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Do green roofs cool the air?

Anna Solcerova [a, *], Frans van de Ven [a, b], Mengyu Wang [c], Michiel Rijsdijk [d], Nick van de Giesen [a]

[a] Delft University of Technology, Water Resources Management, Stevinweg 1, 2628 CN Delft, The Netherlands
[b] Deltares, P.O. Box 177, 2600 MH Delft, The Netherlands
[c] Civil & Environmental Engineering, National University Singapore, Engineering Drive 2, Singapore 117576, Singapore
[d] Municiplaity Utrecht, Stadsplateau 1, 3500 CE Utrecht, The Netherlands

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ABSTRACT

Rapid urbanization and an increasing number and duration of heat waves poses a need to mitigate extremely high temperatures. One of the repeatedly suggested measures to moderate the so called urban heat island are green roofs. This study investigates several extensive sedum-covered green roofs in Utrecht (NL) and their effect on air temperature right above the roof surface. The air temperature was measured 15 and 30 cm above the roof surface and also in the substrate. We showed that under well-watered conditions, the air above the green roof, compared to the white gravel roof, was colder at night and warmer during the day. This suggests that extensive sedum-covered green roofs might help decrease air temperatures at night, when the urban heat island is strongest, but possibly contribute to high daytime temperatures. The average 24 h effect of sedum-covered green roof was a 0.2 °C increase of air temperature 15 cm above the ground. During a dry year the examined green roof exhibited behavior similar to conventional white gravel roof even exhibited slight cooling effect in late afternoon. Interestingly, the pattern of soil temperature remained almost the same for both dry and well-prospering green roofs, colder during the day and warmer at night.

1. Introduction

Heat strokes, decreased quality of sleep, and higher mortality rates, a decrease in labor productivity, and a substantial increase in power consumption for air conditioning are just some examples of negative influences of high temperatures [1,2]. Such negative impacts of extreme heat particularly occur in urban areas, as temperatures there are higher than in the surrounding rural areas. This urban heat island (UHI) phenomenon was already described in London 200 years ago [3]. Climate change, urbanization and urban densification will lead to an increase in frequency and intensity of heat waves [4]. Given all the negative impacts of extreme heat, there is a real need to work towards reducing outdoor temperatures in urban areas.

Increasing the vegetated fraction in a city has shown to be an effective way to decrease urban temperatures [5,6]. Green roofs are suggested as one of the possible ways to achieve this [7–9]. Implementing green roofs is popular due to their versatile effects and functions, such as roof gardens [10], isolation [11], or runoff peak delay [12]. The thermal effects of green roofs on the urban environment are another widely used argument to promote their implementation [13].

Literature focused on temperature measurements of green roofs generally covers two topics: (1) Cooling effect of green roofs on indoor environment and its use as insulation layer and (2) Effect on roof surface temperature. Many studies showed potential benefits of green roofs for the indoor environment of the building, such as energy savings [14] or reduction of indoor temperatures by several degrees [15]. This is closely connected to green roofs' ability to work as insulator and temperature buffer and decrease high surface temperatures [16], as well as low winter temperatures [17].

When it comes to the effect of green roofs on outdoor temperature, most modeling studies agree that green roofs have the potential to decrease UHI [13,18,19]. Those results are supported by several measurement studies [20–23]. Additionally, Peng and Jim (2015) [21] also showed a slight warming effect of green roofs during winter months.

However, measurement studies focusing primarily on effects of

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* Corresponding author.
E-mail address: a.solcerova@tudelft.nl (A. Solcerova).

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green roofs on outdoor temperature are relatively scarce. Berardi et al. [24] summarized the literature about green roofs. From the large number of articles presented in that review, only three dealt with outdoor air temperature measurements [5,25,26]. Another highly cited review article [27] discusses the ecosystem services of green roofs. From 61 references only one [28] focused on urban heat island mitigation.

Some studies discuss possible negative effects of green roofs. Jim (2015) [29] showed that sedum covered green roofs might under tropical conditions increase the air-conditioning energy consumption in apartments below. Contrary to that, MacIvor et al. (2016) [23] promote sedum for its cooling properties as a good choice for temperate continental climates. Previous studies also suggested that green roofs need a certain level of maintenance, because vegetation damage can reduce the desired cooling effects [25], and the temperature of the bare substrate can easily run higher than surface temperature of a bare roof [16].

