TÉCNICO LISBOA

Experimental study of the Thermal Behavior on Green Façades

Extended Abstract

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July 2015

1. Introduction

The green façade development is justified with the importance of buildings' sustainability, mainly in an urban environment where it is crucial to have green spaces due to the high construction density which leads to elevated air temperatures. This fact is associated with the buildings' surface properties such as albedo, the shading effect of leaves and the humidity absorption that balance the concrete domination. This solution also allows making use of a vertical area that traditionally has no other utilization, by bringing gardens to the city.

This technique is more common in Northern America and Northern Europe, where climate is cooler, and this means that there aren't many experimental studies in a Mediterranean climate. This paper's main goal is to understand the thermal behavior on green façades in the referred climate, where mean temperatures are higher in summer. In order to achieve that, two case studies were monitored in Lisbon, Portugal.

In parallel with this work, (Serpa, 2015) made an energetic simulation of green façade also related with the mentioned case studies.

This paper is divided into three distinct parts, through six chapters. The first part focuses on what has already been done in this field, explaining the advantages, the different types of construction and the conclusions of other experimental studies. The second main part is about the experimental phase, explaining what, where and how the monitoring was done, which instruments were used and also all the result analyses of the two campaigns. Thirdly, some conclusions were made about the behavior of green façades.

2. State of the art

The origin of green façades lies in one of the Seven Wonders of the Ancient World: the Hanging Gardens of Babylon, built around 600 BC, by king Nebuchadnezzar II as a present to his wife (Sousa, 2012). More recently, in the late 20th century, vertical gardens appeared to contrast the lack of green spaces in urban areas. The pioneer of this modernized method was Patrick Blanc, a botanist who made it possible to build vertical gardens with no soil involved, by placing the root plants in a geotextile lining which absorbs the necessary nutrients for the development of the plants, while avoiding the spreading of pests that are usually present on the ground.

2.1. Legislation

As far as the legislation is concerned, there are a few laws and directives in some countries that encourage the use of this solution or a similar one. In Seattle, an ordinance requires for buildings in process of construction to have the equivalent of 30% of the surfaces vegetated (Seattle Gov.) and, in New York City, a Bill establishes green walls tax abatement for certain properties (NY Bill). Also, in the European Union, there is a project named *Green Tools for Urban Climate Adaptation* that intends to demonstrate and implement technology to deal with climate adaptations in urban areas and provide financial support.

2.2. Vertical greening systems characterization

The expression “green façade” is associated with all kinds of systems that cover walls with vegetation. However, technically it is associated to a specific system. In other words, there are two distinct groups: the green façades and the living wall system. The first one includes climbing plants supported by cables or trellis or attached directly to the building surface, where the roots are on the ground or in plant boxes at different heights. The living wall system refers to a method that uses hydroponic culture which allows plants to develop with no soil but with all the needed nutrients. Instead of soil, it uses geotextile layers to retain nutrients and support the plants.

This paper will focus on living wall systems. Yet, the expression “green façade” will cover all types of vertical gardens.

2.3. Green façades benefits

By choosing this solution, the increase of green spaces in cities is being promoted, and it may help to improve air quality and reduce temperature (Sheweka, et al., 2012). Evapotranspiration and shading will also lessen the heat that would be irradiated by a bare façade. In addition, the layer of vegetation protects the surface against UV’s so that the materials such as painting, plaster, waterproof membranes and others do not deteriorate (Ottelé, 2011). Besides, it is also possible to harvest rainwater for the watering system, diminishing maintenance costs and relieving the urban gutters. But the main profit analyzed in this paper is the thermal behavior and how it may help improve the internal temperatures of a building.

2.4. Existing experimental studies

There are a few studies that explore the behavior of green façades and how they influence the building. However, because there aren’t many examples of this solution in a Mediterranean climate, studies made on this type of weather are scarce. (Olivieri, et al., 2014) compares a green wall with a bare façade and the results prove that vegetation lowers the temperature experienced indoors. (Pérez, et al., 2011) had similar results in the same climate. (Eumorfopoulou, et al., 2009), also in a similar climate, observed that the heat flux transferred to the inside was lower than in a bare façade.

Regarding the costs associated with this solution, (Perini, et al., 2013) concluded that they can vary from 400 up to 1200€/m^{2,} depending on the height of the building, but it can lead to an energy saving of the air conditioning within 40 to 60%.

