# Design and integration of innovative rehabilitation technique: Improving habitability in social housing

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**Abstract.** The current commitments proposed by the European Union to mitigate the effects of climate change lead to the necessary action on the building sector. Acting on the existing building stock, improving energy efficiency becomes a key point on the road to 2030, where the role of air conditioning will change completely. Unsatisfied basic needs for energy supply characterize the energy-poor social housing districts in Spain. The energy inefficiencies of the dwellings worsen this situation. This situation is aggravated in the south of Spain, presenting a severe overheating problem in cooling, making residents outside the comfort limits a high number of hours. In these cases, conventional strategies to improve the performance of the building envelope are not enough. In this work, an innovative active roof solution of more than 2000m2 is designed and integrated in a district of social housing blocks. Said roof reduces the energy demand for conditioning through the exploitation of thermal inertia and the integration of environmental sinks, enhancing its effect with direct evaporative cooling systems through water micronization. It stands out for being a climate-adaptive design, intelligently controlled based on climate predictions and with different operating modes, which allows it to adapt to the needs of the building. The assessment of the impact of this innovative solution has been analyzed both in the pre-design phase and after the completion of the intervention, thus allowing us to know the actual improvement of the dwellings. Serving as an example of the integration of high-tech components, its objective has been to improve the energy efficiency of the housing stock, allowing it to reduce energy demand, as well as increase comfort levels for residents.

**Keywords.** Adaptative cover, habitability, innovative rehabilitation.
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## 1. Introduction

The Sustainable Development Agenda adopted by all UN Member States in 2015 to mitigate the effects of climate change leads to the necessary action on the building sector. This situation is aggravated in areas where the low energy efficiency of homes can cause a state of continued discomfort and with it serious consequences for the health of the occupants [1]. In Spain, between 3.5 and 8 million people are in a situation of energy poverty, not being able to maintain appropriate temperatures in both summer and winter [2]. This situation is aggravated within the social housing districts in southern Spain where the situation worsens due to the progressive increase in overheating in the cooling months [3]. The rehabilitation of social housing districts includes measures such as improving the transmittance of enclosures by incorporating thermal insulation in them, replacing existing carpentry, improving thermal bridges and increasing watertightness [4]. Said conventional strategies achieve a considerable reduction in the demand for heating [5,6], however, they are not sufficient under cooling conditions in dominant summer climatic zones, as is the case in southern Spain. Along these lines, the interest in the use of passive cooling techniques in buildings stands out, which are based on the use of solar and thermal control techniques, amortization and heat dissipation [7].

The roof is one of the critical elements of the cooling demand due to its extension, exposure to solar radiation and because it is free of obstacles or solar protection elements. Double skin construction are one of the passive heat dissipation technology solutions for energy saving and climate adaptation [8]. These elements have been widely developed and used for passive heating purposes, however, the study and development of these elements for passive cooling purposes is currently very limited [9]. There is a need to re-design ventilated roof solutions to integrate natural heat sinks and achieve an optimal implementation that makes them viable according to the established rules for defining rehabilitation projects [10].

Therefore, this work integrates an innovative solution in more than 2000m2 of active roof in a district of block social housing located in Morón de la Frontera, Seville, serving as an example of integration of high-tech components. It allows reducing the energy demand for conditioning through the exploitation of thermal inertia, being intelligently controlled based on climate predictions and having different operating modes, which allows it to adapt to the needs of the building. This solution also allows the integration of natural heat sinks such as evaporative cooling. In line with these objectives, the document has been structured according to the methodology used. In the first place, the case study is presented and analyzed, justifying the need for action in relation to interior temperatures and thermal comfort. Subsequently, the set of improvement measures and the choice of the optimal solution are described. Finally, the ventilated roof solution necessary to achieve the comfort objectives is defined. Finally, the evaluation of the energy impact in the district under study is shown.

## 2. Case study

As an object of study, two residential complex to the East of Morón de la Frontera have been analysed, divided into phase 3 and phase 4, formed by 11 and 6 blocks respectively (Fig. 1). It is a group of social housing promoted by the Junta de Andalucía, which houses families with a low socio-economic level. Most of the blocks have between 3 and 4 floors, whose floors consist of an entrance, kitchen, living room and 2 or 3 bedrooms. The houses were built in 1981 (phase 3) and 1983 (phase 4).

