PERMEABLE AND VENTILATED ROOFS: AN EMERGING SOLUTION FOR BUILDING COMFORT AND CLIMATE MITIGATION IN URBAN CENTERS. THE PROJECT LIFE SUPERHERO

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ABSTRACT

During the last 15 years, the frequency and intensity of heatwaves have increased in all the EU. In response to warming cities, the growth in environmental impacts and global demand for building cooling are two of the most critical energy issues of our time. Many EU cities are already working on climate mitigation strategies, while urban adaptation is still a novel challenge and requires the urgent development of specific measures to change urban design and structures. Indeed, renovation of existing buildings and design of new ones has a great urban adaptation potential against the "heat" challenge. An effective sustainable and low-cost answer to cities and building overheating is using building "passive cooling" technologies, which allow reducing the temperatures of the building envelope and consequently of the surrounding air, rather than increasing energy demands from artificial cooling. LIFE SUPERHERO seeks to exploit a specific building passive cooling solution: the Ventilated and Permeable Roofs (VPRs) based on roof tile designed during the previous project LIFE HEROTILE.

As the roof is the most exposed element to solar radiation, a "vented roof", obtained through an air space between the installed roof covering and the roof sheathing, could limit the summer heat fluxing into the building, thus reducing roof and wall temperatures. This space reduces heat transfer and allows the roof to "breathe" and disperse the accumulated solar heat. If this ventilation is coupled to a "high permeability" of the roof tiles, it is possible to obtain a considerable increase in the cooling performance. However, current EU national regulations, standards, green rating systems and procurements in the building sector do not recognize the cooling potential of VPRs, mainly focusing on winter heating saving. In particular, there are two main barriers to overcome: the lack of specific policies/legislative frameworks and the lack of people's awareness of their potential. The goals of the project will be achieved:

- by implementing a specific EU standard (ETA) and improving building environmental protocols and national building codes considering HBR (Herotile-Based Roof) benefits;
- through two building demonstrators where the impact of HBR on occupants' behavior will be monitored and consequently public and stakeholders' awareness promoted;
- by entailing the development of free LCA/LCC software, to facilitate the implementation of climate change adaptation strategies and action plans at a local level.

LIFE SUPERHERO thus promotes a synergy between climate adaptation and mitigation actions. The VPR-HBR allows increasing building and city thermal comfort (adaptation) due to the limitation of external building roof temperature in hot seasons, thus reducing the Urban Heat Island phenomenon. The limitation on internal building roof temperature in hot seasons improves occupants' comfort, entailing a reduction of cooling energy demand and GHG (Green House Gases) and accelerating the phase-down of HFC (Hydro Fluor Carbon) included in refrigerants (mitigation).

1-INTRODUCTION

All scientific data and reports on climate risks, at international, national, and local levels [1,2,3] say only one thing: climate changes are very evident, consistent and increasingly high-impact. And it is, therefore, necessary to act, quickly and decisively, to implement mitigation measures, which reduce the concentration of climate-altering gases in the atmosphere, and adaptation, to make our cities and our territories resilient and prepared to face climatic events. In particular, during the last 15 years, the frequency and intensity of heatwaves have increased in all the EU, this being especially evident in urban areas [4], exacerbating Urban Heat Island (UHI) phenomenon.

In the EU, construction is one of the sectors with the highest impacts on the Climate (buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU) and 84% of building heating and cooling is still generated from fossil fuels.

