Associazione Italiana Gestione dell'Energia

6th AIGE/IIETA International Conference and
15th AIGE 2021 Conference
Ancona, Italy, July 8-9, 2021

HYGROTHERMAL ANALYSIS OF CLT-BASED RETROFIT STRATEGY OF EXISTING WALL ASSEMBLIES ACCORDING TO EN 13788 STANDARD

V. Costanzo*, G. Evola, A. Gagliano, L. Marletta, F. Nocera
Department of Civil Engineering and Architecture (DICAR), University of Catania,
Department of Electric Electronic and Computer Engineering (DIEEI), University of Catania

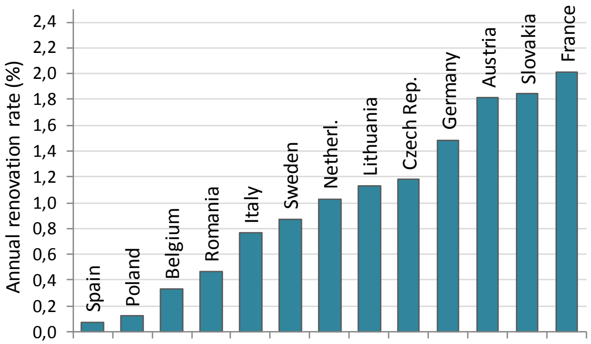
**Corresponding author*: Dr. Vincenzo Costanzo, vincenzo.costanzo@unict.it

THE EU BUILDING STOCK RENOVATION CONTEXT

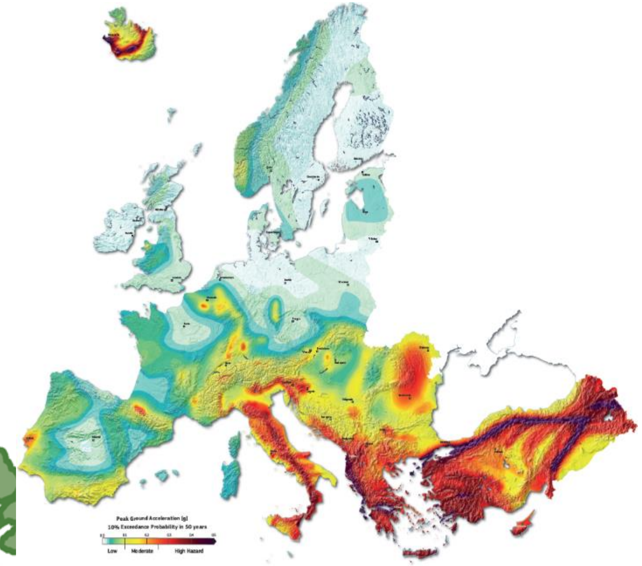
Residential and non-residential **buildings are currently responsible for 40% of the final energy demand in the EU**, and for approximately 36% of all emissions of GHG

EU Member States are committed to define a roadmap leading to the reduction of greenhouse gases (GHG) in the EU by 80-95% by 2050 compared to 1990 levels

However, the **renovation rate is** still highly **unsatisfactory**

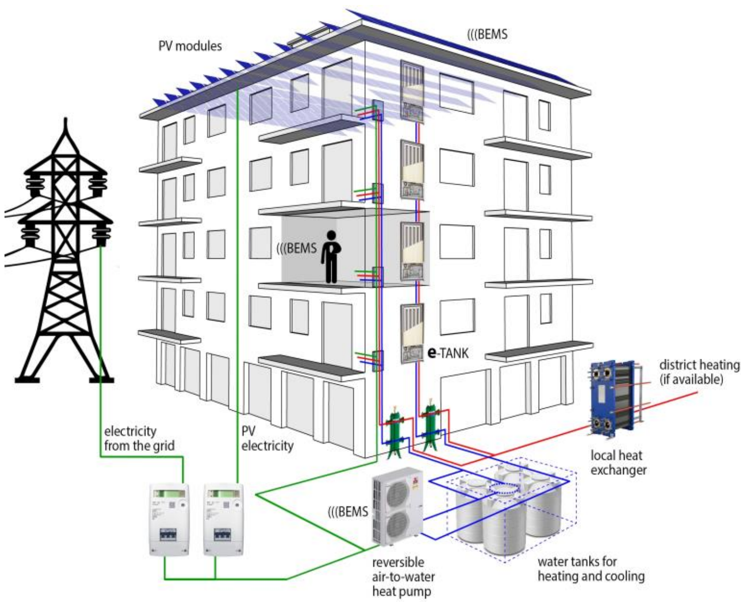


Furthermore, energy efficiency is not the only problem faced by the European building stock because about **50% of the European territory is earthquake-prone**



