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## The energy retrofit of building façades in 22@ innovation district of Barcelona: energy performance and cost-benefit analysis.

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# The energy retrofit of building façades in 22@ innovation district of Barcelona: energy performance and cost-benefit analysis.

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**Abstract.** Under the current Energy Performance of Buildings Directive, EU countries must set building energy renovation as a goal for future development of the cities. The 22@ district of Barcelona is one of the most thriving innovation districts of Europe with an increasing market for office buildings. In this framework, the present paper evaluates the effectiveness of a series of strategies considered the real case project of the energy retrofit of an existing building in 22@. In particular, the study presents the results of different scenarios of building retrofits, where simulations of dynamic envelopes are performed, with the inclusion of a conventional ventilated façade, Living Green Walls and Phase Change Material (PCM) for thermal energy storage. The different scenarios are compared in terms of energy performance, enhanced comfort and cost-benefit analysis. The benefits of latent thermal energy storage, improved thermal inertia and evapotranspiration of the vegetated elements are also assessed. Eventually this study helps understanding the feasibility of the implementation of the nZEB standard in energy retrofit of buildings in the specific context of Barcelona and Spain.

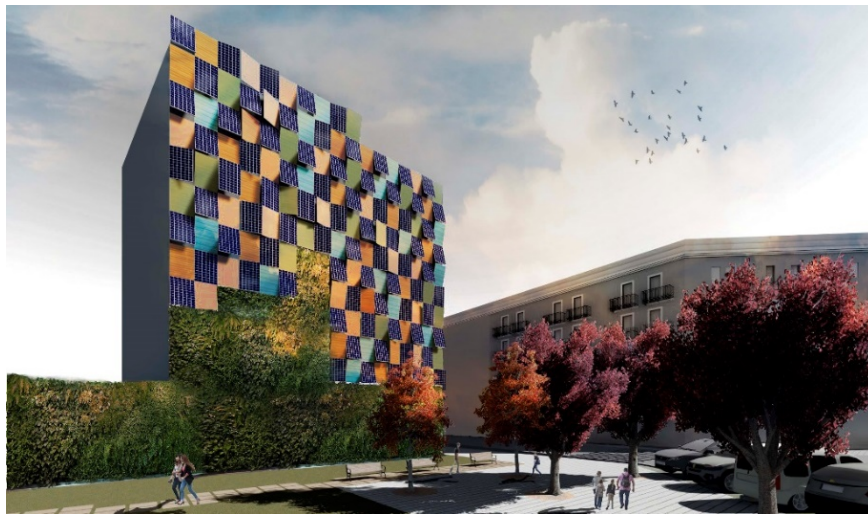
## 1. Introduction

The massive urban development is altering the land surface by concentrating materials which effectively retain heat and create impervious surfaces, thus affecting urban local climate and urban hydrology. Moreover, tall buildings provide multiple surfaces for the absorption of solar radiation that is subsequently reradiated as heat, thus enhancing the efficiency with which urban areas are warmed up [1]. Building renovation is a main issue of recent European policies towards energy efficiency. Today's renovation projects have the challenges of improving the energy efficiency in order to reach the goals of zero emission in the building sector while improving their social and economic value, securing a sustainable use of resources [2] and minimizing the deleterious effects of buildings in the urban environment. The renovation of the building envelope, are a key factor in the energy rehabilitation of buildings and the urban environment. This paper describes three renovation strategies: living walls, ventilated facades with fibre-cement cladding and ventilated facades with PCM materials [3,4,5].

## 2. Case study

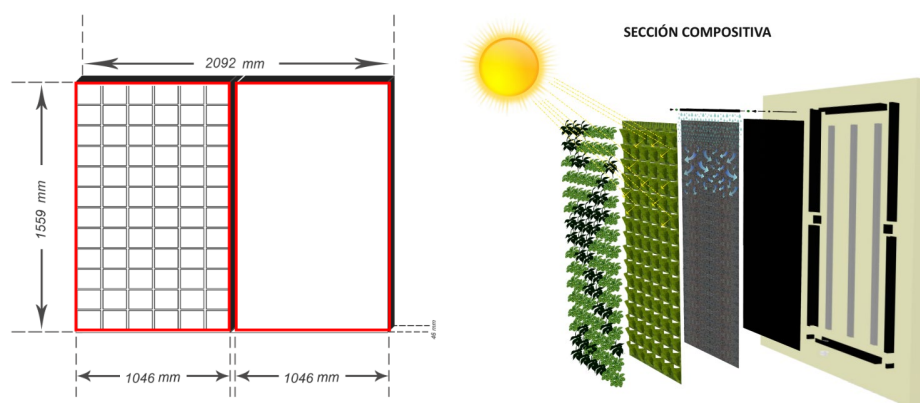
The city of Barcelona and the Association 22@ Network is promoting the restoration of so-called “medianera” walls in the 22@ district. These walls are fully opaque boundary walls that will remain exposed and no future adjoining construction will be allowed by the Barcelona urban planning. These areas belong to the public urban space, and can be restored to bring social value and cultural identity to the urban space of the city.





