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Green control of microclimate in buildings

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Abstract

In the Mediterranean area the solar heat gain in buildings needs to be controlled during the warm seasons in order to keep the internal temperature at comfortable levels and to mitigate the phenomenon of urban warming, known as Urban Heat Island. This phenomenon contributes to increase the outdoor pollutants concentration and the energy demand for air conditioning. Indoor microclimate conditions depend on several parameters related mainly to the building destination, envelope materials and orientation, its technological equipment, and to the specific region climate. The use of green shading can induce energy savings also in winter, by reducing heat losses from the external surface during mainly the night.
An experimental study was carried out at the University of Bari (Italy, 41 ° 05 'N, 16 ° 53 'E) from June 2014 to April 2015 with the aim of investigating the effective influences of this green passive system on a building vertical wall. Three vertical walls were built and equipped with a sealed structure on the backside; the walls were made with perforated bricks. The walls were covered with different evergreen climbing plants: Pandorea jasminoides variegated for the first wall and Rhyncospermum jasminoides for the second one. A third wall was kept uncovered and used as control. A data logger and sensors were used to measure and collect the temperature of the wall, on the surface exposed to the solar radiation and on the inner surface protected by the sealed structure, the external air temperature, the wind speed and direction, the solar radiation falling on the wall. The experimental tests showed that during the daytime of warmest periods the use of the green walls allowed a reduction of the external surface temperature registered on the walls shielded by the green systems: the temperatures observed were lower than the respective temperatures of the control wall of about 3-4.5 °C. During the nighttime of coldest periods the use of the green wall allowed to keep the external surface temperature of the walls shielded by the green systems at values higher than the control wall ones: the temperatures observed were higher than the respective temperatures of the control wall of about 2-3 °C.

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1. Introduction

Urban Green Infrastructures (UGI) have been recently defined as sets of man-made elements that can provide a range of environmental benefits at buildings and urban scales (Pérez et al., 2014). UGI comprise urban forests, street trees, parks, turf-grass, private gardens, green roofs and green walls. They play an important role in contributing to a range of ecosystem services such as improving aesthetically the environment to live and work, removing airborne pollutants and improving air quality, improving the habitat for invertebrates, birds, weeds and plants and promoting and increasing biodiversity, providing sound insulation and noise absorption, enhancing of storm-water management and water run-off quality (Cameron et al., 2014; Kohler and Poll, 2010; Rowe, 2011; Fernandez-Caňero et al., 2013). Moreover, UGI contribute to the mitigation of the frequency and magnitude of the heat events due to urban heat island (UHI), to reduce the ambient temperatures, to improve human thermal comfort and to decrease energy loads on building (Pérez et al., 2014; Cameron et al., 2014; Norton et al., 2015). The UHI phenomenon induces negative outdoor comfort conditions, an increase of energy consumption for cooling, a raise of peak electricity demand, an increase in pollutants concentration and risks for human health (Karlessi et al, 2011; Jaffal et al., 2012; Kalkstein and Davis, 1989; Petralli et al., 2006).

Green roofs and green walls, as UGI, consist in the application of living vegetated horizontal and vertical layers on buildings with the main aim of reducing the energy consumption for air conditioning in summer and of increasing the thermal insulation in winter (Raji et al., 2015; Kanechi, et al., 2014; Blanusa et al., 2013; Cheng et al, 2010; Berardi et al, 2014; Fernandez-Canero et al, 2013; Santamouris, 2012; Vox et al., 2015). The design of green roofs and walls depends on factors as the building characteristics, the climatic conditions of the area and the surrounding conditions (Berardi et al, 2014; Fernandez-Caňero et al., 2013; Santamouris, 2012; Perez at al., 2011; Perini et al., 2011; Francis and Lorimer, 2011; Jim and He, 2011; Fioretti et al., 2010; Castleton et al., 2010; Kontoleon and Eumorfopoulou, 2010; Spala et al., 2008) and their social, environmental and aesthetical positive impacts depend on the climatic conditions of the area, on the urban context, on the greening technology and on the building characteristics (Fioretti et al., 2010; Castleton et al., 2010; Wong et al., 2003; Perini et al., 2011; Wong et al., 2010; Berardi et al., 2014; Santamouris, 2012; Benvenuti, 2014; Rowe, 2011; Kohler, 2008; Francis and Lorimer, 2011; Fernandez-Caňero et al., 2013). The use of vertical greenery in dense cities could be a promising solution to make cities more sustainable; green walls are a more appropriate solution for tall building typologies due to a high wall to roof ratio (Raji et al., 2015; Cheng et al., 2010).

