

Behaviour of green facades in Mediterranean continental climate

Gabriel Pérez

GREA Innovació Concurrent, Universitat de Lleida, Lleida, Spain

Lídia Rincón

GREA Innovació Concurrent, Universitat de Lleida, Lleida, Spain

Anna Vila

GREA Innovació Concurrent, Universitat de Lleida, Lleida, Spain

Josep Maria González

Dept. Construccions Arquitectòniques I, Universitat Politècnica de Catalunya, Barcelona, Spain

Luisa F. Cabeza

GREA Innovació Concurrent, Universitat de Lleida, Lleida, Spain

ABSTRACT: In evaluating the potential of the green vertical systems as passive systems for energy savings in buildings we must consider some important aspects. First, the type of green vertical system, as there are significant differences among systems. The construction system, the types of plants, the maintenance, the operation, vary among systems. Second, the parameters that influence their behaviour must be considered. Basically, the interception of solar radiation by the effect of the shadow produced by the vegetation, the thermal insulation provided by vegetation and substrate, the evaporative cooling that occurs by evapotranspiration from the plants and the substrate, and through the variation of the effect of the wind on the building. Finally, it is important to consider that for the efficient operation of these systems it is essential to know the behaviour of the different species in local weather conditions. According to these considerations, a long-term work has been raised in order to obtain data on the behaviour of green facades in buildings as a passive system for energy savings in dry Mediterranean continental climate. This work presents the results of a year monitoring a double-skin green facade (also called green curtain), made with modular trellis and wisteria sinensis in the village of Golmés, near to Lleida city (Catalonia, Spain). The first results confirm the great ability to provide shade from the green curtain and that the air in the intermediate space is changed, creating a microclimate where environmental conditions are; higher temperature and lower relative humidity in winter (leafless period), and lower temperature and higher humidity in summer (period with leaves).

1 INTRODUCTION

The use of green vertical systems, well designed and managed, can be a useful tool for thermal regulation of buildings with interesting energy savings (Köhler 2008). But in evaluating the potential of these systems as passive systems for energy savings in buildings the following aspects must be considered.

First the type of green vertical system, as there are significant differences between systems. The construction system, the type of plants, the maintenance, the operation, vary among systems (Table 1), and these will affect their behaviour as passive energy saving systems (Pérez et al 2010).

Second, the parameters that influence their behaviour must be considered (Table 2). Basically, there are four fundamental mechanisms that characterise green vertical systems as a passive system for energy savings: the interception of solar radiation by the effect of the shadow produced by the vegetation (Papadakis et al 2001, Stec et al 2004, Miller et al 2005, Hoyano 1988), the thermal insulation provided by vegetation and substrate (Papadakis et al 2001, Hoyano 1988), the evaporative cooling that occurs by evapotranspiration from the plants and the substrate (Papadakis et al 2001, Miller et al 2005, Schmidt 2006), and finally, through the variation of the effect of the wind on the building (Dinsdale et al 2006, Ochoa 1999).

Table 1. Classification of green vertical systems of buildings.

Extensive systems		Intensive systems	
Green facades	Traditional Green Facades		
	Double-skin green facade or green curtain	Modular trellis	
		Wired	
		Mesh	
	Perimeter flowerpots		
Living walls	Panels		
	Geotextile felt		

Table 2. Parameters that influence in the behaviour of the green vertical systems as passive energy-saving systems.

Interception of solar radiation. Shadow	Thermal insulation and storage	Evaporative cooling	Variation of the effect of the wind
Density of the foliage (number of layers)	Density of the foliage (number of layers)	Type of plant	Density of the foliage (number of layers) Orientation of the facade Direction and wind speed
	Changes in the air in the intermediate space	Exhibition	
	Barrier effect of wind	Climate (dry / wet)	
	<i>Substrate: thickness, bulk density and moisture content.*</i>	Wind speed <i>Substrate moisture*</i>	

Finally, it is important to consider that for the efficient operation of these systems it is essential to know the behaviour of the different species in local weather conditions, because the end result may differ greatly from one climate area to another, spoiling the expectations of energy savings that had been planned according to theoretical calculations for a given system.

