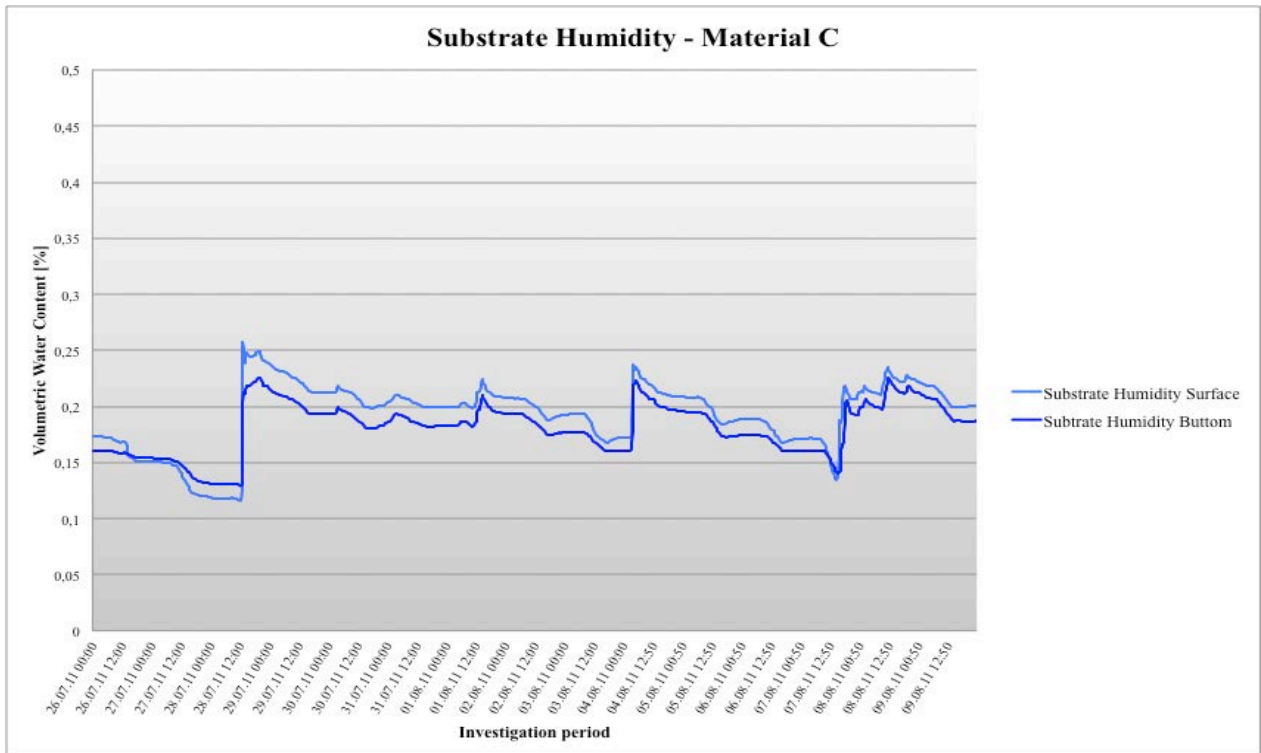


Figure 5: Soil humidity regime of test variant C over the investigation period from 26th of July to 9th of August 2011.