**Figure 1.** Visualization of the case study.

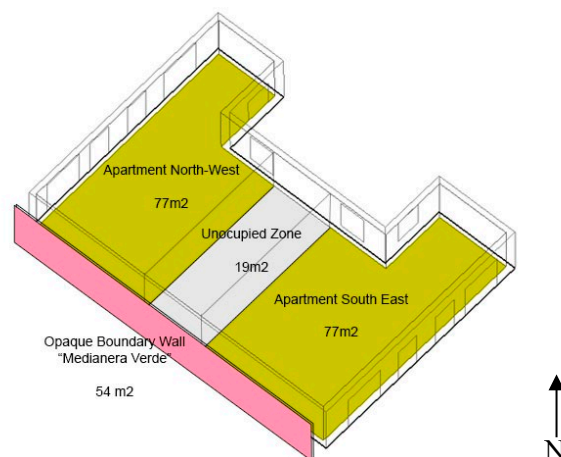
The project “Medianera Verde” (figure 1), or green boundary wall, is a real case retrofit project that proposes an architectural and business model for the restoration of these urban spaces. The façade selected for the intervention is oriented to South-West and is composed of a standard 30 cm non load-bearing masonry wall with a 5 cm air gap and 3 cm of insulation. The project proposes the addition of a green living wall, in the lower part of the building, to establish a continuity of vegetation with the existing public space, and a modular ventilated façade on the upper part. The module consists of a photovoltaic panel (PV) module and an opaque panel (figure 2). This particular configuration is meant to represent the flourishing presence of industrial and commercial companies and start-ups in the 22@ district. The design integrates the business model of this solution where multiple investors can contribute assuming the costs of one or more modules and personalize it according to their marketing strategy and express so their social responsibility and focus on sustainability. The estimated construction cost is provided for each of the considered options: the green living wall cost is 366,2 €/m<sup>2</sup>, the ventilated façade cost is 109,6 €/m<sup>2</sup>, and the façade with PCM cost is 137,8 €/m<sup>2</sup>.



**Figure 2.** Modular unit of the ventilated facade/ Green Living Wall.

### 3. Methodology

The decision-making of the project was supported by a set of energy simulations that allowed comparing different scenarios. The simulation model represents a typical floor plan of the building (figure 3), consisting of two apartments of 77 m<sup>2</sup> connected by an unconditioned zone. The opaque boundary wall is modelled as a thermal zone, classified in Energy Plus as cavity and calculated with the algorithm based on the ISO 15099 standard for narrow vertical cavities.



**Figure 3.** Energy simulation model.

In order to determine the suitability of the application of different façade solutions to the case study, three different strategies of façade renovation are considered and compared to each other:

- 1) Ventilated façade with fibre-cement cladding (VF). A standard ventilated façade with aluminium substructure and fibrocement board cladding.
- 2) Living Green Wall incorporated in the outermost layer of a ventilated façade (GW). The substructure of the Living Green Wall is the same as the previous case. The Living wall system is consisting of a 100% recycled polyethylene board, a felt membrane to regulate water and humidity levels and a geotextile membrane with 15cm x 20cm x 5cm pockets containing the green substrate. The system counts with irrigation system and an integrated monitoring and management system, which ensures in each panel the best operating conditions for the green substrate and the minimum use of water.
- 3) Ventilated façade with a layer of PCM on the external surface of the existing wall. The PCM is the BioPCM M182Q25 where 182 is the heat storage capacity in Btu/ft² and 25°C is the phase change temperature. The parameters considered for each strategy are described in the following table.