**Fig.1 –** Localitation

Figure 2 shows the variance of the average daily temperature in the location in 2019. In it is observed that the daily average maximum temperature is generally above 30ºC in the summer months and generally below 10ºC in the winter months.

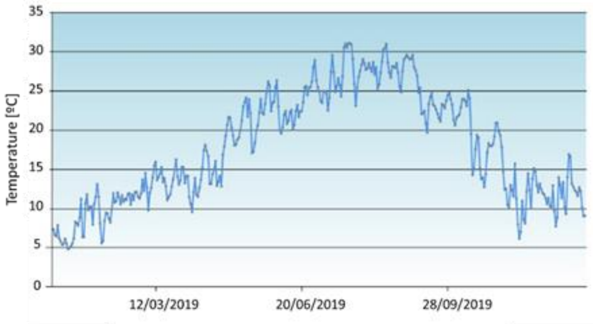


**Fig.2 –** Outdoor temperature (2019)

To evaluate the initial conditions of the houses, a monitoring campaign is carried out. Of all the houses of phases 3 and 4, several were chosen to be monitored, whose owners volunteered for the study. Air temperature and humidity sensors are installed in two of the rooms. After data collection for 4 months, the data was analyzed to select only those dwellings with a set of valid measures. Fig. 3 shows the selection of homes, distinguishing between those homes whose monitoring had failed and therefore there were no measures (owners who requested the uninstallation of the sensors, disconnected emitters, etc.), those that presented failures or periods without data, those whose data were acceptable and those where there was also consumption data.

**Fig.3 –** Representation of the monitored dwellings

As can be seen, of the totality of dwellings, 6 of them are validated for their study, differentiating between dwellings under roof and dwellings on intermediate floors. The experimental measurements on the six monitored dwellings (Fig. 4) reveal substantial differences between them in the periods of heating and cooling and how, especially in the cooling regime, the interior temperatures of the dwellings are very far from the comfort conditions. This highlights the difference between the houses undercover and the houses with intermediate floors with differences of up to 7ºC.

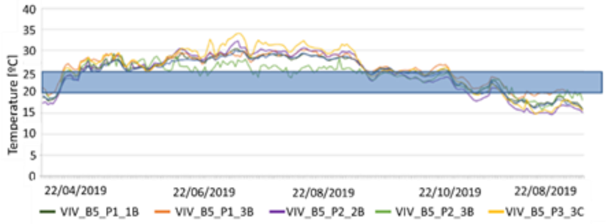


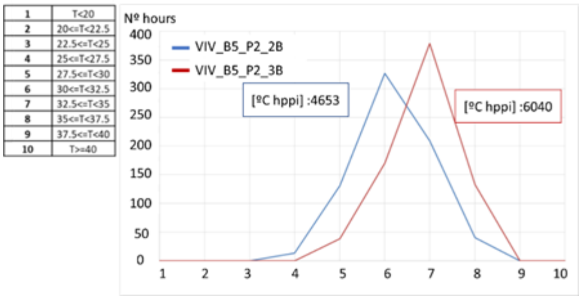
**Fig.4 –** Average daily temperatures measured (2019)

See how house B5_P2_3B presents an operation of the air conditioning during the cooling period. Likewise, house B5_P3_3C has the highest average daily temperatures. A daily average of almost 35ºC on some of its days means excessively high hourly temperatures. It also stands out in heating, where daily measured temperatures reach minimums below 15ºC, which shows the lack of comfort in the homes themselves.

### 2.1 Effect of covers

As previously observed, dwellings undercover present higher interior air temperatures than the houses on intermediate floors.

