Paper title

Thermal performance of green roofs

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Abstract

The structure of dense urban areas causes negative impacts as e.g. nocturnal heat island. A major reason is lack of green and water spaces and high rate of sealed surfaces. Green roofs are often traded as an attractive solution to improve the thermal comfort of cities. But how effective are they compared to standard roofings and where are limits to their positive effects on a building?

A comprehensive investigation assessed the heat flux and temperature profiles (2 m above ground, on surface, in substrate near surface, in between substrate layers, on building envelope) of three extensive roof greenings (A, B and C) with a total height of 12 cm, a 30 cm thick reduced intensive roof greening (D) and three standard roofings (E-gravel, F-bituminous foil and G-tin). The chosen period from 9th to 23rd of July is characterized by a heat wave and two rain events.

Green roofs protect the buildings envelope significantly better than standard roofings. Heat waves diminish the positive effects, since all water is lost. The daily temperature amplitude of a dry green roof may rise up to 17 °C on the building envelope, while the tin roof reached over 55°C amplitude. When it comes to rainfall the temperature amplitude on the building envelope under a green roof falls to 7°C, while the tin roof still accounts over 40°C. The protection effect of the roof greening C is shown in figure 3 impressively. The investigation shows clearly that green roofs are an attractive solution to improve the thermal comfort of cities.

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 his 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.

Heidelinde Trimmel, study of landscape planning at the University of Natural Resources and Life Sciences Vienna (BOKU), Diploma thesis at the Institute of Meteorology, Department Water – Atmosphere – Environment at the BOKU in 2008 in the field of urban microclimate using microscale numeric simulations in comparison with open space analysis and meteorological measurements. Since 2007 deepening of this main focus in the various studies. Further investigation of the role of vegetation, water and permeable surfaces in different urban structures using measurements and simulations.

Background

Industrial Context

Thermal comfort, aesthetic and ecological quality of urban quarters is in public debate today. Urban areas are growing steadily, fostering already existing deficiencies as lack of recreation areas and thermal stress (Urban Heat Island). City centres can be compared to ecological desserts, with high proportions of sealed surfaces (plaster, stone, concrete, asphalt). The potential role of building integrated green (roof and facade greenings) to improve the quality of urban quarters and bring back nature to the cities is often discussed in that context (Fassbinder, 2012). Although the positive effects of green roofs as insulation effect or cooling by evapotranspiration are broadly accepted and known, they are still not included in planning processes and tools.

The roof greening branch developed very well over the last decades. A lot of effort has been put on technical solutions to meet all costumers' wishes. Today green roof technology allows creating parks on buildings as well as low-cost, lightweight, extensive greenings on flat and inclined roofs. The focus of research and development has been laid on material selection, plant selection, greening methods, water storage and drainage etc. In consequence green roofs are constructed on a high technical level today.

Other aspects, as thermal properties, ecological - especially faunistic - relevance and quality of different types of green roofs, microclimatic effects and added value for real estates, have also been investigated and valuable fundamentals created, e.g. by Köhler (2003). Gerder (2007) published her research concerning thermal effects of an extensive green roof in comparison to an insulation foil and a standard roof in 2007 and linked her findings to the energy demand for air conditioning. This linkage of research results and calculable effects is of high importance to the green roof branch, since project developers need to be able to calculate and justify the application of green roofs.

The ability to clearly and reliably quantify the effects (as thermal insulation, Albedo) derived from different kinds of green roofs is a precondition for integration in planning processes, directives and regulations and could boost the whole branch.

Problem

Green roofs could improve our cities microclimate and reduce the energy demand of buildings (for heating and cooling) significantly. Research results concerning the thermal performance of green roofs go back to last century. But still green roofs are not broadly applied or even compulsory on at least every flat roof. Obviously stakeholders and planners are still not fully convinced of the need of green roofs in cities.

Due to the increase of heat waves and urban heat island problematic - as consequence of climate change - the need to transform global radiation (sun energy) to useful outputs as electricity or humidity and temperature reduction (by evapotranspiration) is rising.

To convince stakeholders and planners to apply green roofs comprehensive investigations of the thermal performance (including latent, sensible and soil heat flux and albedo) of green roofs (different materials and construction types) in comparison to standard flat roofings (gravel, tin and bitumen foil) have to be conducted.

Learning Objectives:

- Potential of green roofs to counteract or diminish urban heat island effect.
- Thermal performance of different green roofs in hot and cold weather periods
- Thermal performance of different flat roofings in hot and cold weather periods

Approach

Roofings of buildings are objected to global radiation. Depending on the surface properties the global radiation is

- Reflected (albedo)
- Converted into sensible heat flux
- Converted into latent heat flux
- Converted into heat flux into the building

In the year 2010 a research project was started to investigate the thermal performance of four green roofs and three standard roofings. A measurement setup has been developed to ascertain the albedo, sensible heat flux and heat flux into the building.

The aim of the project is to acquire robust data of the insulation properties of different green roofs in comparison to standard roofings. Hence, allowing pointed and calculable application of green roofs.

Analysis

Figure 1: Test site in Vienna.

Materials

Within this paper four different green roofs and standard roofings are compared concerning their thermal performance in hot and cold weather periods:

Three extensive green roofs (A, B and C) with a total height of 12 cm, a 30 cm thick reduced intensive green roof (D) (according to ASI, 2010) and three standard roofings (E, F and G). The test sites have been constructed on a flat roof in Vienna. Each test variant has a size of 4 m^2. The following table 1 shows the construction of all tested green roofs and standard roofings.

Table 1: Detailed description of the different green roofs and standard roofings.

