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Experimental study of the thermal-energy performance of an insulated vegetal façade under summer conditions in a continental mediterranean climate

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ABSTRACT

The use of vegetal systems in façades affects the reduction of the buildings' energy demand, the attenuation of the urban heat island (UHI) and the filtration of pollutants present in the air. Even so, up to now the knowledge about the effect of this type of systems on the thermal performance of insulated façades is limited. This article presents the results of an experimental study carried out in a vegetal façade located in a continental Mediterranean climate zone. The objective is to study the effect of a vegetal finishing, formed by plants and substrate, on the thermal-energy performance of an insulated façade under summer conditions.

To this effect, the thermal data obtained from two full-scale experimental mock-ups of the same dimensions and composition of the enclosure and only different in the south façade's enclosure where one incorporates a vegetation layer are compared and analysed.

The results show that, in spite of the high thermal resistance of the enclosure, the effect of the vegetation is very positive, particularly in the warmer hours of the day. Therefore, vegetal façades can be used as a passive cooling strategy, reducing the consumption of energy for refrigeration and improving the comfort conditions of the users.

1. Introduction

As a consequence of the growing interest in energy saving and environmental sustainability in buildings, in recent years many studies have been carried out about the potential of vegetal façades in this field [1–8].

Several researches have shown that the use of vegetal systems in the façade affects positively the reduction of the buildings' energy demand [7,9–12], the attenuation of the urban heat island (UHI) [13–16] and the filtration of pollutants present in the air [17,18].

Concerning the reduction of the buildings' energy demand, in a research study conducted in a hot and humid climate, Chen et al. [7] showed the potential of the Living Wall Systems (LWS) in lowering buildings' energy use. One of the aims of the research was to compare the energy use of two identical experimental prototypes on a summer day. The only existing difference between them was that the west façade of one of them was covered with Living Wall System modules. Both spaces had identical air-conditioning systems running at 24 °C for 24 h. Results showed that the energy use of the space with the LWS was 12% less than the energy use of the space with the bare wall. Perini et al. [9] studied the potential of vertical greening systems as passive cooling techniques, by evaluating the contribution of vegetation to the improvement of the thermal behaviour of the building envelope. In particular, the influence of the vegetation on wind speed and its effects on the thermal resistance of the façades were analysed. The experiment was conducted in Netherlands by comparing three different vertical greening systems with bare façades next to them. Results showed that depending on the system, the wind speed reduction varies from 0.43 m/s to 0.55 m/s measuring at 0.1 m in front of the façades. As a consequence of this reduction, wind speed measured next to the vertical greening systems was in each case lower than 0.2 m/s, which implies that the exterior surface resistance (Re) could be equalized to the interior surface resistance (Ri), raising the total thermal resistance of the façade in 0.09 m^2K/W. Touceda et al. [10]

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Table 1
Local weather conditions during the monitoring period. The number of days is shown in percentage with relation to the total number of days of the monitoring period.

Maximum global irradiance [W/m^2]		Mean temperature [°C]			Maximum temperature [°C]		Minimum temperature [°C]		Mean relative humidity [%]	
>900	>1000	>24	>28	<22	>35	>30	<17	>21	<25	>35
85%	36%	64%	20%	15%	17%	30%	28%	23%	28%	32%

evaluated the thermal performance of a pre-vegetated modular façade system installed on an experimental building situated in Seville, Spain. The experimental procedure consisted in comparing data obtained from the pre-vegetated façade with data obtained from others façade cladding solutions implemented in the same building. In particular a bare wall and a ventilated façade were studied. Monitored recordings were analysed and processed by DesignBuilder software in order to compare the enclosures' thermal performances under different conditioning solutions. Most significant results showed that in the case of conditioning systems being switched off, and therefore no natural ventilation, the mean indoor temperature of the space covered by vegetation was 3 °C lower than the space with ventilated façade. Furthermore, in the case of the conditioning system being turned on, the vegetal façade resulted in a 33% energy saving in comparison to the ventilated façade.

