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Surface temperature analysis of conventional roof and different use forms of the green roof

Key words: green roof, conventional roof, termovision, surface temperature

Introduction

In the last decades, the interest towards climate change mitigation and urban climate resilience is growing, green roofs are gaining importance and a wide body of research has been published to ameliorate their performances and to investigate their benefits in different climates (Köhler, Schmidt, Grimme, Laar, Paiva & Tavares, 2002; Wong, Chen, Ong & Sia, 2003; Susca, 2019). Depending on the development and requirements for irrigation, there are two types of green roofs: extensive and intensive. Extensive green roofs, also known as ecological or light roofs, have a substrate layer with a thickness of 2–15 cm (Carter & Keeler, 2008; FLL, 2008; Castleton, Stovin, Beck & Davison, 2010; Karczmarczyk, Baryła & Kożuchowski, 2017). They require minimal or no irrigation and are usually planted from moss, succulents, grasses and some herbaceous plants (Dunnett & Kingsbury, 2004; Oberndorfer et al., 2007; Burszta-Adamiak, Fudali, Łomotowski & Kolasińska, 2019). This type of green roofs is the most widely used and they can be installed on most roofs. The disadvantage of extensive roofs is their smaller retention capacity and faster drying compared to intense roofs (Stovin, Vesuviano & Kasmin, 2012). In intensive greenery with a larger substrate thickness (above 20 cm), low and high development can be distinguished. In low greenery, low plants are used, such as perennials, shrubs, grasses and, to a limited extent, dwarf tree varieties. In contrast, in intensive high greening all types of plants are used, including perennials, shrubs, grasses and occasional coniferous and deciduous trees. Both types of intensive gardens require labour-intensive care, regular fertilization, as well as irrigation and drainage systems (Oberndorfer et al., 2007; FLL, 2008). Green roof installation can be beneficial both at building and urban scale as it can: contribute to energy saving (Takakura, Kitade & Goto, 2000; Theodosiu, 2003; Fang, 2008; Dohojda, Podawca & Witkowska-Dobrev, 2018) decrease thermal oscillations on the rooftop surface that, in turn, can prolong the lifespan of the rooftop membrane (Jelinkova, Dohnal & Picek, 2015) abate noise (Van Renterghem & Botteldooren, 2009), enhance air quality (Yang, Yu & Gong, 2008; Li et al., 2010), contribute to beautification (Oberdorfen et al., 2007), enhance urban biodiversity (Brenneisen, 2006), reduce storm water runoff (Czemiel Berndtsson, 2010; Nawaz, McDonald & Postoyko, 2015; Pęczkowski, Kowalczyk, Szawernoga, Orzepowski, Żmuda & Pokładek, 2018), and mitigate urban heat island (Takebayashi & Moriyama, 2007; Taleghani, Tenpierik, van den Dobbelsteen & Sailor, 2014; Baryła, Gnatowski, Karczmarczyk & Szatyłowicz, 2019). Simultaneously, the aforementioned parameters assume a different importance depending on the environmental conditions (Susca, 2019). Many studies have confirmed that green roofs can effectively reduce surface temperature of bare rooftop, which in turn substantially reduces the cooling energy load and utility costs during hot summer days. Field measurements recorded by Jim and Peng (2012) demonstrated that the extensive green roof tops of the Hong Kong railway station, reduce the rooftop surface temperature by a maximum of 9°C. On the basis of field observations and measurements, Lin, Yu, Su and Lin (2013) demonstrated that extensive green roofs reduced the rooftop surface temperature by up to 22.5°C and 25.1°C in Taipei (northern Taiwan) and Chiayi (southern Taiwan), respectively, during summer. Karachaliou, Santamouris and Pangalou (2016) demonstrated that their green roof could lower the rooftop temperature of a conventional roof by 15°C in Athens, Greece. The aim of the study was the analysis of temperature changes of different roof surfaces (conventional roof, board, intensive roof substrate without plant cover, substrate covered with plants – shrubs, gravel).