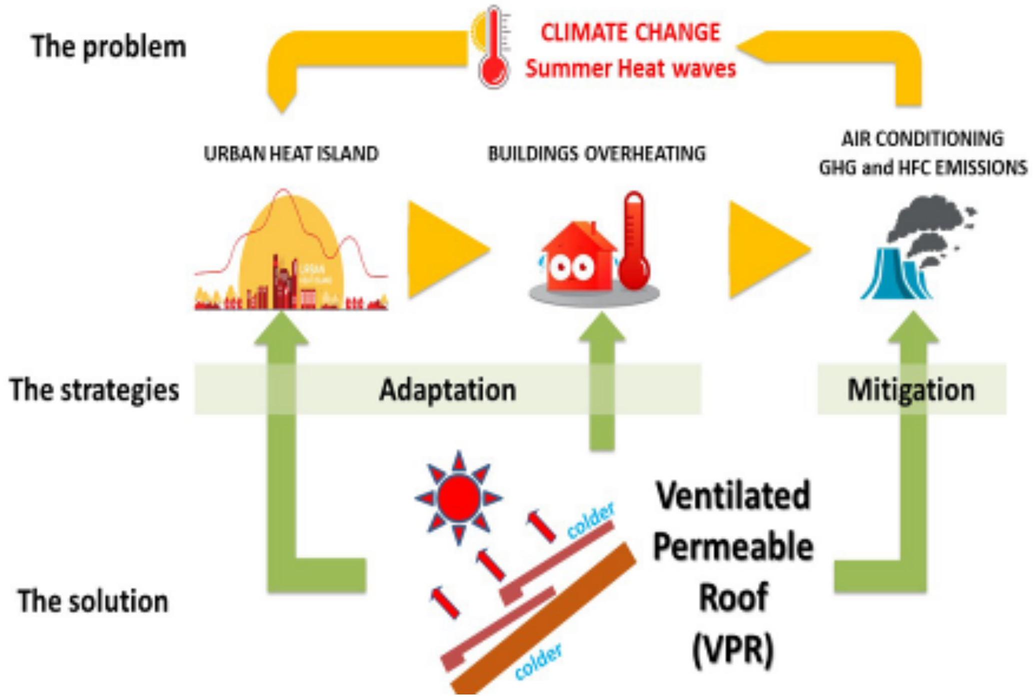


Figure 1 *VPR positive impacts on building and city thermal comfort (adaptation) and on cooling energy and GHG emissions (mitigation)*

In response to the warming of cities, the growth in environmental impacts and global demand for building cooling is one of the most critical energy issues of our time, because of the intense use of air conditioning in buildings and the consequent Greenhouse Gas (GHG) emissions, due to cities and buildings overheating, will contribute to exacerbating the climate emergency resulting in a climate "vicious circle" (Figure 1).

The building sector is therefore asked to reduce its environmental impact, mainly increasing building energy efficiency and reducing their greenhouse emissions. In this context, building roofs, which daily receive a big amount of solar radiation, become one of the most critical elements for reaching 2050 decarbonization goals [5].

2-THE BACKGROUND: THE VENTILATED PERMEABLE ROOF (VPR)

Measures to introduce, upgrade and enforce building energy codes are urgently needed to achieve climate targets. They will need to accommodate rapid building sector expansion while improving the thermal comfort of buildings without significantly raising energy demand and resultant emissions using best practices and suitable technologies. An effective, sustainable and low-cost answer to cities and buildings overheating is using building "passive cooling" technologies, which allow reducing the temperatures of building envelopes (roofs and walls) and consequently of the surrounding air (thus limiting the UHI), rather than increasing energy demands from artificial cooling. The Ventilated Permeable Roof (VPR), made up of clay tiles, is obtained through an air space between the installed roof covering and the roof sheathing. This space reduces heat transfer and allows the roof to "breathe" and disperse the accumulated solar heat, with a high performance that remains stable over time[6].