The cooling effect of UGI is achieved by shading the buildings from solar radiation, by providing evapo-transpirative cooling, by reflecting the solar radiation, by thermally insulating the building with an air cavity, by influencing air speed on buildings (Hunter et al., 2014). The density of foliage and the coverage ratio highly affect the interception and the absorption of the solar radiation (shading effect) that induce a decrease of the external surface temperature (Raji et al., 2015). It has been found a linear correlation between the shading effect of a vertical greening system and the leaf area index: a denser greenery means a greater thermal insulation (Wong et al., 2009). The evapo-transpirative cooling effect leads to lower ambient environment temperatures and consequently to reduce the cooling load of the buildings (Wong et al., 2010; Sunakorn and Yimprayoon, 2011). The air cavity between the green layer and the building wall acts as a thermal buffer able to reduce the heat losses through the building envelope (Raji et al., 2015).

Europe and North America are reported as the regions where green roofs can generate more benefits (Castleton et al., 2010; Refahi and Talkhabi, 2015) because they require low maintenance; nevertheless, in areas with lack of water and high summer temperatures, as in the Mediterranean region, some plants are unlikely to survive without intensive irrigation or without an adequate depth of the substrate (Castleton et al., 2010). More knowledge of greenery systems benefits and characteristics is needed and more research has to be undertaken into plant species suitable for the Mediterranean regions.

The main focus of this paper is to investigate the effective influences of two different climbing plants for green vertical passive systems on a building wall. An experimental test was carried out at the University of Bari during different seasons, and surface temperatures and climatic data were evaluated in order to estimate the reduction of the wall surface temperatures equipped with the vertical greenery systems.

2. Materials and methods

The experimental test was carried out at the experimental farm of the University of Bari located in Valenzano (Bari, Italy; latitude 41° 05' N, longitude 16° 53' E, altitude 85 m ASL) from June 2014 to April 2015. Three vertical walls were built and equipped with a sealed structure on the backside with the aim of realizing some prototype of building vertical wall in scale. The walls were of the following dimensions: a width of 1.00 m, a height equal to 1.55 m, and a thickness of 0.20 m. They were south oriented. The walls were made with perforated bricks having 20 cm thick, 25 cm height and 25 cm length. The wall made of perforated bricks is a commonly used technology of vertical closure for residential and rural construction in the Mediterranean regions. The brick used were characterized by an average weight of the masonry work (including plaster) equal to 695 kg m^{-3}, a thermal conductivity λ (following UNI EN 1745:2012) equal to 0.282 W m^{-1} K^{-1} and a specific heat capacity C equal to 840 J kg^{-1} K^{-1}. The sealed structure built on the backside of the walls was made of sheets of expanded polystyrene, having a thermal conductivity equal to 0.037 $Wm^{-2}K^{-1}$ and a thickness of 30 mm. A blue shading net was positioned onto the sealed structure to reduce the effect of the incident solar radiation.

Two walls were covered with different evergreen climbing plants: *Pandorea jasminoides* variegated, and *Rhyncospermum jasminoides*; a third wall was kept uncovered and used as control (Fig. 1). The plants were transplanted on June 18, 2014. The support for the climbing plants is made of an iron net placed at a distance of about 15 cm from the wall. The irrigation method used for all the plants was the drip one and the fertilization was performed with N: P: K 12:12:12.