Experimental site

Studies on comparing the temperature between a conventional roof and green roofs were carried out in the period from April to September 2015 on the roof of the building of the Faculty of Modern Languages, University of Warsaw (52°14′00″N, 21°01′07″E). The site is located in a mix of humid and mild sea air and dry and raw continental air (transition climate). Two different air masses pass above the city and are exchanged at a high frequency, which causes variable weather. The average annual air temperature is 7–8°C, with the minimum temperature reached in January and the maximum reached in July. There are approximately 40 hot days, with the average temperature above 25°C. The annual rainfall is approximately 520 mm, with the maximum rainfall in July and the minimum in February. Warsaw is covered in snow for 50–60 days a year and the number of frosty days (average temperature below 0°C) is 33. The average wind speed in the city is approximately

$4\ m{\cdot}s^{-1}$ (data from Internet portal https://pl.climate-data.org). The construction of monitored green roof consist of four layers (from the bottom to the top): (1) drainage mate (Platon DE 25, 2.3 cm); (2) filtration layer (ZincoCO, $100\ g{\cdot}m^{-2}$); (3) intensive substrate (SPG-IU 16) and (4) vegetation: *Spirea japonica*, *Spirea betulifolia*. At the warm season, during which the selected plant species require permanent moisture content within the substrate, drainage layer acts as a water reservoir by retaining the water from irrigation or from rain in order to provide the proper moisture conditions for the plant growth. An automated drip irrigation system provides watering throughout the warm period on a regular basis to achieve permanent moisture content within the substrate and the drainage layer. During the experiment, from April to September, irrigation and water storing within the drainage layer occurred every second day at 7:00–8:00.

Measurement step

For the measurement of surface temperature a thermal imaging camera was used. Thermal images were taken for each test stand (green roof, conventional roof) once time per month in the observation period of six months (April–September 2015). Thermal images were taken for each place once a month from 8:00 to 16:00 (once per hour). Air temperature was measured using a Meteo weather station type SP 69. Radiant temperature was measured using a Flir SC620 thermal imaging system operating in the range of 7.5–13 μm, which enabled the acquisition of images with a resolution of 640 × 480 pixels. With this camera it is possible to obtain full-colour pictures in the visible spectrum and process thermal imaging pictures in a selected colour scale (Figs. 1a, 1c and 1e). Individual images were registered on a memory card. The measurement points were marked, and the same distance was maintained for all measurements performed in the subsequent terms (Figs. 1g and 1h). The thermograms registered in a numeric manner were analysed using the FLIR Quick Report 1.2 program. The radiometric temperatures were calculated accounting for the correction of the actual emission coefficient (the emission coefficient for tar paper was assumed at 0.92, whereas for soil as well as vegetation cover, the value of 0.95; Mularz & Wróbel, 2003). The air temperature was assumed to be the temperature of the surroundings, since the surroundings were the same for the entire test area and this did not affect the differentiation of individual fragments of the test field (Mularz & Wróbel, 2003). In order to compare radiation temperatures between the test stands in the analysed terms, vertical transects (vertical white lines at Figs. 1a, 1c and 1e), each consisted of 190 points, were indicated on thermal images. Transects were located in the middle of the width of the roof.

Then on the basis of the radiation temperatures obtained along the measurement lines (190 temperature values for measurement place), all data were compiled for day on the month and analysed. All statistical analyses were carried out using the STATGRAPHICS Centurion XVI software.