Research presented in this paper is based on monitoring results from an extensive, sedum-covered green roof in Utrecht and provides an analysis of these observations. We aim to provide additional insight in thermal behavior of sedum-covered green roofs in a temperate climate, and to contribute to understanding of the role of soil moisture in the cooling effect of green roofs. We also aim to clarify how thermal behavior of a green roof changes under extreme conditions, and compare the effects of a dry green roof to a well prospering green roof, and white gravel roof.

2. Methods

2.1. Monitoring site

The study site is located in Utrecht, The Netherlands (52°5′ N, 5°7′ E). The climate is a moderate sea climate with summer starting in June and ending mid-late September.

We examined seven green roofs installed on a rooftop of a one-story school building two of which were examined in depth (GR4 and GR7); they are considered, and proved by comparison, to be representative of the other ones (Fig. 1). Additionally, those two roofs had preinstalled soil moisture sensors, and therefore provided more information for the analysis. All roofs were installed in 2010 and did not receive routine maintenance. All green roofs were 7 m long and 3.5 m wide, with exception of GR2 which had dimensions 7 × 7.5 m. Part of the installation was also a conventional white gravel (WG) roof which was used as a baseline for comparison (8.5 × 8 m).

The construction of each green roof was as follows. A membrane separated the rooftop from the green roof, above which lied a drainage layer (ca. 2 cm) and a cloth layer (0.3 cm). On top was a substrate layer with vegetation. The combined depth of root zone and substrate layer was approx. 3.5 cm. The vegetation on all the green roofs was a mixture of six sedum species (*S. floriferum ”Weihenstephaner gold”, S. album ”Coral carpet”, S. reflexum, S. spurium ”Fuldaglut”, S. sexangulare, S. album superbum*) and was considered stabilized. As visible from Fig. 1a), the percentual representation of the sedum species was different for each roof.

During the monitoring period (2010–2015), a small meteorological station was installed on the roof including an air temperature sensor 2 m above rooftop level, solar radiation, wind speed, and rainfall. Each roof had two additional temperature sensors positioned 15 cm (T15) and 30 cm (T30) above the ground in the center of each green roof, and one temperature sensor positioned 2 cm under the surface inside the substrate layer or gravel layer (Ts). Runoff was measured from each roof separately [30]. Soil moisture sensors were placed in GR4 and GR7 2.5 cm under the substrate surface. All data were recorded at 5 min intervals. The accuracy of the sensors, as well as the manufacturer and sensor type, can be found in Table 1 Calibration of the sensors was done before installation and the green roofs, as well as the devices, were regularly checked.

2.2. Influence of soil moisture

Influence of initial soil moisture on the thermal performance of green roofs was studied using the 2014 dataset. Two six-day periods in July were chosen for the analysis, further referred to as ”cloudy” and ”clear sky”. First period, 12–17 July was considered as

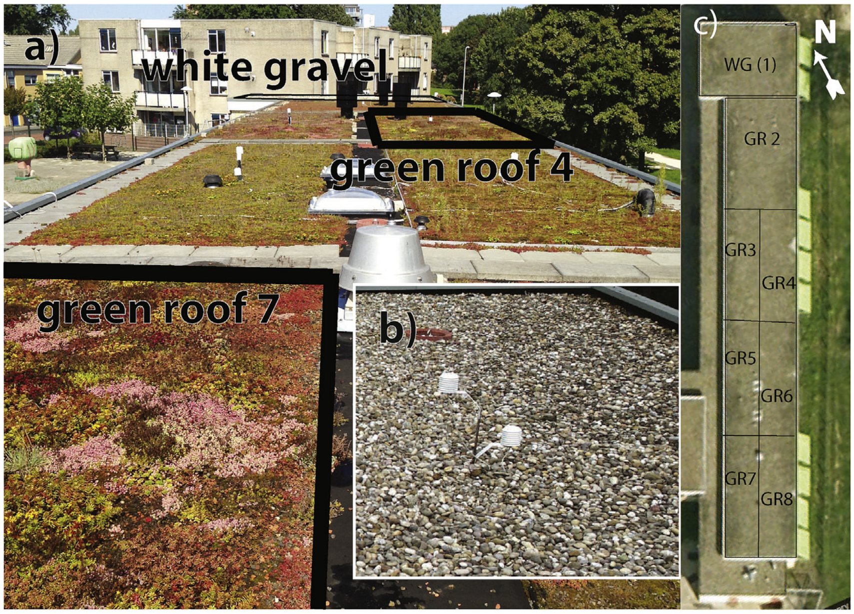

Fig. 1. Green roofs in Utrecht on 03-09-2014. a) plant cover and positioning of GR4, GR7, and WG with respect to each other, and position of temperature sensors b) white gravel roof with temperature sensors, and c) layout of the fields on the roof.