life SUPERHERO

Roofs passive cooling performance through air permeability of tiles: development of a standardized laboratory assessment method

16 January 2025 – TBE

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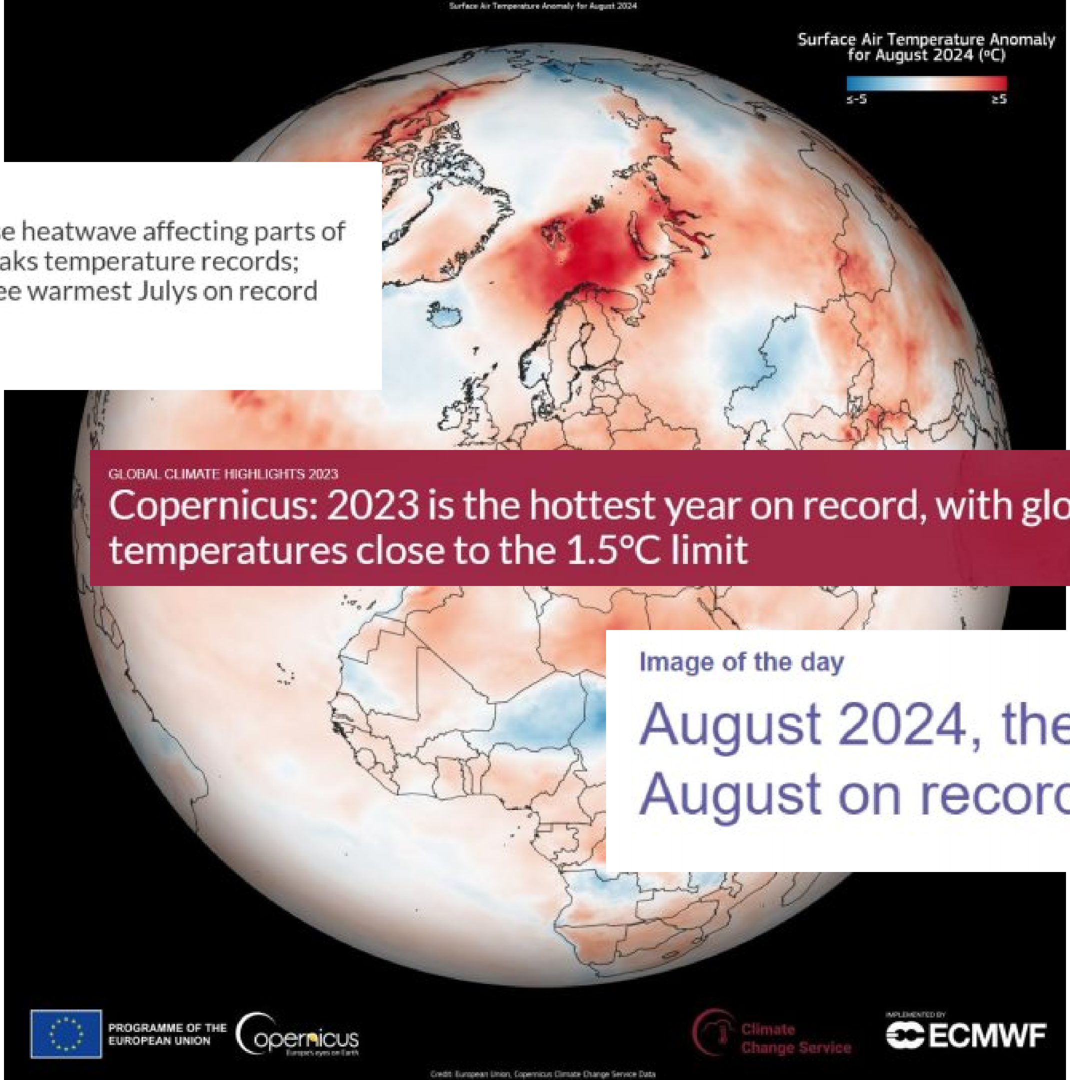
UNIVPM

Home / Press releases

Copernicus: Prolonged and intense heatwave affecting parts of western and northern Europe breaks temperature records; globally, July 2022 was one of three warmest Julys on record

8th August 2022

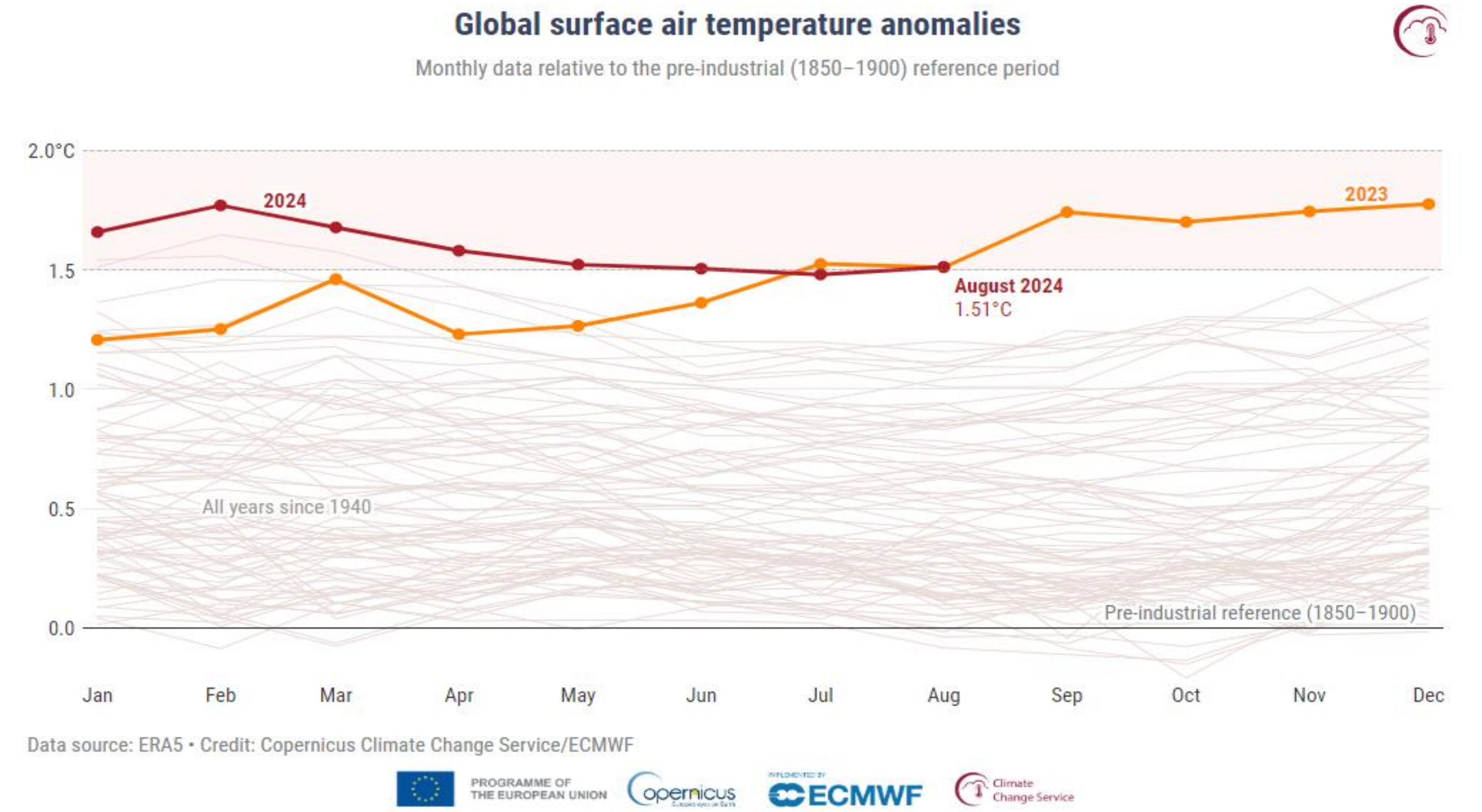


GLOBAL CLIMATE HIGHLIGHTS 2023

Copernicus: 2023 is the hottest year on record, with global temperatures close to the 1.5°C limit

