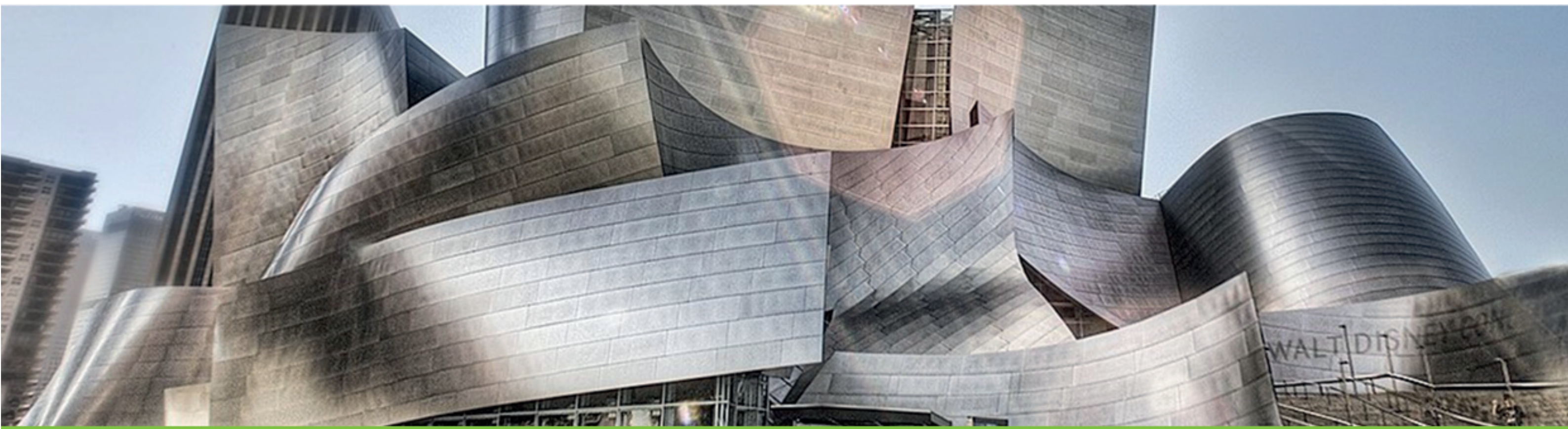
ADVANCED BUILDING SKINS

2-3 October 2017, Bern, Switzerland



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Experimenting sustainable building skins in an existing building

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Abstract

The Technical University of Madrid, through its Center for Innovation in Technology for Human Development (itdUPM), is promoting the transfer of knowledge and innovative solutions that contribute to the development of a more sustainable society. To this end, a University Campus building formerly used for the storage of tools has recently been renovated, transforming it into a living Sustainability Laboratory or "Living Lab". The building that houses the new headquarters of the idtUPM, is characterised by incorporating different innovative technologies that are being monitored by fixed control systems. The ultimate goal is to achieve the first NZEB within the Campus, introducing, in addition to passive measures, renewable energy production systems such as integrated facade and roof photovoltaic panels (BIPV).

Currently, two experimental façades have been installed and are being monitored. The first, which occupies part of the south, east and west façades, is a modular green facade patented by a local company. The system, made with modules of recycled plastic, is 100% sustainable and belongs to the group of non-hydroponic vertical gardens with an organic substrate. This implies a lower dependence on fertilisers, a lower consumption of irrigation water and lower maintenance.
It has been installed as the last layer of a ventilated façade. The data obtained from the motorizations are showing an optimum thermal behaviour, especially in the south and west orientations, providing lower temperatures inside the building than the areas where the green facade has not been installed.
The second system, which occupies part of the northern façade, compares the thermal behaviour of two commercial panels of the PLACO® brand with two panels made with recycled rubber developed under two different experimental methodologies, the first one was made with a cementitious base and The second one was made with polymer resins and a thermo diffusion system. Up to now technical results obtained in summer conditions show differences in temperature between 0.5 and 1.5°C despite the reduced thickness of the plates (10 mm). These results are promising, since the decrease of one degree of temperature (in summer conditions) to the interior of the housing spaces, can represent around 15-20% of energy saving (energy used for refrigeration systems).
The study is completed with energy simulations that allow the estimation of the behaviour of experimental façades in contexts other than the one studied.

Keywords: NZEB, experimental building, green facade, recycled rubber, monitoring system, energy simulation.

1. Introduction

The Center for Innovation in Technology for Human Development – itdUPM, is a transversal centre, which promotes the achievement of the sustainable development objectives approved in 2015 by the

General Assembly of the United Nations, through the incorporation of different innovative technologies.
The main objectives are framed in the search for a dialogue between the university and public, private or community organizations, with the task of disseminating the premises of sustainability.
These objectives are based on two main axes: the generation of interdisciplinary knowledge and the work with multi-actor alliances.