3. Presenting the case studies

Both case studies were monitored during the same time, in winter (from February 11 to March 14) and summer (from June 16 to July 11), of 2014. The first one is a villa located in downtown Lisbon (Figure 1) and the second one is the entrance for a sound studio complex, in Oeiras (Figure 2).

The equipments used were installed and programmed to store all the needed information, in the appropriate schedule, that measured surface and ambient temperatures, in- and outdoors, heat fluxes, solar radiation and relative humidity.

Figure 1: Villa, in Travessa do Patrocínio

Figure 2: Entrance of the sound studios complex, in Oeiras

The instruments used to obtain the required information were Campbell data logger (temperatures, fluxes and radiation), DataTaker50 (temperatures and fluxes), Tinytag and Rotronic (both relative humidity and ambient temperature) in Travessa do Patrocínio, while in Oeiras it was used the Data Logger Delta T (temperatures, fluxes and radiation) and also Rotronic and Tinytag.

The villa has simultaneously green and bare façades, whereas the studio complex has not only a wall but also a roof covered with vegetation. In each case there is an air layer between the building structure and the solution itself. The thickness of that air layer is variable on the villa (22 to 72 cm) and constant on the studio entrance (5cm).

4. Experimental analysis – Travessa do Patrocínio

Although the campaigns occurred almost at the same time in both places, there were some technical problems related to the energy sources, sensors location or malfunction of the equipments. Due to this, during winter, it was not possible to register the vertical solar radiation on the villa. Also, there were two interruptions in the first case study. During summer all the radiation was measured and there was only one interruption due to a technical issue. The sensors used to measure temperature were type T thermocouples. The heat flux sensor used was the Hukseflux HFP01, a thermopile sensor with a measurement range of ±2000W/m². To download the results, the adapter VScom USB-COM-I was used to convert RS422/485 port in USB port. Figure 3 presents the sensors positioning scheme.

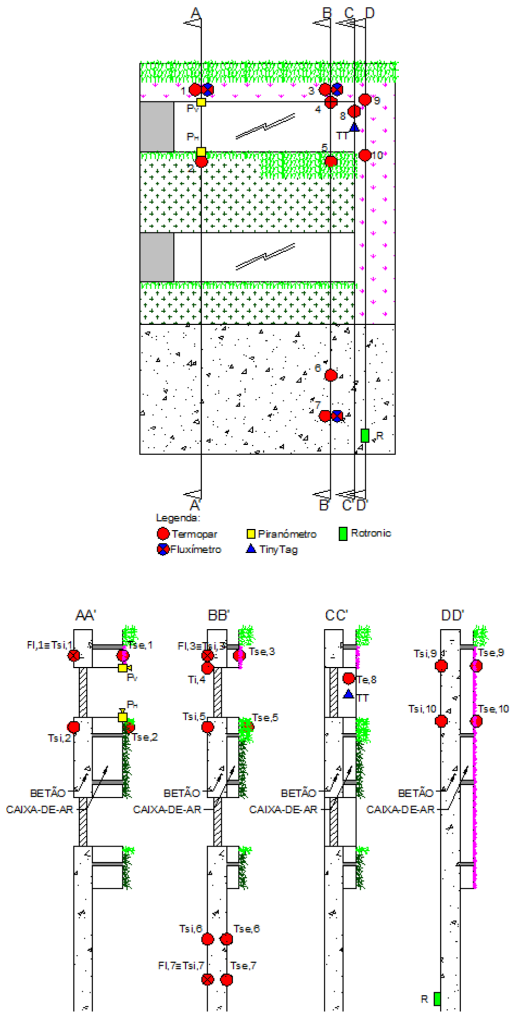


Figure 3: Representation of sensor positions in Travessa do Patrocínio

To understand the façade behavior, standard days were chosen to represent the most extreme conditions of the season. In other words, during winter the standard days were the coolest, the one with the lowest mean solar radiation and the one with the highest mean solar radiation, while in summer the standard days were the hottest and the one with the highest mean solar radiation.