Figure 1: The three walls at the experimental field of the University of Bari; the right wall is covered with *Rhyncospermum jasminoides*, the central wall with *Pandorea jasminoides* variegated and the left wall is the uncovered control

A data logger (CR10X, Campbell, Logan, USA) and sensors were used to measure and collect the temperature of the walls, on the surface exposed to the solar radiation and on the inner surface protected by the sealed structure, the temperature inside the sealed volume, and the external air temperature. The data were measured with a frequency of 60 s, were averaged every 15 min and stored in the data logger. The surface temperature of the wall on the inner side, the surface temperature of the external plaster exposed to solar radiation, and the indoor temperature were measured using thermistors (Tecno.el s.r.l. Formello, Rome, Italy), placed as shown in Figure 2. The external air temperature was measured by using an Hygroclip-S3 sensor (Rotronic, Zurich, Switzerland), adequately shielded from solar radiation.

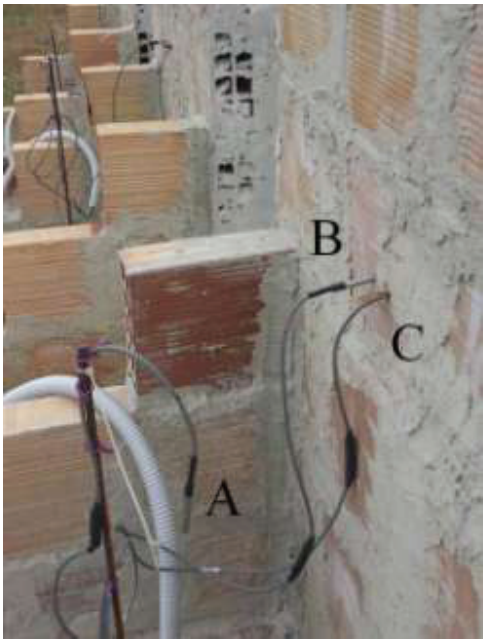


Figure 2: Location of the temperature sensors: sensor for the indoor temperature inside the volume behind each wall (A), sensor for the surface temperature of the wall on the inner side (B), sensor for the surface temperature of the external plaster exposed to the solar radiation (C).

3. Results and Discussion

The field observations showed that the plants covered sufficiently the walls from mid August 2014, even if Pandorea jasminoides variegated was more widespread than Rhyncospermum jasminoides. During summertime, the presence of vegetation mitigates the quantity of solar radiation absorbed by the walls reducing the temperature of the plaster of the external walls covered by climbing plants respect to the control wall; a difference up to 4 °C was recorded between the highest temperatures measured for the control and for the walls covered with plants (data shown in Vox et al., 2015).

Tables 1 and 2 show the average values of the maximum and minimum daily surface temperatures of the external plaster of the walls exposed to solar radiation in the cold period, from October 2014 to February 2015. In the examined period, the average values of the maximum surface temperature of the control, i.e. recorded on the wall not covered with plants, were always higher than the average values of the maximum surface temperature recorded for the vertical walls covered with Rhyncospermum jasminoides and Pandorea jasminoides variegated.

The differences between the highest temperatures recorded for the control and for the wall covered with plants ranged from 2.7 to 4.4 °C. The average values of the minimum surface temperature of the control wall was always lower than the temperatures recorded for the walls covered with plants. In wintertime the presence of vegetation increase the thermal insulation of the wall. The differences between the lower temperatures recorded for the control and for the wall covered with plants ranged from 2.4 to 2.8 °C (Fig. 3).