2. Retrofitting of the existing building

Among the main objectives of the creation of a new headquarter for the itdUPM (Fig.1), there is the search of the first building of almost zero power consumption (NZEB) inside the campus, through the use of passive measures, the reduction of energy consumption and promoting thermal comfort within the building, through strategies such as the integration of vegetal façades which has allowed the reception of a recognition at the World Congress of Green Infrastructure 2016, held in Bogotá, Colombia.

Figure 1: Headquarter of itdUPM inside the University Campus

In order to comply with the thermal requirements of the new proposal, the old building was renovated by adding materials such as glass wool to existing walls, obtaining an improvement in the thermal transmittance of the building: exterior walls 0.413 W/m^2K; basement 0.25 W/m^2K; roof 0.179 W/m^2K.
The proposal of requalification of the building is made mainly from the integration of a vegetal envelope that occupies part of the facades south, east and west, is developed with the use of a commercial module realized in recyclable plastic, pertaining to the systems of non-hydroponic vegetal facades, with organic substrate; this system allows the saving in water consumption and low use of fertilizers.
In the second system that forms the study of new strategies in the building is the north façade, where it is studied and compares the thermal behavior of two commercial plates for enclosures in facade PLACO®, and two plates made of recycled rubber under two experimental methods: one in cement base and reinforced with fiberglass meshes in order to increase its rigidity and durability, and one of the composite materials to generate a multi-layer construction system.
These systems belong to the sustainable experiments and strategies of the new building, both of which are connected through a network of sensors that monitor the behavior of the building and the installed prototypes. This added to the data produced by the installed meteorological station allows following the climatic and energetic evolution of the itdUPM building.

3. Sustainable building skins

3.1 Green walls

The term green walls cover various systems of vegetal facades, which consist of vertical structures formed by vegetation, a substrate for plant growth and an irrigation system; these may or may not be subject to the facade of the building. Depending on the level of complexity, there are several technological solutions, which will vary according to the selected species, the support structure, the irrigation system and fertilization. According to these aspects can be divided into two macro groups: continuous facades and modular facades.

The plant facade incorporated into the new itdUPM building is a modular solution, with pre-cultivated panels fixed to a vertical support which in this case consists of a metal envelope. These façades currently cover an area of 11.25m^2 on the south façade, 6.25m^2 on the east façade and 10m^2 on the west façade, these light and dismantling elements are intended to use the decontaminating capacity of the plants.
The design of this system seeks to reduce dependence on water and fertilizers, as well as the costs of computer systems to control optimal operation.

3.2 Recycled rubber panels

Within the last twenty years most of the constructive elements made with recycled rubber were made from cement mixtures, finding just a few examples with a different procedure as the polymeric resins. One of these materials was an engineering stone cladding developed by Hamoush et al., [2] using an unsaturated polystyrene resin, recycled rubber, sand and a clay among other materials.
The use of polymer resins in construction is mainly focused on the preparation of prefabricated materials such as exterior coatings, decks, countertops, and street furniture among many other examples.
This work was focused on the experimental development and characterization of a construction material that allowed the development and production of prefabricated free-form elements that would take advantage of the properties of the recycled rubber, using production techniques more specific to maritime engineering as the composite materials.
To produce the rubber panel two different procedures were taken. The first procedure consists in a cement matrix and lightweight aggregates combined with around 3-5% of crumbed rubber (by volume). The second procedure consists in a Thermoset Matrix improved with fillers, stabilizers, fire retardants and fibers (synthetic and natural).

4. Monitoring system

A real-time distributed monitoring system has been installed to monitor in real time the behavior of the two experimental façades. The monitoring system is based on an ad-hoc designed embedded system main controller connected through an RS-485 serial bus to several distributed nodes (Fig.2).