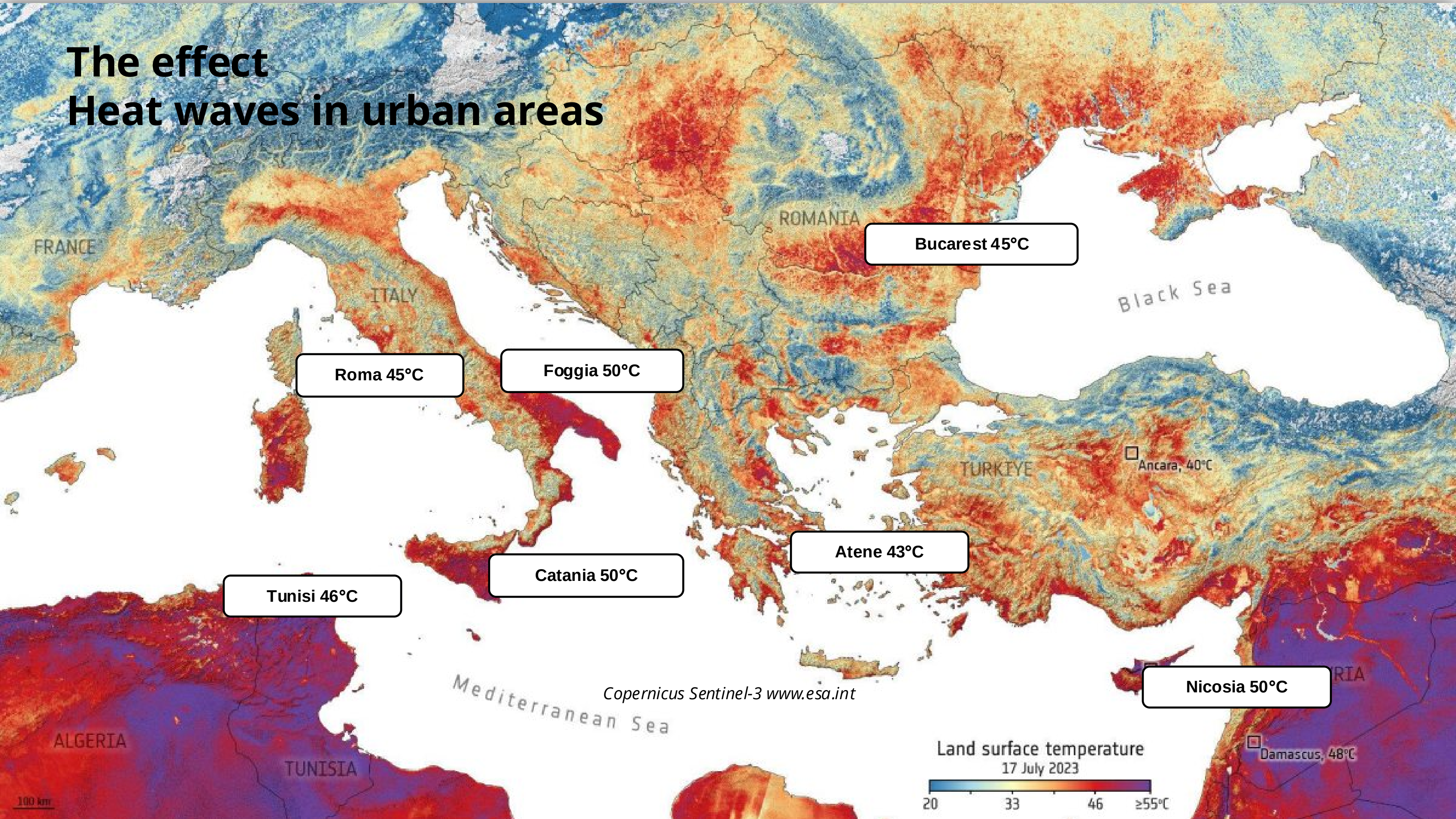
Image of the day

August 2024, the warmest August on record



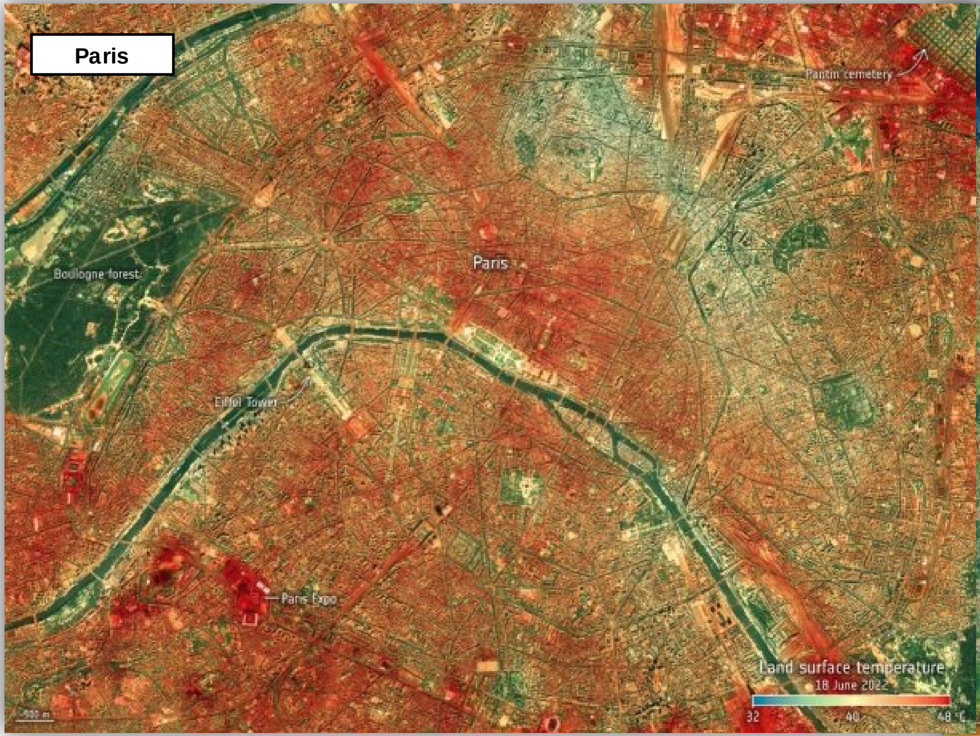
Global surface air temperature anomalies
Monthly data relative to the pre-industrial (1850–1900) reference period
2.0°C
1.5
1.0
0.5
0.0
2024
2023
August 2024
1.51°C
All years since 1940
Pre-industrial reference (1850–1900)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Data source: ERA5 • Credit: Copernicus Climate Change Service/ECMWF
PROGRAMME OF THE EUROPEAN UNION
Copernicus
ECMWF
Climate Change Service

