ENERGY EFFICIENCY OF GREEN ROOFS AND GREEN FACADES IN MEDITERRANEAN CONTINENTAL CLIMATE

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ABSTRACT

There are now many studies concerning the benefits of green roofs and green facades as passive systems in the energy efficiency of buildings. These benefits depend largely on the ability of plants to intercept solar radiation, and therefore their growth. On the other hand, the standard design of these systems makes difficult their implementation in these extreme conditions, and it is imperative to obtain data of their behaviour under local conditions. Moreover, some authors consider the use of green roofs and green facades as a thermal storage technology for buildings. These are the reasons why the research group GREA has initiated an investigation near the city of *Lleida* (Spain), to evaluate experimentally the energy impact of using green roof systems and/or green facades in Mediterranean-continental conditions. This paper presents a state of the art of the energy impact of these systems over the world and the first experimental results.

1. INTRODUCTION

In recent years the benefits of green roofs as passive systems for energy saving in buildings have been studied in depth.

They are basically three fundamental mechanisms, the interception of solar radiation by means of the shadow produced by the vegetation, the evaporative cooling that occurs by evapotranspiration from the plants and the substrate, and finally the thermal insulation provided by vegetation and substrate.

However, there are few studies on the use of green facades as a passive system for energy savings. In addition, while the building systems of green roofs are quite normalized, in the case of green facades there is much difference between building systems, which complicates the interpretation of data being obtained in order to properly evaluate their behaviour.

It is necessary therefore to establish an initial classification of green facades, which clearly distinguishes the different types and from there, be able to separate the behaviour of each of them as a passive system for energy saving.

Much work to do is still needed on the issue of the vegetated facades, and in the integrated use of both systems, roofs and facades, in the same building as a strategy to interpret the building as a global support vegetation.

On the other hand, 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.

The extreme climatic conditions of the area of *Lleida* made even more necessary to study this, as the growth of the species is highly influenced. *Lleida* has a climate classified as Dry Mediterranean Continental, characterized by its great seasonal variations. It has a low rainfall, that is divided in two seasons, spring and autumn and it has a thermometric regime with large differences between a long winter (between the spring and the last frost may take more than 160 days) and a very hot summer. The average annual rainfall of between 350-550 mm, and mean annual temperatures oscillates between 12-14 ºC, with thermal amplitudes of 17-20 ºC. A special mention must be made to the fog, typical of the region in the months of November, December and January that can be given a period of up to 55 days in the absence of sunlight. This is a very similar climate to that of the area of Madrid, while taking this more annual rainfall and fewer days of fog per year.

To respond to these questions a long-term work has been raised in order to obtain data on the behaviour of vegetated roofs and facades in buildings as a passive system for energy savings in Dry Mediterranean climate Continental.

This work is structured in two phases. In a first stage it is aimed to determine which species and substrates are most appropriate for use in the area of *Lleida*, for roofs and for facades, in order to be used as a passive system for energy savings.

In a second phase, it is intended to start an experiment on the real scale with the species selected substrates in the previous phase, in order to check its behaviour in Dry Mediterranean Continental climate and to examine the functioning of integrated vegetated roofs and facades in the same building.

In this article an overview of some of the most relevant precedent studies regarding the use of vegetated roofs and facades as a passive system for energy savings is presented. Then a proposal for the classification of vegetated facades is presented. Finally, one of the experiments that have already begun in the village of *Puigverd de Lleida* is presented and the results of monitoring a green facade built two years ago in *Golmès* village, near to *Lleida*, are explained.

2. OVERVIEW OF GREEN ROOFS AND GREEN FACADES AS PASSIVE SYSTEMS FOR ENERGY SAVINGS

These systems provide basically three fundamental mechanisms in order to be used as a passive system for energy savings, the interception of solar radiation by the effect of the shadow produced by the vegetation, the evaporative cooling that occurs by evapotranspiration from the plants and the substrate, and finally the thermal insulation provided by vegetation and substrate.

Shadow produced by the vegetation

Previous studies with vegetated roofs can conclude that the factor that most affects the functioning of vegetated roofs as a passive technology for energy saving is the leaf density, expressed by the leaf area index (LAI), which affects the amount of shade produced and the evapotranspiration from the plantation. It has been determined that a high leaf area index

(LAI), reducing the temperature of the crop, stabilizes the fluctuations in temperature and reduces the penetration flux. More detailed information can be found in Niachou (2001); Papadakis (2001); Wong (2003); Theodosiou (2003); Kumar (2004).

The use of vegetation in vegetated facades as a blocker of solar radiation is quite efficient, with the advantage that the traditional elements of metal or plastic are heated when they intercept the sun radiation, and this heat is returned to the area around the building, while the vegetation does not. The magnitude of this effect depends on the density of the foliage. More detailed information can be found in Stec (2004); Miller (2007); Köhler (2007).