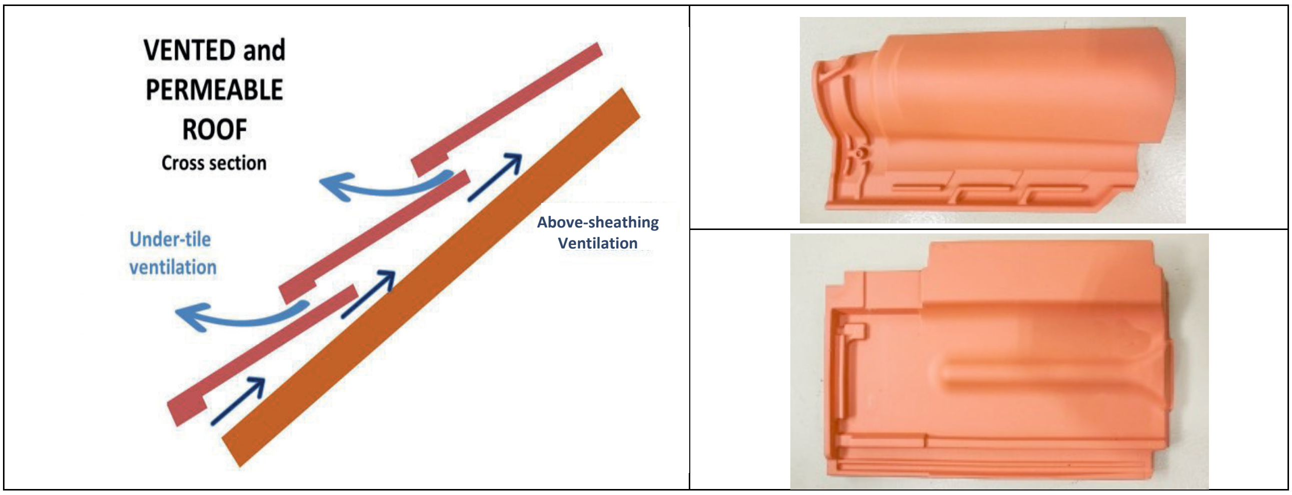


***Figure 2** The concept of a VPR (left), the Herotiles developed during the project LIFE HEROTILE (right)*

This airflow (above-sheathing ventilation) from the eaves to the ridge could be implemented by increasing the air permeability between the clay tiles. A previous LIFE HEROTILE European project developed a novel shape of roof tiles (Figure 2) and demonstrated the effectiveness of the new Ventilated and Permeable HEROTILES-Based Roof (VPR-HBR) i) in reducing up to 50% cooling energy compared to other solutions, ii) in saving up to 30% of CO_2 emissions due to energy consumption compared to traditional tiles and iii) in saving CO_2 emission during the production phase [7,8,9].

3-THE LIFE SUPERHERO PROJECT

Despite these impressive results and recent research [10÷17], actual EU and national regulations, standards, green rating systems, and procurements in the building sector are not able to recognize the cooling potential of the VPR for summer energy saving. They are still mainly focused on winter heating and, consequently, the VPR for climate adaptation and mitigation is still pretty unknown to common people, building stakeholders and policymakers, thus limiting its replicability and transferability. For this reason, a new project has been submitted to overcome these legislative barriers and promote awareness on these new technologies.

The structure of the LIFE SUPERHERO Consortium, encompassing three EU Member States (Italy, France and Spain) includes: roof tile producers (TERREAL, ICP and EDILIANS), Association of Producers (EDICER and HISPALYT), Social Housing Tenants (ACER) and Research Centres (Centro Ceramico, UNIVPM and CTMNC).

The objective of LIFE SUPERHERO is to promote the use of VPRs, and especially the improved HBR, as an effective climate adaptation (increasing building occupant and city summer comfort) and mitigation (decreasing building energy consumption and GHG emissions) solution. To this end, the project includes a strategy based on 4 parallel action pillars:

- Standards and regulations proposal, to overcome the existing policies/legislative/standard barriers to the dissemination of VPRs and HBRs, acting at different levels in terms of diffusion (national and EU) and technical scale (from product to building level). This action will assess the production of a standardized air permeability test method, included in a voluntary ETA and a CEN standard; the proposal of updating building green rating systems and public procurement including VPR environmental benefits; the proposal of improving existing CEN standards in order to include VPR in building energy calculation.
- Best practice for the realization of HEROTILE-Based Roofs (HBR) to develop guidelines on proper roof renovation strategies to be used as climate solutions. A HBR will be installed on two buildings in Reggio Emilia (IT), demonstrating its easy and cost-effective realization, while entailing high energy and environmental performance (reduced covering temperature thus UHI; reduced Air Conditioning use). This will increase public/policy makers'/stakeholders' awareness of HBRs and VPRs.
- Development of SUPERHERO software, a decision support tool for building consultants and public administrations, to assess life-cycle environmental and economic benefits of VPRs and HBRs, in order to select the best design solutions for their projects and climate plans.
- Replicability, transferability and best practice creation for tile producers. This action will set the basis for strong market penetration of VPRs and HBRs, thus amplifying the climate impacts obtained by the project. It will include a set of transferability activities; define a best practice for the easy and cost-effective transformation of traditional roof tiles production processes in HEROTILE ones; realize a business plan; create a HBR trademark and promote the VPR and HBR concept.

The project activities, under the coordination of Centro Ceramico, started just one year ago and focused in particular on the first two pillars of the defined strategy. In the first year, 4 European research laboratories CC, CTMNC, UNIVPM of SUPERHERO Consortium and BMI, which was involved in the previous HEROTILE project have planned a Round Robin Test aimed at carrying out permeability measures on different types of roofs. The purpose is to implement a standardized test method that considers air permeability as a parameter of the roofing system included in a European Technical Assessment (ETA) and in a CEN standard.