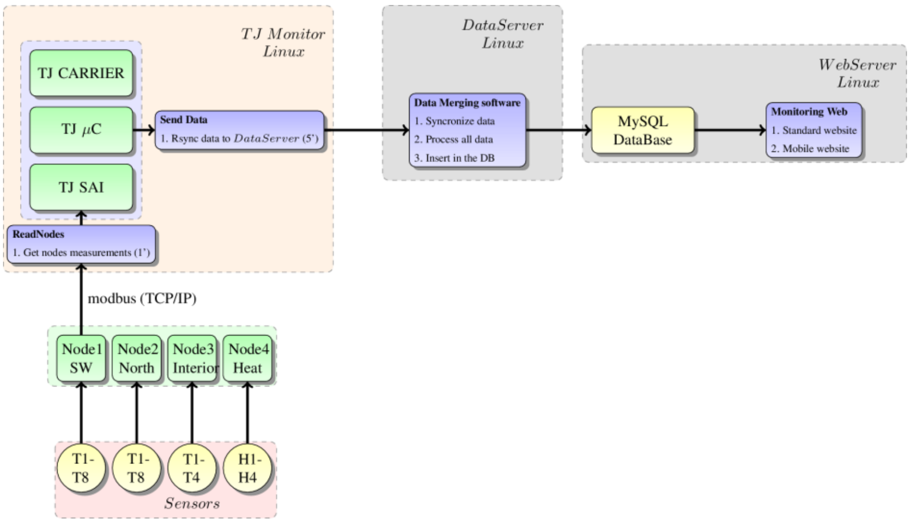

Figure 2: Depiction of the monitoring system

The distributed nodes are located in the south-west and north façades and in the interior of the building. They are directly connected to 20 Type-T thermocouples and 4 heat flux sensors. The nodes are running a real-time operating system which takes care of acquiring all measurements at specific time frames. Every 10 ms. each node obtains information from all the sensors at which it is connected. Every second the monitoring node performs the mean of the last 100 measurements and stores it internally to be acquired by the main controller through an RS-485 RTU-Modbus protocol.
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connected. Every second the monitoring node performs the mean of the last 100 measurements and stores it internally to be acquired by the main controller through an RS-485 RTU-Modbus protocol.
The main controller is based on an embedded Linux operating system. It is made of a microcontroller (TJ uC) with a UPS system (TJ SAI) and an electronic carrier to connect to the nodes. Every minute, the main controller acquires all measurements stored on the nodes and accumulates them on an internal SD card. This information is stored together with the date and time. Moreover, the main controller is located inside the ITC room of the building and it is connected through an Ethernet communication to the processing and monitoring server. Every five minutes the main controller sends the data stored in the monitoring server. The monitoring server is in charge of synchronizing all data, performing all conversions from electrical to physical measurements and running periodic scripts which process the data and upload them to the monitoring database. A monitoring website has been created to allow researchers and the general public observe the behaviour of both façades in real time.

5. Data analysis

5.1 Green Walls: experimental design

The new headquarters of itdUPM in its role of "living laboratory", aims to experiment of monitoring and analyzing of the thermal behavior of vegetal façades, which is done by a system of temperature sensors and a weather station.
The real-time monitoring system has been installed through the use of surface temperature meters called thermocouples, type K with an error range between 0.1ºC and 0.3ºC installed inside and outside the facades, and connected to a system of distribution that allows obtaining information every minute, which can be visualized in the website of itdUPM.
The objective of this analysis is to compare the temperature levels registered in two of the four facades of the building, using two types of solutions, the differences between them will be the orientation south or west, and the use of Living Wall Systems as system of vegetal facade in contrast with the metallic envelope. The façades have been monitored in order to obtain a database corresponding to each enclosure, through the analysis of two thermoelectric pairs (thermocouple) which are installed at different points of the façade: between the metallic envelope and the felt layer of the plants module and between the building wall and the metal envelope.
The variables considered in the analysis are: External temperature (ºC), Relative Humidity (%), Surface temperature on the outside of the metal casing (South / West_Center_Skin), Surface temperature between the metal casing and the inner wall (South / West_Center_Wall), Surface temperature outside the plant module (South_West_Skin / West_South_Skin), Surface temperature between the plant module and the inner wall (South_West_Wall / West_South_Wall)
For the development of the analysis was considered a database between June 2016 and June 2017, a period of 12 months that allows identifying the various behaviors in the different seasons. The data generated are organized in intervals per minute, which were reduced at hourly intervals for the simplification of the database.
For each station, the maximum or minimum temperature recorded was chosen, which gives significant data on the behavior of the façades under extreme conditions.

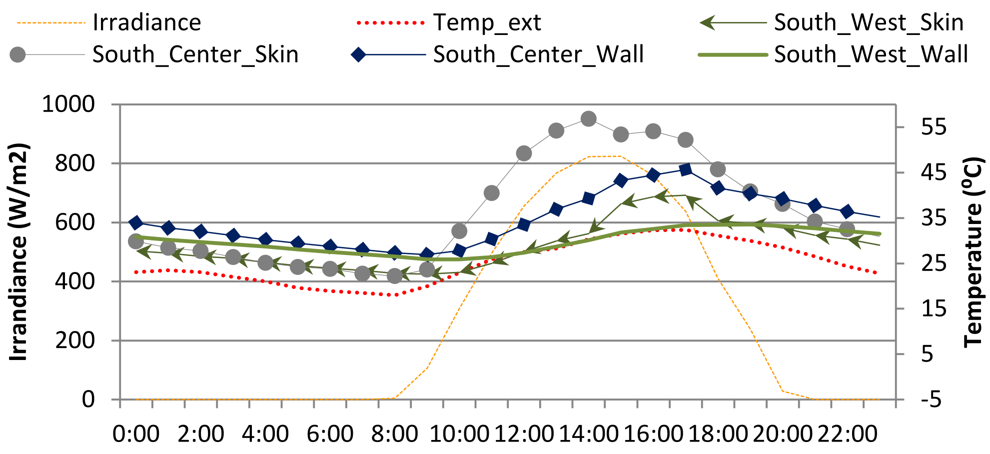
- A sunny summer day with higher external temperature (06.09.2016)
- A sunny winter day with lower external temperature (31.12.2016)

