THE LIFE SUPERHERO PROJECT: PERMEABLE AND VENTILATED ROOFS AS AN EMERGENT SOLUTION FOR CLIMATE ADAPTION AND MITIGATION

B. Ferrari[a]; M. C. Bignozzi[a]; E. Di Giuseppe[b]; M. D'Orazio[b]; A. Gianangeli[b]; H. Mathieu[c]

[a]Centro Ceramico, Joint Lab SMILE, Via Terracini 28, 40131 Bologna, Italy
[b]Department of Construction, Civil Engineering and Architecture (DICEA), Marche Polytechnic University, Via Brecce Bianche 12, 60131 Ancona, Italy
[c]Centre Technique des Matériaux Naturels de Construction, 17 Rue Letellier, 75015 Paris, France

ABSTRACT

The global problem of climate change and the local phenomenon of Urban Heat Islands (UHIs), result during summer in an increasing overheating of cities and buildings with a consequent increase in energy consumption and emissions due to the use of cooling systems. The Above Sheathing Ventilation (ASV) airflow, characterizing ventilated clay tiles roofs, can significantly reduce the incoming thermal heat in summer period and thus the energy required for indoor cooling. If this is combined with an increase in roof "air permeability" by means of improved tile shape ("under-tile" ventilation), a further improvement in summer performance of the roof and benefits for the entire building are obtained. The HEROTILE project, completed in 2019 and funded under the European LIFE "Climate Change Adaption" program, made it possible to develop the HEROTILE roof tile, an innovative ventilated tile designed to improve air breathability while remaining impermeable to water. The HEROTILE project demonstrated the effectiveness of the HEROTILES-based roofs (HBRs) in reducing CO_2 emissions and up to 50% of cooling energy compared to other solutions.

Although the benefits of roof ventilation and air permeability are well-established in the scientific literature and the HEROTILE project has achieved significant technological improvement, the potential of ventilated and permeable roofs (VPRs) and HEROTILES-based roof (HBR) systems is still unknown, thus limiting their replicability and transferability. This work aims to promote an innovative concept of passive building cooling and to disseminate the use of VPRs and HBRs as effective, sustainable and low-cost solutions for climate adaptation and mitigation. The methods and the equipment of a novel experimental "air permeability test", developed as part of the SUPERHERO project (SUstainability and PERformances for HEROtile-based energy efficient roofs) of the LIFE Climate Change Adaption program, are presented. The test, developed on the basis of standards BS 5534 and ASTM C1570, consists of blowing or sucking air down the pipe into a plenum chamber, on top of which there is an assembly of roof tiles. The air pressure difference across the assembly and the volume airflow rate are measured and used to determine the air permeability of the assembly. The test aims to determine the performance of 18 types of roof tiles (including 2 types of HEROTILES), to cover almost all the different types of roof tiles available on the market: curved and flat, moulded and extruded. Preliminary tests contributed to understanding the influence of roof pitch and the importance of assembly operations. In this work, the test method used will be discussed and preliminary results obtained by 3 independent laboratories, partners of the SUPERHERO project, will be presented.

1. INTRODUCTION

Over the past 15 years, the frequency and intensity of heat waves have increased across the EU due to ongoing climate change. This, combined with increasing urbanization, exacerbates the Urban Heat Island (UHI) phenomenon, which leads to higher air temperatures in urban areas than in rural areas (Figure 1). The increasing overheating of cities and buildings has exacerbated other challenges, such as: the use of energy for cooling and the resulting CO_2 emissions; public health risks especially for the elderly and frail; reduced productivity and work efficiency; the inability to use public spaces; and the reduced durability of structures and infrastructure. These direct and indirect impacts strain the economy and quality of life [1]. The number of Europeans living in cities is projected to reach more than 80% in 2050 and energy demand for air conditioning in buildings will more than triple [2-3]. The resulting greenhouse gas emissions will contribute to the aggravation of the current climate emergency in a kind of "vicious circle" that needs to be addressed with specific and effective mitigation strategies, to reduce the concentration of climate-altering gases in the atmosphere, and adaptation, to make our cities and our territories resilient and ready to face climatic events.