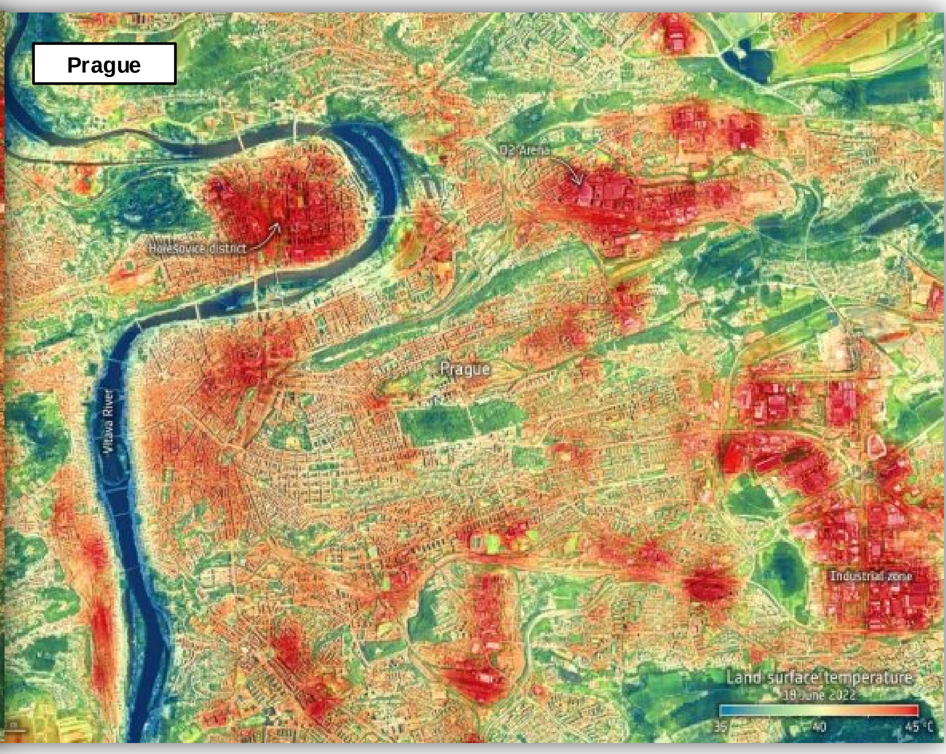
The effect
Heat waves in urban areas



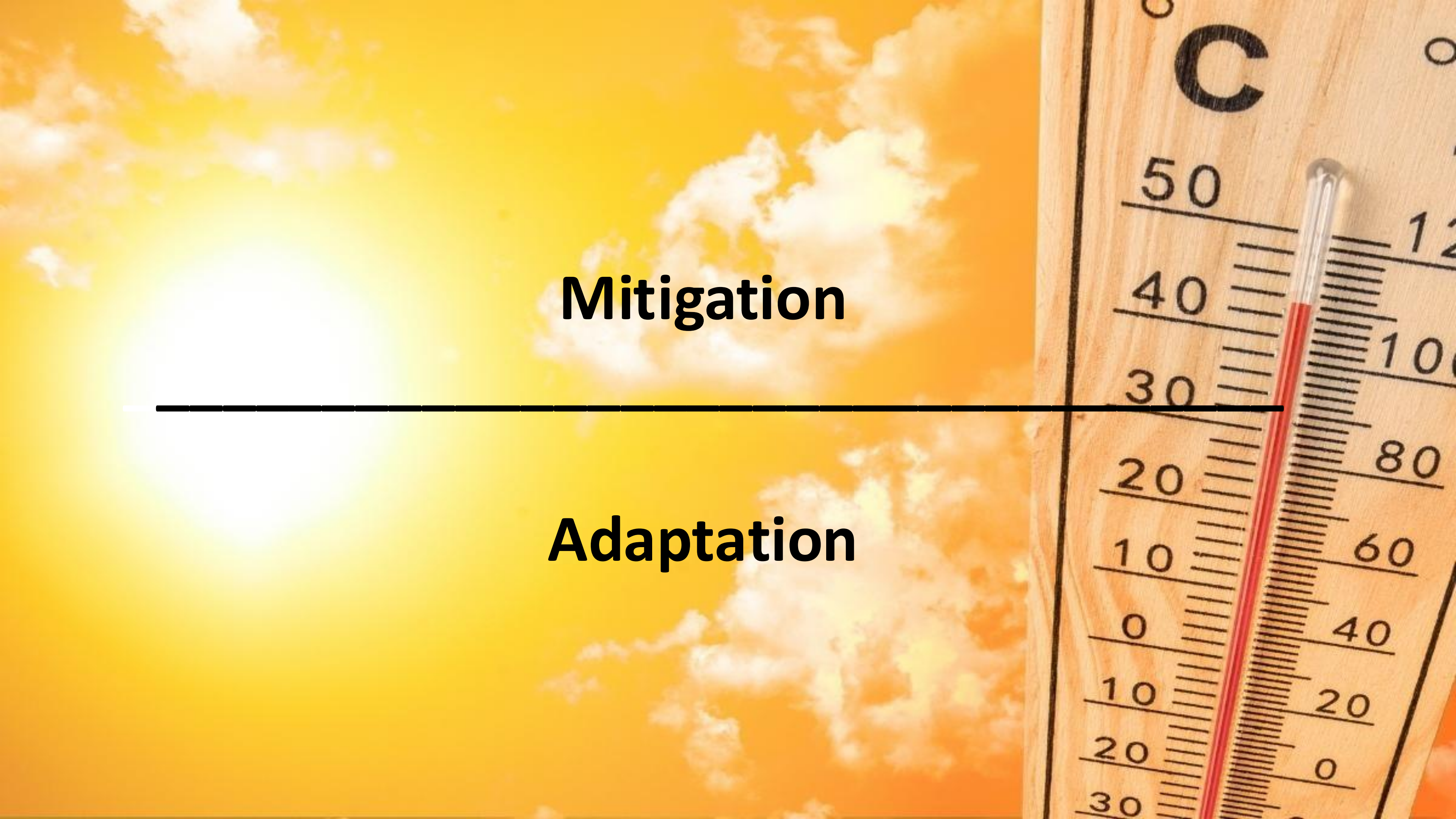
Copernicus Sentinel-3 www.esa.int

Heat waves in urban areas

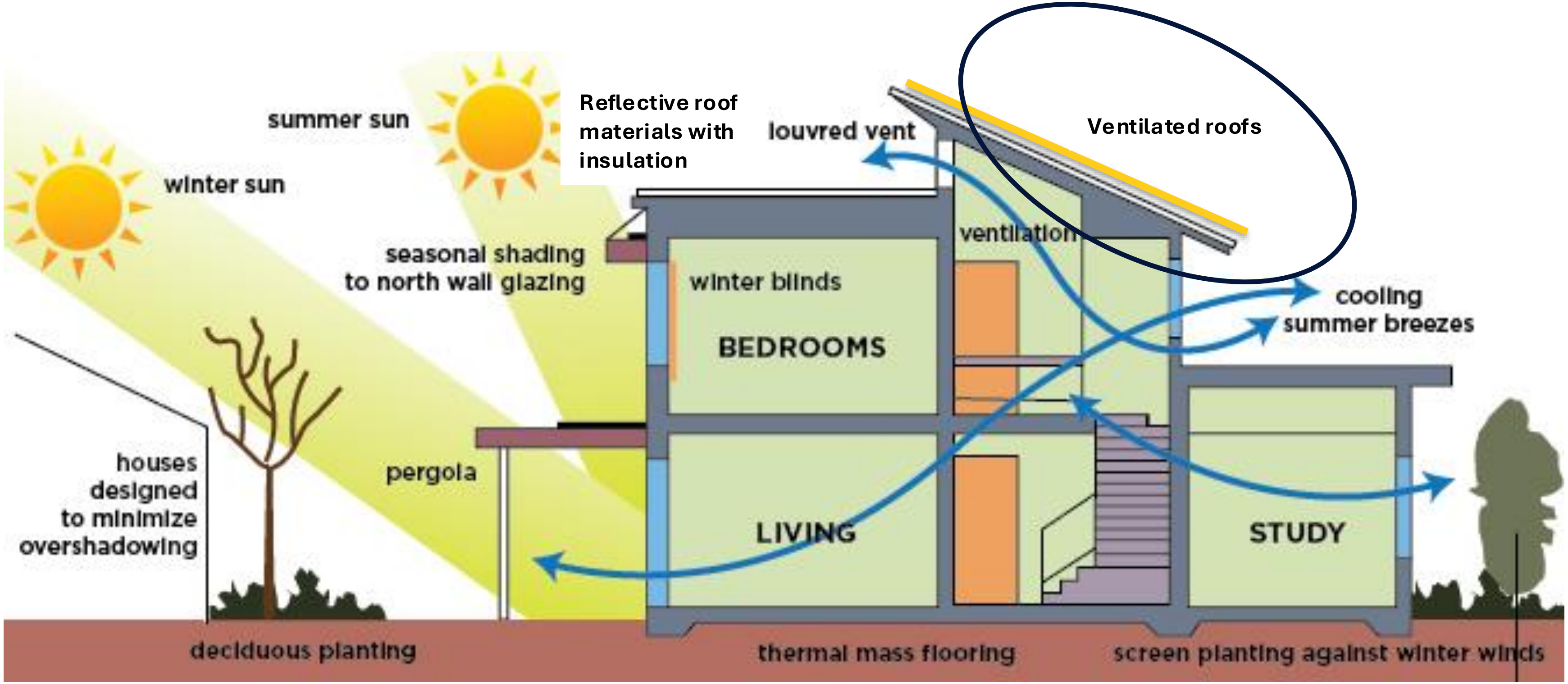




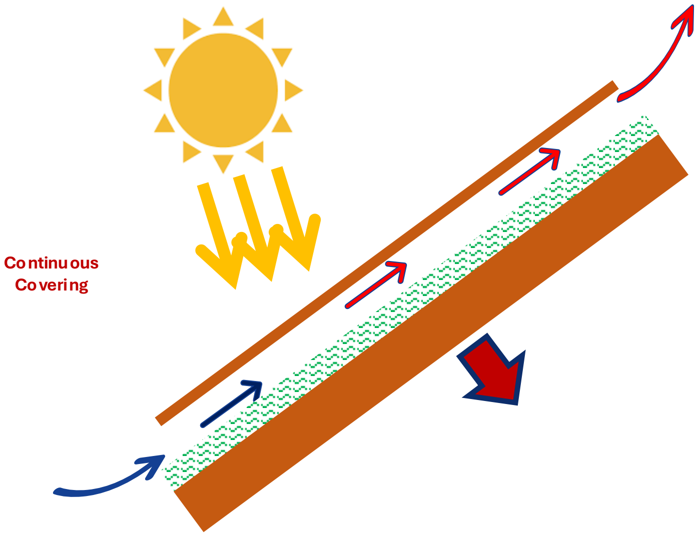
The cooling energy demand tripled from 1990 to today
International Energy Agency


Mitigation
Adaptation

Passive cooling

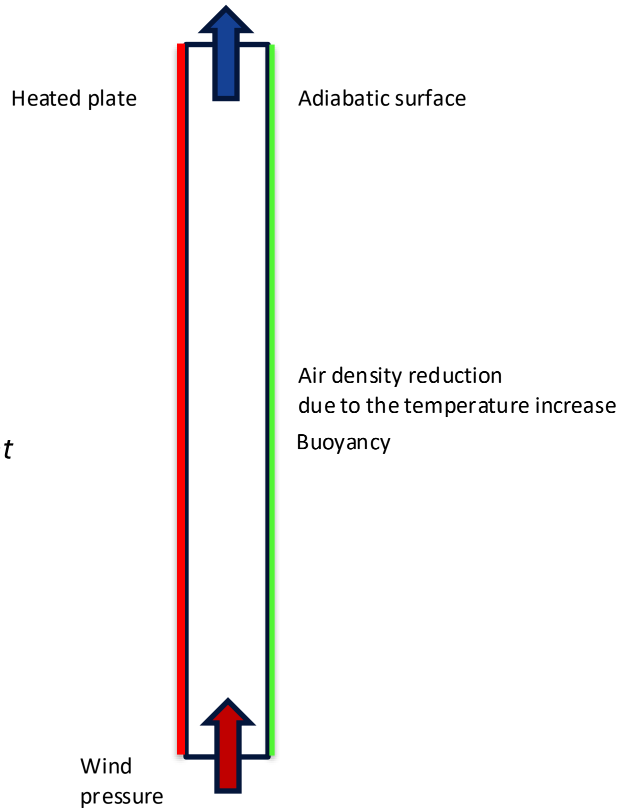


Benefit quantification



Physical model

Chimney effect



Energyplus: Baffle model (Griffith)

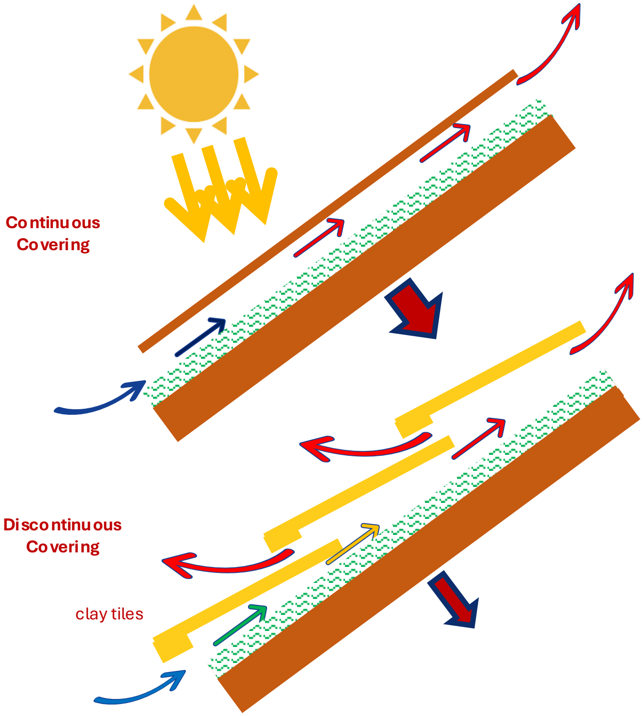
$\dot{V}_{tot} = \dot{V}_{wind} + \dot{V}_{thermal}$ is the total volumetric flow rate of air ventilating in and out of the cavity.

$\dot{V}_{wind} = C_v A_{in} U_\infty$

$\dot{V}_{\text{thermal}} = C_D A_{in} \sqrt{2g\Delta H_{NPL} \left(T_{a,cav} - T_{amb}\right)/T_{a,cav}}$ (if $T_{a,cav} > T_{amb}$)

$\dot{V}_{\text{thermal}} = C_D A_{in} \sqrt{2g\Delta H_{NPL} \left(T_{amb} - T_{a,cav}\right)/T_{amb}}$ (if $T_{amb} > T_{a,cav}$ and baffle is vertical)

The difference between Ventilated (ASV) and “air Permeable” Roofs (VPR)



ASV

Above Sheathing Ventilation
“chimney effect”

VPR

Above Sheathing Ventilation
+
Under Tile Ventilation
=
passage of air through the tiles, due to the effects of wind and the pressure difference between the external air and the cavity.