Table 1: Mean values of horizontal solar radiation and exterior ambient temperature during winter

Date Winter 2014	Ambient mean temperature (°C)	Mean solar radiation (W/m²)
Feb 21	12.1	102.9
Feb 22	12.2	103.1
Feb 23	12.6	113.6
Feb 24	12.7	102.8
Feb 25	13.2	68.5
Feb 26	13.6	89.8
Feb 27	13.4	52.1
Mar 3	13.7	76.7
Mar 4	13.3	79.4
Mar 5	14.5	101.2
Mar 6	14.1	120.7
Mar 7	17.0	128.6
Mar 8	18.0	94.0
Mar 9	15.3	35.0
Mar 10	16.6	104.1

RS-	T-
RS+	T+

The standard days in winter were:

- February 21 – Coolest day (12.1°C);
- March 9 – Lowest mean solar radiation day (35.0W/m²);
- March 7 – Highest mean solar radiation day (128.6W/m²).

The most interesting results show that in winter the plants density has an important influence on superficial temperature, presenting higher values in areas where plants are less dense. The heat flux is superior on the green façade when compared to the concrete one, whether the radiation is stronger or not and during the evening the heat is kept on the inside more efficiently in the room with the green wall.

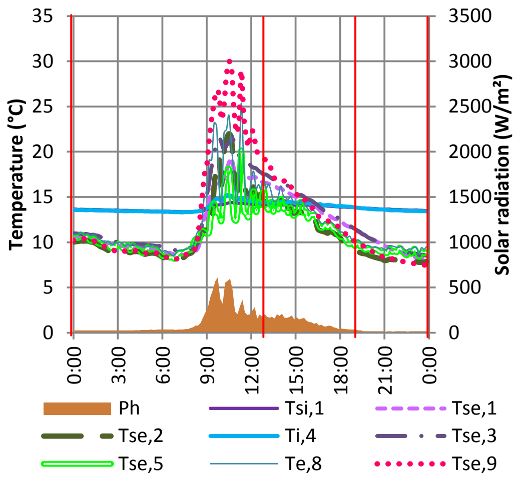


Figure 4: Exterior surface temperature evolution on Feb 21

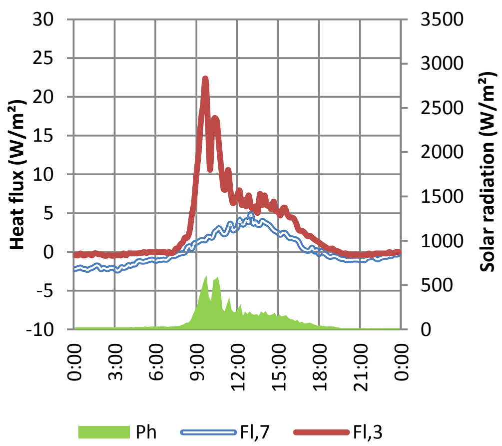


Figure 5: Heat flux vs radiation on Feb 21

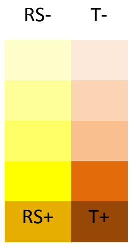
The standard days in summer were:

- June 20 – Highest mean solar radiation day (247.1W/m²);
- July 3 – Hottest day (22.0°C)

During summer, the shading effect has an important role on the temperature control of the exterior surface. The highest values on the concrete wall are similar to those of the species with the lowest density but all the others are lower. Watering also decreases temperature and evapotranspiration reflects on that same effect. Interiorly, ambient temperature is near the comfort values (REH, 2013) even with the sun exposure through glass on the upper floor. The room with the bare façade has no exposed glazing.

Table 2: Mean values of horizontal solar radiation and exterior ambient temperature during summer

Data Inverno 2014	Temperatura média ambiente diária (°C)	Radiação solar média diária (W/m²)
17 Jun	20.2	65.8
18 Jun	20.5	142.7
19 Jun	20.5	237.2
20 Jun	20.5	247.1
21 Jun	20.2	226.3
22 Jun	19.7	194.6
23 Jun	18.5	162.2
24 Jun	20.5	205.8
3 Jul	22.0	189.9
4 Jul	21.8	204.7
5 Jul	21.7	205.9
6 Jul	20.5	124.0
7 Jul	20.2	199.6



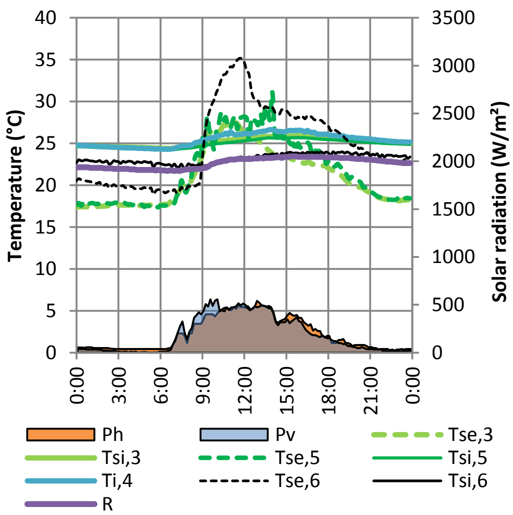


Figure 6: Solar radiation and surface temperature of B-B' cross section on July 3

Some results of the hottest day are presented in Figure 6, and Figure 7 shows the thermal evolution of the green façade depending on species.