Through these temperature measurements, the thermal comfort of the dwellings is evaluated. Fig.5 shows, first and to the left, a table with 10 temperature ranges (interior) from values below 20 to above 40 with a step of 2.5ºC that will facilitate the subsequent calculation of comfort. The graphical results are presented for a dwelling located on the middle floor and a dwelling located on the upper floor based on the resulting indoor temperature data. Thus, for each range defined in the table, the number of hours that each of them is within it for the month of July is shown, as well as the weighted hour degrees out of comfort. The indicator of degrees-hours weighted outside comfort [ºC · h · ppi] not only takes into account the number of hours that the home is out of comfort but also considers the importance of the temperature difference over the comfort.



| | |
|---|---|
| 1 | T<20 |
| 2 | 20<=T<22.5 |
| 3 | 22.5<=T<25 |
| 4 | 25<=T<27.5 |
| 5 | 27.5<=T<30 |
| 6 | 30<=T<32.5 |
| 7 | 32.5<=T<35 |
| 8 | 35<=T<37.5 |
| 9 | 37.5<=T<40 |
| 10 | T>=40 |

**Fig.5 –** Effect of roof on indoor temperatures and degrees-hours weighted out of comfort [ºChppi]

As can be seen, the upper floor dwelling (red) presents a greater number of hours within the higher temperature ranges (air temperatures above 32.5ºC). Furthermore, as is to be expected, depending on the frequency of temperatures obtained, the degree hours weighted out of comfort present a value 30% higher in the house undercover, this being due solely to the effect of the cover.

The same typology of results discussed in the previous figure has been obtained for the different months associated with the cooling regime (June, July, August, and September) and for 2 additional groups of dwellings (Group 2: B5-P1-1B (intermediate floor ), B5-P1-3B (upper floor); Group 3: B5-P3-1C (intermediate floor), B5-P3-3C (upper floor)). Table 1 shows the average results for the 6 dwellings in the 4 months. As can be seen, the average contribution is 43% for the month of June, reaching 50% in the B5-P3-3C dwelling. In the hottest months, the difference caused by the contribution of the roof is less due to the high temperatures that are reached in both dwellings.

**Tab.1 –** Average roof contribution to improve thermal discomfort

| Month | Roof Contribution average[ºC h ppi] (%) |
|---|---|
| June | 43 |
| July | 20 |
| August | 20 |
| September | 30 |

## 3. Improvement measures

### 3.1 Retrofit

The objective of improving habitability in social housing districts is the use of passive improvement strategies adapted to the reality of the tenants, a population with limited resources. In order to solve the situation presented above, various passive improvement strategies are proposed whose objective is to reduce the demand for heating and cooling. For this, it is proposed to improve the transmittances of the enclosures through the incorporation of thermal insulation in them, improvement of the carpentry, thermal bridges, and reduction of infiltrations by improving the air tightness. These improvements have different levels of efficiency, therefore, a set of alternatives is generated with a total of 450 possible combinations of improvement. Each one is associated with a decrease in energy demand in buildings, as well as a cost of its integration. To find the optimal rehabilitation solution from the defined catalog, the optimal cost methodology proposed in the European regulation [11] is followed, seeking to achieve the minimum consumption of primary energy (PEC) and LCC. To do this, the life cycle cost (LCC) is plotted against the total primary energy consumption (Fig.6). Said indicator is required by Spanish regulations [12] and for its calculation the reference system also defined therein is used. The initial situation of the district is shown in red. The selection of the optimal case, in the case of not being subject to regulatory restrictions, would be that combination defined by that energy saving achieved with less LCC. However, the choice of the optimal case is subject to country regulatory restrictions associated with energy demand and consumption for the climatic zone in question [12]. Of the set of combinations defined, figure 6 shows the set of combinations that meet the demand indicators established by the regulations (points marked in dark green). Finally, in addition to the restrictions on demand, restrictions on consumption are applied. The figure shows the consumption limit established by means of a blue line. The combination to be implemented is the one that meets the restrictions on demand and consumption and has a lower LCC (marked in black).

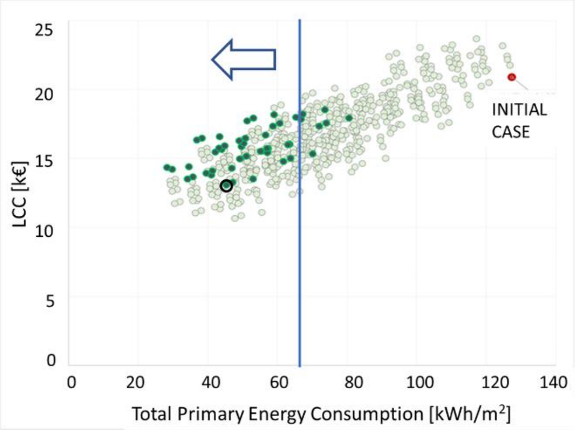


**Fig.6 –** Total primary energy consumption-LCC

The optimal case selected corresponds to the combination of parameters defined in Table 2.