5.2 Results and discussion

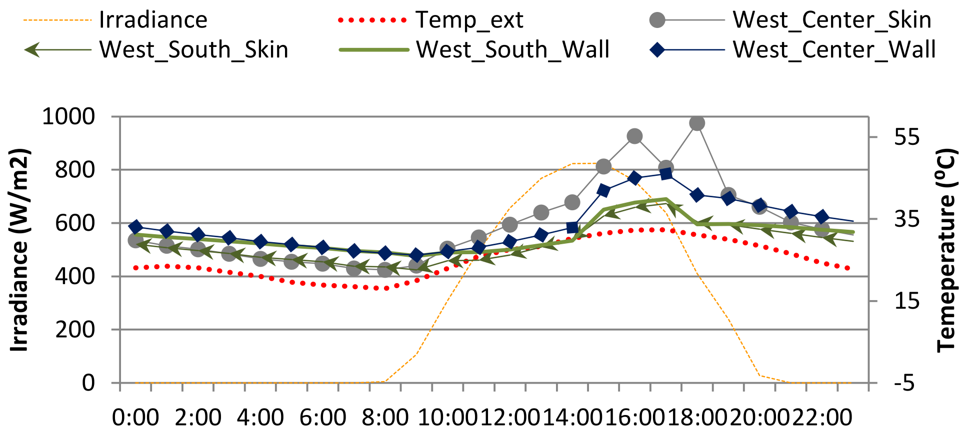
The results of the analysis show the temperature range measured in the two types of façades as well as the influence of these in their immediate internal space.
The following sections explain the analysis performed and the results obtained based on the trend in the behavior of the façades in each case:

5.2.1 Reduction of temperatures:

Fig.3 (a) and (b) shows the reduction of temperature peaks between the metallic skin and the vegetal façade, which in most cases is due to the insulating effect of the vegetation. Based on the maximum temperature recorded on a sunny summer day, the increase in the temperature of the internal surface of the vegetation facade in relation to the external temperature varies between 1ºC and 8ºC, while the vegetation façade fluctuates between 9 ºC and 13ºC.



Case (a): South façade



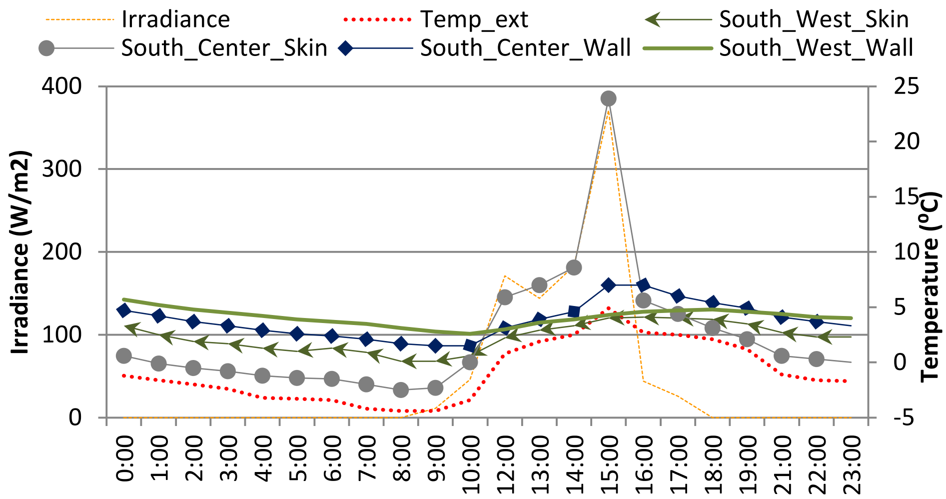
Case (b): West façade

Figure3: Irradiance and temperature values recorded on 6 September 2016 in the south (a) and west façade (b).