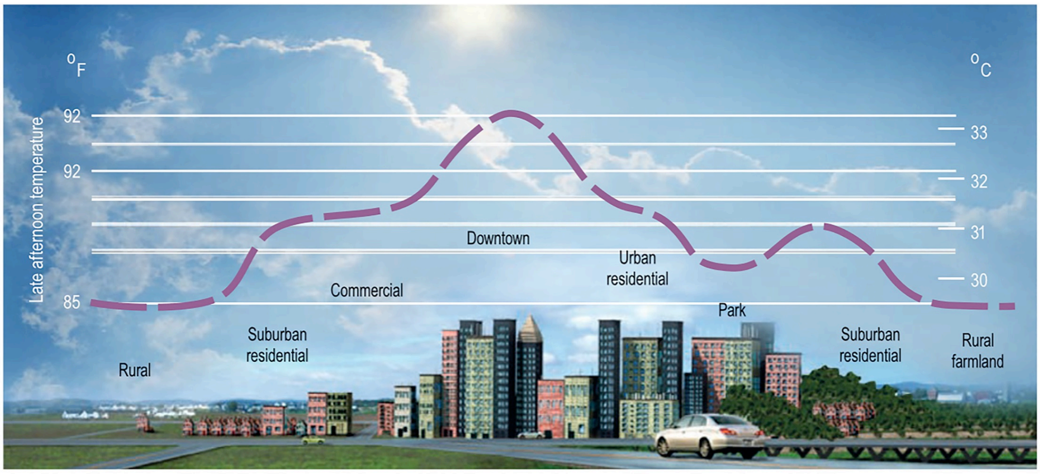


Figure 1: *Qualitative representation of the Urban Heat Island.*

2. VENTILATED AND PERMEABLE ROOFS

About 45% of today's buildings in the EU were built before the 1990s and almost 75% of the building stock is energy inefficient, while the renovation rate of building stock is very limited. The building construction sector is one of the EU sectors with the highest impacts on Climate. Buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU [4] and most building heating and cooling energy demand is still generated from fossil fuels.

An effective response to overheating in buildings is the use of "passive cooling" technologies that reduce the temperature of the building envelope, and consequently of the surrounding air, without energy expenditure. Among these, the use of Ventilated Permeable Roofs (VPRs) with clay tiles makes it possible to disperse accumulated solar heat effectively, both through Above Sheathing Ventilation (ASV) and tile transpiration ("under-tile" ventilation). Figure 2 shows the concept of a Ventilated and Permeable Roof (VPR).