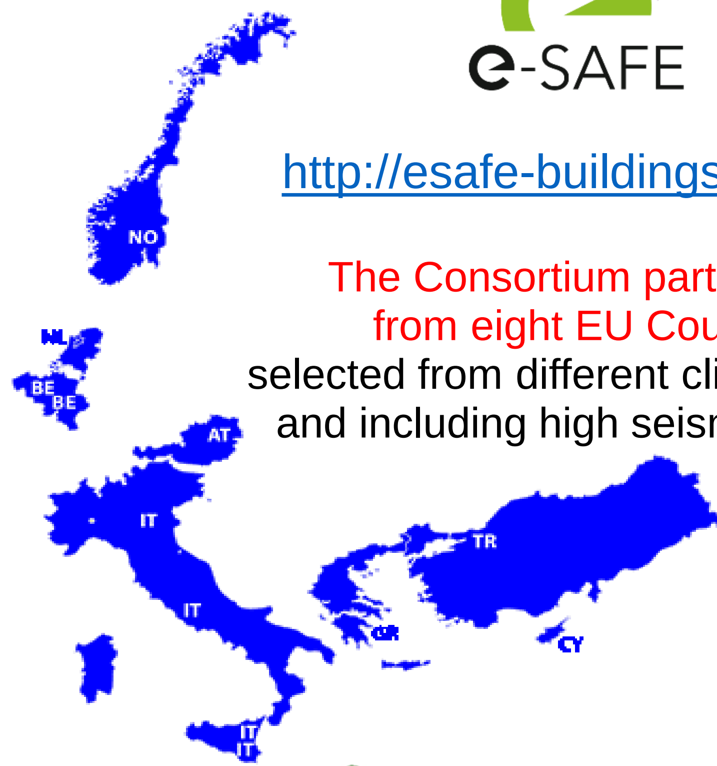
THE e-SAFE H2020 Project

In the framework of the ongoing **EU-funded innovation project** called **e-SAFE** (energy and Seismic Affordable rEnovation solutions), several solutions for the energy and seismic deep renovation of reinforced-concrete (RC) framed buildings in the EU countries are going to be developed and demonstrated



e-SAFE

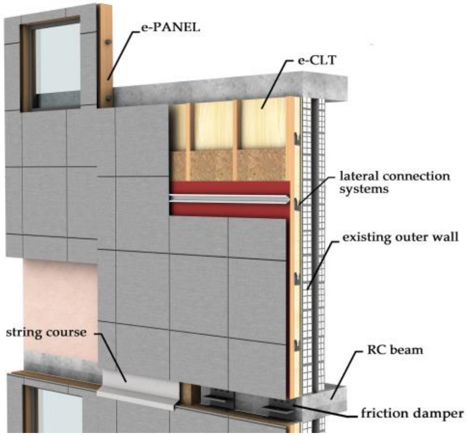
http://esafe-buildings.eu/en/



The Consortium partners are from eight EU Countries selected from different climate zones, and including high seismic regions

THE e-SAFE H2020 Project

One of these solutions makes use of **cross laminated timber (CLT) panels** connected to the existing RC frame through specifically designed dampers to increase the seismic and energy performances of the existing envelope (e-CLT solution)



e-CLT integrates both **local bio-based recyclable (or recycled) insulating materials** and customizable cladding finishing solutions. Size and number of CLT panels to be applied on the façade are determined based on the initial seismic deficiency of the building and the assumed target performance