Ventilated Permeable Roofs significantly reduce the incoming thermal heat in summer season

The Herotiles with improved air permeability

Under Tile Ventilation is strongly related to the specific tile geometry

- Improve the design of tiles to increase their air permeability
- Enhance the global roof ventilation
- **Development** of two shapes: **Portuguese and Marseillaise "Herotiles"**

The effects of the improved air permeability of Herotiles were numerically investigated using CFD models [1-3] and experimentally demonstrated in laboratory tests [3,4] and on real scale mock-ups [5].

1.Bortoloni M, Bottarelli M, Piva S (2017) *Summer Thermal Performance of Ventilated Roofs with Tiled Coverings. J Phys Conf Ser 796:012023.*
2.Bottarelli M, Zannoni G, Bortoloni M, et al (2017) *CFD analysis and experimental comparison of novel roof tile shapes. Propuls Power Res 6:134–139.*
3.Bottarelli M, Bortoloni M, Zannoni G, et al (2017) *CFD analysis of roof tile coverings. Energy 137:391–398.*
4.Bottarelli M, Bortoloni M (2017) *On the heat transfer through roof tile coverings. Int J Heat Technol 35:S316–S321.*
5.Bottarelli M, Bortoloni M, Dino G (2018) *Experimental analysis of an innovative tile covering for ventilated pitched roofs. Int J Low-Carbon Technol 13:6–14.*