Given the extreme climatic conditions in the area of Lleida (continental part of the region of Catalonia, Spain), it is even more necessary to have more knowledge about the development of these species in local weather conditions. Lleida has a climate classified as dry Mediterranean continental, characterized by its great seasonal variations. It has low rainfall and it has a thermometric regime with large differences between a long winter and a very hot summer.. This is a very similar climate to that of the area of Madrid.

According to these considerations, a long-term work has been raised in order to obtain data on the behaviour of green facades in buildings as a passive system for energy savings in dry Mediterranean continental climate. The experimentation started refers specifically to double-skin green facade or green curtain. This typology has been chosen because of its easiness to assemble and disassemble, its easiness to integrate it into the building, and because it requires minimum posterior maintenance.

2 OBJECTIVE

The main objective of this experiment was to study and monitor during one year a double-skin green facade or green curtain, with modular trellis and Glycine (*Wisteria sinensis*), in Mediterranean continental climate.

3 METHODOLOGY

In May 2007 the rehabilitation of a former building in Gomés (Lleida, Spain) as social activities local was finished. A double skin green facade with a structure of steel and *deployè* sheet steel, in the northwest, southwest and southeast facades was included in the project (Figure 2). Different parameters to evaluate this green facade were measured from September 2008 to August 2009.

The species planted on all three fronts is *Wisteria sinensis*, a deciduous climbing plant which is characterized by its rapid growth and great development, well adapted to the conditions of the dry Mediterranean continental climate.

The collection of data was done weekly. Different points of the intermediate space between the structure and the facade, and also the exterior, were measured (Figure 3). This distribution compared the behaviour of the green facade in different orientations with the exterior environment values.



Figure 2. Theatre Lo Casal de Golmés green facade, 2008.

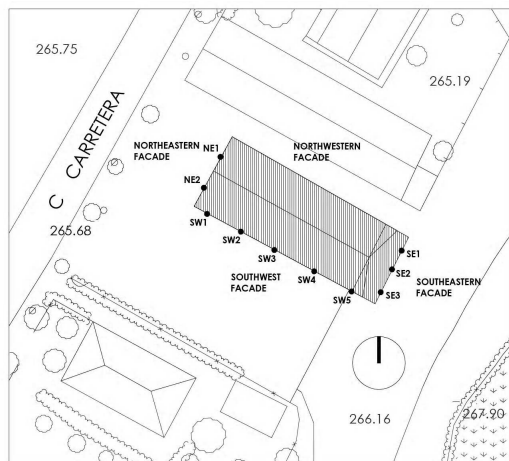


Figure 3. Location of measurement points in Golmés.

The parameters that were monitored were intermediate and exterior illuminance (Lux), with a TESTO 545 light meter, intermediate and exterior environmental temperature (°C) and intermediate and exterior environmental relative humidity (%), with a TESTO 625 digital thermo – hygrometer, surface temperature of the built facade (°C), with a TESTO 845 infrared thermometer, and finally, the wind speed outside (estimate based on the Beaufort scale). These measures were always taken at about 14:00 hours.

4 RESULTS AND DISCUSSION

4.1 Illuminance

Figure 4 presents the evolution of the monthly average illuminance (lux) measured in the intermediate space between the green curtain and the wall of the building for the three orientations (SE facade, NW facade and SW facade), the outside monthly average illuminance (Outside), and finally we have also included the evolution of monthly average value for all vegetated facade, which takes into account the three orientations (All facades). These values measure the ability to produce shade of the green facade.

A different dynamic was found in the three orientations, being the south east orientation, as measures are taken at noon, the best representative of the shadow effect of the vegetation.