The activities already carried out within the second pillar are detailed in the following sections.

4-THE DEMONSTRATION ACTION OF THE LIFE SUPERHERO PROJECT

In accordance with the second action pillar (ACTION C2: Best-practice for HEROTILE-based roofs), a HBR will be installed on two existing multi-story residential buildings with unventilated flat roofs (Figure 3) placed in Reggio Emilia (Center of Italy). This urban area, in the middle of Po Valley, is characterized by a Mediterranean/Humid subtropical and humid continental climate particularly subject to climatic stressors and UHI.

4.1-THE BUILDING CASE STUDIES AND THE RENOVATION PLAN

These two buildings were chosen as demonstrators because they are representative of typical Southern and Continental European buildings, with low energy quality and comfort. Hence, they fully represent an appropriate context to support the creation of a best practice to shift flat roofs into lightweight eco-friendly attic floors with HBRs in the context of a global building renovation, while entailing reduced covering temperature and summer use of air-conditioning.

In particular, building #1 (Street Maramotti n°23) was built in 1984 and the existing roof covers five flats with a surface area of 242 m^2. Building #2 (Street Maramotti n°25) was built in 1981 and the attic is composed of five flats with a surface area of 345 m^2.

The demonstrator buildings will be completely renovated in two steps, while their summer thermal and energy performance monitored during 3 summer periods between 2021 and 2023 (Figure 4).

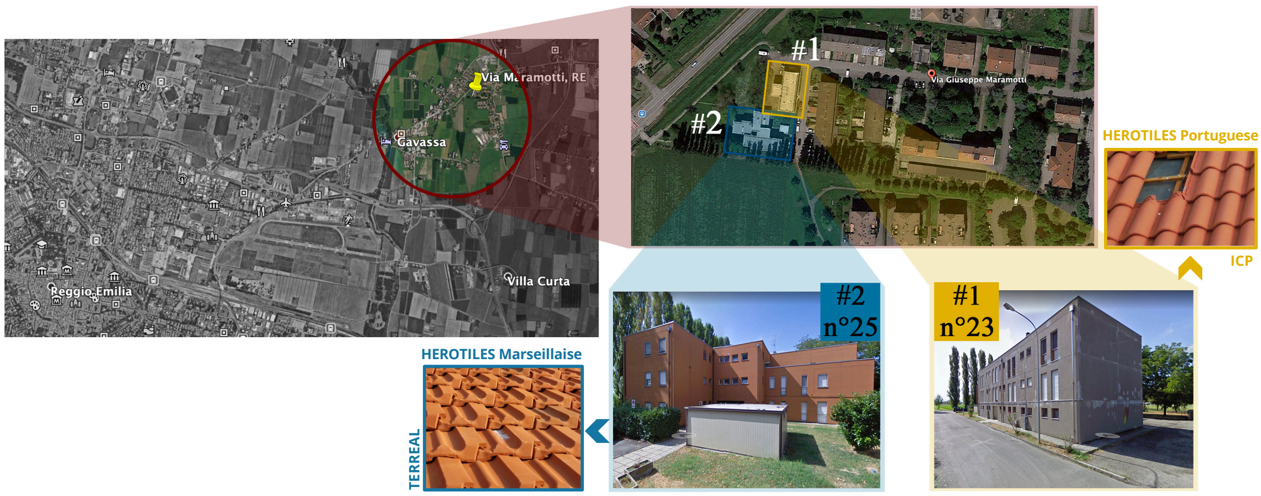


Figure 3 *Localization of the monitored buildings in Reggio Emilia*

Firstly, the existing buildings, were monitored in the summer of 2021. Secondly, during the autumn-winter of 2021-2022, the two buildings will be retrofitted with an external thermal insulation layer and the existing windows will be replaced. Finally, by summer 2023, the buildings will be monitored in their final renovation configuration, which entails the realization of a new attic floor covered by two HEROTILE typologies: Portuguese by ICP for building #1 and Marseillaise by TERREAL for building #2.