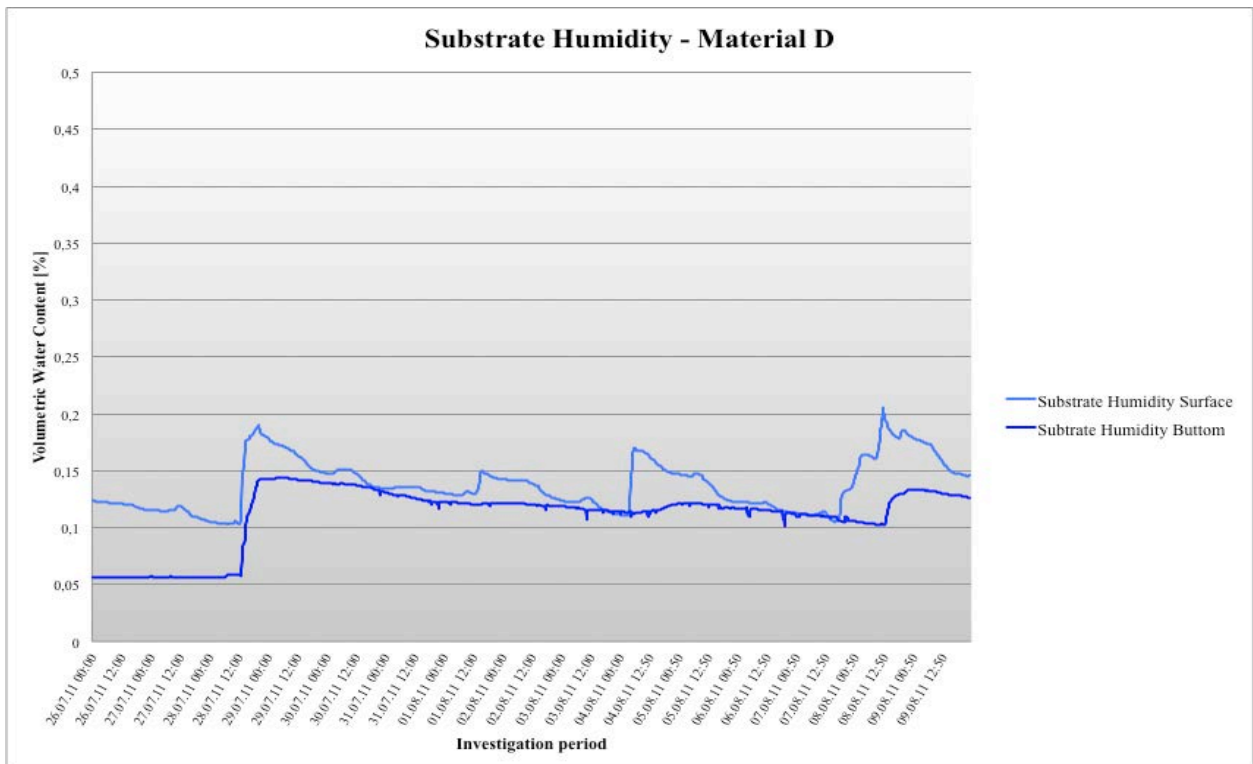


Figure 6: Soil humidity regime of test variant D over the investigation period from 26th of July to 9th of August 2011.

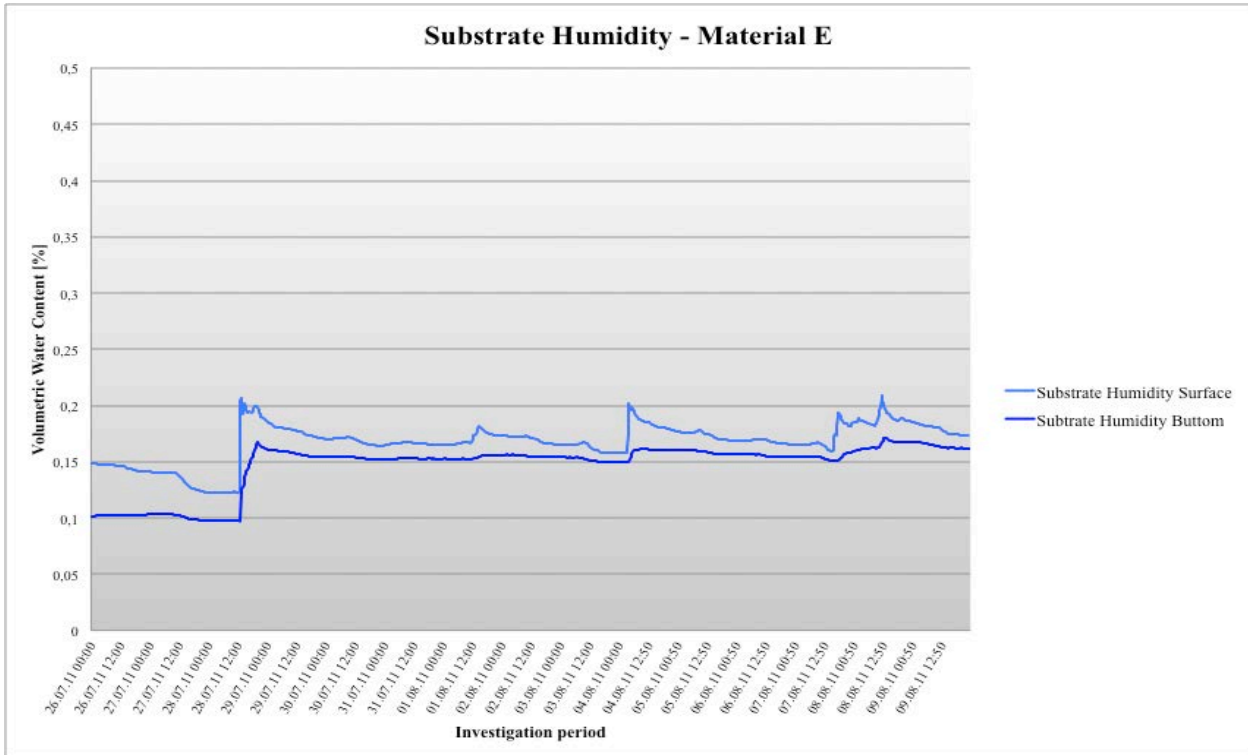


Figure 7: Soil humidity regime of test variant E over the investigation period from 26th of July to 9th of August 2011.