The difference between the intermediate space illuminance and the outside illuminance was about 10,000 to 30,000 lux in the months without leaves. That difference could be attributed to the shade produced by the steel structure, the trunks and the branches. At the time that the foliage began to grow, this difference began to increase, reaching peaks in July and August, when the leaves were fully developed, presenting differences in illuminance higher than 80,000 lux.

Figure 5 shows the light transmission factor of the green curtain, calculated as the ratio between the illuminance in the intermediate space and the illuminance outside, for different orientations and for the total facade. This value varies from 0 to 1, indicating the amount of light radiation that passes through the green screen.

Whereas the measures were taken at noon, the south facade is where the measurements are more representative of the vegetated screen ability for to intercept radiation. These values varied from 0.04 in July to 0.37 in April, season with the foliage developed, and from 0.38 to 0.88 in the period without leaves. These values are comparable to the best values of the shadow factor that can be obtained by using artificial barriers for the south orientation which we can see in Table 3 (Spanish Building Code 2006).

The increase of illuminance in the months of May and June on the south east facade is due to the position of the sun at the time when the measures were taken, because the sunlight came through the top of green facade.

4.2 Building wall surface temperature

Figure 6 presents the temperature of the wall surface of the building in the intermediate space (with shadow), for the three orientations, and in a sunny area in the south-west facade. Although not all data is available, the surface temperature in an area without shade was on average approximately 5.55 °C higher than in areas partially covered by vegetation. This difference was higher in August and September, reaching maximum values of 15.18 °C on the south west side in September.

4.3 Environmental temperature

Figure 7 shows the monthly average environment temperature data. Here, no significant differences were found. In general, during the period without leaves the values of the temperature in the intermediate space were higher than the temperature outside, while in the period with leaves the inside temperature was lower than the outside.

Comparing the different orientations, this effect is especially evident in the south west facade. In July, in the intermediate space of the south west orientation, a temperature 1.36 °C lower than the temperature outside was achieved. On the other hand, the effect is emphasized in winter, with maximum of 3.8 °C higher in the intermediate space than the outside temperature.

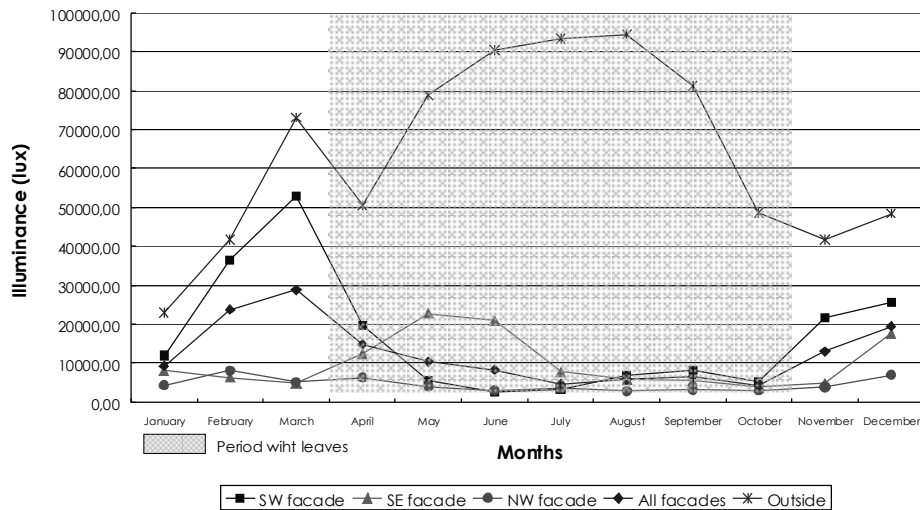


Figure 4. Illuminance measured at the Golmés green facade, in 2009.