Variant	height [cm]	material
A	7	expanded slate, pumice,compost
		filter fleece
	5	drainage board
		protection layer
B	7	clayey mineral substrate, compost
		filter fleece
	5	clayey mineral substrate

		protection layer
C	7	recycling brick, silica sand, compost
		filter fleece
	5	recycling brick
		protection layer
D	15	basalt, lava, compost, perlite
		filter fleece
	15	perlite
		protection layer
E	8	lime stone gravel (light grey)
		protection layer
F	0,52	torch-on polymer bitumen membrane
G	0,2	light grey aluminium sheet-metal roofing

Measurement setup

Every test variant is equipped with

- air temperature and relative humidity sensor (Campbell Scientific CS215 and radiation protection MET20)
- albedo sensor (Apogee CS300 pyranometer)
- heat flux sensor with integrated thermocouple (Wuntronic C01-100-100K-10 Typ K)

Additionally the green roofs and gravel roof have been equipped with two soil moisture and soil temperature sensors (Decagon Echo^2 5TM). The following figure 2 shows the position of the sensors within the test variants schematically.

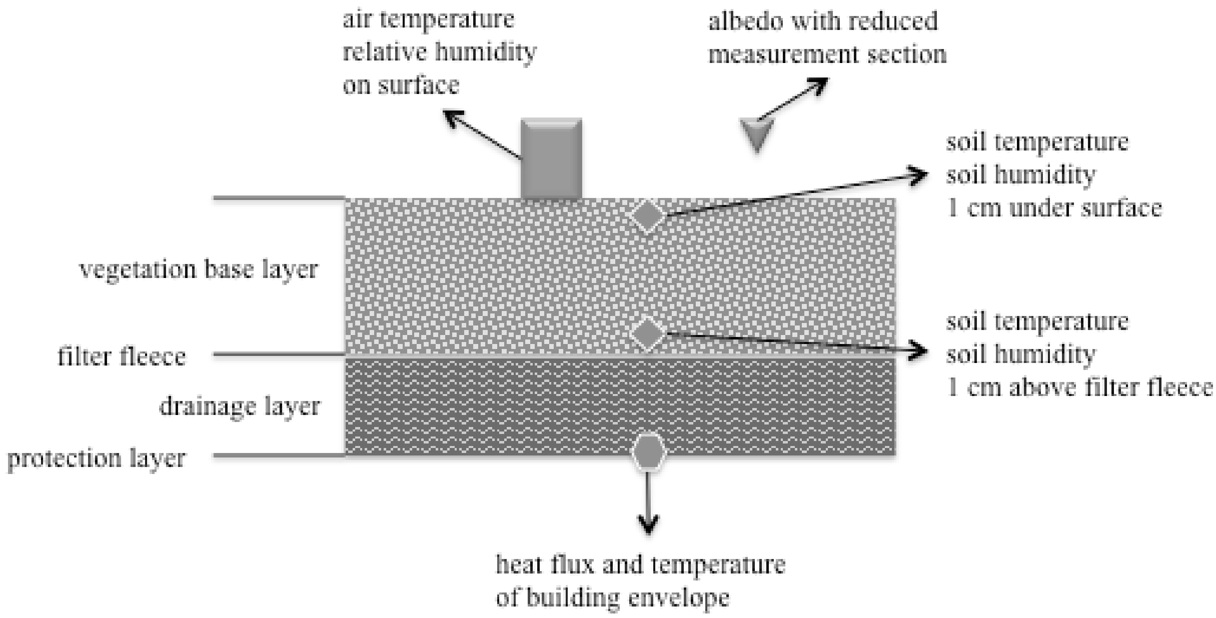

Figure 2: Measurement setup showing the position of the sensors.

A climate station provides the necessary background information on weather properties including precipitation, wind velocity and wind direction, global radiation, air temperature and relative humidity 2 m above ground and 40 cm above ground.

Results

The measurement setup allows monitoring the following parameters:

- Albedo
- Air temperature on surface
- Soil temperature of surface of vegetation base layer
- Soil temperature of bottom of vegetation base layer
- Temperature of building envelope
- Heat flux into building

The parameters have been logged every two minutes and summarized to 10 minutes averages resulting in 144 values per parameter per day. The measurement started in January 2011. To underpin the findings three periods have been chosen to illustrate the thermal performance of the different test variants. The following paragraphs present the results for every parameter and test variant and provide a short summary.

Albedo

Albedo is defined as the ratio of reflected radiation from the surface to incident radiation upon it. Being a dimensionless fraction, it may also be expressed as a percentage, and is measured on a scale from zero for no reflecting power of a perfectly black surface, to 1 for perfect reflection of a white surface (compare http://en.wikipedia.org/wiki/Albedo).

For the purpose of illustrating the differencies between the test variants an analyses from 18th of June 2011 has been chosen.