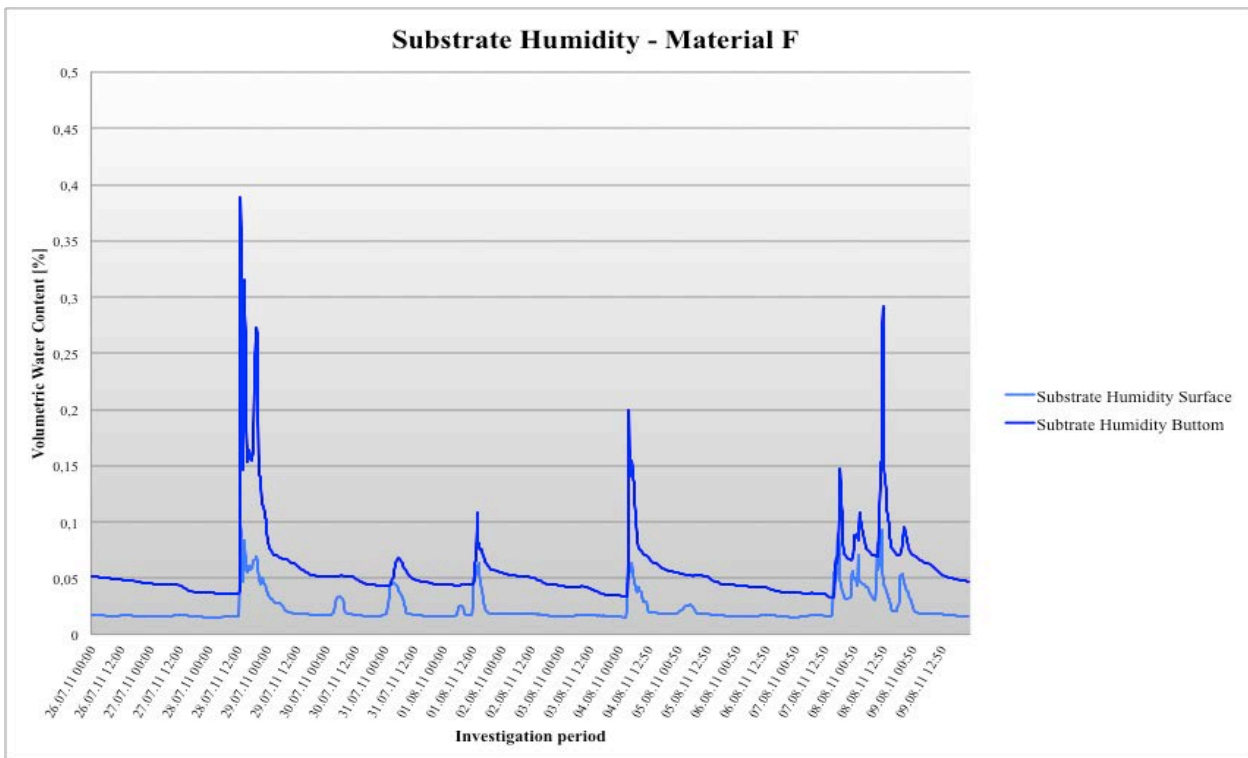


Figure 8: Soil humidity regime of test variant F over the investigation period from 26th of July to 9th of August 2011.

The soil humidity at the bottom of the vegetation base layer of test variant A and of gravel (test variant F) is higher than the surface near soil humidity. The extensive green roof variants B and C show roughly a similar water storage regime, where the regime of the surface near and the bottom soil humidity correlate significantly. The reduced intensive test variants reacted differently on the three precipitation events. The regime of the surface near soil humidity does not influence the bottom humidity as significant as for the other test variants. The soil humidity at the bottom of the vegetation base layer acts buffered and delayed.

Comparison of laboratory test and field test

In this chapter the results of the laboratory test and the soil humidity regimes of the test variants at the three precipitation events are compared. Based on the following tables conclusions are formulated concerning the reliability and applicability of the standard laboratory test in green roof planning processes (see chapter conclusions).