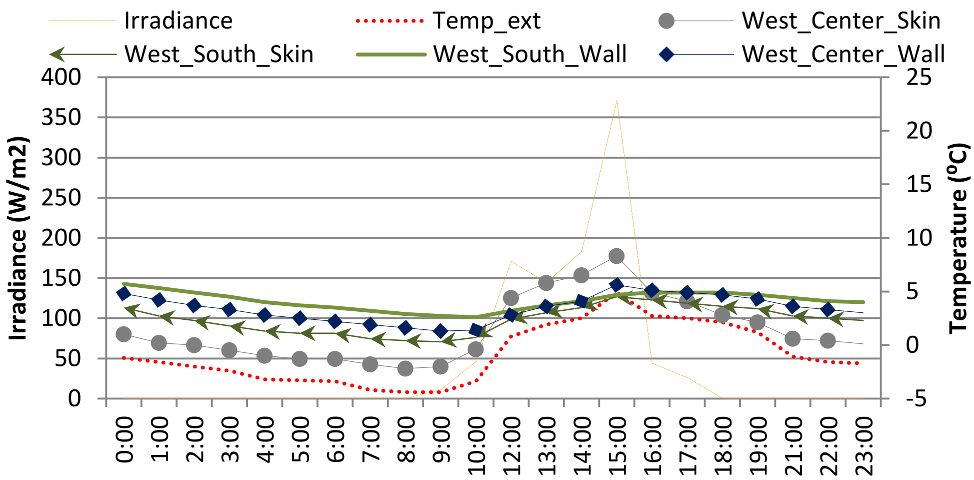
As for the external surface temperatures, the vegetal facade manages to maintain constant temperatures and similar to the external temperature with an average of 28 ºC while the metallic skin during the 24 hours registers temperatures that exceed in a range of up to 26.5 ºC the external temperature. In the southern façade fig.3 (a), the behavior of the vegetal façade contrasts with the metallic skin, where the exterior temperature (Temp_ext) fluctuates between 25ºC and 30ºC, in front of these temperatures, the façade without vegetation responds with temperatures (South_Center_Skin) from 40ºC to 56ºC, representing an increase of 27% in relation to the outside temperature; on the other hand the vegetation façade on its outer surface (South_West_Skin) registers temperatures that only surpass it by 0.9%, with a difference of 1.2ºC.
In the case of the west façade fig. 3 (b), it should be noted the difference in the time range of solar exposition of the façades, whereas the south facade remains exposed for 8 hours, the west façade will have only 5 hours, this condition is an influence in the thermal behavior. The vegetation facade in its exposition towards the west, tends to maintain maximum temperatures in particular cases or to reduce them significantly; In Fig. 2 (b) it is clear to see the peak reached at 18:00, with a difference of 27.3 ° C, between the outside temperature (31.1 ° C) and the external surface temperature (58.4 ° C - West_Center_Skin).

5.2.2 *Maximum temperature time lag:*

These graphs show the effect of vegetation on the lag of the temperatures recorded on the internal surface of the façades, in relation to the maximum temperature on the external surface. Fig. 3 (a) demonstrates how the behavior of both façades differs significantly in the hourly range with lower temperatures comprised in an average of 4ºC (Temp_ext), while the vegetation façade achieves an increase of approximately 6ºC on the surface (South_Center_Wall) in relation with the outside temperature, the plant facade reaches differences of up to 7.5ºC (South_West_Wall).



Case (a): South façade



Case (b): West façade

Figure 4: Irradiance and temperature values recorded on 31 December 2016 in the south (a) and west façade (b).

As to the external surfaces, under the same conditions of external temperature, the metallic skin (South_Center_Skin), registered an increase of 1.9ºC, while the vegetal façade (South_West_Skin) shows an increase of 4.5ºC. The perceived phase-shift from the minimum external temperature to the record of the internal minimum in the plant façade (South_West_Wall) is 2 hours, reaching a temperature ranging from 2.6ºC to 3.1ºC, an increase of 0.6ºC. In Fig. 3 (b) the behaviour of the west façade is evaluated, and the peaks of maximum outdoor temperature, maximum irradiance value, as well as the maximum temperatures recorded on the façade coincide.
In the case of the minimum temperatures, the minimum external temperature -4.4ºC (Temp_ext), the minimum internal temperature in the plant facade (West_South_Wall) 2.7ºC and the minimum internal temperature of the metallic skin (West_Center_Wall) 1.6ºC coincide, however, the vegetal façade registers an increase of 7.1ºC with respect to the outside temperature.
In spite of the extreme conditions, the system of the vegetal facade still offers benefits. On the one hand we obtain a phase shift of 2 hours between the peak time of low temperature in the exterior and minimum temperature in the interior, on the other hand, the increase of up to 7ºC is achieved in the interior of the vegetal façade. This determines the action of vegetation as a buffer of solar irradiation.

5.3 Recycled rubber panels

The methodology used to analyze the thermal behavior of the different materials was the following:

- Four panels were placed for each type of plaque, to create a total area of 1.44 m^2 for each material. Two temperature sensors (for each type of material) were placed inside the wall between the insulation of the wall and the plate.
- A weather station was installed to monitor the climatic variables that directly affected each plate.