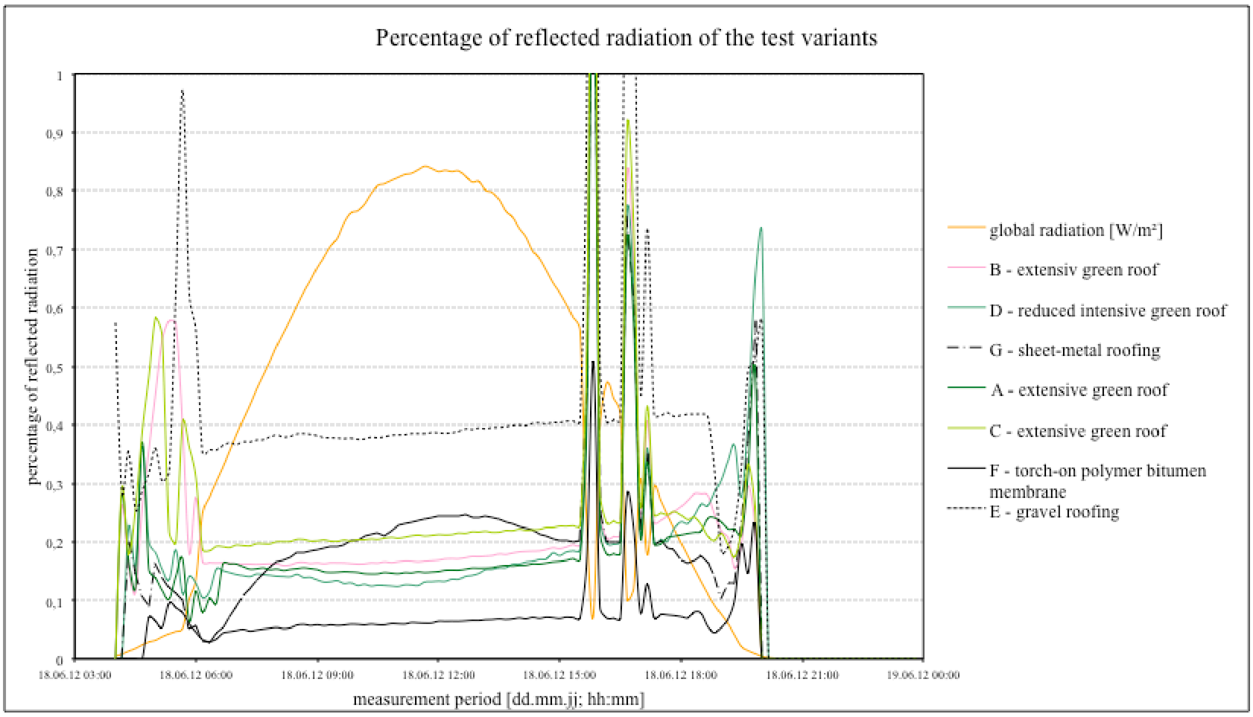

Figure 3: Percentage of reflected radiation of the different test variants in comparison to the global radiation measured on 18th of June 2011.

The reflected radiation (albedo) reduces the radiation input that contributes to the sensible, latent and heat flux into the building. Green roofs can vary strongly in their albedo from 13 % to 21 %. The albedos vary depending on the colour and humidity of substrate, vitality and height of plants.

As figure 3 shows the standard roofings provide albedo values from 7 % for torch-on polymer bitumen membrane, 24 % for metal-sheet roofing and 38 % for gravel roofing.

Although non-vegetated roof surfaces like gravel can have a clearly higher albedo, their inability to evapotranspirate leads them to higher surface and near-surface temperatures than vegetated ones.

Temperature profiles of summer period

The following figures show the temperature profiles of the different test variants from 9th of July until 23rd of July 2011 including two rain events (14th of July 2011- 5 mm, 21st of July 2011- 18,9 mm).

Every figure presents the air temperature 0.4 m above ground, air temperature on surface and the temperature at the building envelope. Additionally the soil temperature near surface and on the bottom of the vegetation base layer is shown for the green roof variants. For gravel the surface near and bottom temperature of the gravel layer is illustrated.

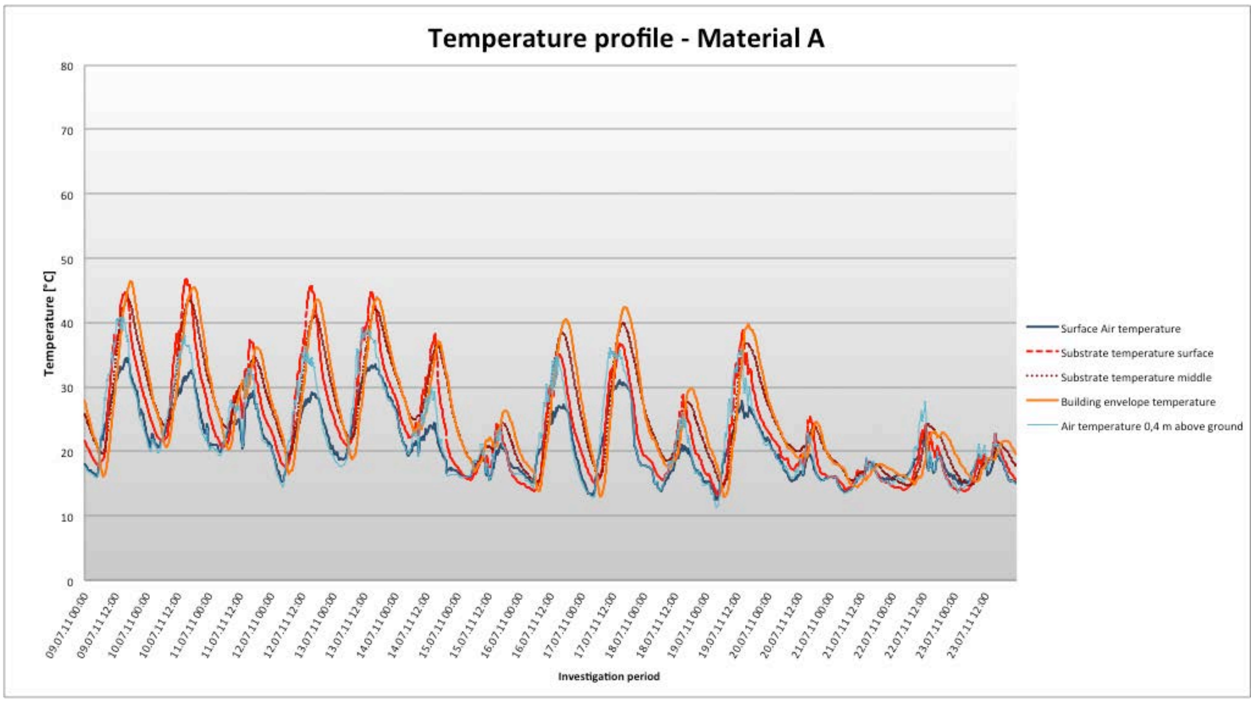

Figure 4: Temperature profile of test variant A – extensive green roof.

