

Green roofs as a strategy for Urban Heat Island mitigation in Bologna (Italy)

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Abstract

Green roofs have received much attention in recent years due to their ability to lower urban temperatures and reduce heat fluxes to the atmosphere. This study shows the results of an experimental investigation and a numerical simulation of the Engineering Campus of the University of Bologna, which have been done to estimate the potential of green roofs in mitigating the UHI effect. The profiles of the air temperature above an extensive green roof have been measured and compared to those measured above a traditional roof. The green roof showed a good ability to lower diurnal surface temperature as demonstrated by the fact that the difference between maximum temperatures for green surface and air was 5.1 °C at 03:00 pm, and consequently 18.9 °C below the reference surface temperature. Moreover, the experimental data have been used to validate a CFD model, realized with the software ENVI-met. The simulation model allows the estimation of the UHI phenomenon across the campus area, and to evaluate the effect of a hypothetical mitigation strategy, which consist in covering all the roofs with intensive green roofs. The simulation results are presented in terms of differences in air temperature at the pedestrian level. The mitigation strategy scenario allows up to 0.5 and 3 °C decrease in air temperature, during the night and the day respectively. The comparison between the two scenarios demonstrates the validity of green roofs in reducing the UHI and in improving human comfort.

Keywords: Cooling effect; ENVI-met; Temperature profiles

INTRODUCTION

The Urban Heat Island (UHI) is a microclimatic phenomenon, which increases the temperatures of the cities compared to their out-lying rural surroundings (Santamouris, 2015). It is widely demonstrated that the UHI affects communities by increasing the summertime peak of the energy demand, air conditioning costs, greenhouse gas emissions, heat-related illness, and by decreasing urban water quality (Cipolla et al., 2014; EPA, 2008; Santamouris, 2014). One way to mitigate UHI is the use of green and cool roofs. A green roof (GR) is an engineered multilayer system designed to support vegetation on top of conventional impervious roofs. GRs are able to improve the building's thermal insulation and to reduce the roof's surface temperature (Bevilacqua et al., 2017; Cipolla et al., 2016a).

In his peer-review study, Santamouris (2014) underlines the scarcity of experimental studies carried out to evaluate the UHI mitigation of vegetative roofs, while Peri et al. (2016) pointed out that there is a lot of uncertainty regarding the choice of the parameter values used in the thermal models of simulation codes. Urban planner frequently uses thermal models, which evaluate the impact of vegetation, in the design phase (Mirzaei, 2015), although monitoring activities to calibrate these models, in particular under Mediterranean climate condition, are limited. From this broader context, the current study presents both field investigations and a modelling approach. The case study is the Engineering Campus of Bologna (Italy), which already host a full scale extensive GR (Cipolla et al., 2016b). Firstly, the analysis of the surface temperature on the experimental GR located into the campus will be presented, and secondly the results of the simulations will be shown.

MATERIALS AND METHODS

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The experimental site is located on a flat roof (44.513058°N, 11.318787°E) at the Engineering Campus of the University of Bologna (Fig.1). The site, fully described in Bonoli et al. (2013), covers about 120 m² and is divided into two full-scale plots: a Reference Roof (RR) which is bare as benchmark, and a GR plot (SR). The RR plot is a rectangular shaped horizontal roof (5.15 m x 11.30 m), covered by 4 mm of waterproofing PVC membrane, while the SR is a built-in-place system (5.15 m x 11.30 m), and realized using an extensive GR package covered by a mix of *Sedum* vegetation (Fig.1). The monitoring equipment consists in an Onset Hobo weather station that has been collecting climate data since August 2013, and 7 thermocouples that record the temperature every 5 minutes since October 2014. The sensors installed at 10, 20 and 30 cm above the surfaces, which are covered with insulating white tape, and kept shaded in order to avoid the effects of solar radiation (Fig.1).