**Tab.2 –** Selected rehabilitation measure

| | Select combination | |
|---|---|---|
| Heating reduction alternative | Walls [W/m2K] | 0.28 |
| | Roof [W/m2K] | 0.22 |
| | Floor [W/m2K] | 0.32 |
| | Windows [W/m2K] | 2.0 |
| | Linear transmittance of Thermal Bridges | 75%reduction |
| | Infiltrations + Ventilation | 3 |
| Cooling reduction alternative | Solar control (g-value of Windows in summer) | Base |
| | Night ventilation [1/h] | 4 |

In the optimal case selected, the installation of an external thermal insulation system (SATE) is carried out, which is arranged on the exterior face of the building's façade; the carpentry is replaced by break of thermal bridge windows and thermoacoustic glass 5 + 15 + 6b; transmittance of walls, ceiling, floor, and windows is 0.28, 0.22, 0.32, and 2 W/m$^2$K respectively, with a 75% reduction in thermal bridges and a n50 level of 3 as alternatives for reducing heating. In the case of cooling reduction, 4 h-1 of night ventilation is contemplated, keeping the g-value of Windows in summer as the base case.

### 3.2 Passive cooling

As mentioned, the roof contributes significantly to the thermal discomfort of the building under cooling conditions and therefore the interest in its intervention. In view of this, the present study also carried out the integration of a ventilated roof solution.

The active roof is made up of a 5 cm high air chamber between the existing roof and the exterior wall, in such a way that it resembles a conventional ventilated façade (Fig.7) . The exterior wall is insulated in the form of an EPS "sandwich", with a total thickness of 8 cm, providing a great insulation capacity as well as lightness and thus helping to reduce the temperature transfer achieved in the chamber towards the outside. The inner sheet is located in the lower part, with one of its surfaces bordering the interior of the building. This element is where the cold that will be directed to the interior of the building is stored. Therefore, it is desirable that it has a high thermal mass and at the same time be a good conductor of heat. In the case under study, the inner sheet corresponds to the existing roof, which has 25 cm of concrete with a density of 1330 kg/m3.

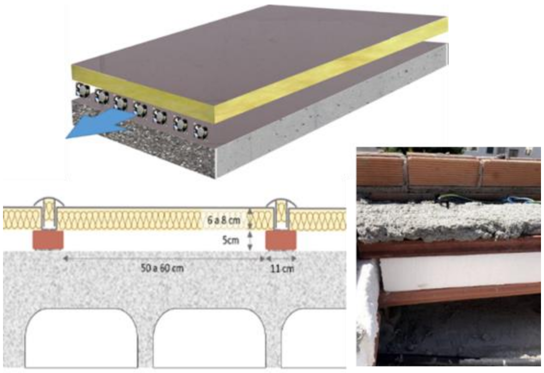


**Fig.7 –** Description of the innovative solution

The designed cover stands out for being an adaptive design to the climate. Therefore, this solution has two modes of operation:

In the cooling mode of operation, during the day, the air circulation is stopped. The insulated outer blade repels most of the heat while preventing the cold stored overnight on the inner blade from escaping to the outside. During the night, when the outside temperature is low enough, the air circulation is activated and dissipates heat from the inner sheet of the cover which consequently cools down. However, in case the minimum nighttime temperatures do not drop enough, an evaporative cooling system is included to achieve a further reduction in air temperature.

During the heating regime, the air chamber remains watertight and due to the high insulation of its outer sheet, high performance in the heating regime is guaranteed.

