The green roof research facility Dresden – a high resolution monitoring system for coupled water, heat and matter fluxes in green roofs

L'installation des recherches sur les toitures végétalisées à Dresden – une système de surveillance à haute résolution des flux de chaleur, d'eau et de matières

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RÉSUMÉ

Les toits verts atténuent le stress thermique et d'autres problèmes environnementaux dans les zones urbaines. L'irrigation des toits verts est bénéfique pour les plantes de toiture et la performance thermique. Néanmoins, il existe peu d'études sur l'irrigation des toits verts et cette pratique est souvent considérée comme non durable. La nouvelle installation de recherche sur les toits verts de Dresde fournit un système de surveillance des flux couplés d'eau, de chaleur et de matière dans les toits verts. Les eaux grises sont recyclées dans le système, prétraitées dans une lagunage et utilisées pour l'irrigation. 21 cellules d'essai fournissent des observations sur l'impact de l'ombrage, le développement et la sélection des plantes, l'intensité de l'irrigation et le type de substrat. La configuration du système et le choix des capteurs sont décrits. Une simulation préliminaire du bilan thermique des toits verts irrigués et non irrigués montre l'effet de refroidissement de la chaleur latente par évaporation pour le système irrigué. Nous mettons l'accent sur les orientations futures possibles de la recherche, suivons une politique ouverte des données et encourageons la recherche et l'enseignement universitaire sur place coopératives.

ABSTRACT

Green roofs mitigate heat stress and other environmental challenges in urban areas. Irrigation of green roofs is beneficial of the roof plants and the thermal performance. Nevertheless, few studies on irrigation of green roofs exist and the practice is often considered unsustainable. The new green roof research facility in Dresden provides a monitoring system for coupled water, heat and matter fluxes in green roofs. Grey water is recycled in the system, pre-treated in a constructed wetland and used for irrigation. 21 test beds provide observations on the impact of shading, plant development and selection, irrigation intensity and type of substrate. The system configuration and sensor selection are described. A preliminary simulation of heat budget in irrigated and non-irrigated green roofs demonstrates the cooling effect of evaporative latent heat for the irrigated system. We highlight potential future research directions, follow an open data policy and encourage cooperative research and academic teaching on site.

KEYWORDS

Green roof, grey water reuse, heat stress mitigation, online monitoring, stormwater retention

1 INTRODUCTION

In the light of global warming and ongoing urbanization, more and more people suffer from the impacts of intensifying heat waves in densely populated areas. Furthermore, both aspects amplify each other and drive the urban heat island (UHI) effect. Increased heat storage, lower reflection of solar radiation and lacking evaporation potential as compared to natural areas contribute to a changed energy balance and higher temperatures in urban areas. (Wouters et al., 2017) found that cities in Belgium will experience 40 to 50 % more heat stress increase than their surrounding area by mid-century due to an aggravated UHI effect.

Green roofs can contribute to alleviate UHI and other urban environmental challenges by providing habitats and species diversity (Oberndorfer et al., 2007), stormwater retention (VanWoert et al., 2005), (Todorov et al., 2018), building insulation (Tam et al., 2016) as well as the abatement of air pollution (Currie and Bass, 2008) and sound pollution (Van Renterghem and Botteldooren, 2011). Irrigation of green roofs decreases sensitive heat emission and surface temperatures (Coutts et al., 2013) and supports plant diversity (Price et al., 2011) and may even become a necessity in summer in order to keep the vegetation vital (MacIvor et al., 2013). Despite the potentials, previous research predominantly focused on non-irrigated extensive green roofs. Only 5% of the studies reviewed by (Van Mechelen et al., 2015) involve irrigation demands and consequences. (Oberndorfer et al., 2007) demand focused research on water quality dynamics in green roofs and specifically potentials and challenges related to greywater reuse.

A new research facility at the botanical garden of Technische Universität Dresden will dedicate to research on water, energy and matter fluxes in irrigated and non-irrigated green roofs as well as unplanted gravel roofs. The experimental design of 21 test beds provide observations on the impact of shading, plant development and selection, irrigation intensity and type of substrate. Implementation of the sensor system is going to take place during springtime 2018. This paper concludes the research setup and potential questions.

2 MEASUREMENT CONFIGURATION

The research facility is located on the rooftop of a basement level building, which is used for service amenities of the botanical garden employees. Figure 1 shows a schematic representation of the water fluxes and sensor locations in the system. Grey water from showers and washing amenities is collected, stored and treated in a constructed wetland. A controlled irrigation system pumps water the water to the 21 test beds and distributes it by dripper hoses. The test beds are all located at the edge of the roof and grouped in sections of varying exposure to shade from a neighbouring three-storey building. A storage cylinder with a bottom orifice measures the outflow of each bed and directs it either to the combined sewer system or back to the storage tank. Table 1 concludes the measurement configuration and sensor selection. The combination enables recording of temperature profiles with 3 cm vertical resolution in the substrate and at the surface boundary layer.