**Table 1.** Renovation strategies.

	Description	Existing Wall thickness [m]	Cavity width [m]	Outer layer [m]	U value [W/m²K]
VF	Ventilated façade, fibrocement cladding	0.30	0.08	0.14	0.58
GW	Living Green Wall, ventilated façade with vegetation	0.30	0.08	0.03	0.58
PCM	Ventilated façade with PCM	0.37	0.08	0.03	0.58

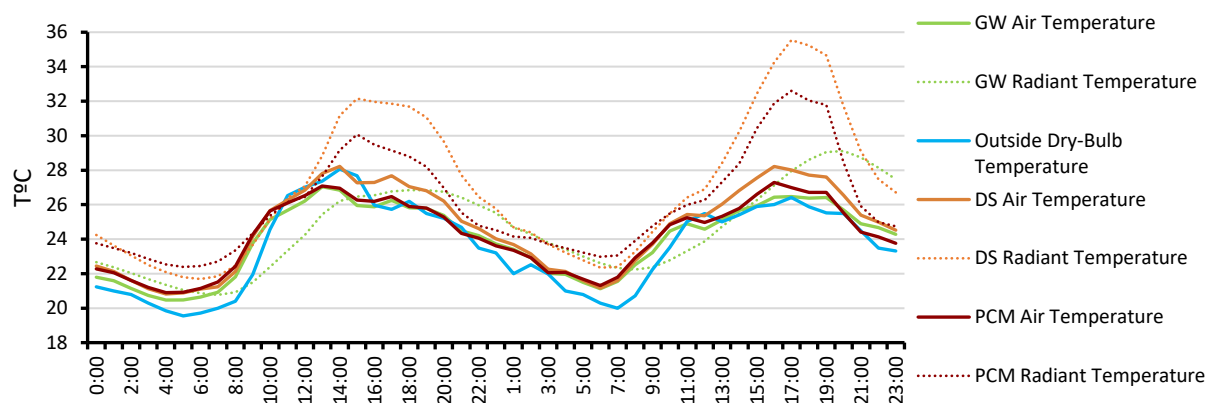
The U-value has been set-up equivalent for all three options in order not to influence the results. The energy performance of the three proposals is evaluated through energy simulation with EnergyPlus, carried out from the 22nd to the 28th of June. The Energy plus built-in model used to simulate the green façade was developed for low-sloped exterior surfaces (roofs). However, it can be an approximate model of green walls by bearing in mind that the irrigation would behave differently to roofs. Since in the real case living wall the irrigation is maintained at optimal conditions through a monitoring system, the model is a reasonable approximation. In the Barcelona's living wall, the selected plant was *Ficus Repens*, considered in its mature stage (average height of 0.25 m, Leaf Area Index of 2.7, minimum stomatal resistance 180 s/m). The leaf emissivity was 0.95 while the leaf reflectivity was calculated from

the biological model PROSPECT-D [6], a software that calculates the leaf spectral transmittance based on the leaf pigment content (chlorophylls, carotenoids, and anthocyanins). The resulting leaf reflectivity coefficient was 0.22. For the substrate layer, a thickness of 0.06m was considered. For dry conditions of the substrate, the density is about 1800 kg/m<sup>3</sup>, the thermal conductivity 1.18 W/m-K, and the specific heat at constant pressure 1250 J/kg-K. The ability of the soil to retain water was considered through two variables: the saturation volumetric moisture content of the soil layer set at a value of 0.5 m<sup>3</sup>/m<sup>3</sup>, corresponding to a saturated substrate, and the residual volumetric moisture content of the soil layer of 0.01 m<sup>3</sup>/m<sup>3</sup>. This value is used to calculate the hourly stomatal resistance of the plant [7]. The initial volumetric moisture content of the soil layer is 0.5. The irrigation is set to 0.0018 m<sup>3</sup>/h-m<sup>2</sup>, regardless of the current moisture state of the soil. The monitored irrigations system will maintain these values constant to ensure the correct functioning of the system and decrease maintenance costs.

## 4. Results

### 4.1 Cavity air and radiant temperature

In the first simulation (figure 4), air temperature and radiant temperature were studied in the cavity space of the ventilated facade. While there was only slight but consistent difference in the air temperature, it is the radiant temperature that shows the difference in the three studied options. While the radiant temperature in the cavity for the VF and PCM options is significantly higher than the Exterior dry-bulb temperature, up to 9.36°C for VF and up to 6.25°C for PCM, in the GW option it remains mostly below.