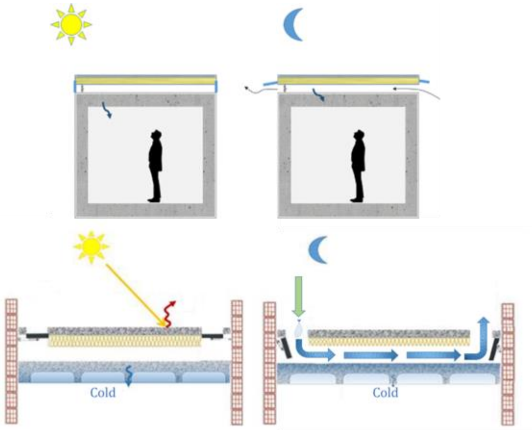


**Fig.8 –** Operation of the active roof

For its implementation, 3 types of modules were designed using CFD techniques with ANSYS software (Fig.8). Each module has different dimensions and geometry. The designed distribution must guarantee a uniform flow throughout the roof from a centralized air inlet and outlet of the module. Hot or cold spots must be avoided. Figure 9 shows the integration of the modules in the district blocks.

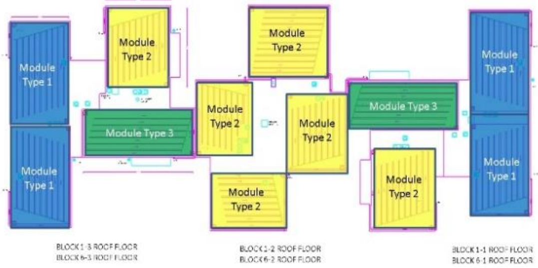


**Fig. 9-** Distribution of modules

The air extraction is carried out using fans, which must be capable of generating an air flow in the chamber such that the speed is approximately 1 m / s in order to avoid high-pressure losses. Finally, the water spray system must generate droplets with a size smaller than 20 micrometers and with a total water flow greater than 2.5 l/h for each meter of width of the roof. The sprinkler nozzles must be located inside the air chamber, near the inlet, downstream of the inlet hatch, and arranged in such a way as to favor the evaporation of the water in the air stream and at the same time avoid, as much as possible, surfaces to get wet.
The Figure 10 shows the assembly of the cover and its construction details.

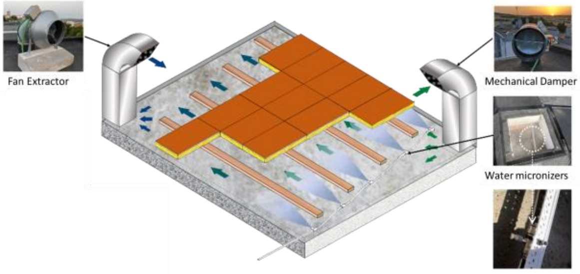


**Fig. 10-** Assembly of cover

## 4. Results

The change after the retrofit in the district is visually remarkable as shown in Fig. 11.

**Fig. 11-** Current state of the district

On the other hand, the cover has become a flat cover that can be fully used, with fans and extractors for air entry and exit (Fig.12).

**Fig. 12-** Current state of floor

Regarding the energy impact, this being the most important thing, the thermal evaluation of the buildings is carried out under the same climatic conditions as previously with the aim of subsequent comparison. For this purpose, the LIDER-CALENER Unified tool (HULC for its acronym in Spanish) is used, the official energy certification tool for buildings in Spain [13] and used by numerous studies in the recent literature [14,15]. The effect of different operating operations for one of the houses under cover in a cooling regime is analyzed. The operating operations analyzed are: ventilation operation during 8 hours at night, ventilation operation and evaporative cooling during 8 hours at night, and ventilation operation and evaporative cooling throughout the day.

**Tab.3 –** Evaluation of diferent operations

| Type of operation | Cooling needs (kwh/m$^2$ year) | % Improvement |
|---|---|---|
| Initial case | 24.7 | - |
| Conventional rehabilitation | 21.5 | - |
| Conventional rehabilitation + vent 8h | 15.56 | **28** |
| Conventional | 13.19 | **39** |