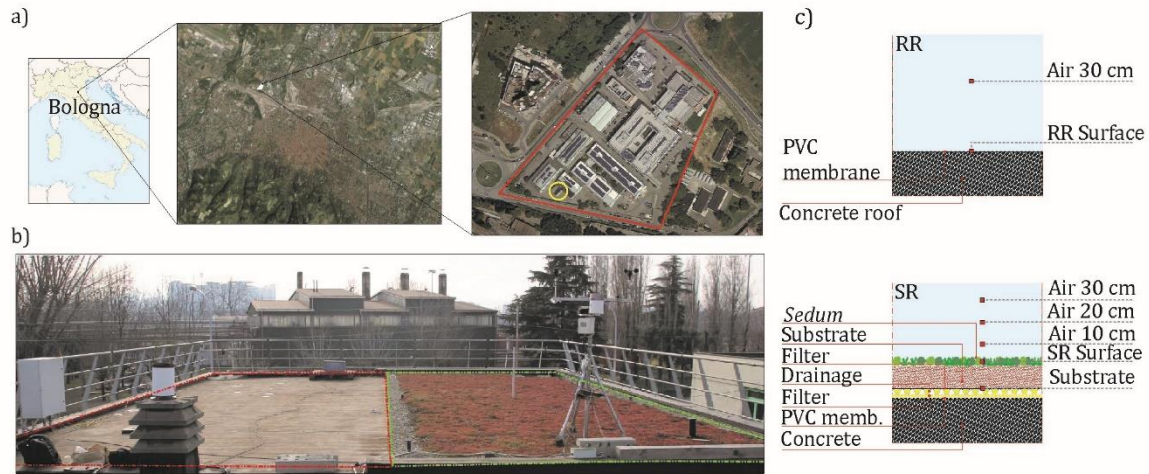


Figure 1. Study site and model domain (red line), picture of the experimental roof (b), stratigraphy (c), and position of the temperature sensors (c).

ENVI-met is a grid-based three-dimensional CFD numerical model, which is capable of simulating the built environment surface-air-plant thermal interactions based on fluid dynamics and heat transfer fundamentals, solar movement and vegetation databases. Modelling the Engineering Campus area using ENVI-met involves the calculation of fluid dynamics and thermodynamic processes at surfaces/walls/roofs and plants. The model domain covers the entire area of the site, which is 300 m wide and 350 m long. The main model area includes 150 x-Grids, 175 y-Grids, 30 z-Grid, plus 5 external nesting grids to extend the area of interest in a zone around the borders. The cell size was set 2.00 m per grid in the x-y axes and 1.5 m on the z-axis. Two scenarios have been simulated namely “As Is” and “Green Roofs” respectively. The “As Is” scenario represents the actual situation; in which each building’s roof is covered by the real cover, while “Green Roofs” scenario assumes that all roofs are covered by 5 cm tall dense vegetation located 10 cm above substrate. The software requires the following structural information of the plant canopy: LAD (leaf area density), the minimum stomatal resistance (MSR) of the vegetation and the shortwave albedo (SWA). These parameters have been defined according to the values proposed by De Munk et al. (2013), equal to: LAD= 1.5 [m⁻¹]; MSR= 150 [s*m⁻¹], and SWA= 0.1554 [-]. Simulations were conducted for a real clear and hot fall day (October 24th) with typical sub-Mediterranean weather characteristics. The choice of the simulation date was mostly driven by the simultaneous availability of environmental data from the HOBO weather station and surface temperatures from the thermocouples. Table 1 lists the modelling input data. The building’s model parameters between the “As Is” and the “Green Roof” scenario differs by the thermal transmittance of roofs equal to 3.5 and 0.67 W/m²K and for the albedo equal to 0.1 and 0.2 respectively for “As Is” and the “Green Roof” scenario.

Table 1. Model input parameter for the ENVI-met simulation

Model parameter	Model value
Simulation data	24 th October 2014
Starting time	00:00 on 24 th October 2014
Simulation duration (h)	24
Wind speed at 10 m above ground (m·s ⁻¹)	0.3
Wind Direction (0:N,90:E,180:S,270:W.)	47
Roughness Length z0 at Reference Point	0.1
Specific Humidity in 2500 m (g water/kg air)	3
Relative humidity at 2 m (%)	65.4

RESULTS AND DISCUSSION

This section shows the vertical temperature patterns during the 24th of October 2014 for all the studied surface. It was a hot sunny day without precipitation; the hourly average minimum and maximum air temperature were 13.2 °C (at 7.00 am) and 27.3 °C (at 03:00 pm). The daily amplitude of the surface temperatures is obviously related to the solar radiation as it clearly emerges in Fig.5. The temperature sets a baseline to evaluate the beneficial cooling derived from the installation of GRs. It reached a peak at 02:00 pm with an average temperature of 42.2 °C, which is 15.6 °C higher than the air temperature at the same time, while throughout the night the air temperature and the RR surface temperature were almost the same. On the contrary, SR shows a good ability to reduce diurnal surface temperature of the roofs, where the SR maximum temperature was 5.2 °C below the air temperature at 03:00pm, and consequently 19.9 °C below those of the control plot.