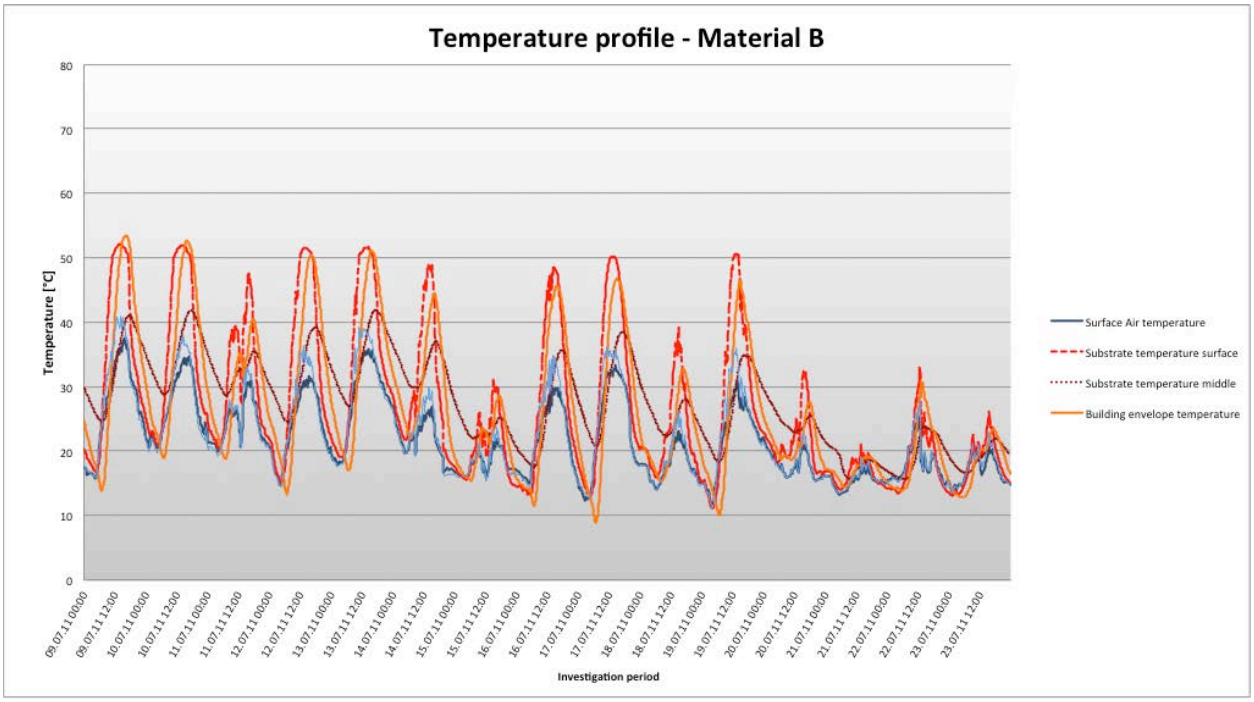

Figure 5: Temperature profile of test variant B – extensive green roof.

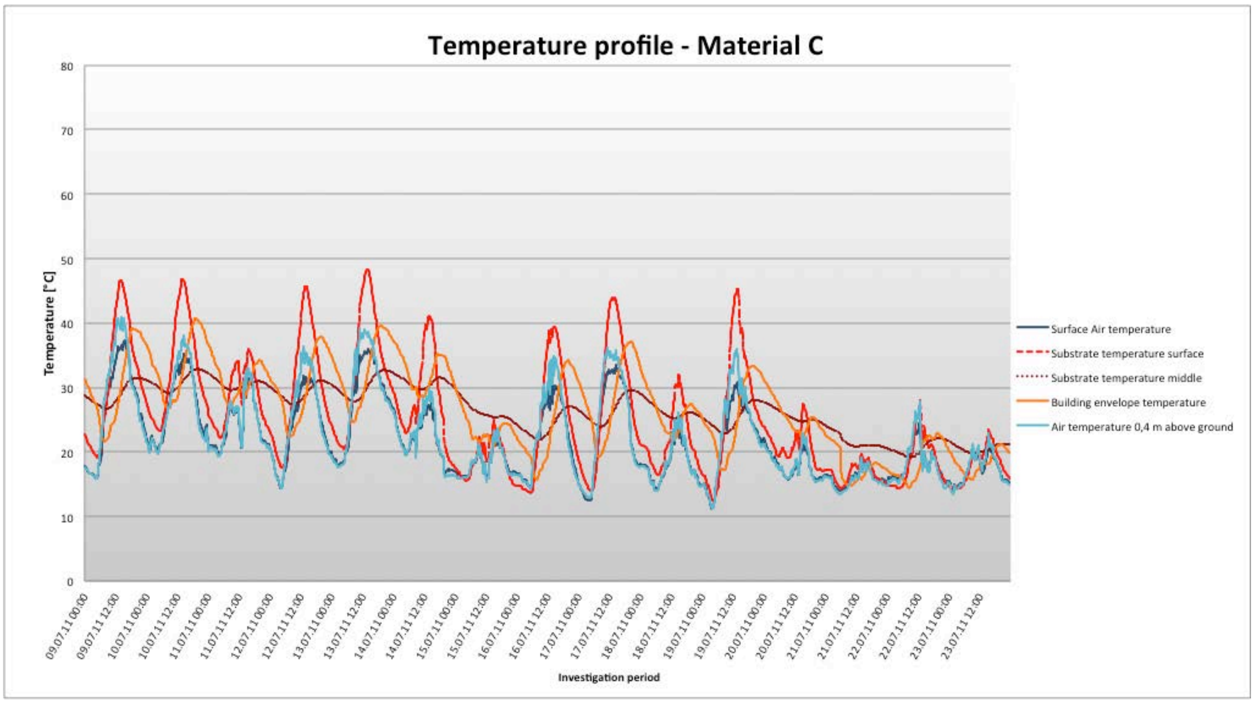

Figure 6: Temperature profile of test variant C – extensive green roof.