Out of all the vegetal façade systems existing in the market [1,5,19,20], the systems constituted by substrate and vegetation seem to be the most effective from an energy point of view. The substrate works as a natural insulating material, due to its low thermal conductivity and high thermal mass; whereas the vegetation reduces the solar gains thanks to its high albedo and the evapotranspiration phenomena that take place in it. Wong et al. [21] studied eight different vertical greening systems installed on free standing concrete walls in Singapore. One of the aims of the research was to study the thermal impacts of different vertical greening systems on the performance of buildings based on the surface and ambient temperatures. They are found to depend on specific vertical greening systems. In particular, vertical greening systems consisting of modular panels and substrate showed better capacity in lowering the temperature of the wall surface and having the lowest diurnal range of average wall surface temperature variation. These systems also showed a good capacity in reducing the ambient air temperature, being its effect felt as far as 0.60 m away. On the other hand, the system consisting of climber plants in planters forming green screen across mesh panels on the wall had hardly any effect on the ambient temperature.

Building on these results, it can be said that the use of vertical greening systems to cool the ambient temperature in building canyons is encouraging. In addition, air intakes of air-conditioning at a cooler ambient temperature bring to save energy in the cooling load.

Most of the researches done about the performance of vegetal façades in temperate climates focus on the analysis of enclosures with high U-values. Even though all these studies agree on the positive effects related to energy saving in buildings and environmental comfort of the users, the advantages are usually linked to specific cases and not only to the vegetal layer performance [2,22–25]. Furthermore, the cooling capacity depends on the species. Plant physiology and leaf morphology should be considered when selecting species to maximize cooling in green wall applications [26]. Eumorfopoulou and Kontoleon [22] analysed the influence of a plant-covered wall on the thermal characteristics of building envelopes by a thermal analysis performed during the summer for a east oriented building envelope that incorporated insulated wall surfaces with or without vegetation. The building was situated in the north of Greece. The cooling effects were analysed, among other things, by the daily temperature reduction in the interior surface of the assumed façade due to plant-covered sections. Results showed that the temperature reductions of the maximum values in the interior surface of the wall, due to the leaf cover, varied from 0.4 °C to 1.6 °C for the time period of the filed measurements.

Mazzali et al. [24] monitored three vertical greening systems situated in a Mediterranean temperate climate (northern and central Italy) in order to investigate the effects of the green envelope on the energy behaviour of the buildings. In each case, the performance of the green vertical system was compared with a bare wall. Results showed that the effect of the vegetal layer on the thermal balance of the wall is always positive but its rating varies according to the composition of the wall and to the presence of a conditioning system in the ambient area behind the wall. The analysis of the heat flux of the three monitored vertical greening systems during a sunny day showed relevant differences. In the case of a 0.3 m concrete wall with no conditioning system, the heat flux balance is 0, both in the green and the bare wall. In the case of a 0.4 m concrete wall with conditioning system, the green wall showed an overall outgoing heat flux of −87 W/m^2 against the incoming heat flux of 30 W/m^2 of the corresponding bare wall. In the case of a 0.4 m brick wall with conditioning system the green wall registered an outgoing heat flux of −37W/m^2 against the outgoing heat flux of −23 W/m^2 of the corresponding bare wall.

Regarding the influence of vegetal systems on the thermal performance of insulated enclosures, the knowledge is still limited. Some studies confirm that the use of high insulation could reduce the cooling effect caused by vegetal surfaces. Many of them base their conclusions on results of simulations However, since vegetation is a difficult element to characterize and simulate, it seems necessary to keep analysing monitoring data.

The experimental campaign described in this study aims to provide new knowledge to this research line, studying the effects of a vegetal finishing formed by plants and substrate on the thermal-energy performance of an insulated façade in a continental Mediterranean climate in summer conditions.

2. Material and methods

2.1. Local climate conditions

The monitoring is carried out during the summer of 2012 in a full-scale experimental building in Colmenar Viejo 40° 39′ N, 3° 45′ W, a locality 40 km north of Madrid, in the Guadarrama mountain range.

In order to have a direct control of the local weather conditions during the monitoring period, a weather station installed near the experimental building (100 m away from the façades) is used to log global irradiance, air temperature, relative humidity and pluviometry data.

The monitoring begins on July 1 and ends on September 5, needing to be interrupted thrice due to power supply problems: between July 8 and 11, between July 26 and 31 and between August 6 and 7.

Colmenar Viejo is characterised by a continental Mediterranean climate, with hot-dry summers. As shown in Table 1 during the monitoring period, the horizontal global irradiance exceeds 900 W/