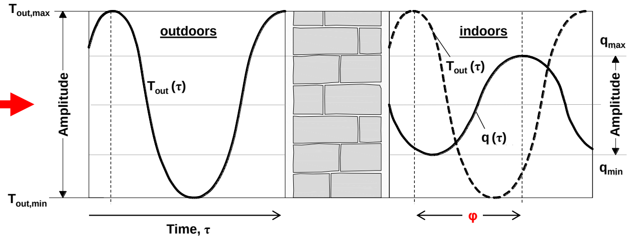
A pilot building in Catania owned by IACP (Italian social housing institute) will be renovated through the use of e-CLT, along with other envelope and technical systems solutions

HYGROTHERMAL PERFORMANCES: aims and objectives

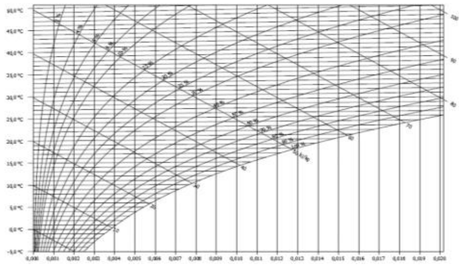
The main goal of this research is to **understand the hygrothermal behavior of existing wall structures retrofitted with e-CLT.**

In particular, this presentation reports on:

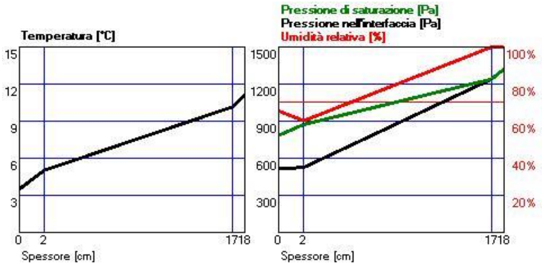
- Stationary and dynamic thermal parameters



- Surface condensation and mold growth

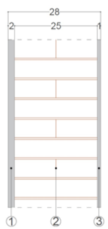


- Interstitial condensation issues

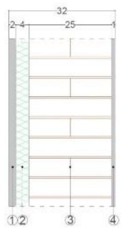


HYGROTHERMAL PERFORMANCES: methodology

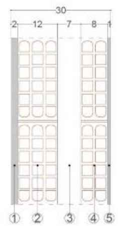
- The **hygrothermal performances** are assessed through the methods prescribed by the **EN 13788:2013 Standard** (stationary calculation) for surface condensation/mold growth and interstitial condensation (Glaser's method)
- Various **existing wall structures**, typical of the non-historic Italian residential building stock and **retrieved from the Italian report of the EU Tabula project**, are considered as both base case assemblies and substructures to apply e-CLT
- The **thermophysical properties** of the materials used in the various wall assemblies, along with those pertaining to CLT panels, are listed below and are gathered from the **EN ISO 10456:2007 Standard**



WALL ID1:
Solid bricks

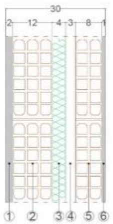


WALL ID2:
Solid bricks with poor external insulation



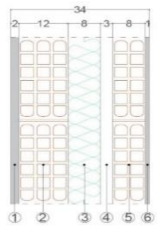
WALL ID3:
Cavity wall with hollow clay bricks

WALL ID4:
Reinforced concrete wall



WALL ID5:
Cavity wall with poor insulation in the air gap

WALL ID6:
Reinforced concrete wall with poor external insulation



WALL ID7:
Cavity wall with poor insulation in the air gap

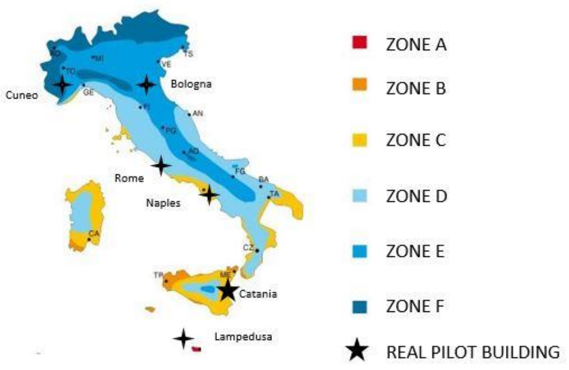
Material	Density ρ (kg·m^{-3})	Thermal conductivity λ (W·m^{-1}·K^{-1})	Specific heat C_p (J·kg^{-1}·K^{-1})	Water vapour resistance μ (-)
External plaster	1800	0.90	1000	10
Internal plaster	1400	0.70	1000	10
Solid brick	1800	0.72	1000	10
Wooden-based insulating layer	50	0.038	2100	1
Hollow clay brick	800	0.40	1000	10
Still air gap (vertical, 2 cm)	1	0.11*	1004	1
Still air gap (vertical, 3 cm)	1	0.16*	1004	1
Still air gap (vertical, 7 cm)	1	0.38*	1004	1
Reinforced concrete	2400	2.00	1000	80
External wooden cladding	1350	0.28	1674	110
CLT panel	420	0.12	1600	60