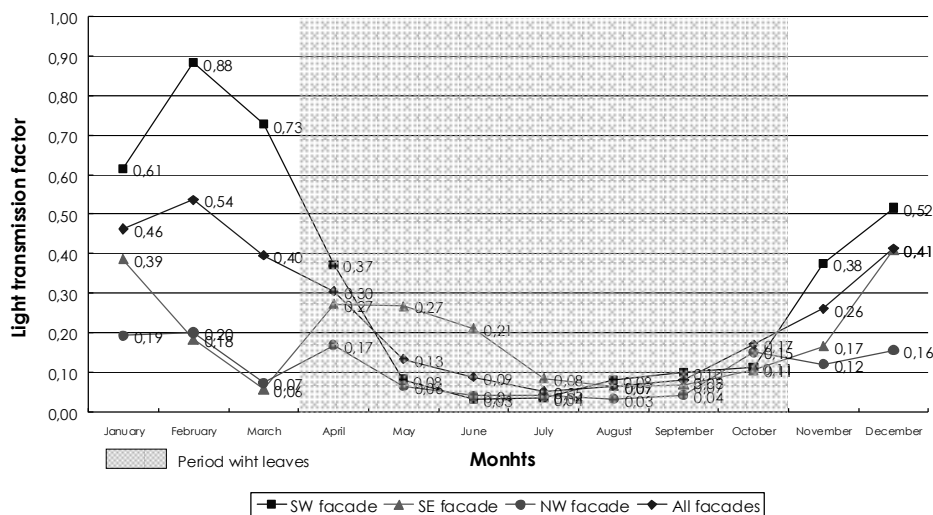


Figure 5. Calculated light transmission factor for the Golmés green facade, in 2009.

Table 3. Shadow Factor for artificial barriers in south orientation

Artificial barrier	shadow factor
Cantilever	0.16 – 0.82
Setback	0.17 – 0.82
Opaque awnings	0.02 – 0.43
Translucent awnings	0.22 – 0.63
Horizontal slats	0.26 – 0.49
Vertical slats	0.32 – 0.44

4.4 Environmental relative humidity

Figure 8 shows the evolution of the monthly average relative humidity of the environment. In general, for all orientations, it was observed that during the period with leaves the relative humidity of the intermediate space was higher than the outside. This difference increased with the growth of the foliage, being this effect very evident in the south west facade, which was

around 7% higher in July. In the period without leaves, the relative humidity in the intermediate space was lower in all directions, being also the south west facade the one where the effect was most evident, in December, with maximum differences of approximately 8%.

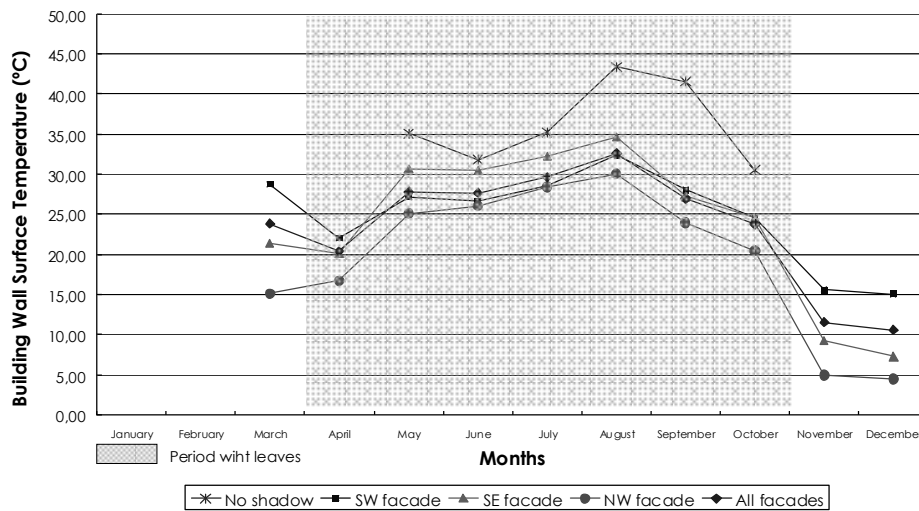


Figure 6. Building wall surface temperature measured at the Golmés green facade, in 2009.