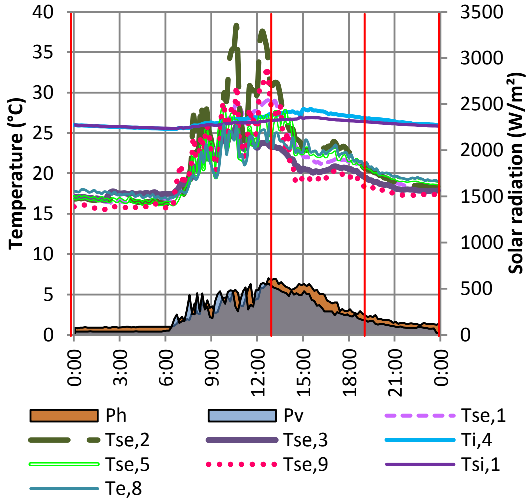


Figure 7: Surface temperature evolution on June 20

Thermal conductivity test

In order to obtain an estimated value on the thermal conductivity, an experimental test was made with the instrument Isomet 2114. Because it was not possible to obtain a sample of the solution so that the test could be made under controlled conditions, it was made *in situ*, in Travessa do Patrocínio, in the winter and before the watering system was activated.

Figure 8: Presentation (Fernandes, 2014) and installation of Isomet 2114

The obtained results are presented on Table 3.

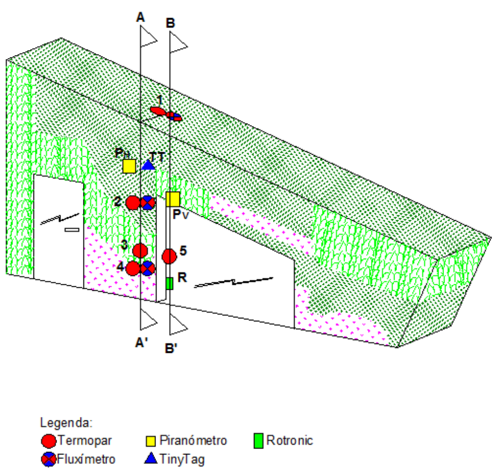
Table 3: Obtained results

λ (W/m.°C)	0.2364
cp x10^6 (J/m^3.°C)	0.3217
α (m^2/s)	0.7349
T_{mean} (°C)	19.607
ΔT (°C)	9.8992

5. Experimental analysis – Atlântico Blue Studios

As it was already mentioned, both case studies campaigns occurred at the same time. During winter, in Oeiras, it was not possible to register the radiation values and there was also an interruption on data acquisition due to a battery fail. In summer campaign no issues were registered, only the memory full on 3rd and 4th of July. The sensors used were the same as in the villa with an exception to one thermocouple which was type K due to the necessary length to get to the roof. So, Delta T data logger had to be programmed depending on the type of the thermocouples. Figure 9 presents the sensors positioning scheme.

The house has a pergola with retractable shades that cover the monitored area when open.



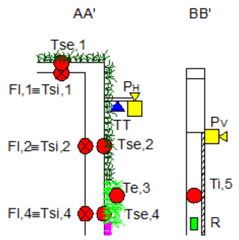


Figure 9: Representation of sensor positions in Oeiras

Table 4: Mean values of horizontal solar radiation and exterior ambient temperature during winter

Data Inverno 2014	Temperatura média ambiente diária (°C)	Radiação solar média diária (W/m²)
13 Fev	15.4	16.4
14 Fev	13.7	22.4
15 Fev	12.2	97.9
16 Fev	10.9	114.0
17 Fev	10.1	88.0
18 Fev	11.9	148.6
19 Fev	12.9	102.6
27 Fev	13.4	52.1
28 Fev	13.7	-
1 Mar	13.7	-
2 Mar	14.0	-
3 Mar	14.7	76.7
4 Mar	13.7	79.4
5 Mar	15.9	101.2
6 Mar	16.3	120.7
7 Mar	16.8	128.6
8 Mar	18.3	94.0
9 Mar	15.0	35.0
10 Mar	17.2	104.1
11 Mar	18.1	-
12 Mar	16.8	-
13 Mar	16.0	-