To that purpose the water storage potential has been calculated using the water capacity results from the laboratory test. The water content before start of the rain event was subtracted from the calculated water storage potential to calculate the resuming water storage potential.

To characterize the soil humidity regimes of the test variants the volumetric water content (VWC%) is presented just before the start of the rain event as well as 1 and 24 hours after the start of the rain event. The maximum volumetric water content is also shown in the tables.

Table 3: Comparison of the soil humidity regime of the test variants and the calculated water storage based on the laboratory test results at the heavy rain event from 28th of July 2011.

Soil humidity regime comparison of heavy rain event												
Precipitation: 20,5 mm			Start date: 28. July 2011						Start time: 12:30			
Test variant	A		B		C		D		E		F	
	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom
Water capacity Laboratory test [VWC%]	35,6		35,3		51,5		51,5		41,3		12,0	
Calculated water storage [mm/m ²]	24,9		24,7		36,1		77,3		62,0		9,6	
Pre-saturation [mm/m ²]	12,0		6,9		8,6		5,7		7,7		1,8	
Resuming water storage potential [mm/m ²]	12,9		17,8		27,4		71,6		54,3		7,8	
Start of rain event [VWC%]	16,8	17,4	11,2	8,5	11,7	13,0	10,4	5,8	12,2	9,8	1,6	3,6
1h after start of rain event [VWC%]	19,8	43,9	20,3	16,3	25,3	21,2	14,2	7,2	20,7	12,2	9,2	36,2
Maximum [VWC%]	20,0	45,2	21,0	16,3	25,7	22,6	19,0	14,3	20,7	16,7	9,8	38,9
24h after start of rain event [VWC%]	18,9	23,0	16,9	8,7	22,2	14,3	16,3	14,3	17,7	15,7	1,9	6,1
Difference start to maximum [VWC%]	3,2	27,8	9,8	7,8	14,0	9,6	8,6	8,5	8,5	6,9	8,2	35,3
Difference maximum to 24h after [VWC%]	-1,1	-22,2	-4,1	-7,6	-3,5	-8,3	-2,7	0,0	-3,0	-1,0	-7,9	-32,8

Table 4: Comparison of the soil humidity regime of the test variants and the calculated water storage based on the laboratory test results at an average rain event from 7th to 8th of August 2011.

Soil humidity regime comparison of average rain event												
Precipitation: 11,3 mm			Start date: 7. to 8. August 2011						Start time: 16:00			
Test variant	A		B		C		D		E		F	
	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom
Water capacity Laboratory test [VWC%]	35,6		35,3		51,5		51,5		41,3		12,0	
Calculated water storage [mm/m ²]	24,9		24,7		36,1		77,3		62,0		9,6	
Pre-saturation [mm/m ²]	12,0		5,9		9,6		7,6		10,9		1,7	
Resuming water storage potential [mm/m ²]	12,9		18,8		26,4		69,7		51,1		7,9	
Start of rain event [VWC%]	17,0	17,2	8,6	8,2	13,4	14,1	10,6	11,0	15,9	15,1	1,6	3,3
1h after start of rain event [VWC%]	17,6	17,9	14,7	8,0	18,7	15,0	10,6	11,0	17,5	15,1	5,0	5,1
Maximum [VWC%]	19,2	26,1	20,1	16,2	23,6	22,7	20,5	12,5	20,9	17,2	9,4	29,2
24h after start of rain event [VWC%]	18,7	23,3	17,5	9,7	22,4	12,5	18,3	12,5	19,0	16,9	2,4	8,0
Difference start to maximum [VWC%]	2,2	8,9	11,5	8,0	10,2	8,6	9,9	1,5	5,0	2,1	7,8	25,9
Difference maximum to 24h after [VWC%]	-0,5	-2,8	-2,6	-6,5	-1,2	-10,2	-2,2	0,0	-1,9	-0,3	-7,0	-21,2

Table 5: Comparison of the soil humidity regime of the test variants and the calculated water storage based on the laboratory test results at a moderate rain event from 4th of August 2011.