The LIFE SUPERHERO project

SUstainability and PERformances for HEROTILE-based energy efficient roofs

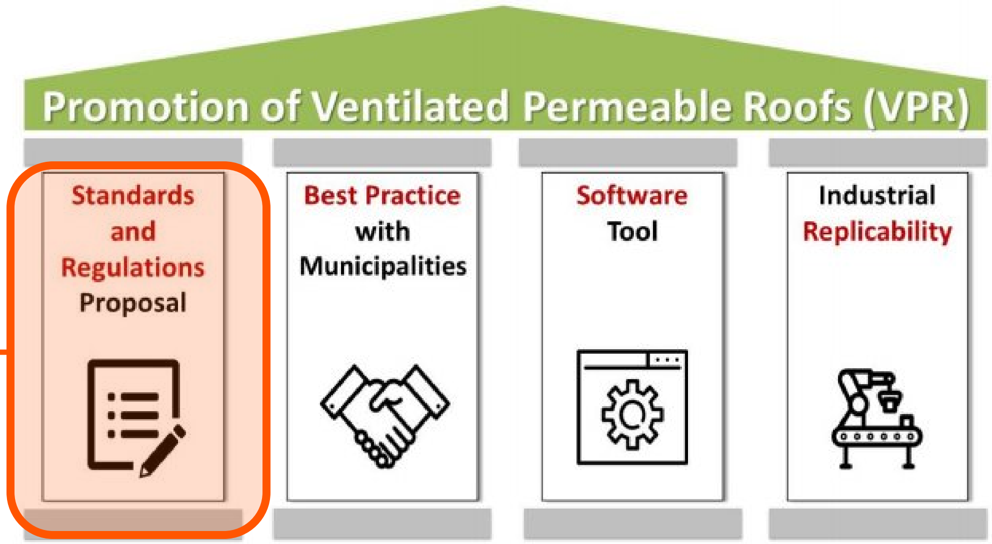
www.lifesuperhero.eu

LIFE19 CCA/IT/001194
With the contribution of the LIFE financial instrument of the European Community

The new **European project LIFE SUPERHERO** aims to promote VPR and Herotiles-Based Roofs (HBR)

- Increase the global awareness on VPR and Herotiles' performance
- Extend their recognition at the regulatory and standardization level
- Support replicability and transferability of the novel concepts

The LIFE SUPERHERO project



- Development of a standardized test method to assess the air permeability of tiled roofs
- Development of a recognized classification way for covering products
- Arrangement of a round-robin test

life SUPERHERO

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In this work, **the developed test method to assess tiles permeability and the preliminary results obtained on 9 tiles typologies are presented**

Test partially based on **British Standard BS 5534 – Annex L** «*Method of test for air permeability of unsealed small element roofing assemblies*» and **ASTM C1570** **«***Standard Test Method for Wind Resistance of Concrete and Clay Roof Tiles (Air Permeability Method*)», whose purpose is determining the **wind uplift pressure of unsealed small element roofing assemblies**.

However, differently from these standards, the test does not want to reach the critical pressure difference required to induce an uplift of the sample, thus it **covers a range of quite lower pressure differences between the chamber and the outside air**.

Figure L.1 Arrangement of apparatus

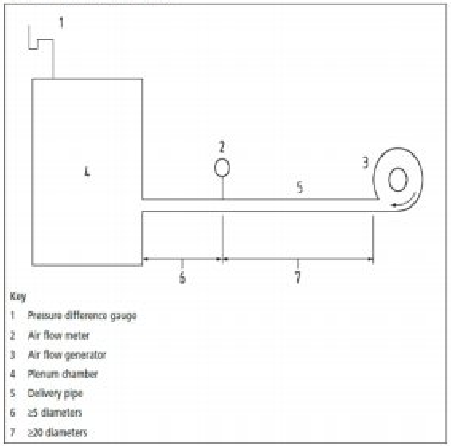
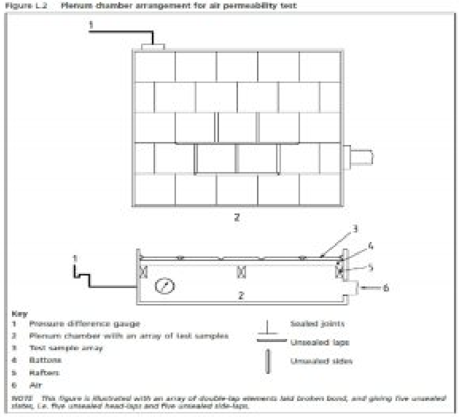


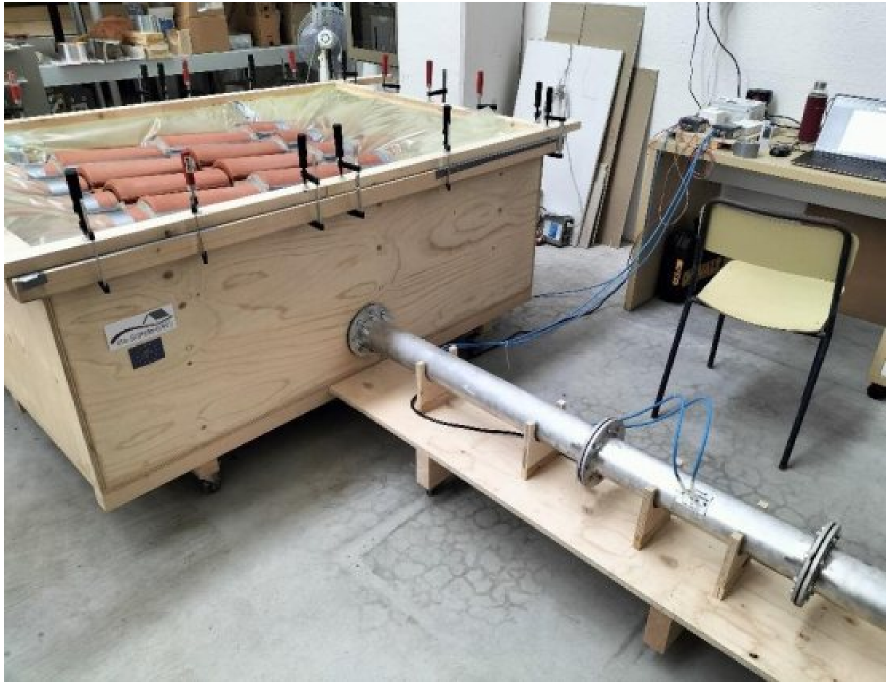
Figure L.2 Plenum chamber arrangement for air permeability test



The test consists of **blowing or aspirating air down a pipe into a plenum chamber covered by an assembly of roof tiles.**

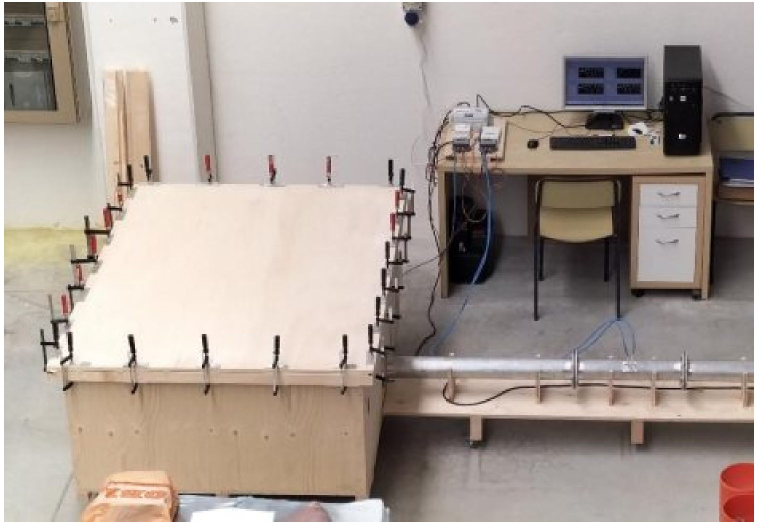
The measured **air pressure differences** inside and outside of the chamber and the measured **volume airflow rates** are used to determine the **air permeability** of the tiles.

The chamber is designed to have a volume much bigger than the volume flow rate through the assembly, then **air speeds in the chamber are very low and the internal pressure is kept constant**.