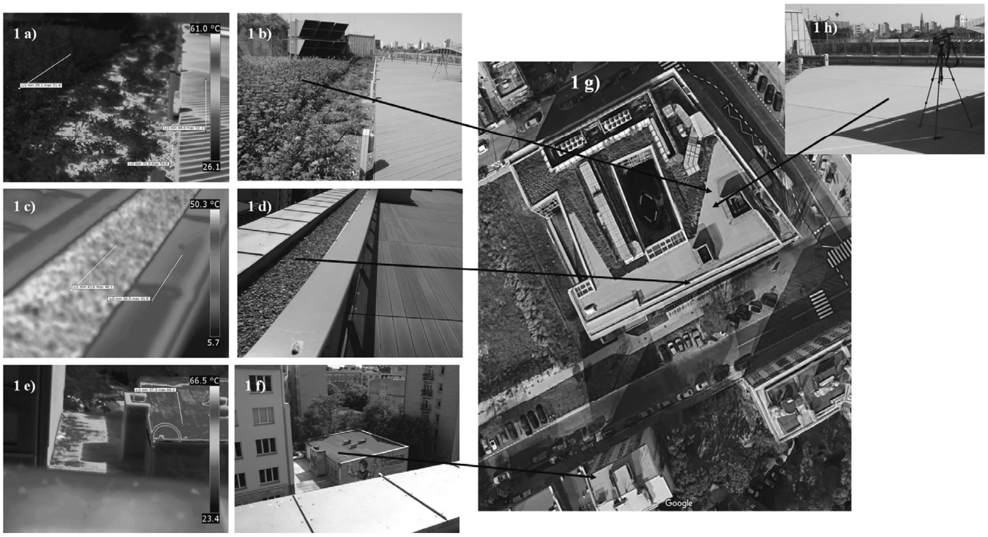

FIGURE 1. Thermal (1a, 1c, 1e) and digital (1b, 1d, 1f) image on the 12 June 2015 (green roof, gravel band, conventional roof); 1g – green roof on the building of Faculty of Modern Languages, University of Warsaw (www.googlemaps.pl) ; 1h – photograph of the experimental setup

Results and discussion

The studies carried out in the April––September period of 2015 showed that the average surface temperature of green roofs were from 14.6°C (May) to 28.0°C (July), whereas for the roof covered with bitumen, were from 18.2°C (May) to 59.1°C (June) – Figure 2. The maximum temperature of the conventional roof reached 62.9°C, whereas for green roofs, it was 31.7°C, at an air temperature of 27°C. The largest temperature differences between a conventional roof and a green roof were recorded in the summer months (June, July, August), the lowest in May and September. In June, the difference between the surface temperature of conventional and green roofs was 31.3°C, while in May the difference was 3.55°C. Our research confirms the studies of other authors showing that green roofs reduce the temperature of roof surface which is heated up on hot days.

Walawender (2015) conducted research in Kraków, which showed that the temperature of the green roof was lower than the temperature of the roofs of the Old Town buildings by about 8––10°C and as much as about 20°C from the roof of the shopping center. The surface temperature of the green roof was close to that of urban greenery (Planty). Research conducted by Teemusk and Mander (2010) showed that the difference between the temperature amplitude under planted roofs and traditional roof surfaces was on average 20°C. This increased peak and the high summer temperatures connected with it, have a significant influence on the durability of the roof membrane, thus shortening its lifespan (Bevilacqua, Mazzeo, Bruno & Arcuri, 2017).

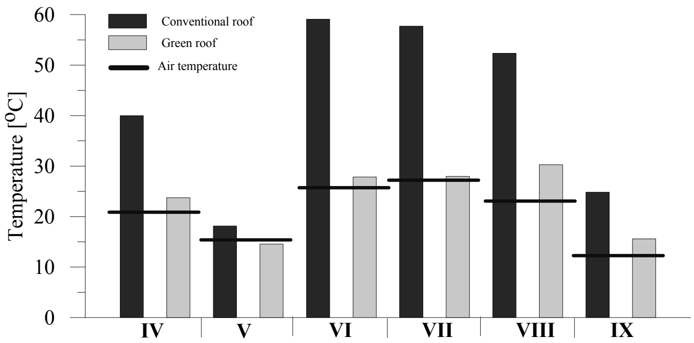

FIGURE 2. Comparison of surface temperature of conventional roof, green roof and air temperature over six measurement dates in the period April–September 2015

The selected two histograms of the warmest and the coldest day in the course of this research showed that in June, the difference between surface temperature of the green roof and the conventional roof is significant, while in September the differences are small (Fig. 3). On the 12th of June, with an air temperature of 26°C, the average temporary temperature of the green roof was 29.6°C (max 32°C) and the conventional roof was 59.1°C (Fig. 3a). In contrast, in September the average temporary temperature of the green roof was 15.6°C and the conventional roof was 24.8°C (Fig. 3b).