Soil humidity regime comparison of moderate rain event												
Precipitation: 5,8 mm Start date: 04.Aug.11 Start time: 03:10												
Test variant	A		B		C		D		E		F	
	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom	soil humidity surface	soil humidity bottom
Water capacity Laboratory test [VWC%]	35,6	35,3	35,3	35,3	51,5	51,5	51,5	51,5	41,3	41,3	12,0	12,0
Calculated water storage [mm/m ²]	24,9	24,7	24,7	24,7	36,1	36,1	36,1	36,1	77,3	62,0	9,6	9,6
Pre-saturation [mm/m ²]	12,3	6,9	6,9	6,9	11,7	11,7	11,7	11,7	10,8	10,8	1,7	1,7
Resuming water storage potential [mm/m ²]	12,6	17,8	17,8	17,8	24,4	24,4	24,4	24,4	69,4	51,2	7,9	7,9
Start of rain event [VWC%]	17,1	17,9	11,0	8,6	17,2	16,1	11,1	11,3	15,8	15,0	1,5	3,4
1h after start of rain event [VWC%]	18,6	22,4	18,4	13,2	23,5	22,1	13,7	11,4	20,1	15,1	5,7	16,2
Maximum [VWC%]	18,8	23,1	19,6	13,8	23,7	22,3	17,0	12,1	20,2	16,2	6,4	20,0
24h after start of rain event [VWC%]	18,1	20,6	16,0	8,1	20,8	12,1	14,6	12,1	17,6	16,0	2,4	5,4
Difference start to maximum [VWC%]	1,7	5,2	8,6	5,2	6,5	6,2	5,9	0,8	4,4	1,2	4,9	16,6
Difference maximum to 24h after [VWC%]	-0,7	-2,5	-3,6	-5,7	-2,9	-10,2	-2,4	0,0	-2,6	-0,2	-4,0	-14,6

Test variant A

Test variant A, an extensive green roof without drainage layer, cannot absorb a heavy rain event. The drainage water cumulates and impounds at the bottom of the vegetation base layer concluding in volumetric water content that exceeds the laboratory test result. In contrast the lack of a drainage layer causes retention of the precipitation within the vegetation base layer.

Test variants B and C

The two extensive green roofs with drainage layer (test variant B and C) show similar soil humidity regimes. The laboratory water capacity is by far not reached at all rain events. This may be accounted to the drainage layer that. Surplus water can drain away from the vegetation base layers. This fact is underpinned clearly by the 24h volumetric water content values of the test variants B and C.

Test variants D and E

The two reduced intensive green roof variants D and E are able to store the precipitation in the investigation period sufficiently. This can be seen by the increase of soil humidity and the little decrease of the bottom soil humidity after 24 hours.

Test variant F

The gravel roof is not able to store the precipitation. The difference of the maximum volumetric water content and the 24 hours value shows that gravel is not even able to store the moderate rain event from 4th of August 2011.

Results and Business Impacts

Key Findings

Green roofs can play a decisive role in the adaption of urban areas to heavy rain events. The chosen materials and type of construction (reduced extensive, intensive etc.) are substantial to

their water storage performance. Accordingly green roofs may be used in planning processes to pointedly counteract water retention deficiencies of urban areas.

The water storage performance of gravel roofs cannot be compared to green roofs. Gravel roofs cannot be applied as means to counteract urban water management deficiencies.

Business Impacts

This paper shall give an impulse to the discussion of the green roof branch with stakeholders. The positive effects of green roofs are underpinned by the results of the research, which shall be taken up to convince stakeholders and foster the application of green roofs.

The green roof branch itself is challenged to provide better, robust and reliable information on the water storage performance of their products. Urban water management will play an even more important role for cities worldwide. It is up to the green roof branch to provide solutions.

Conclusions

The investigations show clearly that the laboratory test of the water capacity is not suitable to calculate the water storage and retention properties of green roofs. The test constitutes significantly higher values for all test variants. An explanation can be found in the process of material preparation, in concrete the compaction in the Proctor cylinder. The porosity of the materials is modified by the hammer strokes severely. The measured water capacity differs from the field tests accordingly.

A measurement method has to be developed, which provides realistic and reliable information about the water capacity of green roofs as a precondition of the integration of green roofs in urban water management and urban planning. Consequently the research is prolonged with a new laboratory water balance measurement method to ascertain the water storage performance of the test variants and other green roof constructions.

By no means the frequently used gravel roof can be taken as substitute or alternative to green roofs in terms of water retention.

The investigation shows that green roofs have a high potential to contribute to the solution urban water management deficiencies and adaption of urban areas to extreme weather conditions due to climate change. A full integration in planning processes still needs research efforts, dissemination of research findings to convince stakeholders of the necessity of green roofs.

Key Lessons Learned:

- Standard laboratory water capacity measurement methods cannot serve as basis for water storage performance of green roofs, urban water management and urban water planning.
- By no means gravel roofs are an appropriate alternative to green roofs concerning water retention.
- The water storage performance of green roofs depends significantly on the height of the construction.
- A drainage layer leads to water loss from the vegetation base layer but prevent

oversaturation and decomposition of the vegetation base layer.

- Green roofs may be applied pointedly in urban water management planning to counteract deficiencies.

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