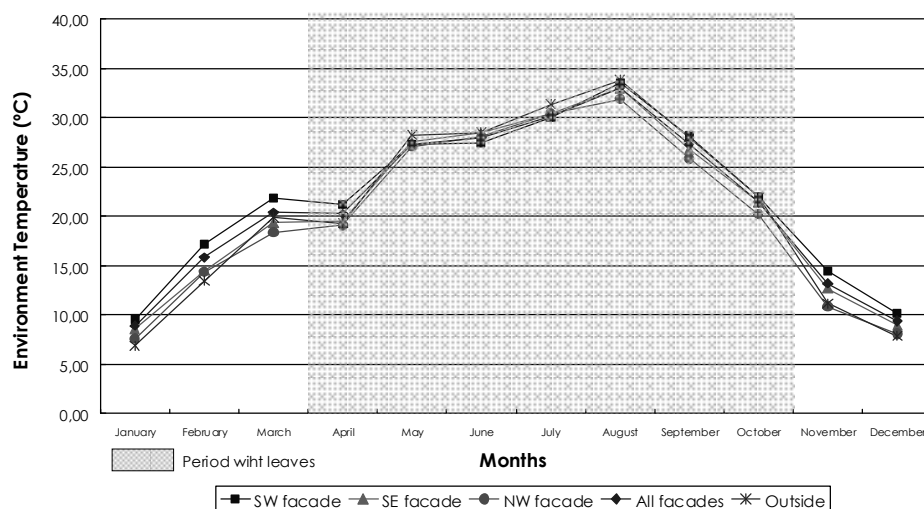


Figure 7. Environment temperature measured at the Golmés green facade, in 2009.

4.5 Wind effect

Figure 9 shows the variation of wind speed estimated according to the Beaufort scale. This information, although it was estimated, is of great interest in order to interpret the data of temperature and relative humidity. The persistence of a weak to moderate wind means that the values of outdoor temperature and humidity are lower than those achieved with calm wind. In summer, with the foliage developed, the shadow effect reduces the temperature in the intermediate space (Figure 7), but the wind effect makes the difference between outside and intermediate space temperatures to be lower. The relative humidity (Figure 8) is higher in the intermediate space in summer, and is higher outside in winter. In months with strong wind, for example in March, April and May, these differences are reduced.

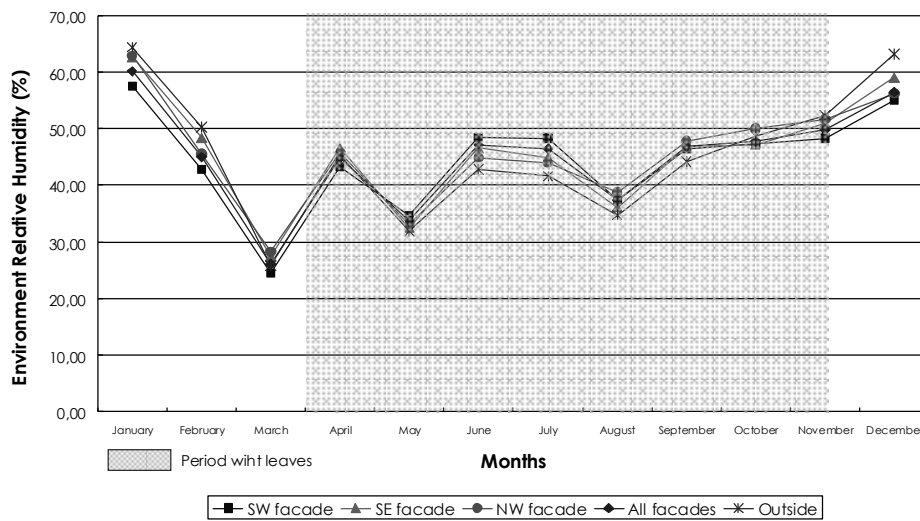


Figure 8. Environment relative humidity measured at the Golmés green facade, in 2009.