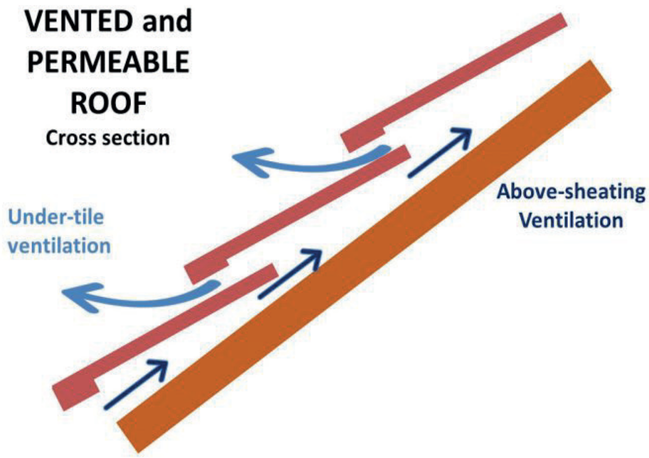


Figure 2*: The concept of a Ventilated and Permeable Roof (VPR)*

Compared with other popular technologies from recent decades, such as cool or green roofs, which require constant maintenance to ensure performance over time, VPRs are made with clay tiles, characterized by high durability and stable performances. A VPR is a sustainable and cost-effective solution for building "passive cooling", increasing building occupants' and cities summer comfort (adaptation) and decreasing buildings' energy and green-house gasses emissions (mitigation). The effectiveness of this solution is also derived from the results of the LIFE HEROTILE project (LIFE14 CCA/IT/000939) in which new types of clay tiles, called HEROTILES, whose aerodynamic shape allows their air permeability to be optimized, were designed and tested (Figure 3). The project, which ended in 2019, also demonstrated the effectiveness of Herotile Based Roofs (HBRs) in reducing up to 50% of the energy used for air conditioning in buildings [5].

***Figure 3**: The HEROTILES developed during the LIFE HEROTILE project.*

3. THE LIFE SUPERHERO PROJECT

Although the benefits of ventilation and air permeability of roofs are well established in the scientific literature [6-13] and the LIFE HEROTILE project has achieved significant technological improvement, the cooling potential of VPR and HBR roofs is still severely limited by current EU and national regulations, standards, green rating systems and procurements, which only take into account alternative technologies including green and cool roofs. They are also still mainly focused on winter heating, 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 (SUstainability and PERformances for HEROtile-based energy efficient roofs) Consortium, covering three EU Member States (Italy, France and Spain) includes: roof tile producers, producers associations, social housing tenants and research centres.

The objective of LIFE SUPERHERO is to promote the use of VPRs, and especially the improved HBR, as an effective climate adaptation and mitigation solution.

With this aim, the project includes a strategy based on 4 parallel action pillars:

1. 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 dissemination (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 the VPR into the building energy calculation.
2. Best practice for the realization of HEROTILE-Based Roofs (HBRs) to develop guidelines on proper roof renovation strategies to be used as climate solutions. HBRs will be installed on two buildings in Reggio Emilia (IT), demonstrating their easy and cost-effective realization, while entailing high energy and environmental performance (reduced covering temperature and thus lower UHI; reduced Air Conditioning use). This will increase public/policymaker/stakeholder awareness of HBRs and VPRs.
3. 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.
4. 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.

Project activities, under the coordination of Centro Ceramico, began in 2020 and are still ongoing. Activities already carried out under pillar 1, are detailed in the following sections.

4. AIR PERMEABILITY TEST METHOD

In these months, 3 European research laboratories of the SUPERHERO Consortium (CC, CTMNC, UNIVPM) have planned a Round Robin Test aimed at carrying out permeability measures on 18 different types of roof tiles (including 2 types of HEROTILES) to cover almost all the different types of roof tiles available on the market: curved and flat, moulded and extruded.

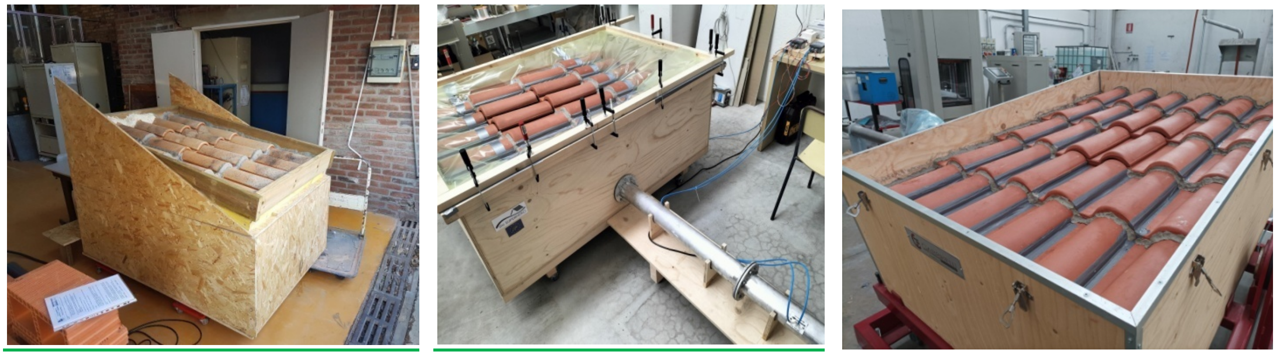
The purpose is to implement a standardized test method that considers "air permeability" as a parameter of the roofing system included in a European Assessment Document (EAD) or in a CEN Technical standard.