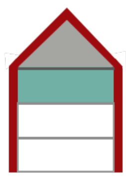
2021	2022	2023
Existing buildings with unventilated flat roof	Renovated buildings (external insulation and new windows)	Renovated buildings with HBR
		
Monitoring before renovation	Monitoring after renovation	Monitoring after renovation with HBR

Figure 4 *The monitoring schedule*

4.2-THE MONITORING PLAN

The monitoring activity aims to detect the indoor and outdoor environmental conditions, the occupants' behavior and the roof thermal performance.

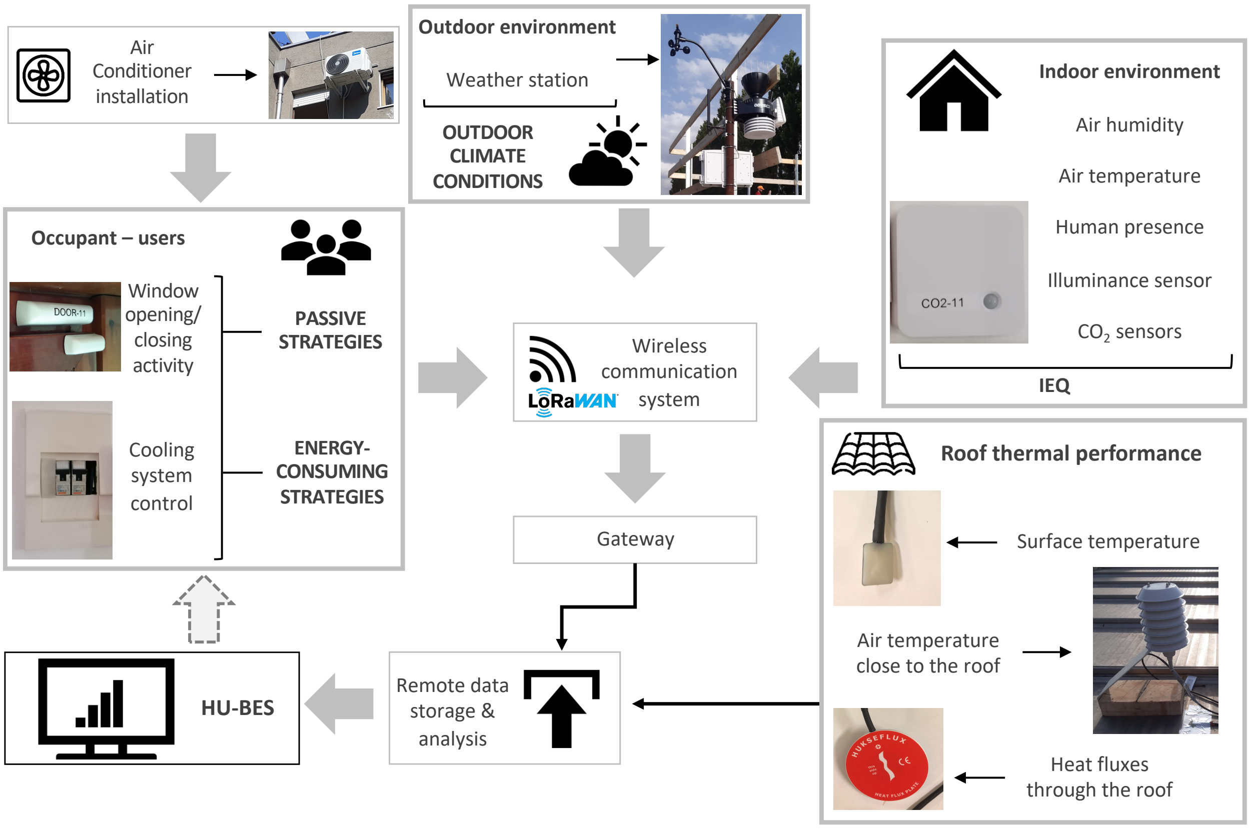


Figure 5 *The monitoring system*

It entails a wireless communication system including several devices (Figure 5) aimed at collecting data on:

- the outdoor climate conditions (air humidity/temperature, global solar radiation, wind velocity/direction, rain);
- the indoor environmental quality (air humidity/temperature, illuminance, CO_2 emissions) in the living rooms and bedrooms of the monitored attic flats;
- the occupants' energy use for cooling and behaviors (windows opening/closing)

The roof thermal performance (indoor/outdoor surface temperature, heat flux, air temperature close to the tiles) is also monitored (Figure 6).

The installation of the monitoring system was concluded in June 2021 and data have been collected since August 2021. Interviews with buildings' occupants were also performed to monitor their overall thermal sensation and energy behavior. The next section sums up some preliminary results of these activities.