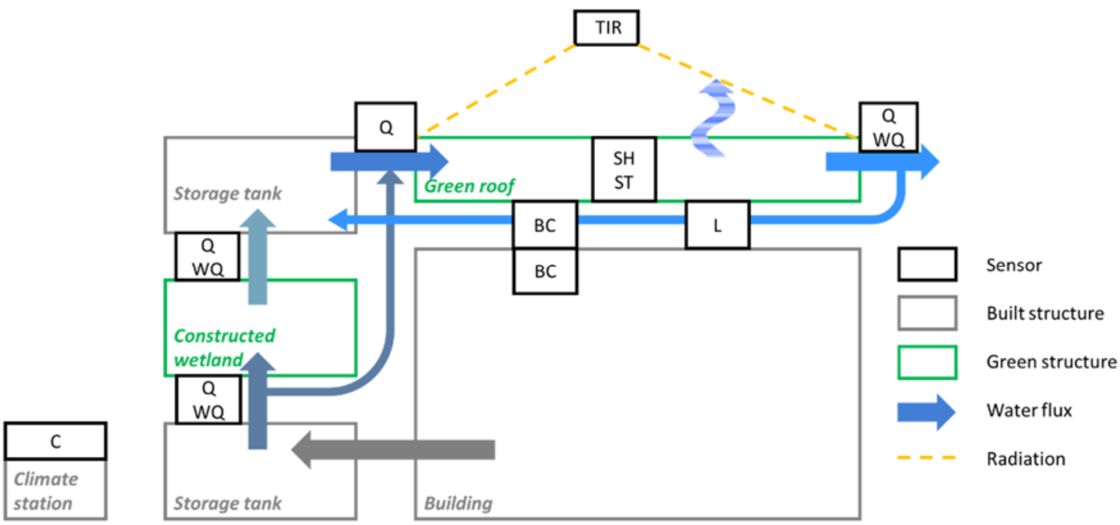

Figure 1: Schematic representation of green roof setup and measurement configuration. Sensor groups are C – climate, Q – flow, WQ – water quality, L - lysimeter, SH – substrate humidity, ST – substrate temperature and TIR – Infrared surface temperature

Table 1 Sensors and measured variables in the different subsystems of the green roof system

Sensor group	Variables	Sensor type	Range	Resolution	Accuracy (typical)
Climate	relative humidity	capacitive	0 – 100%	0.1%, 5 min	+/- 2%
	temperature	band-gap	-30 - +70 °C	0.1 K, 5 min	+/- 0.2K
	barom. pressure	capacitive	0.5 – 1.2 bar	0.1 mbar, 1s	+/- 1 mbar
	wind speed	propeller	0 – 100 m/s	0.1 m/s, 1 s	+/- 0.3 m/s
	wind direction	potentiometer	0 – 360°	1°, 1 s	+/- 3 °
	short wave radiation	pyranometer	0.3 – 2.8 µm	20 s	+/- 1%
	long wave radiation	pyrgeometer	4.4 – 50 µm	20 s	+/- 1%
	precipitation	tipping bucket	0 – 100 mm/h	0.1 mm, 1 min	+/- 2 %
Building climate	relative humidity	capacitive	0 – 100%	0.1%, 5 min	+/- 2%
	temperature	Pt 100	-30 - +70 °C	0.1 K, 5 min	+/- 0.2K
	heat flux	thermocouple	-2 – 2 kW/m²	0.1 W/m², 1 min	+/- 5%
	surface temperature	infrared emiss.	-40 – 200 °C	0.02K, 1 s, 2 cm²	+/- 1 K
Lysimeter	weight	capacitive	0 – 2000 kg	0.1 kg, 1 s	+/- 1%
	flow rate	tipping bucket	0 – 6 l/s	0.1 l, 1 s	+/- 1%
Substrate	temperature	Pt 100	-20 – 50 °C	0.4 mK, 10 s, 3 cm	+/- 0.1 K
	water content	permittivity	0 – 100%	0.1 %, 10 s	+/- 1%
	electric conductivity	permittivity	0.01 – 1.5 S/m	1 mS/m, 10 s	+/- 0.02%
Flow	flow rate	MID	0 – 30 l/s	0.01 l/s, 0.1s	+/- 3%
	water level	capacitive	0 – 1 m	0.5 mm, 2 s	+/- 0.1 mm
Water quality	temperature	Pt 100	0 – 50 °C	0.4 mK, 2 s	+/- 0.1 K
	electric conductivity	capacitive	0 – 2 S/m	1 mS/m, 2 s	+/- 0.02 mS/m
	Nitrate, Nitrite	spectrometry	3 – 70 mg/l	0.1 mg/l, 10 s	+/- 3%
	TOC, DOC	spectrometry	2 – 300 mg/l	0.1 mg/l, 10 s	+/- 3%
	Turbidity / TSS	spectrometry	1 – 200 NTU	0.1 NTU, 10 s	+/- 5%