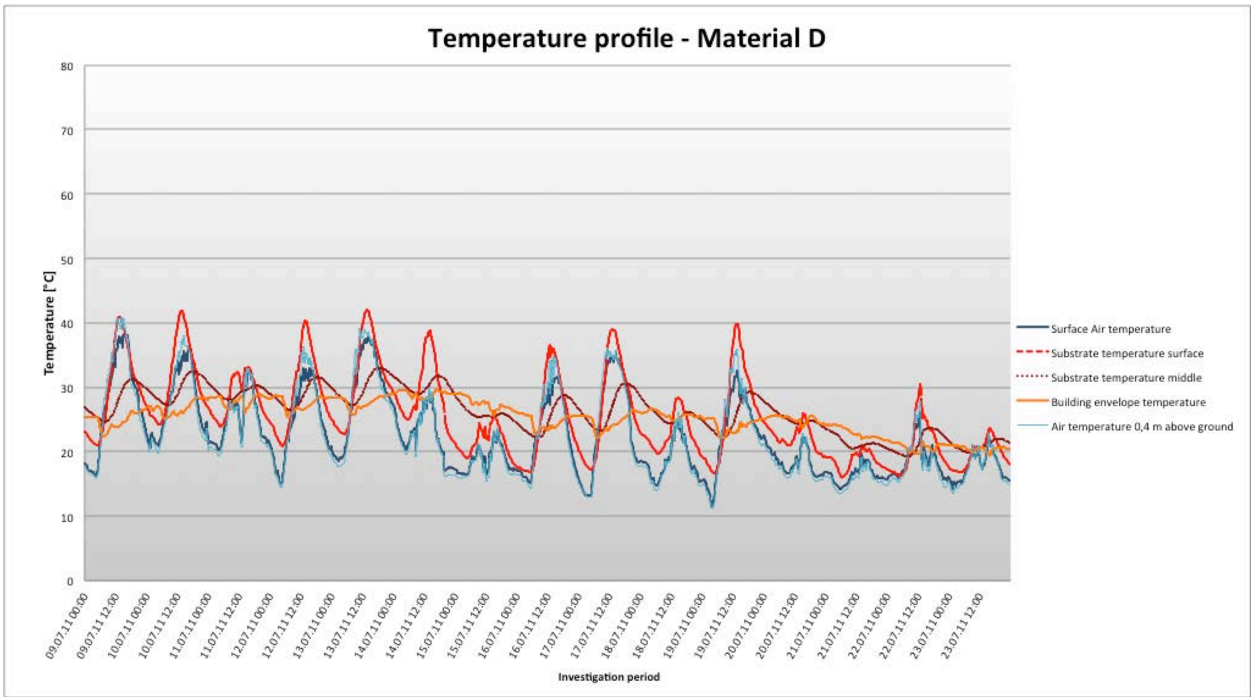

Figure 7: Temperature profile of test variant D – reduced intensive green roof.

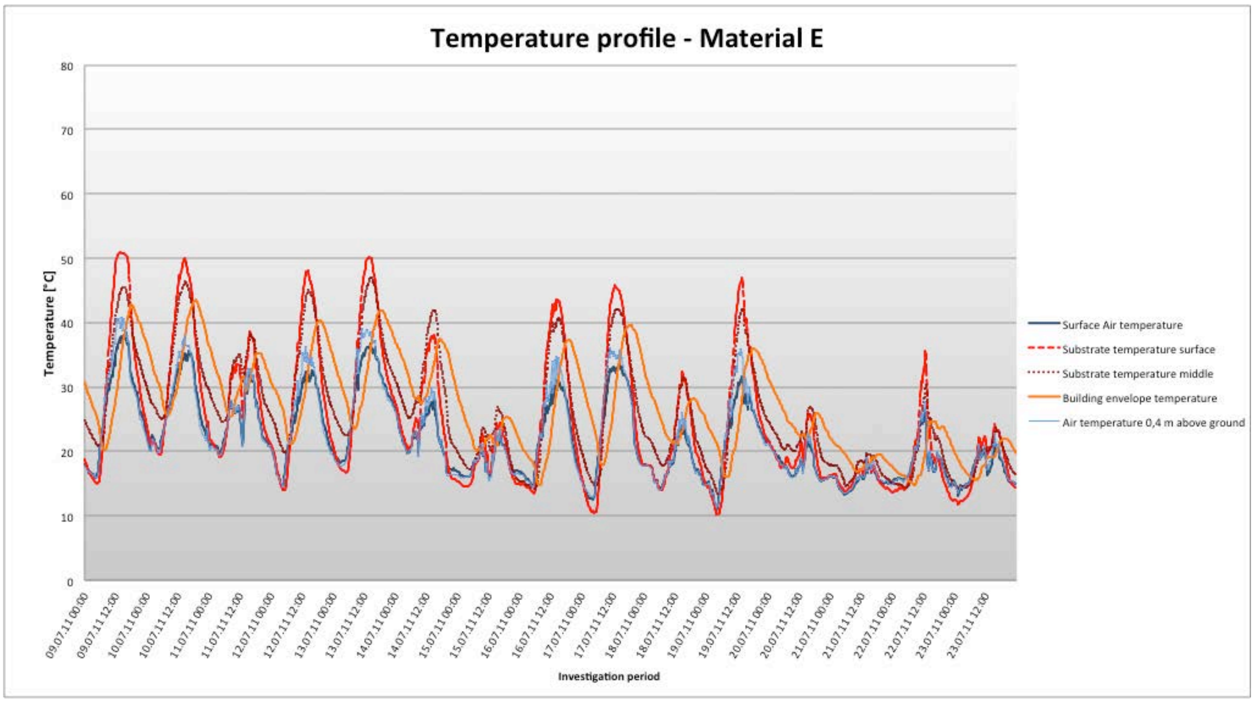

Figure 8: Temperature profile of test variant E – gravel roofing.