The test consists of blowing or sucking air down a pipe into a plenum chamber (see Figure 4), on top of which there is an assembly of roof tiles with 4 unsealed elements, and of calculating air permeability (C_d) according to the following expression:

$$C_d = \frac{Q}{A} = \frac{1}{\sqrt{\frac{2 \cdot \Delta p}{\rho}}}$$

Where:

Δp pressure difference between the inside and outside of the plenum chamber [Pa];
Q volume air flow rate [m^3/s];
ρ density of air [kg/m^3];
A effective area of the roofing assembly [m^2];



(a) (b) (c)

Figure 3: *Test assembly from Centre Technique del Matériaux Naturels de Construction (a), Marche Polytechnic University (b) and Centro Ceramico (c).*

The test assembly and the procedure are compliant with the standard provided in [14] and [15]. Methods and results were also compared with previous studies carried out during the LIFE HEROTILE project [16-17]. The flow rate is controlled by an airflow generator (such as an electrically powered fan) able to induce a maximum pressure difference between the inside and outside of the plenum chamber of not less than 100 Pa. The flow rate is measured using an airflow meter, capable of measuring an air volume flow rate of not less than 0,25 m3/s in the delivery pipe. A manometer is used to measure the pressure difference (not less than 1000 N/m^2). The flow rate is record when a target pressure drop over a range of set values is achieved. Additionally, the laboratory pressure and temperature are measured to calculate the local air density (ρ). The plenum chamber, rectangular in plan, with a depth of not less than 0,5 m is large enough to accommodate at least 2 m^2 of clay roof tiles.

To check the airtightness of the assembly, the top of the plenum chamber was closed by attaching and sealing the edges of the cover panel to ensure there are no leaks except where connected to the delivery pipe.

Each type of roof tile is laid in accordance with the manufacturer's data sheets and using the recommended parameters (such as batten gauge and coverage width).

All non-representative joints and tile junctions are sealed, except for a minimum of 4 side locks and 4 head locks in the middle of the tile array (see Figure 4). Tests were performed using different roof pitch angles (0°, 10° and 25°).

Figure 4: *Unsealed elements of the assembly.*

RESULTS

The results for the Portuguese model Herotile (HT), developed in the LIFE HEROTILE project, and a Portuguese Classic (PC) that is taken as a reference are presented below. Table 1 and Figure 5 show the results obtained from the different laboratories compared.

Table 1	Aerodynamic area $Cd \cdot A$ [mm^2]					
	Herotile (HT)			**Portuguese Classic (PC)**		
	UNIVPM	CC	CTMNC	UNIVPM	CC	CTMNC
BLOW mode	8723	7082	11.832	5683	4780	6089
SUCK mode	9175	7295	-	5670	5395	-

Table 1: *Aerodynamic area $Cd \cdot A$ [mm^2] of Herotile and Portuguese Classic obtained by the different laboratories (CC, UNIVPM and CTMNC).*