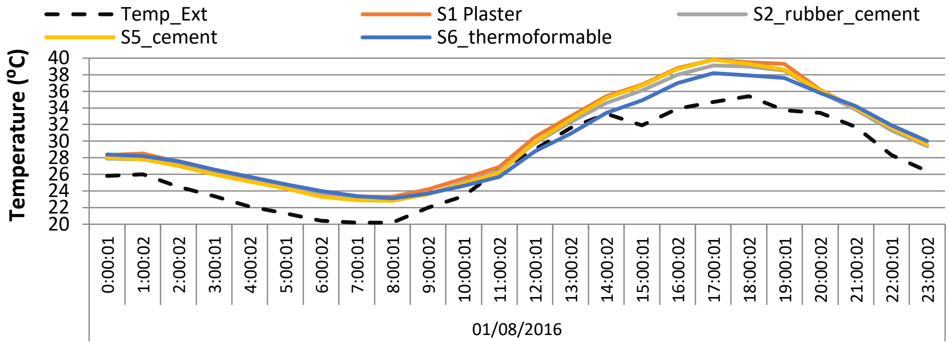
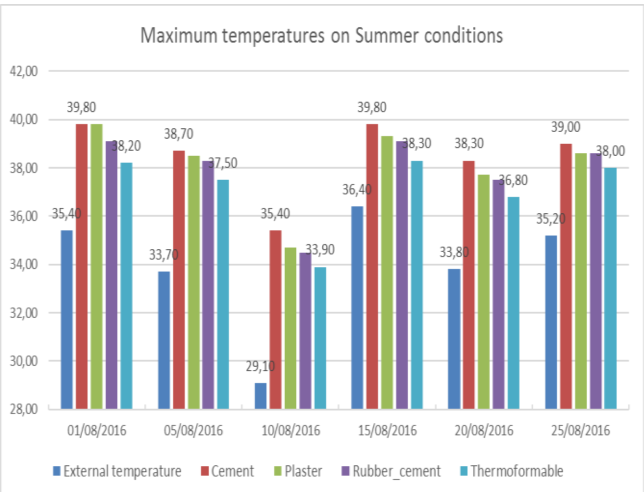


Figure 5: Variable temperature range for one summer day.

For the analysis, the values obtained from the probes of each material were averaged and compared with the outside temperature (Fig.5).

The experimental development has monitored the behavior of the different materials over a year. In order to facilitate the analysis and to adjust the obtained values, only 6 different days were taken into account for the summer conditions (days when no errors were present in the measurement probes) and 6 days for the winter conditions. Later, the maximum and minimum temperatures of the plates were analyzed, as well as the percentage of reduction (improvement) of each plate with respect to the one obtaining the highest / lowest temperature (Fig. 7)



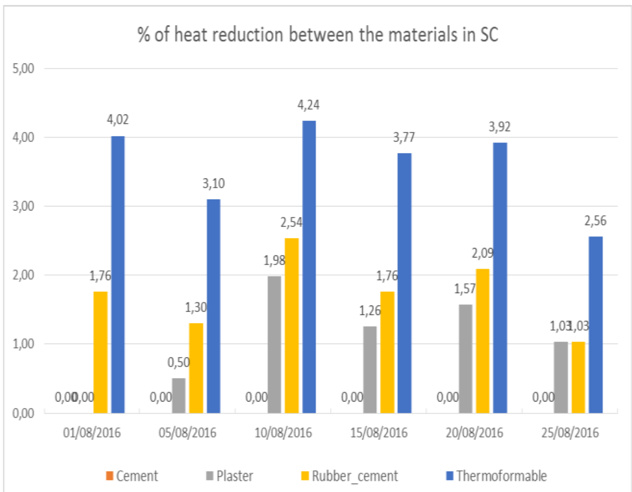
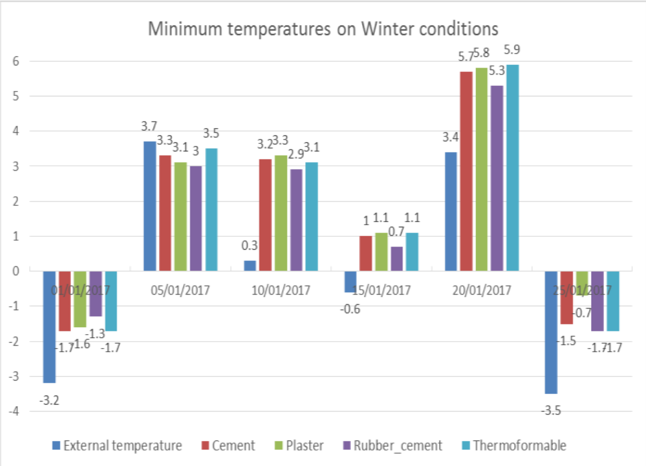


Figure 6: Maximum temperatures on summer conditions.
Figure 7: Percentage of heat reduction on summer conditions.

In Summer Conditions (SC) the Rubber_Cement and Thermoformable plates have in all cases lower temperatures in comparison with the higher temperature reached by all the materials, that in all cases were the plate made with cement. The percentage of reduction varies from 1% to 4.24%. Thermoformable plates reached in all cases lower temperatures under the same external conditions (Figure 7). At temperatures below zero, the material that has better performance is the gypsum boards. The material that has the worst behavior in general under these conditions is the rubber cement mixture, which in 5 of the 6 occasions has the lowest temperatures.