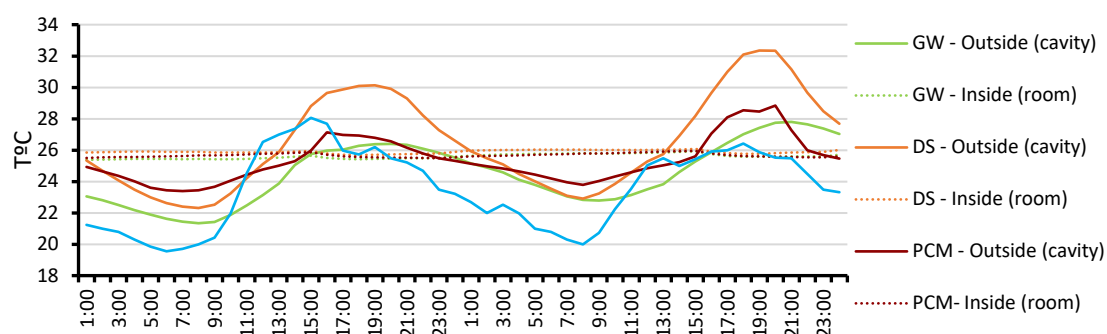


**Figure 4.** Cavity air temperature and radiant temperature.

In the VF and PCM options, no significant delay can be found, while in the radiant temperature observed in the cavity for the GW option, occurs a time delay of up to four hours in the peak of the temperature.

### 4.2 Surface temperature on exiting wall faces

The surface temperature on both faces of the existing wall were studied in order to better understand the impact of the three solutions to the thermal zone (figure 5).



**Figure 5.** Surface temperature on the outside and inside face of the original wall.

The surface temperature on the inside face of the wall is strongly influenced by the fact that the interior space is set up as air-conditioned, therefore quite constant surface temperature is achieved. However, the lowest temperatures can be observed for the GW option and highest temperatures for the VF option. The average temperature difference in this case is 2,54°C. The PCM system has different behavior, where the maximum surface temperatures become only slightly higher than the exterior temperature (by 0,68°C in average) during the day period (8:00-20:00), while it remains much warmer (by 2,47°C in average) during the night period (20:00-8:00). The exterior face of the wall in the GW system becomes colder than the previous two cases during the night hours (by 1,49°C in average), and it becomes colder than the exterior dry-bulb temperature during the day hours (by 1,05°C in average). There is a time delay in all three cases.

## 5. Discussion and Conclusions

The study presents the analysis of three façade typologies included in the project for the 22@ Green Wall. These analyses were used as part of the decision making of the project and helped obtaining the final configuration of the façade. The analysis of the air and radiant temperature in the cavity of the three ventilated façades showed a significantly better behaviour for the GW where the air and the radiant temperature was found more than 1°C lower than the outside dry-bulb temperature, showing a significant effect of the evapotranspiration of the green substrate. The air temperature of the cavity in the PCM case resulted about 1.5-2°C lower than the VF case but not lower than the outside dry-bulb temperature. This is caused by the phase change of the material that shows a frequency of activation of 35%, that is the percentage of time in which the PCM undergoes phase change. In the GW case the air temperature in the cavity results the lowest of the three cases and even lower than the exterior temperature. The benefit of the GW is significantly higher than the other two solutions. The energy demand for cooling of the zone studied was reduced by a 14% with the application of the GW whereas there wasn't any significant improvement in the other two cases. The effect of the evapotranspiration of the plants, the shading effect of the leaves and the increased thermal mass of the envelope are considered as the main cause of the improved performance of the GW compared to the other two ventilated façades studied in this paper. Furthermore, considering the Living Green Wall, the implementation of IOT technology helps minimizing the use of water down to 0,5 liters/m<sup>2</sup>, much less compared to conventional systems that have an average nominal water consumption between 2 and 6 liters/m<sup>2</sup>. Therefore, the green substrate has a stable hygrothermal conditions with here proven significant benefits on the thermal performance of the façade and allowing more predictable energy simulations with the energy plus green roof model. This system gives an important contribution during the maintenance phase when green walls often show a significant cost. This aspect will be relevant during the operational phase to verify the precision of the simulation algorithm for green roofs used in vertical surfaces. Based on these results, the living wall façade was chosen to be a consistent part of the façade, due to its better performance compared to the other solutions presented. This aspect was crucial since the cost of the living wall is considerably higher compared to a conventional ventilated façade (366,2 €/m<sup>2</sup> compared to 109,6 €/m<sup>2</sup> in the studied case). The PCM however showing little improvements in reducing the air temperature of the cavity, as confirmed in previous research, it didn't improve the energy performance of the zones and it is not a cost-effective solution (137,8 €/m<sup>2</sup> in the studied case) for exterior envelopes; its application was discarded from the project. As a general conclusion, the use of living walls in urban retrofit projects could be an interesting solution in case of low efficient buildings since it can efficiently replace the use of thermal insulation with substantial benefits in summer for buildings energy performance and for the exterior urban environment. In the case of Barcelona this walls are considered public spaces, so the construction and maintenance is not charged to the building's occupants.

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