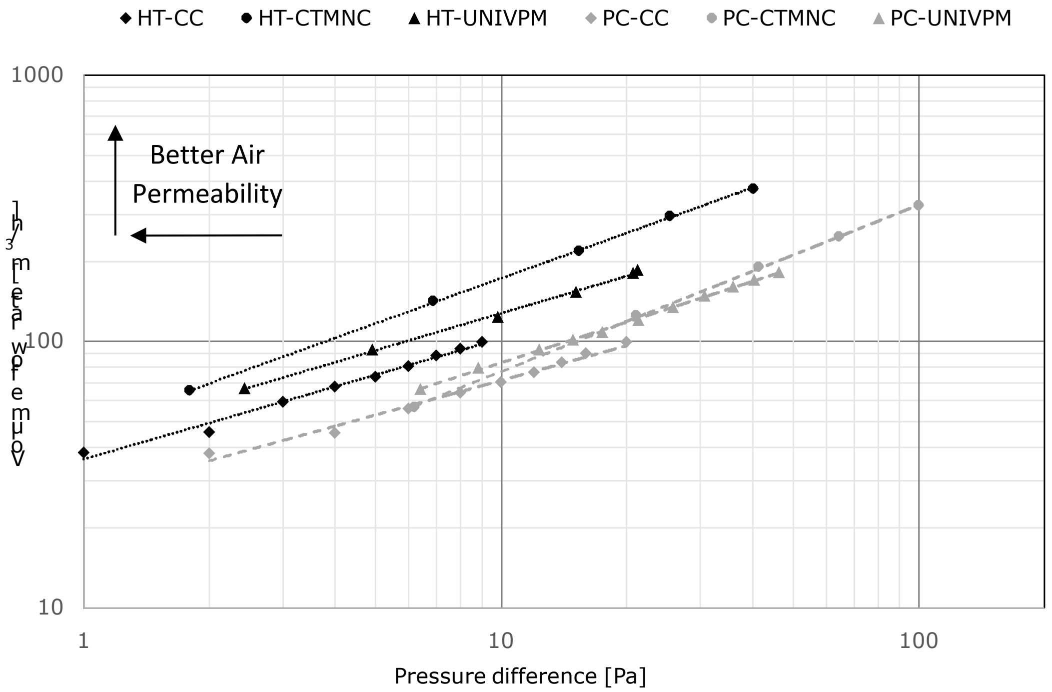


***Figure 5**: Air permeability of Herotile (in black) and Portuguese Classic (in grey) in blow mode.*

Figure 6 compares the results of the tests conducted by UNIVPM on both samples, varying the mode of fan operation from blowing to sucking. Finally, Figure 7 shows how air permeability varies as the pitch of the roofing system changes.