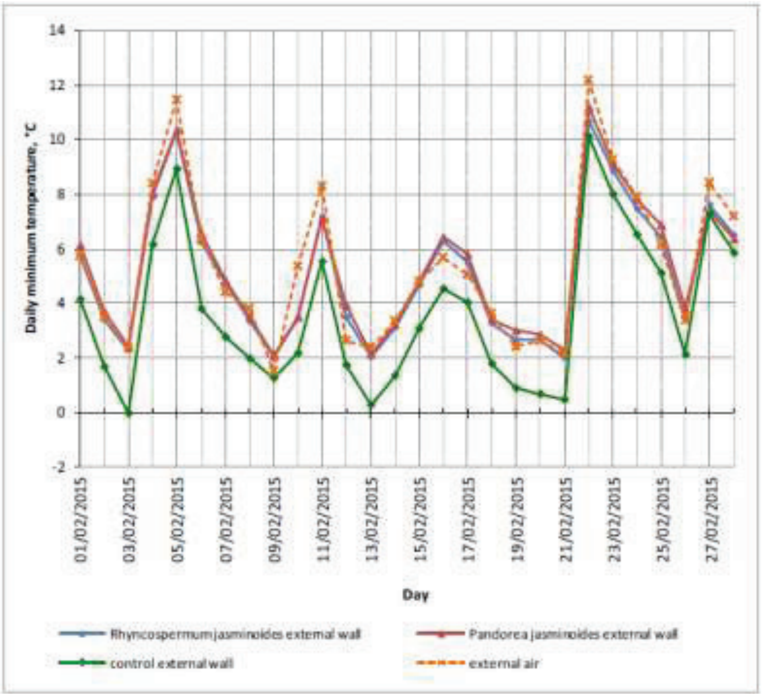
Table 1 Average values of the maximum daily external air temperature and surface temperature of the external plaster of the three walls exposed to solar radiation from October 2014 to February 2015.

Exposition period	Maximum temperatures			
	Rhyncospermum jasminoides external wall (°C)	Pandorea jasminoides variegated external wall (°C)	control external wall (°C)	external air (°C)
october 2014	24.0	22.5	25.1	23.9
november 2014	20.3	19.1	20.7	20.2
december 2014	16.2	14.6	16.4	15.1
january 2015	15.1	13.7	15.4	14.2
february 2015	13.6	12.5	14.1	14.1

Table 2: Average values of the minimum daily external air temperature and surface temperature of the external plaster of the three walls exposed to solar radiation from October 2014 to February 2015.

Exposition period	Minimum temperatures			
	Rhyncospermum jasminoides external wall (°C)	Pandorea jasminoides variegated external wall (°C)	control external wall (°C)	external air (°C)
october 2014	14.2	14.3	13.1	14.0
november 2014	12.2	12.5	10.9	12.1
december 2014	7.3	7.5	5.9	7.0
january 2015	5.4	5.3	4.0	5.4
february 2015	5.1	5.3	3.7	5.4

Figure 3: Daily minimum surface temperature of the external plaster of the three walls exposed to solar radiation and daily maximum external air temperature measured during February 2015.



4. Conclusions

The experimental test was conducted on vegetated vertical systems from August 2014 to February 2015 in South Italy taking into consideration both warm and cold periods. The application of the green walls during warm months allowed cutting the heat gain due to solar radiation by reducing the external surface temperature in daytime hours up to 4.4 °C. The use of the green walls during cold months allowed increasing the thermal insulation performance of the walls by keeping the external surface temperature in nighttime hours up to about 2.8 °C over the surface temperature of the wall not covered with plants.

Green roofs and vertical greenery popularity is growing because of their high potential to be used as sustainable solution for enhancing the thermal performance of building envelopes and for reducing energy consumption in the sector of residential and rural constructions in the Mediterranean area. Like other forms of green infrastructure, they offer many ecosystem services like the mitigation of the urban heat island effect, the creation of natural habitats for improving urban biodiversity, noise attenuation, improved air quality and aesthetical impact of constructed areas. Moreover the greening technology offers the additional benefits of reducing the energy consumption for air conditioning in summer and increasing the thermal insulation in winter

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