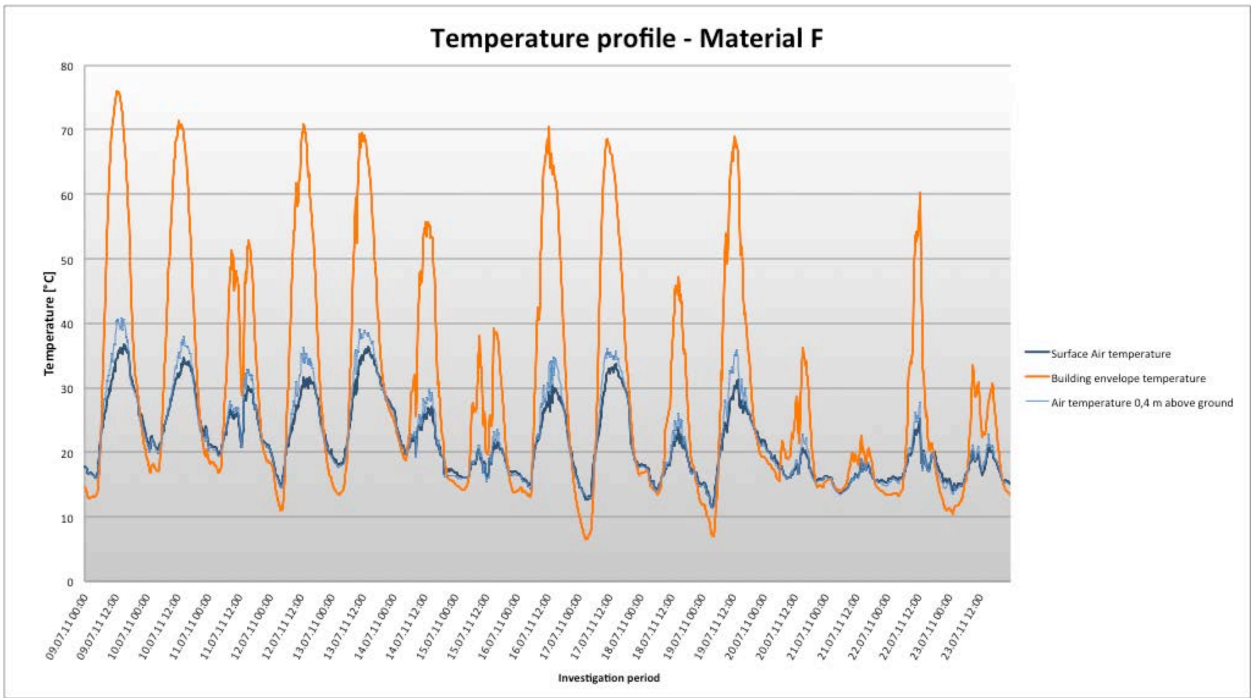

Figure 9: Temperature profile of test variant F – torch-on polymer bitumen membrane.

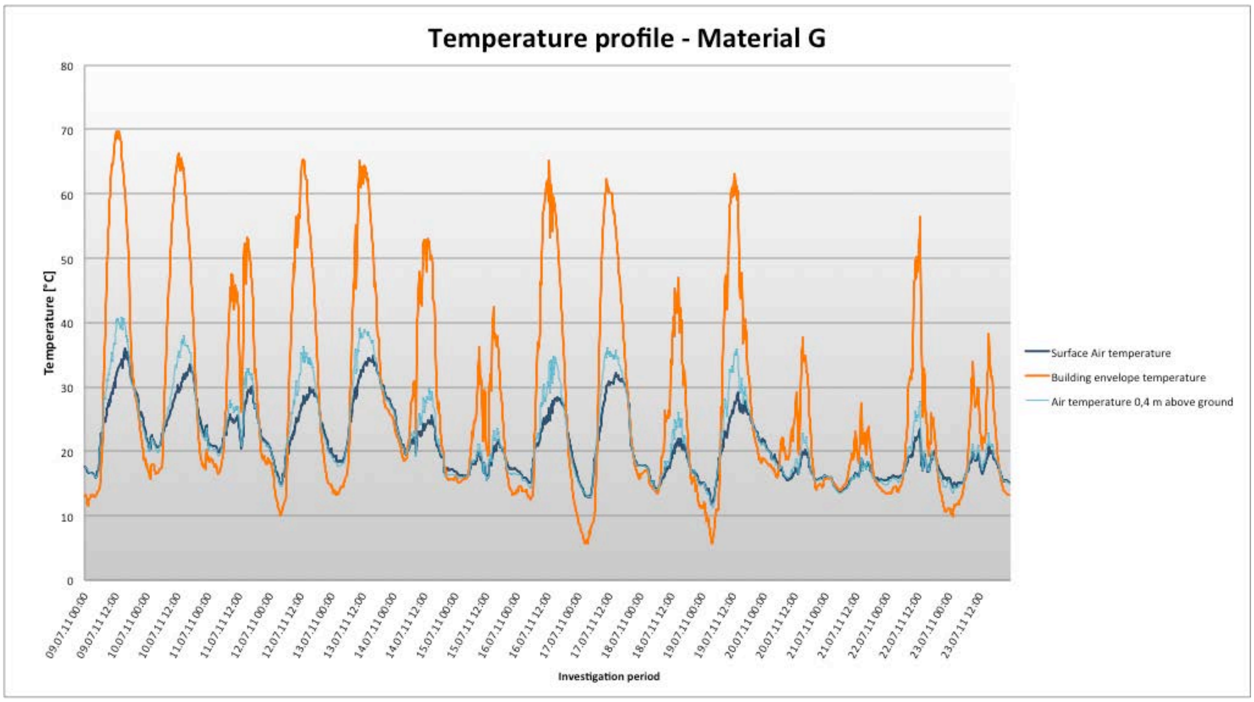

Figure 10: Temperature profile of test variant G – sheet-metal roofing.