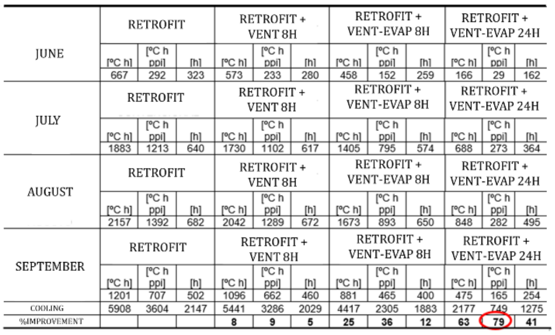
| | | |
|---|---|---|
| rehabilitation + vent-evap 8h | | |
| Conventional rehabilitation + vent-evap 24h | 7.66 | **65** |

As can be seen in Table 3, the operation of the ventilated roof in cooling mode increases the percentage of reduction in cooling demand from a minimum of 28% when it operates only at night in ventilation mode, to 65% when operates in ventilation and evaporative cooling mode 24 hours a day. The solution studied in the present work highlights that it is capable of achieving the maximum percentage of reduction of the load expected in the literature without causing an increase in the heating load.

In addition to the results on demand, the impact on the interior temperature of the house is evaluated, and therefore, the improvement of thermal comfort achieved after the implementation and operation of the ventilated roof. For a house under cover, the interior temperature of the house can drop up to 4 degrees compared to the non-operation of the cover when it works in ventilation and evaporative cooling mode throughout the day.

Finally, the impact is evaluated in terms of thermal comfort (Tab. 4). The results show that the operation of the active cover in ventilation mode at night reduces thermal discomfort by up to 9% compared to the conventional improvement situation (the ventilated cover does not operate). The use of the evaporative cooling system considerably increases the improvement of thermal comfort, being 36% when the operation of the same occurs only at night but reaches 80% if the use of said system occurs (ventilation and evaporative) throughout the day.

**Tab.4 –** Thermal comfort results



| | RETROFIT | | | RETROFIT + VENT 8H | | | RETROFIT + VENT-EVAP 8H | | | RETROFIT + VENT-EVAP 24H | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JUNE | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] |
| | 667 | 292 | 323 | 573 | 233 | 280 | 458 | 152 | 259 | 166 | 29 | 162 |
| | RETROFIT | | | RETROFIT + VENT 8H | | | RETROFIT + VENT-EVAP 8H | | | RETROFIT + VENT-EVAP 24H | | |
| JULY | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] |
| | 1883 | 1213 | 640 | 1730 | 1102 | 617 | 1405 | 795 | 574 | 688 | 273 | 364 |
| | RETROFIT | | | RETROFIT + VENT 8H | | | RETROFIT + VENT-EVAP 8H | | | RETROFIT + VENT-EVAP 24H | | |
| AUGUST | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] |
| | 2157 | 1392 | 682 | 2042 | 1289 | 672 | 1673 | 893 | 650 | 848 | 282 | 495 |
| | RETROFIT | | | RETROFIT + VENT 8H | | | RETROFIT + VENT-EVAP 8H | | | RETROFIT + VENT-EVAP 24H | | |
| SEPTEMBER | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] | [ºC h] | [ºC h ppi] | [h] |
| | 1201 | 707 | 502 | 1096 | 662 | 460 | 881 | 465 | 400 | 475 | 165 | 254 |
| COOLING | 5908 | 3604 | 2147 | 5441 | 3286 | 2029 | 4417 | 2305 | 1883 | 2177 | 749 | 1275 |
| %IMPROVEMENT | | | | **8** | **9** | **5** | **25** | **36** | **12** | **63** | **79** | **41** |

The results obtained show not only the importance of integrating the ventilated roofing solution but also the optimal operating mode, which will clearly depend on the climatic zone where said system is located.

## 5. Conclusions

The social housing districts of southern Spain are subject to energy poverty and buildings overheating. In order to mitigate this problem in a set of real houses located in Morón de la Frontera, Seville, in the present work the design and integration of a reinforced comprehensive retrofit solution has been carried out through the use of a ventilated roof solution as a passive cooling technique. The proposed roof design allows the integration of two environmental heat sinks: cold night air and evaporative cooling. The results of the evaluation of the energy impact of the solution show that the integration of the roof solution as a passive cooling technique can achieve a reduction of the cooling load of 65% without penalizing the heating regime. The present study also highlights the real integration of the proposed solution in more than 2000 m2 and being one of the first real experiences in the world of such magnitude.

## 6. Acknowledgement

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