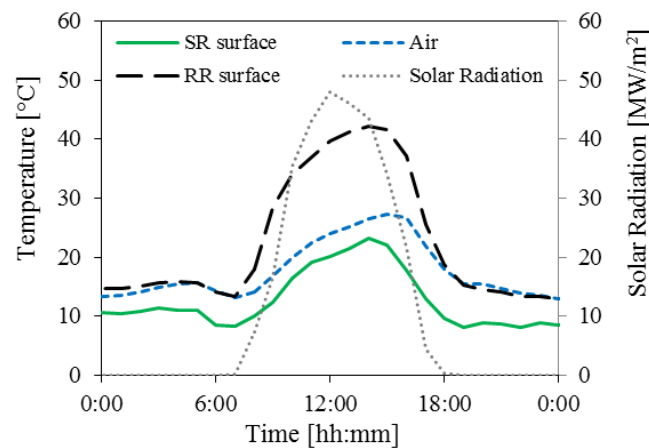


Figure 2. Average hourly solar radiation, air temperature and surface temperature pattern at the Reference plot (RR) and at the Sedum Plot (SR) on 24th October 2014

The “As Is” simulation has been considered as the benchmark of the actual situation. The cooling effects are reported by comparing the simulation results of the “As Is” scenario with those of the “Green roofs” from 1.35 m above ground (Fig.3). Cooling effects were defined as the potential temperature differences between the “As Is” and the “Green Roofs” scenarios. The comparative results show that the cool air generated by GRs moves downwards improving the pedestrian-level (1.35 m above ground level) microclimate as illustrated in Fig.10. Results indicate that the presence of GRs reduce the pedestrian-level air temperature up to 3.7 °C at 15:00, and in effect all the area is much hotter in the “As Is” scenario as indicated by yellow and red color representation. The “Green roof” scenario shows that GRs have a positive effect on reducing the air temperature above the building and so UHI effect. The positive effect of GRs mitigation actions is mainly due to the increased albedo of the roofs and consequently reduced surface temperature.

CONCLUSIONS

The aim of this study was the evaluation of the green roofs potential in mitigating the Urban Heat Island. It has been performed by measuring the ambient temperature on a full-scale extensive green roof located in Bologna (Northern Italy) during a warm sunny autumn day (24th October). The study found that the extensive experimental GR was able to reduce the ambient temperature, confirming that GRs provide an important mitigation effect. In the second part of the study the environmental data, collected during the monitoring activity, have been used to validate a model realized with the software ENVI-met. The simulation results of the "Green Roofs" scenario demonstrate till 0.5 and 3 °C decrease in air temperature, respectively during the night and day. The comparison between the real case scenario and the designed one demonstrates the validity of GRs in reducing the UHI improving human comfort.

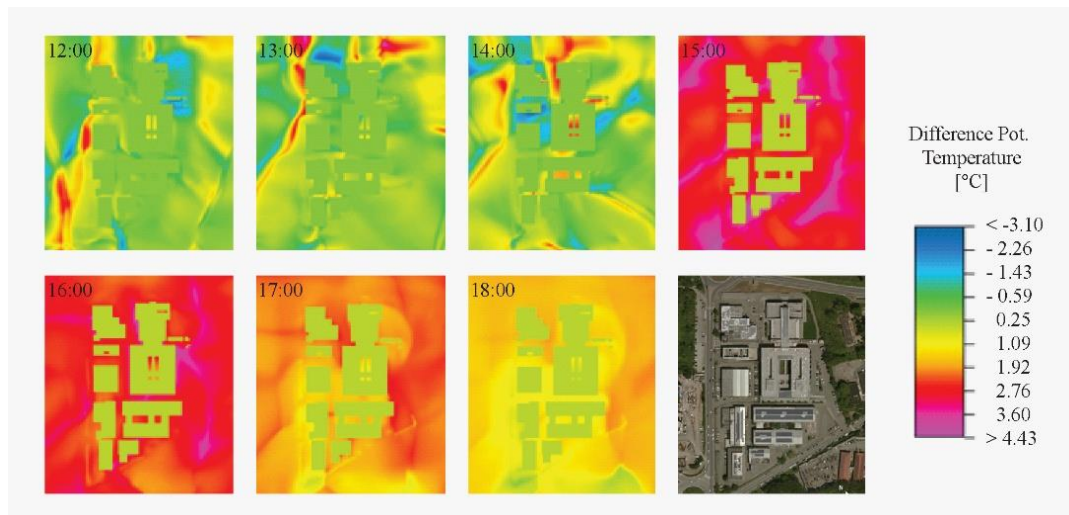


Figure 3. The horizontal distribution of cooling effects at the pedestrian level (1.35 m) during the warmer hours of the day.

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