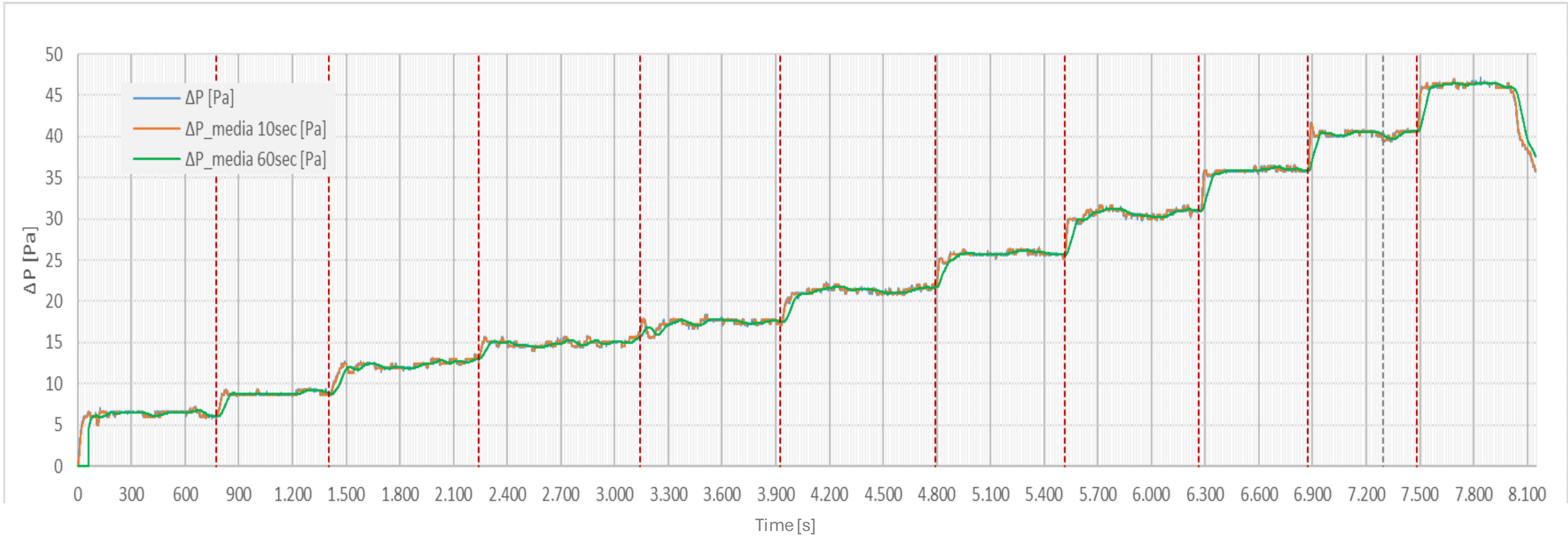
The chamber is airtight except for the upper face which receives the tiles assembly or a **cover panel** (for a preliminary airtightness test)

All joints and tile junctions of the assembly are also **sealed, except for 4 side locks and 4 head locks** in the middle of the tile array, which are kept unsealed.



During each test, both in **pressurization** and **depressurization** modes, the flow rate is recorded when the target pressure drop reaches **steady-state conditions**.

A series of target pressure differences are studied, **from about 2 Pa up to 100 Pa**. The lower and upper limits depend on the air-open tile designs.



The average value of the **aerodynamic area of the tile assembly**, **Cd·A [m2]**, is calculated by averaging the aerodynamic area value for each step, calculated according to eq. (1):

$$\mathbf{Cd} \cdot \mathbf{A} = \frac{Q}{n\sqrt{\frac{2 \cdot \Delta p}{\rho}}} \quad (1)$$

Where:

Δp is the pressure difference between the inside and outside of the plenum chamber [Pa]

Q is the volume air flow rate [m3/s]

ρ is the air density in the laboratory [kg/m3]

n is the flow regime radix, obtained by a fitting procedure on the power law curve

An **index** expressing the **air permeability** of the tiles array **AP [%]** is then obtained by eq. (2):

$$\boldsymbol{AP = \frac{Cd \cdot A}{Ar} * 100} \qquad (2)$$

Where the **effective area of the roofing assembly**, **Ar [m2]**, is calculated according to eq. (3):

$$\boldsymbol{Ar = N \cdot B \cdot Ga} \qquad (3)$$

and:

N is the number of roof tiles not sealed during the test [-]

B is the coverage width of a roof element [m]

Ga is the batten spacing, which is also the exposed length of the tile [m]

CTMNC (France)

CC (Italy)

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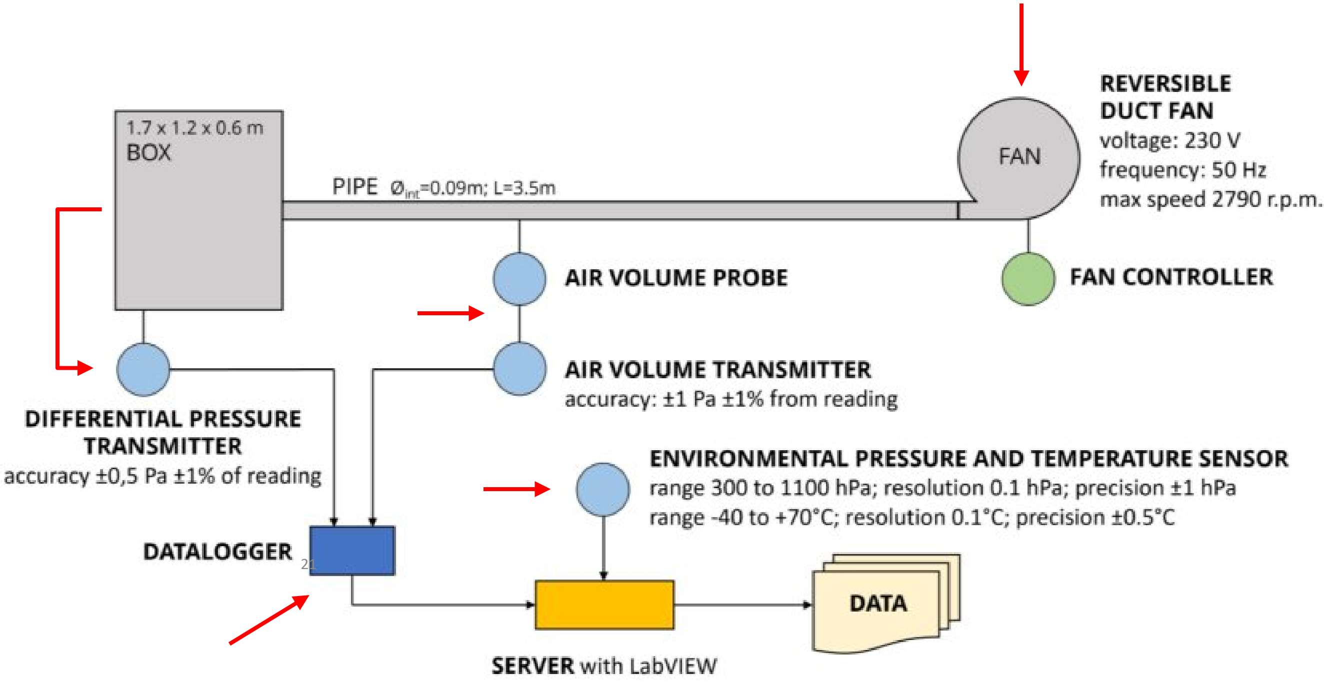
UNIVPM Lab

Wooden plenum chamber (internal dimensions 170x120x60 cm) connected to an iron pipe 3,5m long (Ø=90mm)



- A reversible fan provides (or extracts) the airflow through the pipe with a manual speed controller (induce Δp)
- The flow rate is measured through an air volume probe inserted in the pipe and connected to a transmitter
- The pressure difference is measured by a differential pressure transmitter
- The UNIVPM Lab air pressure and temperature are measured to calculate the local air density
- All devices are connected to a datalogger, data managed through LabVIEW

UNIVPM Lab

Tested tiles: 1 Herotile, 4 Portuguese Tiles (“P”), 1 Coppo Tile (“C”), 3 Marseillaise (“M”) Tiles

Marseillaise types were tested both in straight (solutions “A”) and in broken bond (solutions “B”)