RS-	T-
RS+	T+

The standard days in winter were:

- February 17 – Coolest day (10.1°C);
- February 13 – Lowest mean solar radiation day (16.4W/m²);
- February 18 – Highest mean solar radiation day (148.6W/m²).

Because of the existing air conditioning system during the working days, it was interesting to analyze the results that were registered on Sundays, when the refrigeration equipment was off. So, as the second coolest day was on a Sunday (February 16th), it was also considered.

The 16th and 17th February had similar mean temperatures. However, the temperature range was higher on the 16th. Nevertheless, the inner temperatures maintained a similar behavior, proving that the solution is a good insulation means. Through all days, the difference between species is noticed even on the internal surface, where denser vegetation has lower temperatures. The roof is more exposed to solar radiation, so those values are higher.

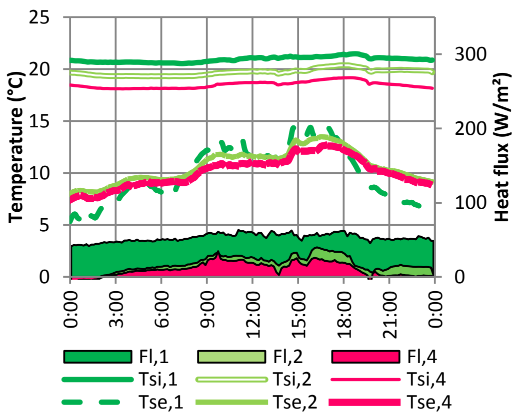


Figure 10: Heat flux and surface temperatures on Feb 17

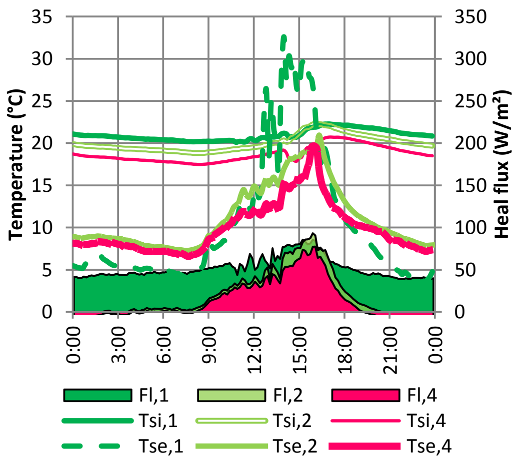
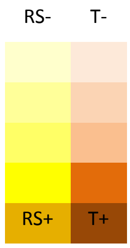


Figure 11: Heat flux and surface temperatures on Feb 16

Figure 10 and Figure 11 show that even with the air conditioning operating, the temperature felt on the interior surface almost does not vary. The heat flux is positive, which means that the energy is being stored inside, warming up the ambient in the winter season. The 1pm watering period is clear due to temperature decreasing on the exterior, which increases humidity and leads to a higher conductivity of the geotextile that allows the heat to penetrate through the wall.

Table 5: Mean values of horizontal solar radiation and exterior ambient temperature during summer

Data Inverno 2014	Temperatura média ambiente diária (°C)	Radiação solar média diária (W/m²)
18 Jun	20.9	289.3
19 Jun	19.4	344.9
20 Jun	19.7	347.6
21 Jun	20.2	288.7
22 Jun	19.1	158.7
23 Jun	18.5	205.8
24 Jun	20.1	246.1
25 Jun	21.3	285.1
26 Jun	21.4	347.5
27 Jun	21.5	351.9
28 Jun	21.7	223.4
29 Jun	20.7	352.5
30 Jun	21.6	351.8
1 Jul	22.2	218.4
2 Jul	22.7	262.5
5 Jul	21.7	300.7
6 Jul	20.6	169.4
7 Jul	20.3	319.8
8 Jul	21.3	328.0
9 Jul	22.9	326.7
10 Jul	23.3	327.2



The standard days in summer were:

- June 29 – Highest mean solar radiation day (352.5W/m²);
- July 10 – Hottest day (23.3°C)

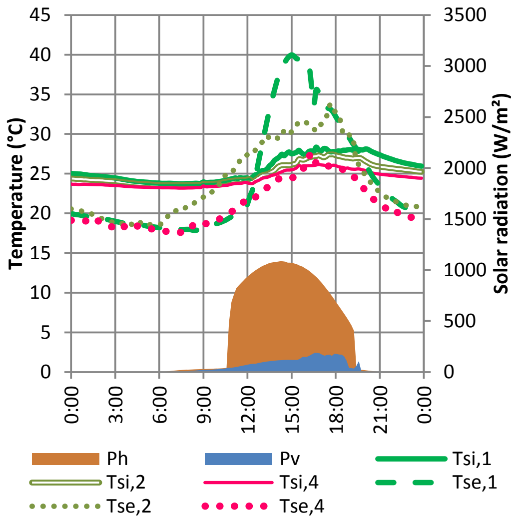


Figure 12: Surface temperatures and solar radiation evolution on July 10

The huge difference between horizontal and vertical radiation is related to the pergola that shades the façade. It is important to understand that the monitored façade area was under the retractable shades so the radiation results are reliable. Figure 12 shows an accentuated increase of exterior surface temperatures when radiation has higher values but there is also a deceleration when watering is activated (1pm) that also influences the interior surface and the heat flux, proving that evapotranspiration influences the thermal behavior by slowing the heating process during the hottest period of the day, allowing the plants to humidify the surrounding environment.

However, this effect is faster on this season, so the geotextile conductivity doesn't increase as much as in winter, making it more difficult for the heat to penetrate that layer.

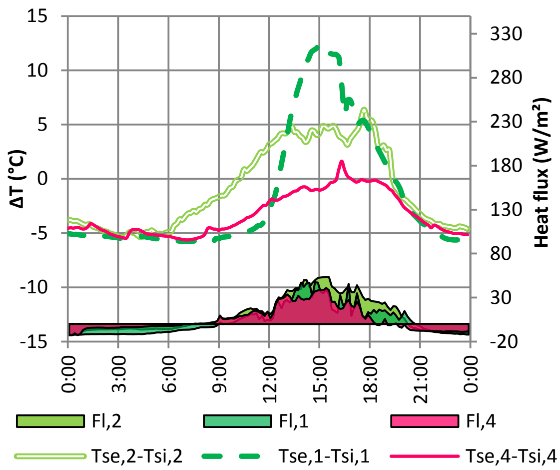


Figure 13: Surface temperatures and heat flux on July 10

It is also interesting to observe the heat flux variation that shows negative values during the night, meaning that the heat is being released to the outside (Figure 13). More important is the peak value that never exceeds the values registered during winter, evidencing the good insulation behavior.

Once again, the roof values are superior to the façade because of the higher solar exposition. However, it is important to notice that the temperature felt on the roof is almost the same as the air temperature, enhancing the intrinsic properties of the solution that attenuate the building emissivity.

6. Conclusions

On both case studies there are not only common but also distinct conclusions. The differences remain on the construction such as the air cavity thickness, the exposure of the façade to radiation and the dimension and use of the building.

The heat fluxes results show an optimistic behavior depending on the season. In winter the entrance values are higher than in summer while the exit values are higher during the night, in summer. This effect is due to evapotranspiration which occurs after irrigation and allows the plants to release water vapor. This process is faster during heating season so it leads to a better performance of the solution by cooling down the surrounding environment and insulating the building because the humidity levels of the substrate are lower than in winter, which means that thermal conductivity is inferior in summer. Also (Valadas, 2014) concluded the same on green roofs.

The space between the vertical garden and the structure of the building is thicker in Travessa do Patrocínio and, according to ISO 13789, it is considered a non used space with different thermal resistance.

It was also possible to monitor the roof in Oeiras, allowing to study different behaviors in the same space.

In both case studies, it is clear that different species influence the results and that is very important to know how it affects the thermal behavior. For instance, the species in zone 2 of both buildings were deteriorating and it is crucial to avoid these situations not only for aesthetic reasons but also financial ones.

Albedo is an important feature related to this solution once it influences the reflected and absorbed energy. Vegetation doesn’t retain as much radiation as a darker façade but the reflected energy is attenuated by evapotranspiration that reduces superficial temperature.

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