The thermoformable mixture almost always exceeds the commercial mixture of cement, having a worse behavior when temperatures fall below zero degrees. It is possible that the voids and the texture of the plates made with recycled rubber, negatively affect the behavior of the plates in winter conditions, causing the formation of icy surfaces, possibly due to the moisture contained within their structure, since these materials count with a greater amount of open porosity.



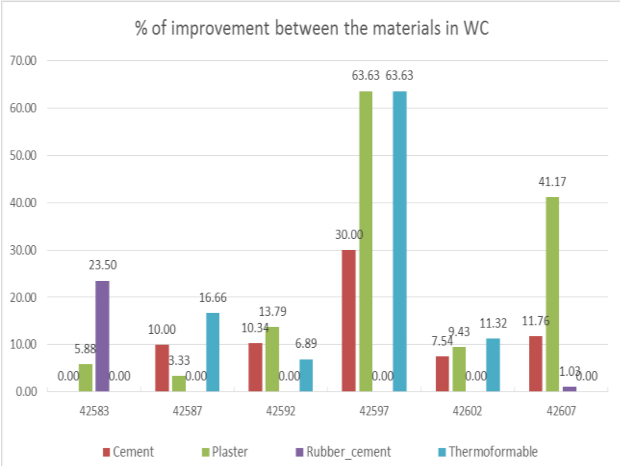


Fig.8: Minimum temperatures on winter conditions.
Fig.9: Percentage of improvement between the materials in winter conditions.

It can be observed that the materials made with recycled rubber, significantly improve the behavior of the enclosure in summer conditions (especially those plates made with a thermoformable manufacturing process). It is also observed that due to the greater amount of open porosity of these materials, they are affected by the moisture that adheres to its surface (especially the rubber-cement mixture) and present slightly lower temperatures than the rest of the materials tested under winter conditions (Figs. 8 and 9).

6 Energy simulation

The physically based model of the energy balance of a vegetated rooftop integrated into the EnergyPlus (i.e RoofVegetation) has been considered for building energy simulations. This green roof module allows the energy modeller to explore green roof design options including growing media thermal properties and depth, and vegetation characteristics such as plant type, height and leaf area index. The complexity of the calculation system integrated into the GreenRoof module needs to specify a large number of parameters describing the green roof in detail. The RoofVegetation module is related only to the soil substrate, the last component of the roofing unit, which generally also includes draining, insulating, and anti-root layers and which are modelled in EnergyPlus in the "Materials" descriptive sheets.
The RoofVegetation module was developed and specifically tested for flat external surfaces so that the use of this module is therefore not recommended to simulate the behaviour of highly inclined surfaces (e.g., vertical walls). For this reason, a method was developed to optimise the green façade (green façade optimisation, GFO) with a parametric study. The research method uses 3D parametric tools, Grasshopper®, in particular, which is a graphical algorithm editor integrated with Rhinoceros, a 3D modelling program. More specifically, the research uses a variety of plug-ins in Grasshopper, such as Ladybug, Honeybee and Galapagos, a mathematical computational solver.
The Galapagos tool was used to find values to assign to the material panels (optimised values). The unknown parameters of the GreenRoof module were determined during this phase to obtain internal surface temperatures closer to those measured during the same period of time.
The simulation phase considered all material values studied previously and the simulated values agree with measured values as shown in Figure 10 (validation phase) for July month and in (Fig.11) for all data set July- December. There is a good agreement between simulated and monitored data (inner surface temperature) so that the parametric methodology is able to simulate the behaviour of the green wall.
In the second phase, a new interesting location (Abu Dhabi) has been considered to evaluate the behaviour of the green wall. Abu Dhabi has a sub-tropical climate and July is usually the hottest

month of the year with diurnal temperatures ranging between 28°C and 42°C and long term extremes between 22°C and 49°C.

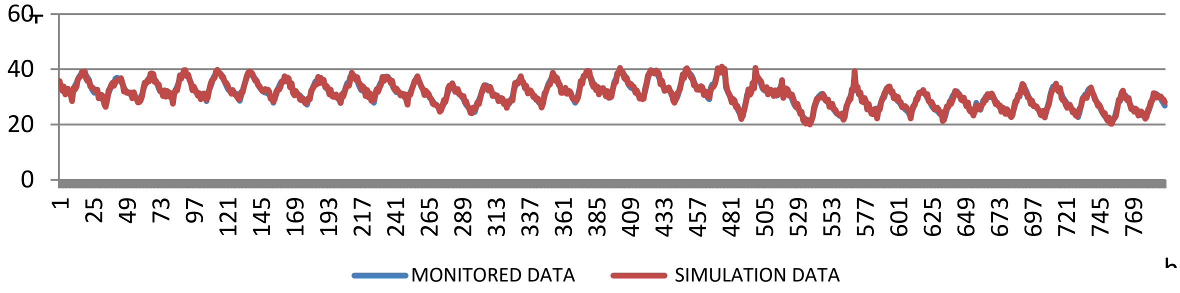


Figure 10: Comparison between monitored and simulated data monitored (July 2016).