12 tested **configurations** in both **blow** and **aspiration modes**

Type	**Hero**	**P_1**	**P_2**	**P_3**	**P_4**	**C_1**	**M_1A**	**M_1B**	**M_2A**	**M_2B**	**M_3A**	**M_3B**
Lenght (mm)	487	410	445	453	495	500	437		471		460	
Width (mm)	268	250	263	294	305	210-170	258		313		306	
Weight (kg)	4,2	3,1	3,9	3,8	4,83	2,7	3,2		4,4		4,3	
Coverage width (mm)	215	200	218	225	245	230	215		276		268	
Batten gauge (mm)	380	347	377	376	410	410	360		390		376	
Installation in straight bond	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes		Yes	
Installation in broken bond	No	No	No	No	No	No		Yes		Yes		Yes
Ar (m^2)	0,3268	0,2776	0,3287	0,3384	0,4018	0,3772	0,3096		0,4306		0,4031	

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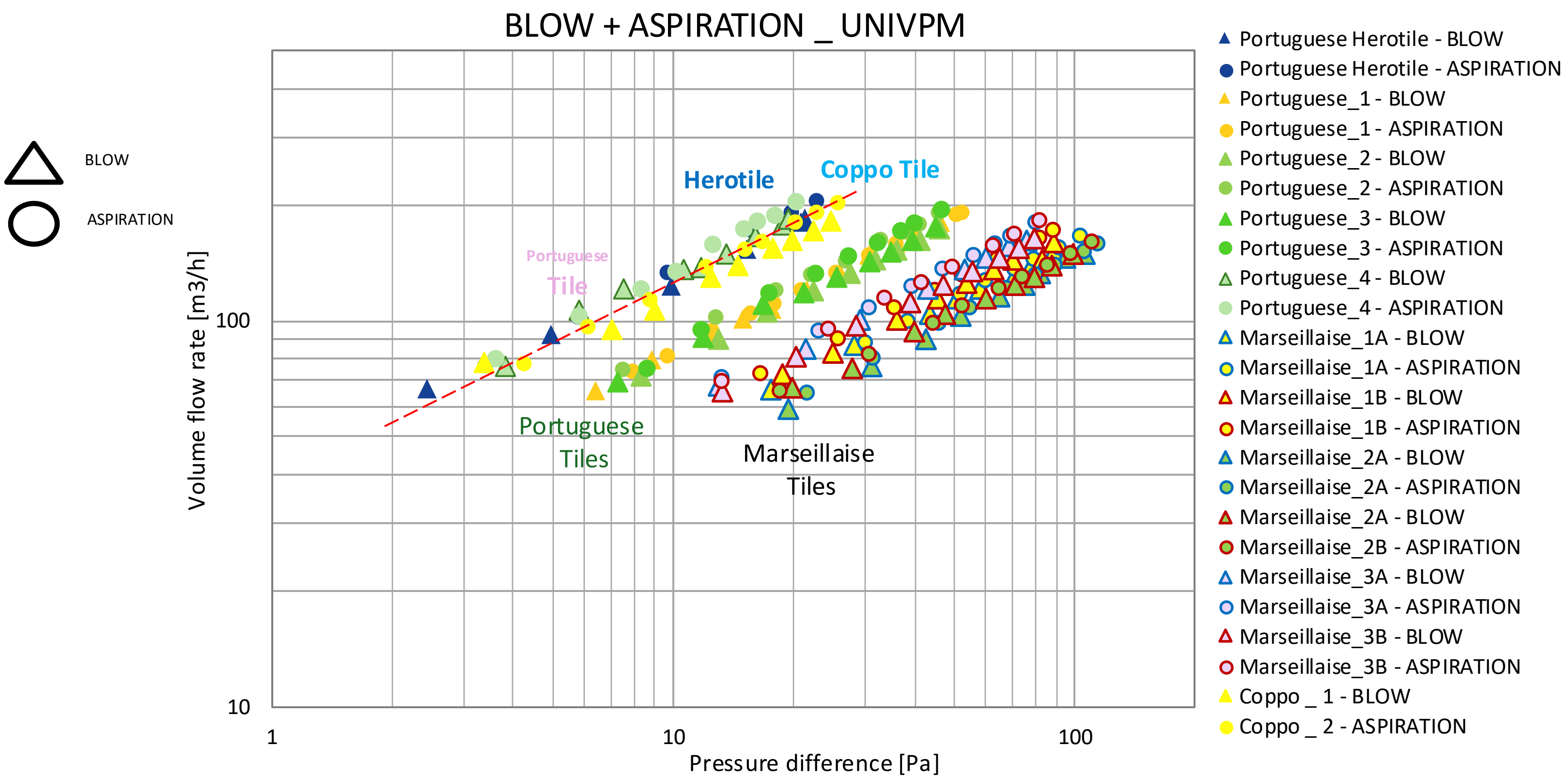

Recorded pressure difference and corresponding volume flow rate

UNIVPM Lab

	BLOW			ASPIRATION		
	n	Cd · A	AP	n	Cd · A	AP
	[-]	[m2]	[%]	[-]	[m2]	[%]
Portuguese Herotile	0,4632	0,00965	3,0%	0,5192	0,00868	2,7%
Portuguese_1	0,5079	0,00553	2,0%	0,5008	0,00565	2,0%
Portuguese_2	0,5097	0,00518	1,6%	0,5036	0,00587	1,8%
Portuguese_3	0,4946	0,00567	1,7%	0,5404	0,00508	1,5%
Portuguese_4	0,4991	0,00882	2,2%	0,5501	0,00789	2,0%
Coppo_1	0,5097	0,00763	2,0%	0,5036	0,00818	2,2%
Marseillaise_1A	0,4973	0,00340	1,1%	0,5123	0,00323	1,0%
Marseillaise_1B	0,4991	0,00361	1,2%	0,5131	0,00362	1,2%
Marseillaise_2A	0,5624	0,00224	0,5%	0,5277	0,00269	0,6%
Marseillaise_2B	0,4984	0,00314	0,7%	0,5052	0,00309	0,7%
Marseillaise_3A	0,503	0,00395	1,0%	0,5151	0,00396	1,0%
Marseillaise_3B	0,5083	0,00379	0,9%	0,5355	0,00366	0,9%