Table 2 compares the surface air temperatures and the building envelope temperatures on 9th of July 2011 (in the middle of a heat wave) and on 21st of July 2011 after a rain event.

Table 2: Comparison of the surface air temperatures and the building envelope temperatures of the test variants on two selected days within the analysis period.

time	09.07.2011, 12:00 temperature [°C]			21.07.2011, 12:00 temperature [°C]		
variant	surface	building envelope	difference	surface	building envelope	difference
A	31,22	30,48	-0,74	16,82	15,14	-1,68
B	33,88	41,09	7,21	16,1	17,45	1,35
C	34,15	25,55	-8,6	17,01	15,48	-1,53
D	35,46	23,77	-11,69	17,42	22,53	5,11
E	34,99	28,28	-6,71	16,4	17,25	0,85
F	34,12	74,8	40,68	16,69	19,65	2,96
G	31,48	68,99	37,51	16,83	21,8	4,97

The surface air temperature vary from only 31.22 °C to 35.46 °C on 9th of July 2011 and from 16.1 °C to 17.42 °C on 21st of July 2011. The minor variations of the surface air temperatures on both days origin from the permanent air exchange caused by the wind on a flat roof. The temperature correlates with the roughness of the surfaces of the test variants e.g. the highest surface air temperatures have been measured on test variant D – reduced intensive green roof – with the highest degree of plant coverage.

The temperatures at the building envelope show that the thermal performance of the different test variants varies severely. The highest temperatures have been documented for the torch-on polymer bituminous membrane (74.8 °C). The lowest temperature at the building envelope has been recorded for test variant D (23.77 °C). The temperature values measured on the 21st of July, a cloudy and rainy day, illustrate that the thermal performance depends on the input of global radiation.

The following table shows the diurnal variation of the surface air temperature and the building envelope temperature of the different test variants on the 9th of July 2011.

Table 3: Minimum and maximum of surface air temperature and building envelope temperature on 9th of July 2011.

time	09.07.2011, 0:00 - 24:00 surface air temperature [°C]			09.07.2011, 0:00 - 24:00 building envelope temperature [°C]		
variant	minimum	maximum	difference	minimum	maximum	difference
A	16,03	34,56	18,53	16,17	46,56	30,39
B	15,78	37,44	21,66	13,8	53,42	39,62
C	15,81	37,34	21,53	21,55	40,73	19,18
D	16,21	38,5	22,29	22,33	28,39	6,06
E	15,95	38,5	22,55	20,27	43,5	23,23
F	15,99	36,78	20,79	12,89	75,97	63,08
G	15,95	35,9	19,95	11,55	69,79	58,24

While the diurnal variation of the surface air temperature varies from 18.53 °C to 22.55 °C the diurnal variation of the temperature at the building envelope ranges from 6.06 °C to 63.08 °C.

Heat flux in winter and summer period

The reflection of the global radiation (albedo) and the transformation into sensible, latent heat flux of the test variants obviously influences the soil heat flux and the heat flux into the building. The following figures show the characteristics of the test variants using a summer (9th of July 2011 to 16th of July 2011) and a winter period (5th of February 2011 to 12th of February 2011).

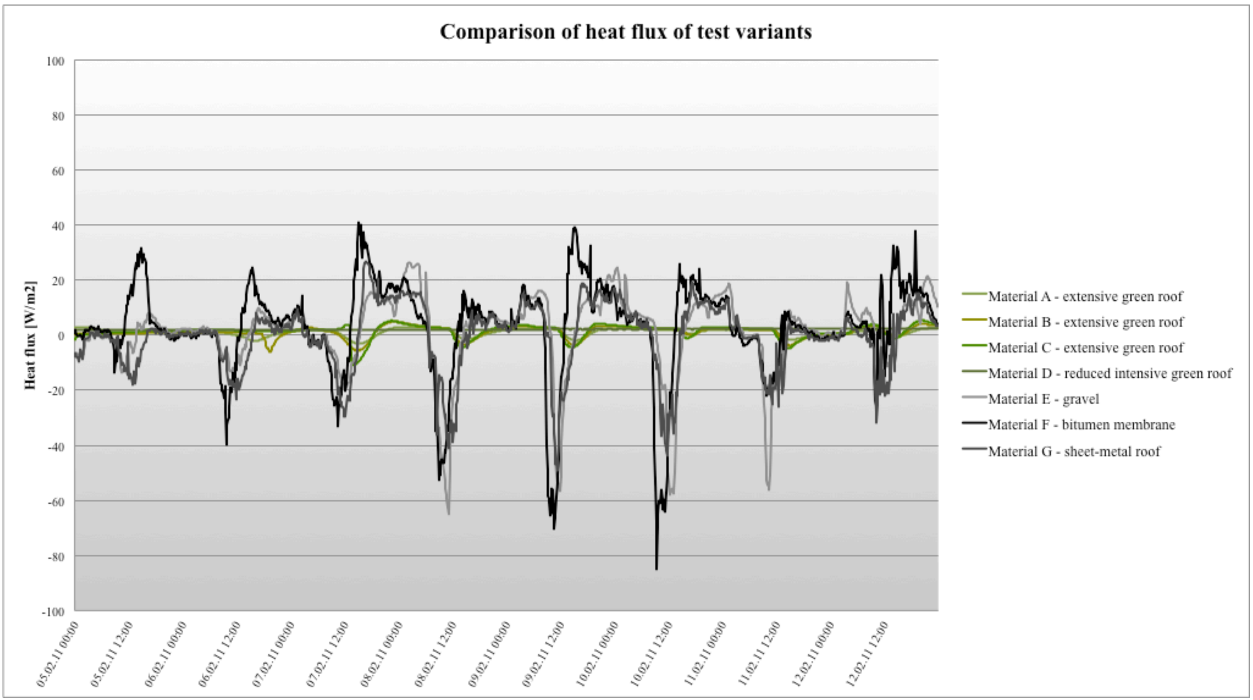

Figure 11: Comparison of the heat flux of the test variants in winter period (5th of February 2011 to 12th of February 2011).