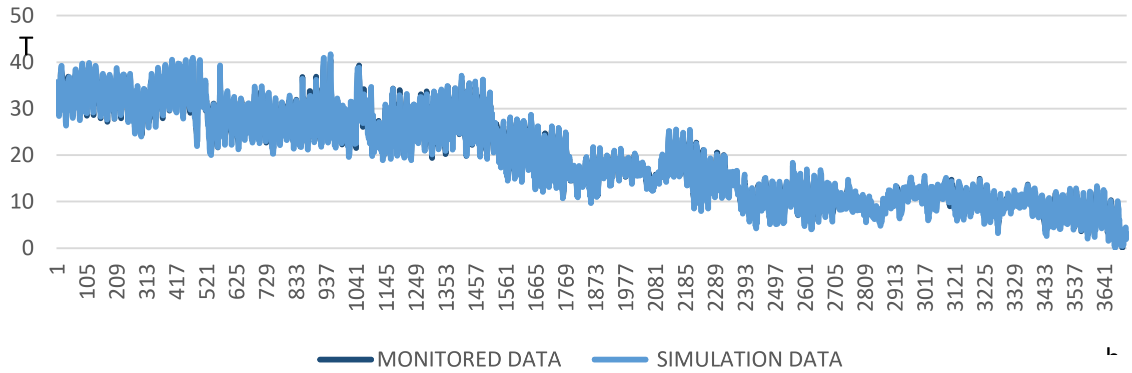


Figure 11: Comparison between monitored and simulated data monitored (July-December 2016).

A comparison between the bare wall and green wall in the same period (July-December) is depicted in (Fig. 12). It is interesting to note how these results are promising since the decrease of temperature of some degrees (in the warmer months, July and August) can represent a good amount of energy saving to cool the ambient.

This shows that vegetation effect is stronger when external conditions are extreme, with high values of radiation and air temperature. The use of green facades seems recommendable in case of climates characterised by many hours of solar radiation, confirming that their use brings thermal benefits compared to a conventional wall.

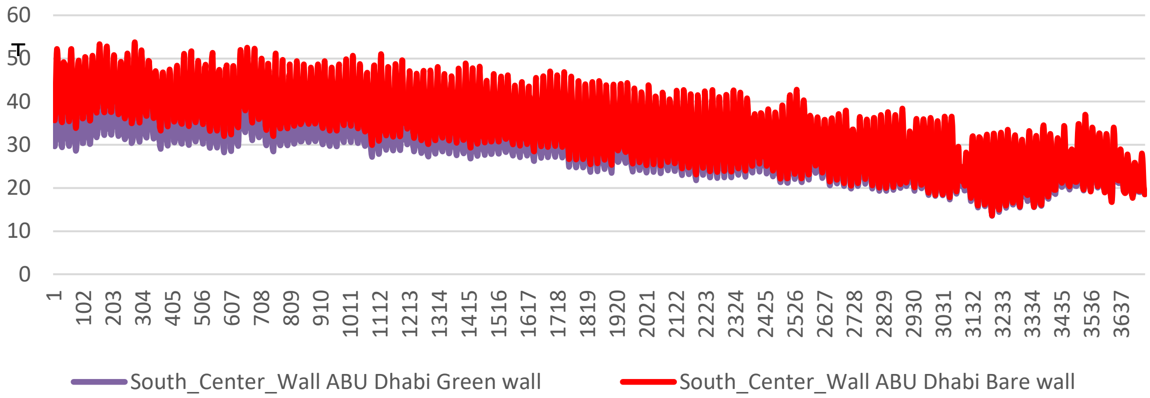


Figure 12: Simulated behaviour for the bare wall (red line) and green wall (purple line) July-December.

7 Conclusion

This research aims to analyze the effects of vegetation as a building envelope, based on a modular vegetation system constituted by plants and organic substrate, from a monitoring system installed in the new itdUPM headquarters in Madrid, Spain. The results obtained reflect the ability of vegetation to isolate extreme temperatures and reduce the transmission of these to the interior of the building, particularly in cases of high temperatures in summer. According to the results obtained, the use of vegetal façades can be confirmed as a strategy for energy saving in buildings.

It also can be observed that in the façade north those plates made with recycled rubber, significantly improve the behavior of the enclosure in summer conditions (especially those plates made with a thermoformable manufacturing process). It is also observed that due to the greater amount of open porosity of these materials, they are affected by the moisture that adheres to its surface (especially the rubber-cement mixture) and present slightly lower temperatures than the rest of the materials tested under winter conditions.

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