3 EVALUATION POTENTIALS

The high resolution and comprehensive combination of captured variables enables process driven understanding of green roof performance. The temperature is resolved in 15 layers of the massive roof, the functional layers of the green roof and the boundary layer in and above the vegetation. This supports dynamic parameterization of heat transfer systems (Sun et al., 2013). The reuse of grey water facilitates more sustainable irrigation, yet the dynamics of matter accumulation, and transformation during dry periods and their release during storm events are hardly understood. Improved root development and vitality of the green roof plants is expected to increase hydraulic retention capacity during storm events.

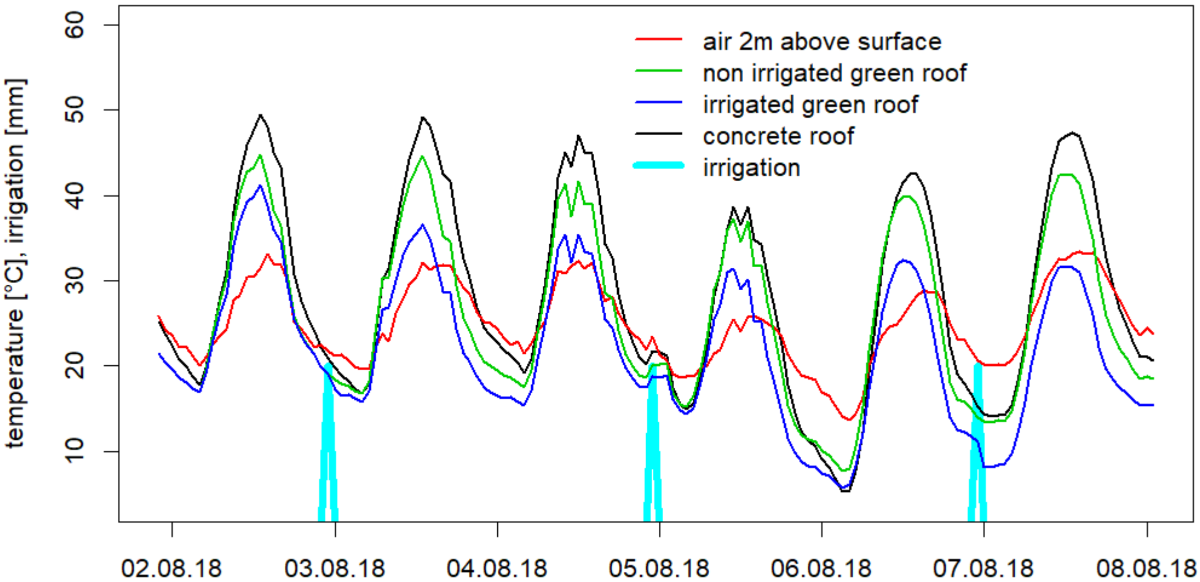

Figure 2: Simulated surface temperatures of non irrigated and irrigated green roof, concrete roof and reference air temperature 2 m above ground for the period 02. – 08.08, with climate forcing data from Dresden Klotzsche meteorological station.

Figure 2 provides an example for the evaluation potentials of the measured data. Climatic boundary conditions from Dresden Klotzsche meteorological station drive a simple single layer heat flux balance model for three roof types. The simulated period in summer 2018 represents a heat wave with prolonged dryness. The surface temperatures of a conventional concrete roof are compared to irrigated and non irrigated green roofs. As the evaporative latent heat potential depletes, the thermal behaviour of the non irrigated green roof shifts to similar behaviour as the concrete roof.

4 CONCLUSION AND OUTLOOK

The described research facility provides comprehensive database for enhanced understanding of heat, water and matter fluxes in green roofs and their interaction. It resolves processes and driving forces within the layers of vegetated surfaces. Long-term effects of irrigation with grey water, plant selection and irrigation scheming are expected results of the measurements.

The data obtained will be provided in an open database as a reference for model development and benchmarking. We invite cooperation on specific experiments, or on interpretation of the long-term data. College level courses on design, management and simulation of green roofs in the fields of water management, landscape engineering and architecture are intended to propagate knowledge about this green infrastructure.

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