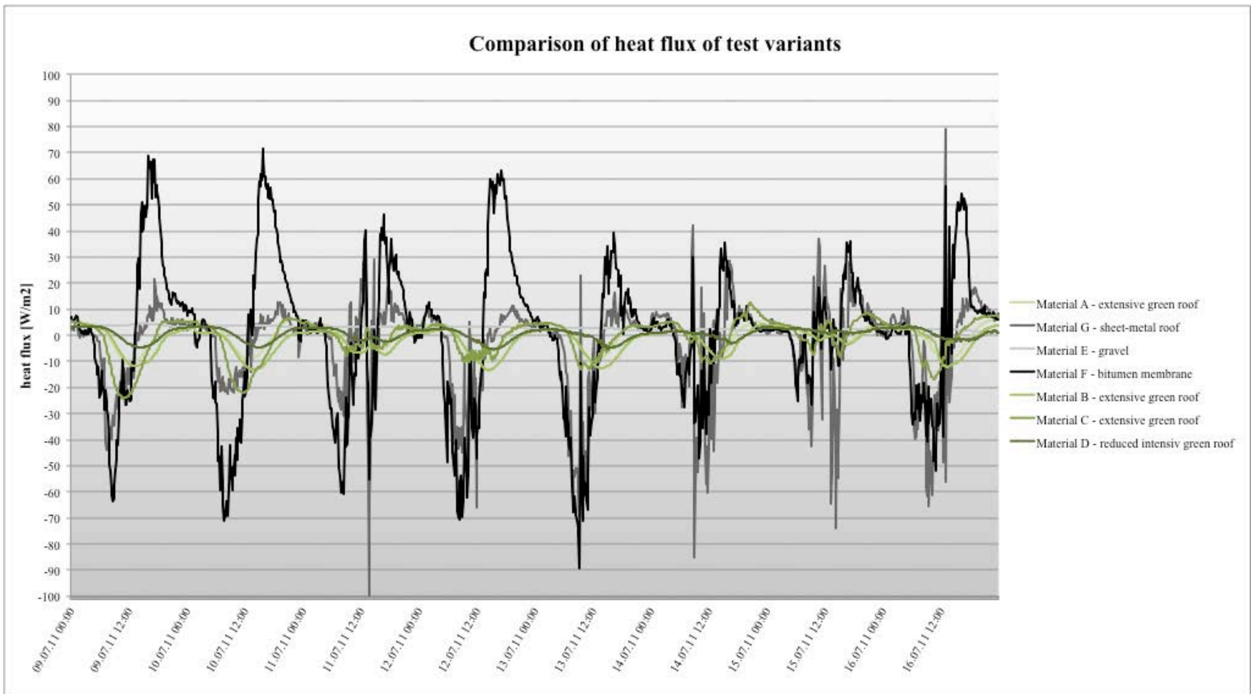

Figure 12: Comparison of the heat flux of the test variants in summer period (9th of July 2011 to 16th of July 2011).

Table 4: Variation of the heat flux of the test variants in summer and winter 2011.

period	winter 05.02.2011 - 12.02.2011 heat flux [W/m2]			summer 09.07.2011 - 16.07.2011 heat flux [W/m2]		
variant	minimum	maximum	difference	minimum	maximum	difference
A	-3,12	2,79	5,90	-11,05	6,37	17,42
B	-6,19	4,95	11,13	-24,21	6,50	30,71
C	-11,07	5,44	16,51	-4,62	3,47	8,09
D	1,84	2,22	0,38	3,00	4,66	1,66
E	-64,96	26,43	91,39	-13,25	3,45	16,70
F	-85,00	40,71	125,71	-71,25	71,43	142,68
G	-49,27	26,52	75,79	-43,99	21,50	65,49

The green roof test variants have better insulation properties than the standard roofings. The insulation effect depends on the construction type, the water storage capacity and the degree of plant coverage. High heat flux amplitudes characterize the standard roofings F and G. Thanks to its porosity standard roofing E – gravel provides good thermal insulation in summer but poor results in winter.

Results and Business Impacts

Key Findings

Green roofs have significantly better insulation properties than standard roofings. The insulation effect depends on the construction thickness and materials and the degree of plant coverage. Even thin, lightweight, extensive green roofs have a notable better thermal performance than standard roofings. Thanks to their unique properties they contribute to a reduction of energy demand for heating and cooling. In contrast to standard roofings they do not conduce to warming up the urban areas but reduce the air temperature thanks to evapotranspiration.

Business Impacts

The major business impact to be derived from this paper is a proof of the insulation effects of green roofs and hence a reduction of energy demands for heating and cooling. In times of energy scarcity and broad public debates on sustainable development, climate change, transition to sustainable to sustainable energy sources etc. the presented results can be used as strong and robust arguments to change our cityscapes.

Conclusions

The motivation to this research was to acquire robust data on the thermal performance of green roofs in comparison the most common standard roofings for flat roofs. The focus of the research was laid on the investigation of a whole representative cross section of green roofs and standard roofings and not only on single construction types. The hypothesis that green roofs (extensive variants and reduced intensive) provide better thermal performance than standard roofings could be approved.

The findings of the research should be used in discussions or marketing actions of companies to convince stakeholders and costumers not only of the aesthetic and ecological benefits of green roofs but also of their economic advantages compared to standard roofings.

Key Lessons Learned:

- Green roofs have significant better thermal performance than standard roofings
- Construction type, materials, thickness and degree of plant coverage influence the thermal properties of green roofs
- Sheet-metal roofs and torch-on polymer bitumen membranes cause severe temperature amplitudes and heat flux within a diurnal variation
- Gravel roofs provide insulation effects only in summer
- In times of rising energy prices or even energy scarcity stakeholders should appreciate the key findings and promote green roofs

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