Carbon Neutral Cities - Energy Efficiency & Renewables in the Digital Era

PRELIMINARY INVESTIGATION ON THE TRANSIENT HYGROTHERMAL ANALYSIS OF A CLT-BASED RETROFIT SOLUTION FOR EXTERIOR WALLS

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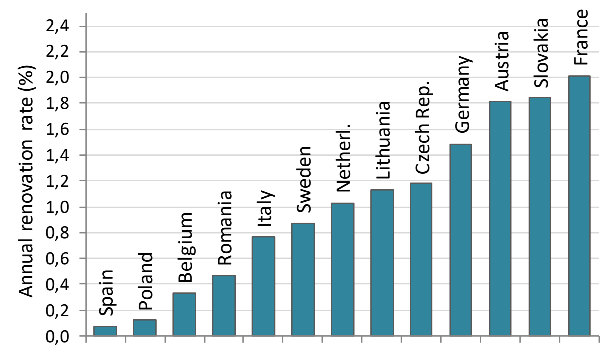
BACKGROUND: *the EU building stock renovation context*

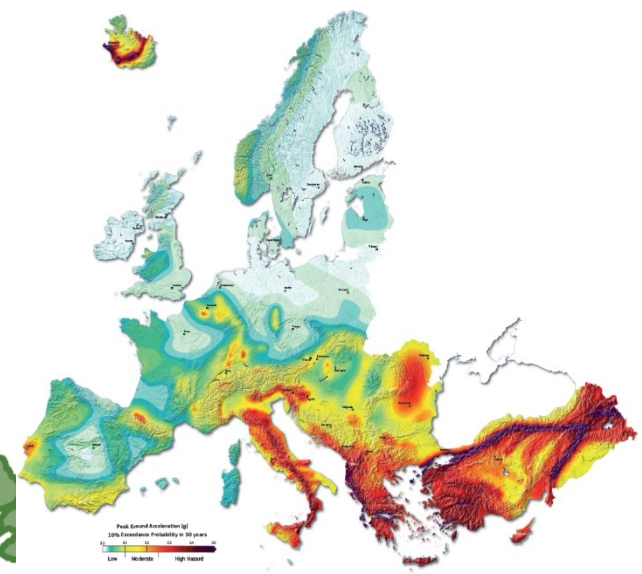
Residential and non-residential **buildings are currently responsible for 40% of the final energy demand in the EU**, and for approximately 36% of all emissions of GHG

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**

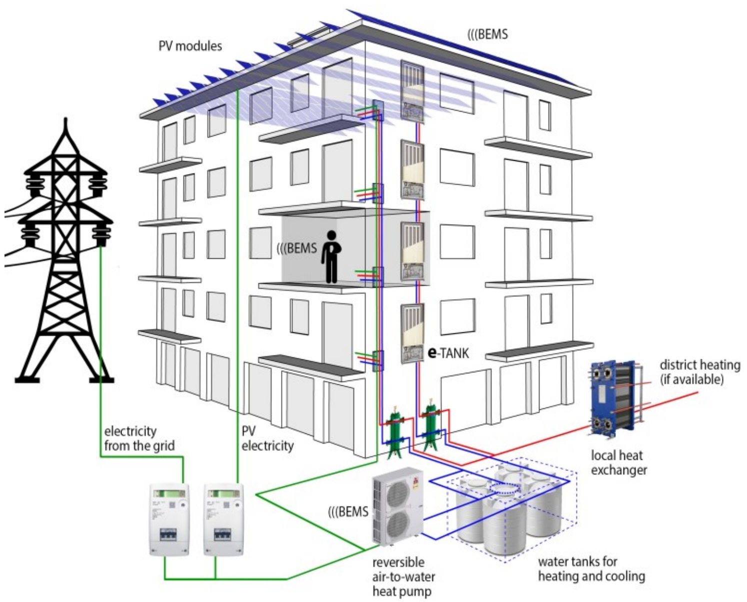


Furthermore, energy efficiency is not the only problem faced by the European building stock because about **50% of the European territory is earthquake-prone**