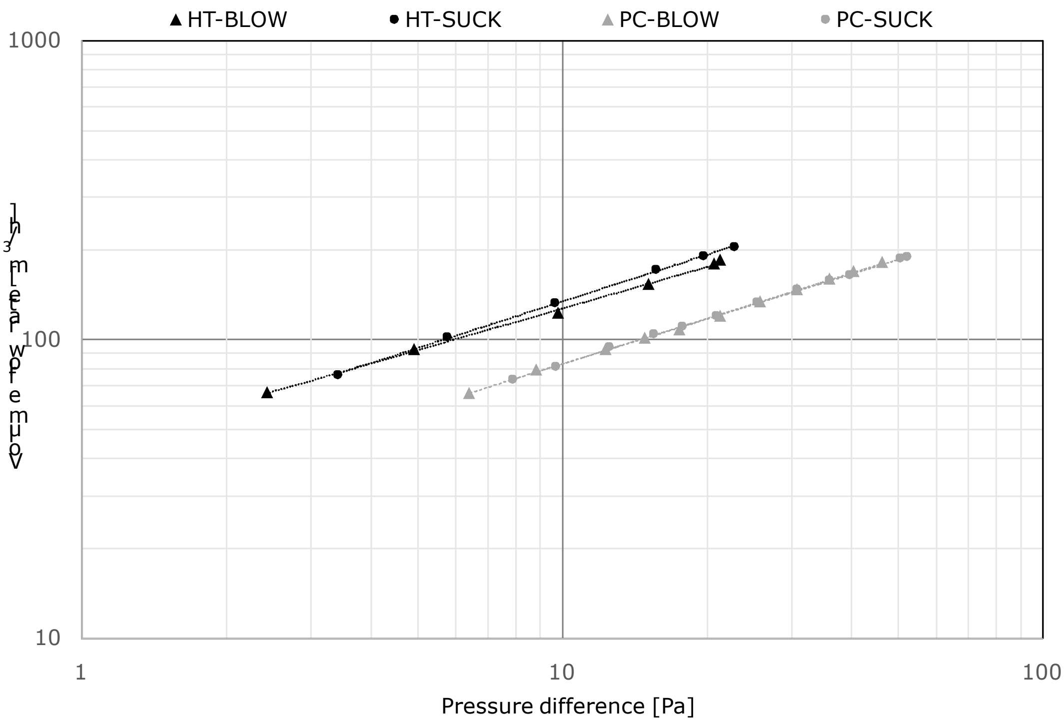


***Figure 6:** UNIVPM results of Herotile (in black) and Portuguese Classic (in grey) in blow and suction mode.*

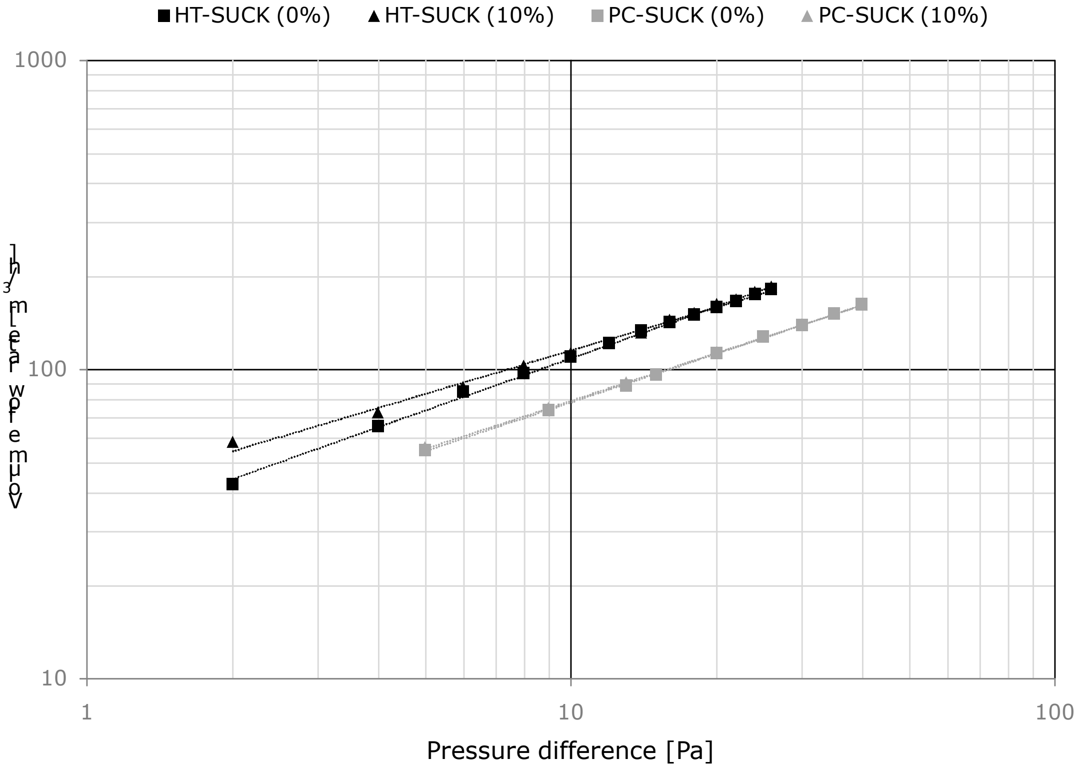


Figure 7: *CC results of Herotile (in black) and Portuguese Classic (in grey) in suction mode and varying the inclination of the assembly (0-10°).*

CONCLUSION

In conclusion, this study aimed to evaluate the air permeability of the roofing system using an innovative method. To validate the data obtained and demonstrate the system's effectiveness, a Round-Robin test was carried out by 3 independent laboratories. By comparing the results of air permeability, a difference in behaviour can be observed between the two types of Portuguese tiles analysed. In particular, all laboratories highlight that the Herotile (HT) is characterized by lower pressure differences and higher air flow rate than the Portuguese Classic (PC), thus demonstrating better air permeability. The values recorded by the different laboratories are characterized by some variability, probably due to the tile laying operations. The objective of the next tests will be to minimize the range of variability in the results. From the first results analysed, there is no evidence of significant variation in permeability as a function of the blowing/suction mode or roof pitch angle.

