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Green façades to control wall surface temperature in buildings

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A B S T R A C T

Green façades can represent a sustainable solution for construction of new buildings and for retrofitting of existing buildings, in order to reduce the energy demands of the cooling systems, to mitigate the urban heat island and to improve the thermal energy performance of buildings. Green façades can allow the physical shading of the building and promote evapotranspiration in summer, and increase the thermal insulation in winter. An experimental test was carried out at the University of Bari (Italy) for two years. Three vertical walls, made with perforated bricks, were tested: two were covered with evergreen plants (*Pandorea jasminoides variegated* and *Rhyncospermum jasminoides*) while the third wall was kept uncovered and used as control. Several climatic parameters concerning the walls and the ambient conditions were collected during the experimental test. The daylight temperatures observed on the shielded walls during warm days were lower than the respective temperatures of the uncovered wall up to 9.0 °C. The nighttime temperatures during the cold days for the vegetated walls were higher than the respective temperatures of the control wall up to 3.5 °C. The thermal effects of the facades at daytime was driven by solar radiation, wind velocity and air relative humidity. The highest cooling effect of such parameters occurred with a wind speed of 3–4 ms^{-1}, an air relative humidity within the range 30–60% and a solar radiation higher than 800 Wm^{-2}.

The long-term experimental test demonstrated that both *Pandorea jasminoides variegated* and *Rhyncospermum jasminoides* are suitable for green façades in the Mediterranean climatic area. The results shown in the present research allow to fill the gap in literature concerning the lack of data for all the seasons of the year, in order to obtain a complete picture of the building thermal performance in the Mediterranean climate region.

1. Introduction

In dense urban areas the progressive replacement of green areas with artificial surfaces is one of the major causes of the so called urban heat island (UHI) effect, the phenomenon that generates a temperature difference between cities and surrounding rural or suburban areas. As a city grows, more heat is trapped with a consequential increase of the air temperature in downtown even up to 6–8 °C higher in comparison to the surrounding areas [1–5]. Building surfaces and pavements are made mainly with non-reflective and water-resistant construction materials, consequently accumulating incident solar radiation during daytime and then releasing heat at night [6]. Heat is trapped also because the decrease of green areas in cities induces a reduction of shades and radiation interception, together with the reduction of the infrared radiation emitted towards the atmosphere, the limitation of the circulation of air in urban canyons and the high production of waste heat from cooling systems, motorized vehicular traffic and industrial processes [1,3,7]. UHI negatively influences outdoor comfort conditions as well as induces a more use of air conditioning systems with a raise of peak electricity demand. Nowadays, energy use in buildings accounts up to 36% of Europe's CO_2 emissions [8].

The importance of green infrastructures applied on building roofs or façades in cities has been increased due to their ability to sustainably improve the energy efficiency of buildings [3,9–16] and to mitigate the UHI effect [17–21].

Green vertical systems can be used because the surface area of the building envelopes is generally left bare while surrounding areas at ground level are increasingly occupied by buildings and paved surfaces, and portions of the roofs are occupied by building services [22,23]. Green vertical systems offer several benefits on the façade, as the extension of wall lifetime, the thermal insulation of the wall, and the reduction of solar absorbance. They also offer benefits on the building, as the reduction of the heat load and energy consumption, the improvement of the internal comfort due to a reduction of the surface temperature and the attenuation of temperature fluctuations. The enhancement of the acoustic comfort, the increasing of the property values, the implementation of spaces for recreation and amenity are other advantages. Vertical gardens protect the exterior finishes and masonry

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Fig. 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.

Table 1
Thermo-physical properties and geometrical characteristics of the experimental cuboids.

	Wall width (m)	Wall height (m)	Material	Thickness (m)	Total thickness (m)	λ[a] thermal conductivity ($Wm^{-1}K^{-1}$)	d density ($kg\ m^{-3}$)	Cp heat capacity ($Jkg^{-1}K^{-1}$)	α_s solar absorption coefficient (%)	ε_{LWIR} LWIR emissivity coefficient (%)
south exposed vertical walls	1.00	1.55	masonry (bricks single layer joined with mortar)	0.20	0.22	0.282	695	840	42.1	95.3
			plaster coating	0.02		0.55		1000		
north, east and west exposed vertical walls and roof	1.00	1.55	expanded polystyrene	0.03	0.03	0.037	15	1404	–	–

[a] Ref. [36].

Table 2
Description of the vertical greenery systems in Valenzano (Bari).

Experimental wall	LAI	Average thickness (m)			
		Wall	Air gap	Plants	Total
Green façade with *Rhyncospermum jasminoides*	2–4	0.22	0.10	0.20	0.52
Green façade with *Pandorea jasminoides variegated*	1.5–3.5	0.22	0.11	0.15	0.48

from ultra violet radiation, rain, extreme temperature fluctuations and presence of moisture even if they could damage the wall they are covering. Other benefits can be found at a larger scale: energy consumption reduction (decreasing cooling and heating loads); urban heat island effect decreasing; air pollution mitigation (enhancing urban air quality, reducing dust and heavy metal accumulation in air, filtering airborne particles); sound absorption (sound insulation and noise absorption); water management improving (enhancement of stormwater management, water run-off quality, urban hydrology and use of rainwater). Moreover, vertical planting contributes to improve health and well-being and to preserve urban biodiversity, acting as habitat for colonizing species such as spontaneous plant species, weeds, beetles, bees, ants, spiders and birds.

Green vertical systems are classified according to construction techniques and characteristics into green façades and living walls [22,24,25]. Green façades are characterized by climbing plants rooted in the ground or in pots at different heights of the façade; the plants climb on the building façade directly through morphological features (such as aerial roots, leaf tendrils and adhesion pads) or indirectly on a structural support (such as wire, mesh, trellis) located to a small distance to the wall. Living walls are classified as continuous or modular: the former is based on lightweight and permeable screens in which plants are inserted individually; the latter is composed of modular elements, such as trays, vessels, planter tiles and flexible bags, which include the growing media where plants can grow [26]. The modular elements are fixed to a wall or freestanding frame with artificial irrigation and fertigation system. The presence of a gap between the building wall and the greening system (generally from 3 cm to 15 cm) acts as a thermal buffer, improving its thermal insulation impact on building [27].

Although the cooling influence of the green walls is well recognized, few authors reported experimental data under Mediterranean climatic conditions and no one considered two years of experimental data.

Coma et al. [28] reported the results obtained on experimental houses-like cubicles with a green wall system tested in Catalonia, Spain. In two short winter periods, the green wall registered the highest external wall temperature reductions, equal to 16.5 °C, on the south while in east and west the reductions were 4.5 °C and 6.5 °C, respectively. The results obtained experimentally by Hoelscher et al. [1] in Berlin, Germany, showed the cooling effects through shading and transpiration of three different climbing plants as part of direct and indirect green façades. The additional vegetation layer, compared to bare walls taken as control, reduced the surface wall temperatures, by up to 15.5 °C and