A detailed analysis was carried out for the warmest and coldest day (Fig. 4). The surface temperature of seven different surfaces was compared. On the hottest day of June on the 12th the average surface temperature of conventional roof was 59.1°C, plant 28.8°C, green

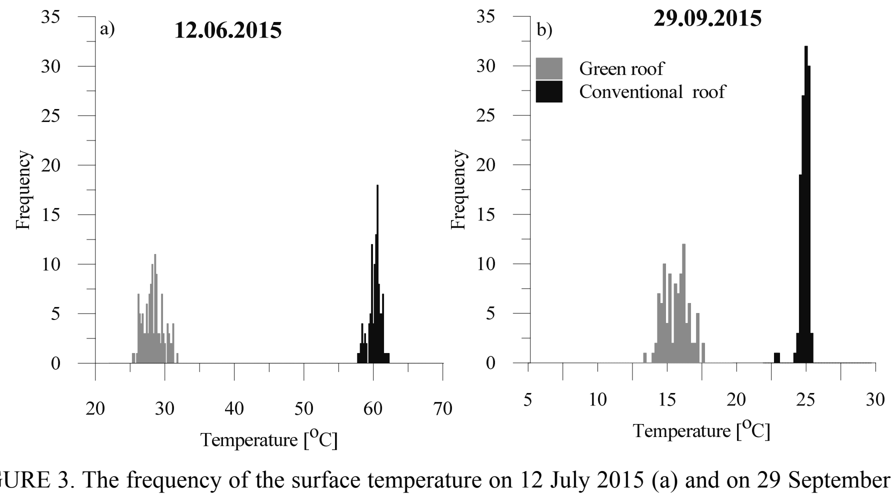

FIGURE 3. The frequency of the surface temperature on 12 July 2015 (a) and on 29 September 2015 (b) at 12 h (green roof, conventional roof). The frequency distribution histogram is plotted vertically as a chart with bars that represents number of observations temperature in line within certain ranges (bins) of values