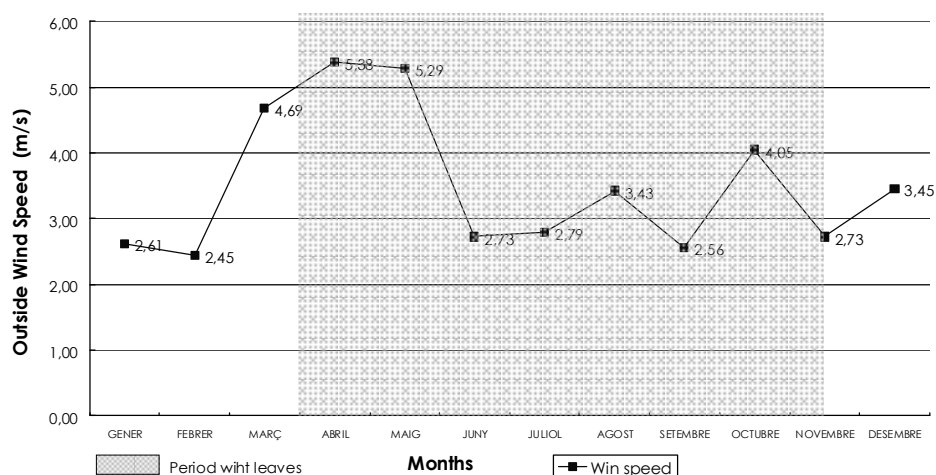


Figure 9. Outside wind speed at the Golmés green facade estimated according to the Beaufort scale, in 2009.

5 CONCLUSIONS

In the use of green vertical systems as passive systems for energy savings in buildings, one must consider the type of system, the parameters that influence their behaviour, and finally it is essential to know the behaviour of the different species in local weather conditions.

Studying and monitoring a double-skin green facade or green curtain, using modular trellis and Glycine, in Mediterranean continental climate, it was found that:

- The difference between the intermediate space illuminance and the outside illuminance was about 10,000 to 30,000 lux in the months without leaves, difference that can be attributed to the shade produced by the steel structure, the trunks and the branches. At the time that the foliage began to grow, this difference began to increase, reaching peaks in July and August, when the leaves were fully developed, with differences of more than 80,000 lux.
- For the south west orientation the values of the light transmission factor were from 0.04 in July to 0.37 in April, with the foliage developed, and were between 0.38 and

0.88 in the period without leaves. These values are comparable too to the best values of shadow factor that can be obtained by using artificial barriers for the south orientation.

- The building wall surface temperature in an area without shade was on average approximately 5.5 °C higher than in areas partially covered by vegetation. This difference was higher in August and September, reaching maximum values of 15.2 °C on the south west side in September.
- The illuminance and light transmission factor values, as well as the differences in the building wall surface temperatures, confirm the great capacity of the green screen to intercept the radiation.
- During the period without leaves, the values of the temperature in the intermediate space were higher than the outside temperature, while in the period with leaves the inside temperature was slightly lower than the outside. In the south west orientation, the intermediate space reached 3.8 °C higher temperatures in winter, and 1.4 °C lower in summer.
- It is observed that during the period with leaves, the relative humidity of the intermediate space was higher than the outside (7% higher in July) and lower in the period without leaves (8% lower in December).
- The air in the intermediate space changed, creating a microclimate where environmental conditions are higher temperature and lower relative humidity in winter (leafless period), and lower temperature and higher humidity in summer (period with leaves). This fact verifies that the green facade acts as wind barrier and shows the effect of evapotranspiration of plants.
- The wind can change this tendency by reducing the differences between the values of the intermediate space and the outside.
- The results do not allow to withdraw conclusions about the insulation effect of a green facade.

6 ACKNOWLEDGEMENTS

The work was partially funded by the Spanish government (project ENE2008-06687-C02-01/CON) and the European Union (COST Action COST TU0802), in collaboration with Fundación Mapfre, the Cityhall of Golmés and the Cityhall of Puigverd de Lleida. The authors would like to thank the Catalan Government for the quality accreditation given to their research group (2009 SGR 534).

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