Insulation provided by vegetation and substrate

A well-designed and maintained green roof can become a good tool for thermal insulation in the summer period, because it reduces the heat flux through the roof. The main parameters that influence this effect is the LAI, which represents the relationship between the surface of leaves per unit area of land, as well as the angle of the foliage.

In the other hand, the thickness of the layer of soil, its apparent density, and its moisture content, determine the thermal diffusivity of the soil, which increases with the apparent density and decreases with the moisture content. The evapotranspiration and the exchange of air between the vegetation and the external air, play an important role in the hydrothermal state of the vegetation, and also have an effect on the flow of heat through the roof. More detailed information can be found in Palomo del Barrio (1998); Niachou (2001); Papadakis (2001); Theodosiou (2003); Santamouris (2005); Köhler (2007); Spala (2007); Wong (2007).

As for green facades, the transmission of heat through a wall of concrete is significantly lower if it is externally covered by a layer of vegetation. Other interesting effects in terms of regulating heat in buildings is the ability to reduce the speed of the wind affecting the facade of the building, and the change in climate that occurs in the space between the green screen and the facade of the building. More detailed information can be found in Hoyano (1988); Bass(2007); Köhler (2008).

Evaporative cooling by evapotranspiration

For the process of evapotranspiration to occur there must be energy. This physical process generates the so-called "evaporative cooling", which represents 2.450 Joule for every gram of water evaporated. This evaporative cooling for the leaves and soil, depends on the type of plant and exposure. Also climatic conditions influence it, because dry environments or the effect of wind increase the evapotranspiration. Another factor is the humidity of the substrate. More detailed information can be found in Papadakis (2001); Wong (2003); Theodosiou (2003); Lazzarin (2005); Reichmann (2006); Schmidt (2006).

Vegetated facades provide an aesthetic and technical shade. They require maintenance, but offer similar shadow effects to other systems with an increase of evapotranspiration. More detailed information can be found in Reichmann (2006); Miller (2007); Köhler (2007).

3. TYPOLOGIES OF GREEN FACADES. PROPOSAL FOR CLASSIFICATION

Traditionally it has been considered as green facades the typical facades of buildings covered by vigorous climbing plants, which have developed mechanisms of self subjection which requiring little or no additional support in order to cover the vertical sides of the buildings .

Typically too, this practice of landscaping has been associated with damage to the facade materials, animal attraction and maintenance costs.

However, on the lasts years, different building systems are developing that allow greening the facades of buildings, which have evolved technically and conceptually with respect to the traditional ones.

Considering the different building systems that can be found in the market, we can already begin to establish different groups depending on how the greening of the facade of a building or construction is done.

In general, all systems could be grouped under a common name as ***Green Vertical Systems of Buildings*** (Table 1).

Table 1. Classification of the *Green Vertical Systems of Buildings*.

	Extensive systems		Intensive systems
1.Green facades	1.1. Traditional Green Facades		
	1.2. Double-skin green facade or green curtain	1.2.1. Modular trellis	
		1.2.2. Wired	
		1.2.3. Mesh	
			1.3.Perimeter flowerpots
2. Living walls			2.1. Panels
			2.2. Geotextile felt

In this classification, significant differences among the Green Vertical Systems can be seen: different systems of construction, the plant species used, the subsequent maintenance, and so on.

As it happens with vegetated roofs, a difference can be made between extensive systems, namely those of easy implementation and minimum future maintenance and intensive systems, with a more complex implantation and that require a high level of subsequent maintenance.

4. METHODOLOGY

The experimentation started refers to green facades, specifically 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.

On the one hand in the town of *Puigverd de Lleida* an experiment has been implemented to compare the growth of four different climbing plants under Dry Continental Mediterranean climate conditions, as well as their ability to intercept solar radiation.

Two perennials and two deciduous plants have been chosen to be able to contrast with the data collected over a year, the differences between these two types of species. The species were chosen from a previous list of thirty climbing plants which adapt well to the Dry

Mediterranean Continental climate. In the selection the hardiness of the species, the height that it can reach, their goodness of the adaptation of the growth to the modular trellis support, and the availability in plant nurseries were rated.

The species chosen are *Hereda helix* and *Lonicera japonica* as perennial plants, and *Parthenocissus quinquefolia* and *Clematis sp.* as deciduous plants. The latter, the Clematis, perhaps are not such strong as the other three but was also considered appropriate to try them for their ornamental component.

To set up the experiment, during June 2008 four structures of steel modular trellis were built, with an area of 1 x 3 m, ready to accommodate in its base a kindergarten (1 x 0.4 x 0.4 m).

In July of 2008 the four species were planted, which are in a growth phase, so data is not available yet.