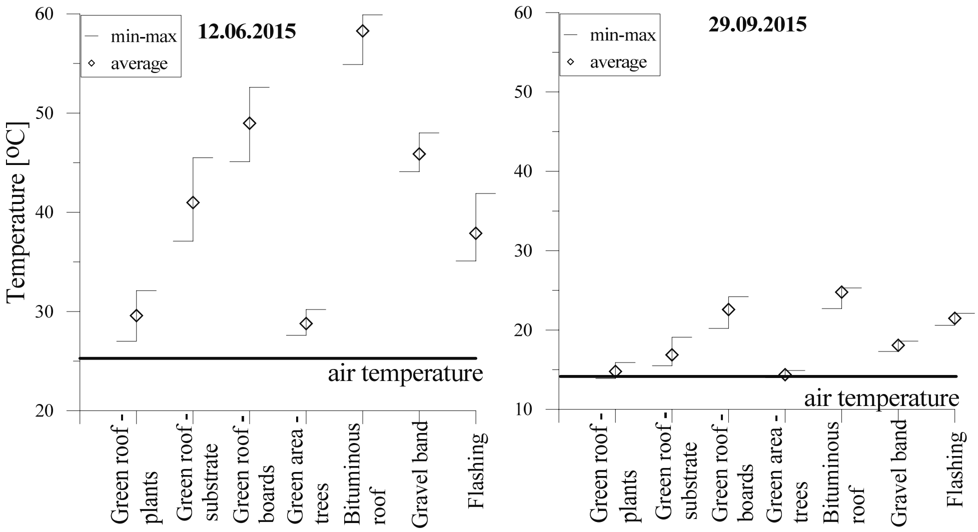

FIGURE 4. Result of comparing averages

roof 29.6°C, flashing 37.9°C, substrate of green roof 41°C, gravel band 45.9°C, boards of green roof 49°C. The vegetation on the green roof had an average temperature similar to urban vegetation and air temperature (26°C). The other surfaces, however, had much higher temperatures. ANOVA showed that there are statistically significant differences between the average temperature values in the individual columns – $F(_{7.750})$ = = 5,032.63 at 95.0% level of confidence. In order to determine which groups differed statistically from each other, multiple comparisons using Tukey's test were carried out. On the basis of the test, similarities in air temperature, green roof and urban plant were confirmed. The different surfaces (conventional roof, board, intensive roof substrate without plant cover, gravel, flashing), on the other hand, did not reveal similarities to the remaining columns and was characterized by higher average values.

In September there were no such large difference in surface temperatures as in June. Temperature of conventional roof was 24.8°C, plant 14.4°C, green roof 14.8°C, flashing 21.5°C, substrate of green roof 16.9°C, gravel band 18.1°C, boards of green roof 22.6°C (Fig. 4). ANOVA showed that there are statistically significant differences between the average temperature values in the individual columns – $F(_{7.750})$ = = 5,738.14 at 95.0% level of confidence. In order to determine which groups differed statistically from each other, multiple comparisons using Tukey's test were carried out. On the basis of the test, similarities in air temperature, green roof and urban plant were confirmed.

Recapitulation

According to the literature, energy phenomena on a green roof create a complicated energy budget that depends greatly on a variety of factors such as climate, plant selection and moisture content. The present work presents a comparing the surface temperature of green roof with a different surfaces (conventional roof, board, intensive roof substrate without plant cover, gravel, flashing) in a moderate climate, accounting for April to September periods. During the summer, the temperature differences between the green areas (green roof, urban green) were similar to the air temperature. However, the remaining surfaces have been significantly different. The largest difference in surface temperature was between the temperature of the green areas and the conventional roof. The greatest differences in surface temperature were obtained in the summer periods, at maximum heating up. This confirms the results reported by other authors showing that green roofs reduce the temperature of roof surface which is heated up on hot days (Heusinger & Weber, 2015; Solcerova, van de Ven, Wang, Rijsdijk & van de Giesen, 2017). In September, the differences of heating of different surfaces were lower than in summer (the maximum difference between the green area and the conventional roof was 10°C). Studies have shown how different materials on the roofs affect the temperature of heating the roof surfaces.

The introduction of green roofs on a broader scale is one of the strategies to tackle the negative effects of the city's climate, primarily to halt the urban heat island effect, which contributes significantly to improvement of the life quality of the inhabitants. The results can provide a support to architects, decision makers and city councils to design efficient by laws and regulations to prioritize interventions to mitigate urban heat island.

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Summary

Surface temperature analysis of conventional roof and different use forms of the green roof. Increasing urban populations raises a number of problems and risks that are strengthened by observed and projected climate change. An increase in green areas (so-called green infrastructure) has turned out to be an effective means of lowering temperature in the city. Green roofs can be one of the possible measures leading to achieving this aim. The aim of the study was the analysis of temperature changes of different roof surfaces (conventional roof, board, intensive roof substrate without plant cover, substrate covered with plants (shrubs). Studies on comparing the temperature between a conventional roof and green roofs were carried out in the period from April to September 2015 on the roof of the building of the Faculty of Modern Languages, University of Warsaw. The measurement was performed using the FLIR SC620 thermal imaging system. As a result of the tests, it was found that in the summer months the differences between the temperature of the green roof and the conventional roof amounted to a maximum of 31.3°C. The obtained results showed that the roof with vegetation can significantly contribute to the mitigation of the urban heat island phenomenon in urban areas during summer periods.

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