- Flow regime radices, Aerodynamic Areas and Air Permeabilities

Average values of air permeability

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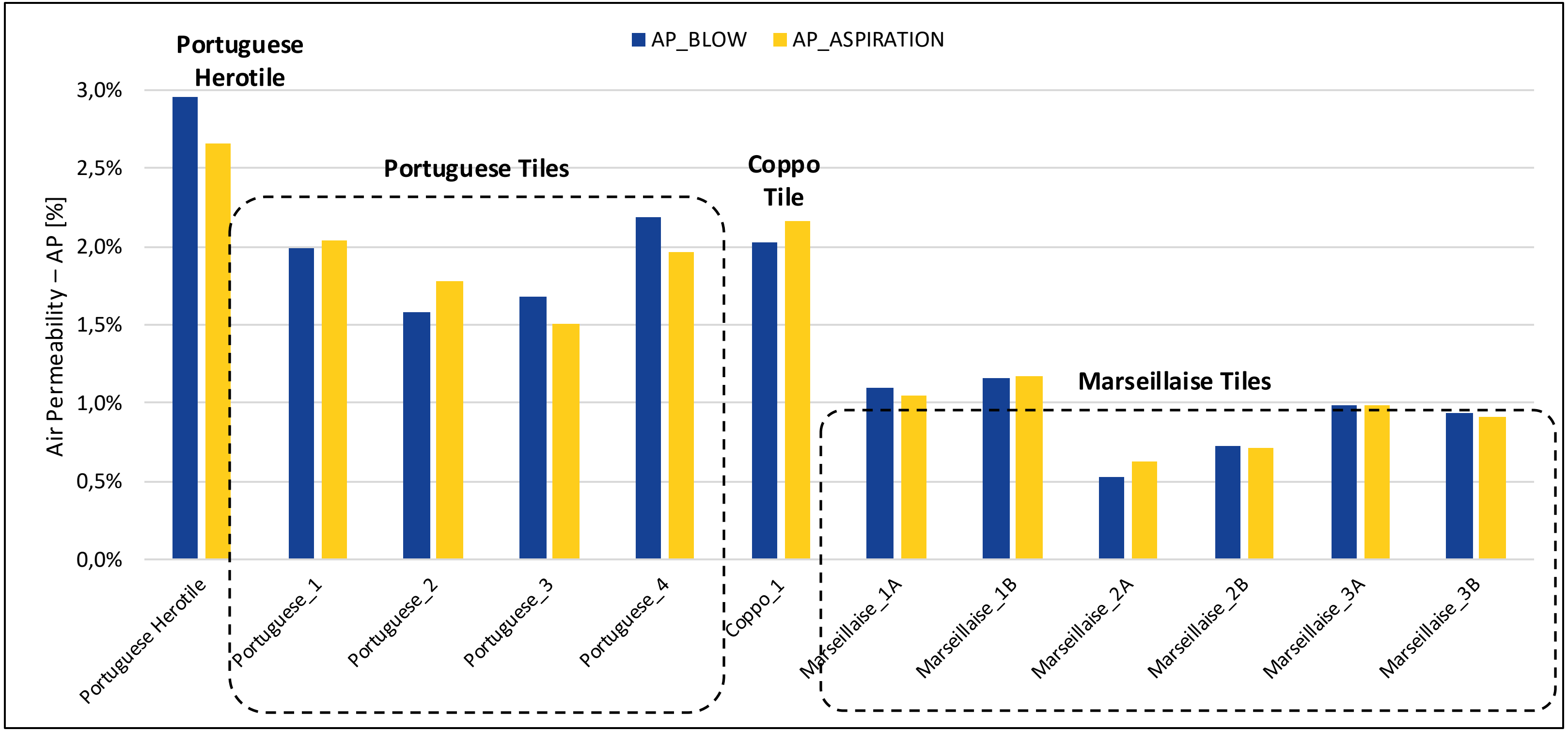

How to include this concept into energy calculation methods ?

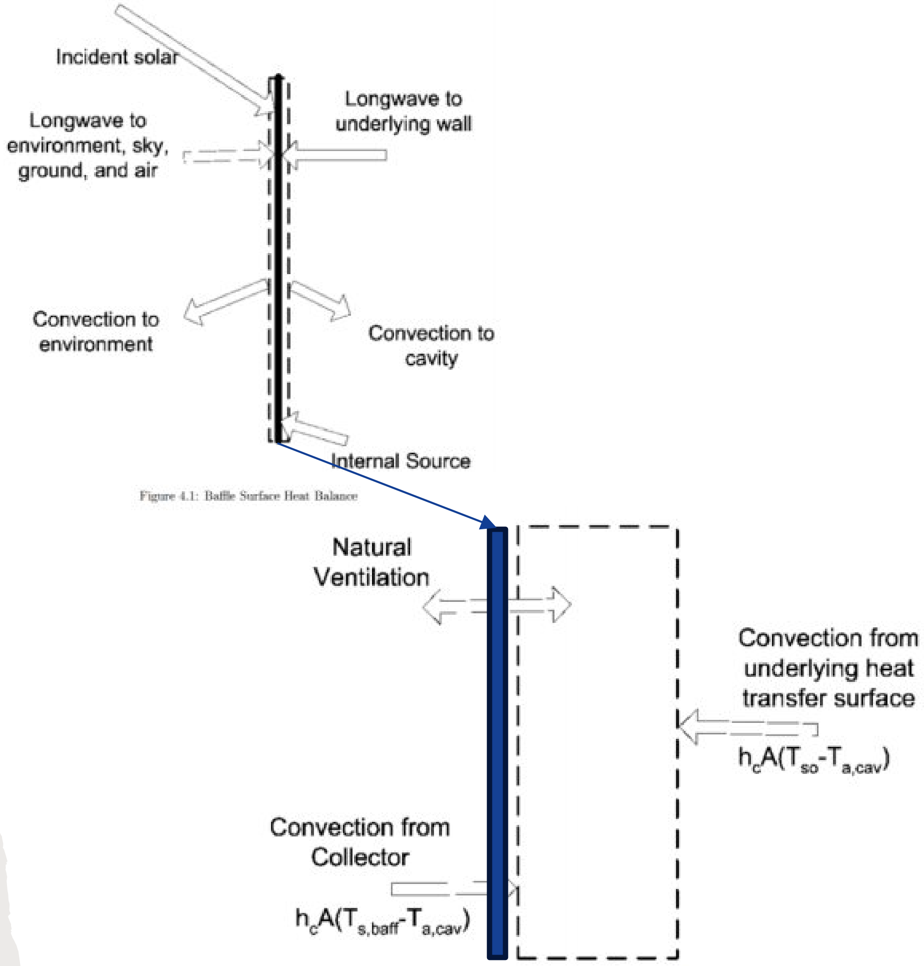

Figure 4.1: Baffle Surface Heat Balance

Figure 4.2: Cavity Air Heat Balance

The heat balance on the cavity air control volume is:

$$\dot{Q}_{vent} + \dot{Q}_{co} + \dot{Q}_{c,baff} = 0$$

where,

$\dot{Q}_{vent}$ is the net rate of energy added from natural ventilation – where outdoor ambient air exchanges with the cavity air.

$\dot{Q}_{co}$ is the net rate of energy added by surface convection heat transfer with the underlying surface.

$\dot{Q}_{c,baff}$ is the net rate of energy added by surface convection heat transfer with the collector.

$$T_{a,cav} = \frac{(h_{c,cav} A T_{so} + \dot{m}_{vent} c_p T_{amb} + h_{c,cav} A T_{s,baff})}{(h_{c,cav} A + \dot{m}_{vent} c_p + h_{c,cav} A)} \tag{4.4}$$

where,

$\dot{m}_{vent}$ is the air mass flow from natural forces [kg/s]

Modeling natural ventilation air exchanges in a general way is challenging. Simplistic engineering models are used to model $\dot{m}_{vent}$ resulting from natural buoyancy and wind forces. Reasoning that the configuration is similar to single-side natural ventilation, we elect to use correlations for natural ventilation presented as equations (29) and (30) in Chapter 26 of ASHRAE Handbook of Fundamentals (2001).

$$\dot{m}_{vent} = \rho \dot{V}_{\text{tot}} \tag{4.5}$$

where,

ρ is the density of air [kg/m^3], and

$\dot{V}_{tot} = \dot{V}_{wind} + \dot{V}_{thermal}$ is the total volumetric flow rate of air ventilating in and out of the cavity.

$\dot{V}_{wind} = C_v A_{in} U_\infty$

$\dot{V}_{\text{thermal}} = C_D A_{in} \sqrt{2g\Delta H_{NPL} (T_{a,cav} - T_{amb}) / T_{a,cav}}$ (if $T_{a,cav} > T_{amb}$)

$\dot{V}_{\text{thermal}} = C_D A_{in} \sqrt{2g\Delta H_{NPL} (T_{amb} - T_{a,cav}) / T_{amb}}$ (if $T_{amb} > T_{a,cav}$ and baffle is vertical)

C_v is the effectiveness of the openings that depends on opening geometry and the orientation with respect to the wind. ASHRAE HoF (2001) indicates values ranging from 0.25 to 0.6. This value is available for user input.

C_D is the discharge coefficient for the opening and depends on opening geometry. This value is available for user input.

C_V → wind

Similar but not equal

C_D → buoyancy

Correlations between experimental data and analytical results

Conclusion

The results confirm the **impact of the tiles shape on the air permeability of the assembly**.

✓ In particular, the newly developed Herotile achieves a double air permeability compared to some types of traditional tiles.

A standardized evaluation of the air permeability would allow to obtain a recognized classification of the cooling performance of roof tiles, then a greater recognition and awareness on the potential of VPR/HBR solutions at technical and regulation levels.

Thank You!

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