Figure 1. *Puigverd de Lleida*. September 2008

On the other hand, during September 2008 the collection of data in a double-skin facade green or green curtain built in May 2007, in the village of *Golmès*, near to *Lleida* city began. This is the project of rehabilitation of a former building as social activities local, where a green facade was built by a structure of steel and *deployè* sheet steel, in the northeast, southwest and southeast facades.

Figure 2. *Golmés*. September 2008

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. This new specie was not used in *Puigverd de Lleida* because it was already experimented in *Golmès*.

The collection of data is weekly and it takes place in different points of the intermediate space between the structure and the facade, and also in the exterior. This distribution will compare the behavior of the green facade in different orientations with the exterior environment values.

The parameters that are being monitored were intermediate and exterior illuminance (Lux), intermediate and exterior environmental temperature (°C), intermediate and exterior environmental relative humidity (%), surface temperature of the built facade (ºC), and wind speed outside (estimate based on the Beaufort scale). These measures are always taken at about 14:00 hours.

5. DISCUSSION OF FIRST RESULTS

The first results obtained in *Golmès* correspond to the months of October, November and December. During the first two months the plants still had the foliage, which went wither over the last few weeks of November, and in December they had all fallen. Therefore there is only the steel structure and the timber plants (trunks and branches).

In reference to the interception of light from the green curtain for the studied period, it has been measured 6.3 times higher average external illuminance than those of the intermediate space between the structure and the facade (Table 2).

If the three facades are observed individually, as far as the plants lose their leaves and the sunlight can more easily enter, the south-west facade decreases more quickly the illuminance relationship between exterior and the intermediate space, from 7.42 in October with leaves, to 5.68 in November, and 2.90 in December, without leaves. It is remarkable the difference between external illuminance and the internal in the northeast facade, which is about 9.1 times greater.

Table 2. Exterior/Interior illuminance ratio

	INTERIOR SE FAÇADE	INTERIOR SW FACADE	INTERIOR NE FAÇADE	ALL FAÇADE
OCTOBER	5.18	7.42	Not available	7.04
NOVEMBER	8.10	5.68	9,52	7.17
DESEMBER	8.49	2.90	10,48	6.09
PERIOD	6.83	4.99	9,11	6.33

With regard to the relationship between the environment exterior temperatures and the environment temperatures in the space between the green curtain and the building wall, in general measured indoor average temperatures are slightly higher than the average exterior temperatures in the south sides. The difference was 0.88 ºC for the southeast side and 2.42 ºC to southwest face (Table 3). On the other hand, in the northeast face, the average outside temperature was 1.78 ° C higher.

Table 3. Average, wall surface and interior temperatures for the period (ºC)

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	INTERIOR SE facade	INTERIOR SW facade	INTERIOR NE facade	ALL facade	EXTERIOR
AVERAGE TEMPERATURE	11.98 ºC	13.52 ºC	9.32 ºC	12.58 ºC	11.10 ºC
WALL SURFACE TEMPERATURE	9.30 ºC	16.86 ºC	5.76 ºC	12.37 ºC	---
INTERIOR TEMPERATURE	11.98 ºC	13.52 ºC	9.32 ºC	12.58 ºC	---
AVERAGE HUMIDITY	53.82 %	50.18 %	52.15 %	51.66 %	55.96 %

As for the surface temperatures, it is observed that in the southeast and northeast facades, these are lower than both the average temperature of the space inside and the outside temperature (11.10 º C) (Table 3). In contrast, in the southwest facade the average surface temperature is higher than both the average temperature inside as the outside temperature average.

Finally, with regard to the relative humidity of the atmosphere, in all faces the value of the average environmental relative humidity was slightly lower than the average exterior relative humidity (Table 3). The highest difference was measured in the southwest facade with a 5.78% lower than the exterior relative humidity.

6. CONCLUSIONS

There are different types of green facades clearly distinguished, each with different construction systems. Therefore, it is necessary to differentiate them and study individually their suitability as passive systems in the energy efficiency of buildings.

Regarding to the experimental monitoring of a double-skin green facade or green curtain in Dry Continental Mediterranean climate, in the first results for the period October, November and December 2008, the following findings can be pointed out:

- As for the interception of light from the green curtain that have been measured for the studied period, exterior luminance 6.3 times higher than those of the intermediate space between the structure and the façade were observed.
- Intermediate temperatures measured are slightly higher than the exterior temperature in the south sides. The difference was 0.88 ºC for the SE side, and 2.42 ºC for the SW face.
- It is observed that in the SE and NE facade, the surface temperatures are lower than both the average temperature of the space inside and the outside temperature.
- In all the facades the average environmental relative humidity was slightly lower than the average relative humidity of the exterior. The highest difference was measured in the SW side, with values 5.78% lower than the outside ones.

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