*this is the equivalent thermal conductivity corresponding to a thermal resistance of 0.18 m^2·K·W^{-1}

HYGROTHERMAL PERFORMANCES: methodology

- **Reference climate conditions** indoors and outdoors are set according to the **EN ISO 15927-1:2004 Standard**
- Various locations in Italy – ranging from warm to cold – are thus investigated according to their **Heating Degree Days (HDD)**

Climate zone	Representative city and relative HDD (°C·day)	Heating period
A	Lampedusa (588)	December 1^{st} – March 15^{th}
B	Catania (833)	December 1^{st} – March 31^{st}
C	Naples (1034)	November 15^{th} – March 31^{st}
D	Rome (1415)	November 1^{st} – April 15^{th}
E	Bologna (2259)	October 15^{th} – April 15^{th}
F	Cuneo (3012)	Throughout the year when needed



- **Indoor air temperature** is set to 20 °C during the heating periods listed in the Table above, while it coincides with the outdoor air temperature value in the remaining of the year (a lower threshold of 18 °C applies in case of particularly cold outdoor conditions)
- **Indoor relative humidity** values are derived by adding to the vapour partial pressure in the outdoors a contribution associated to indoor vapour sources. Two "different vapour class productions" are considered: *"class production 3"* – houses without mechanical ventilation and with unspecified occupancy pattern – and the more demanding *"class production 4"* – gyms, kitchens and canteens

HYGROTHERMAL PERFORMANCES: methodology

- The **stationary and dynamic thermal parameters** are calculated according to the Standards EN ISO 6946:2017 and EN ISO 13786:2017. To this aim, the values of the internal and external surface thermal resistance are set to 0.13 $m^2 \cdot K \cdot W^{-1}$ and 0.04 $m^2 \cdot K \cdot W^{-1}$ respectively

- Finally, **the amount of condensate that is detected in the various assemblies' layers is compared against the threshold values** set by the EN ISO 13788:2013 Standard and reported in the following Table 3. In case of materials not included in the table, the amount of condensate should not exceed 500 $g \cdot m^{-2}$

Material	Density ρ ($kg \cdot m^{-3}$)	Maximum condensate ($g \cdot m^{-2}$)
Clay	600–2000	≤ 500
Concrete	400–2400	≤ 500
Wood and derived materials	500–800	$\leq 30 \cdot \rho \cdot s$
Plasters and mortars	600–2000	$\leq 30 \cdot \rho \cdot s$
Organic fibers with waterproof glue	300–700	$\leq 20 \cdot \rho \cdot s$
Organic fibers with non-waterproof glue	300–700	$\leq 5 \cdot \rho \cdot s$
Mineral fibers	10–150	$\leq 5000 \cdot \rho \cdot s \cdot \lambda \cdot (1-1.7 \cdot \lambda)^{-1}$
Cellular plastic materials	10–80	$\leq 5000 \cdot \rho \cdot s \cdot \lambda \cdot (1-1.7 \cdot \lambda)^{-1}$

- **All the calculations are performed through the freeware software PAN v.7.1.0.4**, a tool developed by the Italian National Association for Thermal Insulation (ANIT) that complies with all the relevant European and National Standards listed above

HYGROTHERMAL PERFORMANCES: results

The **stationary and dynamic thermal parameters** are significantly improved thanks to the application of e-CLT:

- The **superficial mass** is improved of about 33 kg·m^{-2}
- The **U-value** is strongly reduced for every wall assembly by more than 60%
- The **Y_{IE}-value** is always well below the normative threshold of 0.10 W·m^{2}·K^{-1}
- The **attenuation factor** guarantees a good dampening of the ingoing heat wave
- The **phase shift** allows to delay the peak ingoing heat wave by more than 13 hours for every wall assembly

BASE CASE

Wall ID	Superficial mass (kg·m^{-2})	U-value (W·m^{-2}·K^{-1})	Y_{IE} (W·m^{-2}·K^{-1})	Attenuation factor (-)	Phase shift (h)
1	500	1.81	0.43	0.25	10
2	501.2	1.09	0.15	0.14	11
3	210.1	1.11	0.59	0.53	7.1
4	410	3.55	1.52	0.47	5.3
5	211.2	0.72	0.32	0.44	8.4
6	411.8	1.20	0.31	0.27	7.1
7	212.4	0.61	0.27	0.44	8.2

WITH e-CLT

Wall ID	Superficial mass (kg·m^{-2})	U-value (W·m^{-2}·K^{-1})	Y_{IE} (W·m^{-2}·K^{-1})	Attenuation factor (-)	Phase shift (h)
1r	533.3	0.31	0.01	0.04	17.5
2r	534.5	0.28	0.01	0.03	19.1
3r	243.4	0.28	0.02	0.08	15.3
4r	443.3	0.34	0.04	0.11	13
5r	244.6	0.25	0.01	0.05	17
6r	445.1	0.29	0.02	0.07	15
7r	245.8	0.23	0.01	0.04	16.5

HYGROTHERMAL PERFORMANCES: results

Issues concerning the existing wall assemblies are evident in terms of surface condensation and mold growth risks, especially for higher indoor vapor production rates

BASE CASE – VAPOR CONCENTRATION CLASS 3

Climate zone	Risk assessment	Wall ID 1	Wall ID 2	Wall ID 3	Wall ID 4	Wall ID 5	Wall ID 6	Wall ID 7
Climate zone A	Surface condensation and mould growth	✓	✓	✓	✗	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone B	Surface condensation and mould growth	✓	✓	✓	✗	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone C	Surface condensation and mould growth	✗	✓	✓	✗	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone D	Surface condensation and mould growth	✗	✓	✓	✗	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone E	Surface condensation and mould growth	✗	✓	✓	✗	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	!	✓	✓	✓
Climate zone F	Surface condensation and mould growth	✗	✓	✓	✗	✓	✗	✓
	Interstitial Condensation	✓	✓	✓	!	✓	✓	✓

BASE CASE – VAPOR CONCENTRATION CLASS 4

Climate zone	Risk assessment	Wall ID 1	Wall ID 2	Wall ID 3	Wall ID 4	Wall ID 5	Wall ID 6	Wall ID 7
Climate zone A	Surface condensation and mould growth	✗	✓	✓	✗	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone B	Surface condensation and mould growth	✗	✓	✓	✗	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone C	Surface condensation and mould growth	✗	✗	✗	✗	✓	✗	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone D	Surface condensation and mould growth	✗	✗	✗	✗	✗	✗	✓
	Interstitial Condensation	✓	✓	✓	!	✓	✓	✓
Climate zone E	Surface condensation and mould growth	✗	✗	✗	✗	✗	✗	✓
	Interstitial Condensation	✓	✓	✓	✗	✓	✓	✓
Climate zone F	Surface condensation and mould growth	✗	✗	✗	✗	✗	✗	✗
	Interstitial Condensation	✓	✓	!	✗	✓	✓	✓

HYGROTHERMAL PERFORMANCES: results

<u>Surface condensation and mould growth risks are solved for all wall structures</u> and indoor vapour production analysed, while some interstitial condensation is predicted in coldest climate zones E and F

WITH e-CLT – VAPOR CONCENTRATION CLASS 3

Climate zone	Risk assessment	Wall ID 1r	Wall ID 2r	Wall ID 3r	Wall ID 4r	Wall ID 5r	Wall ID 6r	Wall ID 7r
Climate zone A	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone B	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone C	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone D	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone E	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone F	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	✓	✓	!	✓	✓	✓	✓