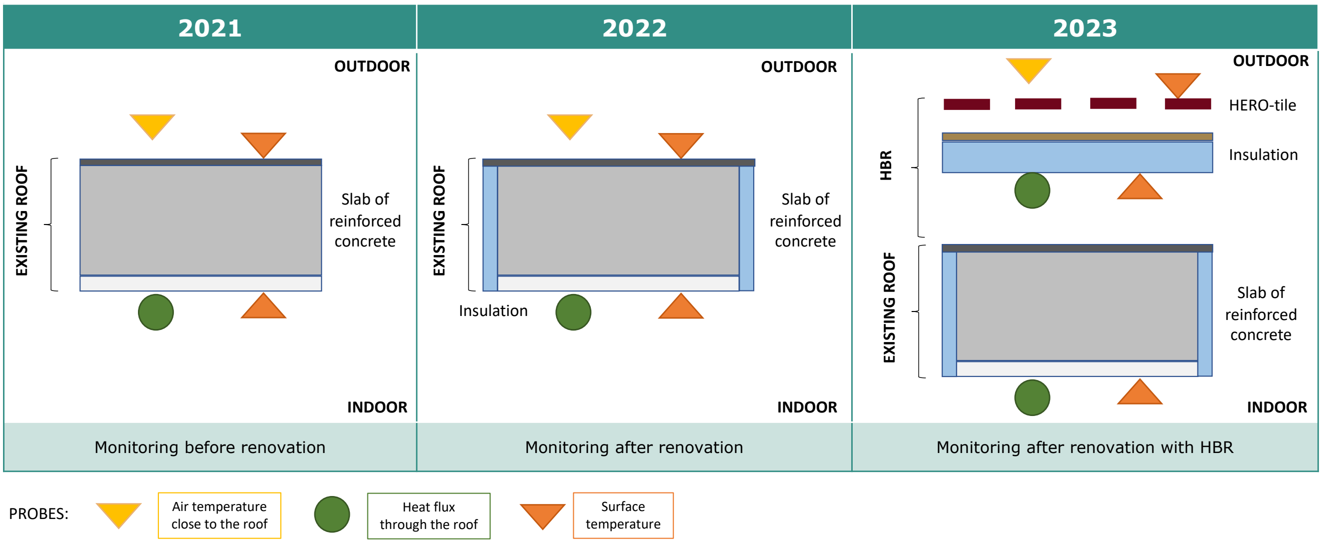


Figure 6 *The monitoring probes on the roof across the three summer periods*

4.3-THE PRELIMINARY RESULTS

Results of the monitoring campaign are presented for an unoccupied and an occupied apartment of building #23. In particular, the unoccupied apartment is characterized by west-facing windows only, closed during the monitoring period and without blinds. The direct afternoon solar radiation is, however, shielded by the row of trees placed in front of the windows. Conversely, the occupied apartment is characterized by east-facing windows only.

In Figure 7, the outdoor and indoor air temperatures ($T_{air,o}$ and $T_{air,i}$, respectively) and the surface indoor and outdoor temperatures of the roof ($T_{s,i}$ and $T_{s,o}$) are reported for the two flats and during three hot days in summer. These days are characterized by quite high daily temperatures, with peaks between 36°C and 38°C. As expected, $T_{s,o}$ reach very high values in both cases (peaks between 65°C and 75°C), due to the external metal finishing of the actual roof.

In general, in the unoccupied flat, without a conditioning system, the indoor environment is characterized by a very high temperature of both air and indoor roof surface (about 30°C). In the occupied flat, a lower $T_{air,I}$ is reached, caused by the occupant's use of the conditioning system, as also showed by the irregular oscillation of the indoor air temperature trend in this case.