ACKNOWLEDGMENTS

The authors express their gratitude to the BMI Group for granting access to their expertise and for discussing the results obtained and methodologies applied. In addition, special thanks are extended to the industries involved in the LIFE SUPERHERO project for their technical support and the samples provided.

REFERENCES

[1] EEA Report 12/2016. Urban adaptation to climate change in Europe 2016: Transforming cities in a changing climate (2016)

[2] European Environment Agency. The European environment – state and outlook 2020. https://www.eea.europa.eu/soer/publications/soer-2020.

[3] International Energy Agency. The Future of Cooling. 2018.

[4] European Commission. Energy efficiency in buildings. https://commission.europa.eu/news/focus-energy-efficiency-buildings.

[5] LIFE HEROTILE. https://www.lifeherotile.eu/it/

[6] D'Orazio, M., Di Giuseppe, E., Di Perna, C., Cozzolino, N.: Una "riflettanza equivalente" per coperture ventilate in laterizio. Costr. Laterizio. 177, 76–91 (2018).

[7] D'Orazio, M., Di Giuseppe, E., Cozzolino, N., Allen, R., Di Fusco, A., D'Anna, G.: "Equivalent" reflectance of tiled pitched roofs. Assessment of benefits for cooling buildings and Urban Heat Island. Laterservice Edizioni (2019).

[8] Di Giuseppe, E., D'Orazio, M., Di Perna, C., Cozzolino, N.: Riflettanza equivalente di coperture ventilate. LIT, LATERIZI D'ITALIA. 5, 35–39 (2018).

[9] Bortoloni, M., Bottarelli, M., Piva, S., Summer Thermal Performance of Ventilated Roofs with Tiled Coverings, Journal of Physics: Conference Series. p. 012023 (2017).

[10] D'Orazio, M., Di Perna, C., Di Giuseppe, E.,The effects of roof covering on the thermal performance of highly insulated roofs in Mediterranean climates (2010): https://doi.org/10.1016/j.enbuild.2010.04.004

[11] Dimoudi, A., Androutsopoulos, A., Lykoudis, S.: Summer performance of a ventilated roof component. Energy Build. 38, 610–617 (2006): https://doi.org/10.1016/j.enbuild.2005.09.006

[12] De With, G., Cherry, N., Haig, J.: Thermal Benefits of Tiled Roofs with Above-sheathing Ventilation. J. Build. Phys. 33, 171–194 (2009): https://doi.org/10.1177/1744259109105238

[13] Di Giuseppe, E., Sabbatini, S., Cozzolino, N., Stipa, P., D'Orazio, M.: Optical properties of traditional clay tiles for ventilated roofs and implication on roof thermal performance, (2018): https://doi.org/10.1177/1744259118772265

[14] BS 5534:2014 Slating and Tiling for Pitched Roofs and Vertical Cladding – Code of Practice, BSI Standard Limited, (2015)

[15] ASTM C1570-22 Standard Test Method for Wind Resistance of Concrete and Clay Roof Tiles (Air Permeability Method), ASTM International, (2022)

[16] Bottarelli, M., Zannoni, G., Bortoloni, M., Allen, R., Cherry, N.: CFD analysis and experimental comparison of novel roof tile shapes, (2017): http://dx.doi.org/10.1016/j.jppr.2017.05.006

[17] Bottarelli, M., Bortoloni, M., Zannoni, G., Allen, R., Cherry, N.: CFD analysis of roof tile coverings, (2017): http://dx.doi.org/10.1016/j.energy.2017.03.081