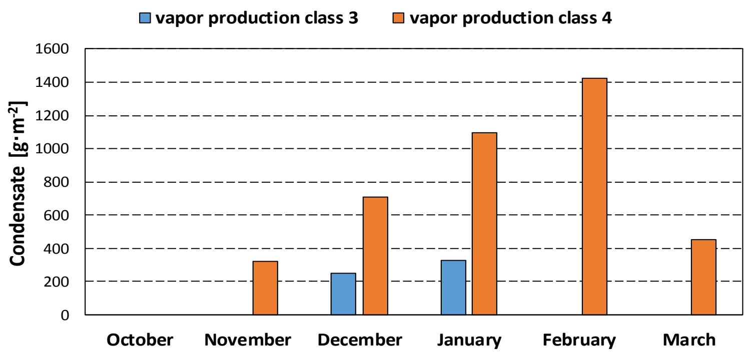
WITH e-CLT – VAPOR CONCENTRATION CLASS 4

Climate zone	Risk assessment	Wall ID 1r	Wall ID 2r	Wall ID 3r	Wall ID 4r	Wall ID 5r	Wall ID 6r	Wall ID 7r
Climate zone A	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone B	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone C	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone D	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	✓	✓	✓	✓	✓	✓	✓
Climate zone E	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	!	!	!	✓	!	✓	!
Climate zone F	Surface condensation and mould growth	✓	✓	✓	✓	✓	✓	✓
	Interstitial Condensation	!	!	!	✓	!	✓	!

HYGROTHERMAL PERFORMANCES: results

A **limited amount of condensate is predicted for uninsulated concrete walls** (Wall ID4) only **in the coldest climate zones** (E and F) at the interface between the internal plaster and the reinforced concrete layer. The amount of cumulated condensate in the coldest period (November to February) is about 330 g·m^{-2} for vapour production class 3 and completely re-evaporates within the year

Wall ID4 – Base case, Climate Zone F



When applying e-CLT, some condensate is present at the exterior face of the insulating material for vapour concentration class 3 in the case of wall ID 3r (cavity wall with air gap and no insulation) in the coldest climate zone F, but **the very low amount predicted** (2.2 g·m^{-2}) **is easily re-evaporated**. When considering an increased indoor vapour production (vapour concentration class 4), some interstitial condensation may occur in climate zones E and F for five out of the seven wall structures, but once again the amount of condensate is low (below 20 g·m^{-2}) and re-evaporated

CONCLUSIONS

- e-CLT significantly improves both the thermal and hygrometric behavior of typical wall structures located in different climate zones in Italy

- As examples, the **U-values** achieved after applying CLT panels to solid brick walls and cavity walls **drop down** from 1.81 $W \cdot m^{-2} \cdot K^{-1}$ and 1.11 $W \cdot m^{-2} \cdot K^{-1}$ to 0.31 $W \cdot m^{-2} \cdot K^{-1}$ and 0.28 $W \cdot m^{-2} \cdot K^{-1}$ in order

- In addition, the summer thermal performance is significantly improved thanks to the **supplementary thermal mass** brought by CLT panels (about 33 $kg \cdot m^{-2}$)

- From the hygrometric point of view, the **e-CLT** solution **eliminates any surface condensation and mold growth risks** present in various typical wall structures (most notably solid bricks and concrete walls)

- The **additional water vapor resistance** brought by the CLT panel ($\mu \approx 60$) **reduces the maximum amount of condensate predicted** to only 20 $g \cdot m^{-2}$ in the worst scenario (renovated concrete walls in coldest climate zone F, indoor vapor production class 4), which is well below the maximum threshold of 500 $g \cdot m^{-2}$ set by the normative and the corresponding amount achieved by the same wall without the application of e-CLT (1400 $g \cdot m^{-2}$)

- **Further studies are planned** to assess other condensation mechanisms such as vapor convection, capillary transport and surface diffusion **through advanced transient hygrothermal simulations** and explore the use of water vapor barriers/retardants

THANK YOU FOR YOUR ATTENTION!!

Dr. Vincenzo Costanzo, vincenzo.costanzo@unict.it

e-SAFE has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 893135.