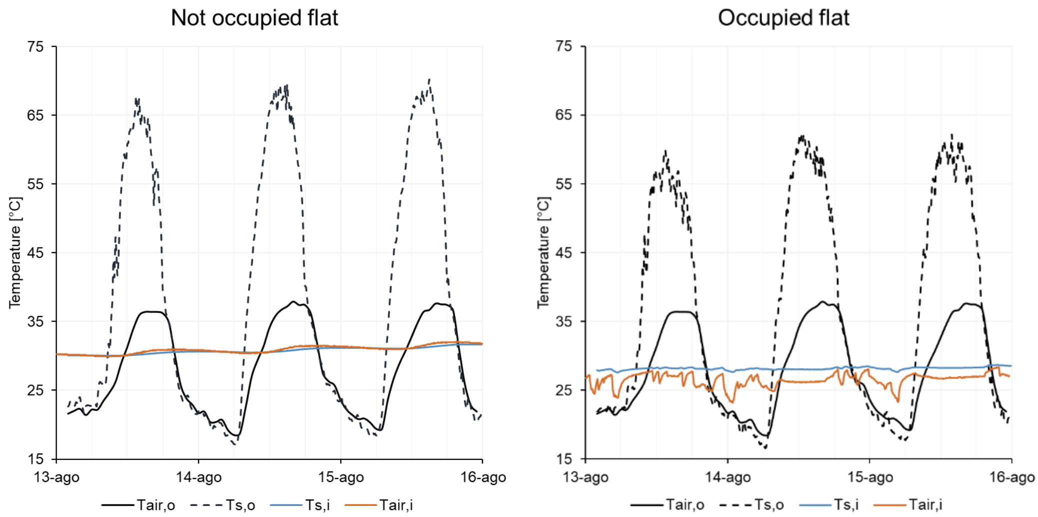


Figure 7 *Preliminary results of the monitoring campaign.*

Questionnaires provided to the occupants of both buildings confirm a general thermal discomfort in the indoor environment. As reported in Figure 8, all the occupants consider their thermal environment warm or hot (Figure 8a), with 80% of them considering it unpleasant in terms of thermal comfort (Figure 8b). Finally, all of them consider their thermal environment just acceptable when a cooling system is used (Figure 8c).

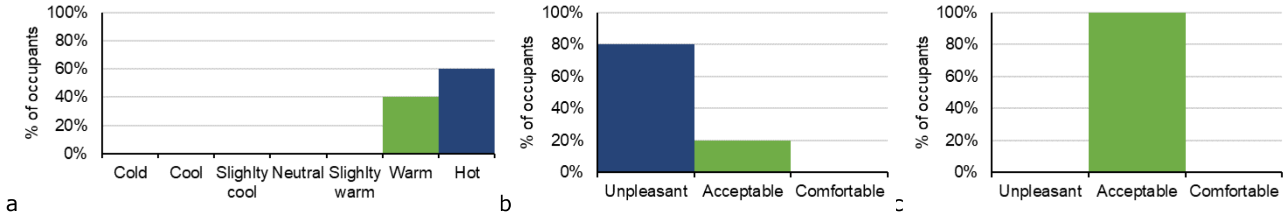


Figure 8 *Results of the questionnaires provided to the occupants. a) Thermal sensation vote on the indoor environment; b)Thermal comfort before the installation of the cooling system; c) Thermal comfort after the installation of the cooling system.*

5-CONCLUSION

The LIFE SUPERHERO project aims to disseminate the use of the HEROTILE-based roof concept as a sustainable passive cooling technology. In this context, one of the main project actions is the "Best-practice for HEROTILE-based roofs", i.e. the demonstration of the easy and cost-effective realization of a HBR over existing buildings and its in situ high energy and environmental performance.

Before summer 2021, a monitoring campaign of the energy and thermal performance of two existing buildings in Reggio Emilia (Italy) was planned and put in place. The measurement data collected in summer 2021 describe the current performance of the existing buildings, which are characterized by a high-transmittance envelope. These data highlight a general unpleasant indoor environment, due to the high air temperatures reached when the air conditioning is not working. The buildings inhabitants report a general hot or warm thermal sensation in summer and thus the need of using air conditioning to reach an "acceptable" feeling of comfort.

These results underline the need for a general improvement of the building envelope to reach a more comfortable environment, as provided by the next renovation steps for the buildings.

6-ACKNOWLEDGEMENTS

LIFE HEROTILE project (LIFE14 CCA/IT/000939) "High energy savings in building cooling by Roof TILEs shape optimization toward a better above-sheathing ventilation" was funded by the EU LIFE "Climate Change Adaptation" programme https://www.lifeherotile.eu/it/

The work of LIFE SUPERHERO (LIFE19 CCA/IT/001194) "SUstainability and PERformaces for HEROTILE-based energy efficient roofs" is performed with the contribution of the LIFE Programme "Climate Change Adaptation" of the European Union

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