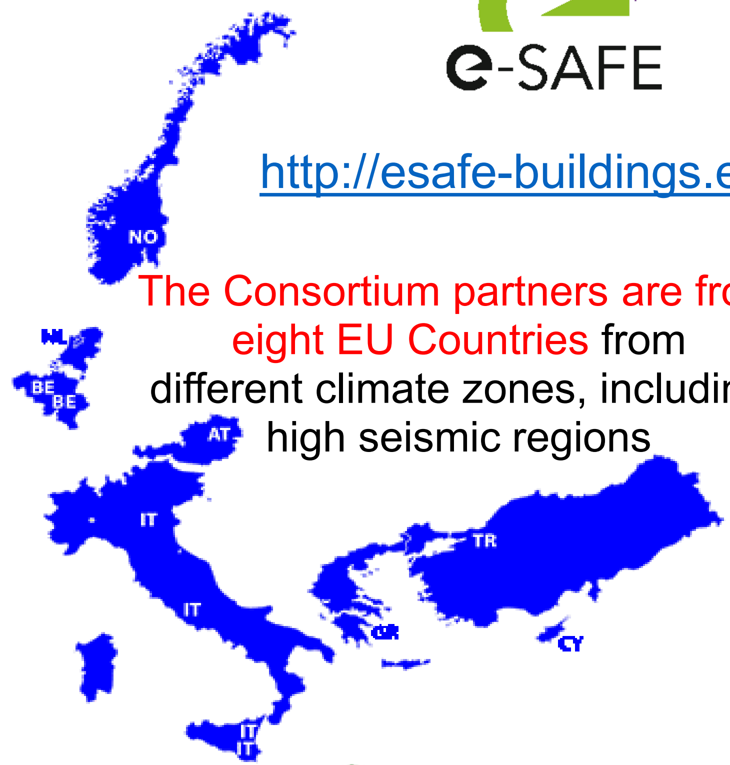
THE e-SAFE H2020 Project

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

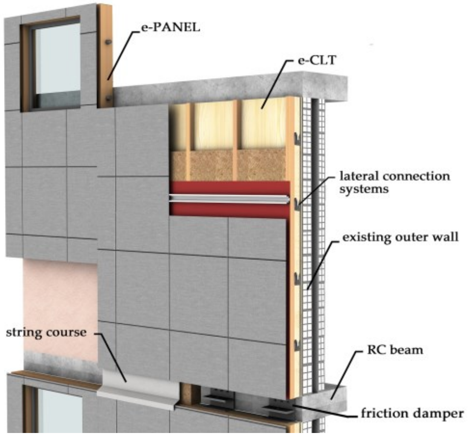
http://esafe-buildings.eu/en/



The Consortium partners are from eight EU Countries from different climate zones, 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

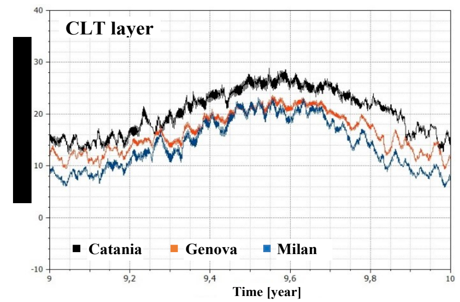
A pilot building in Catania (Italy) owned by IACP (Italian social housing institute) will be renovated through the use of e-CLT, along with other envelope and technical systems solutions

AIMS AND OBJECTIVES

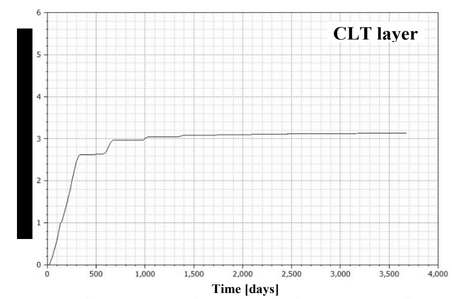
The main goal of this research is to **understand the hygrothermal behavior of existing wall structures retrofitted with e-CLT**

In particular, this presentation reports the preliminary results of transient Heat And Mass Transfer (HAMT) simulations accounting for **water vapour diffusion and capillary transport** mechanisms. The main simulation outcomes discussed are:

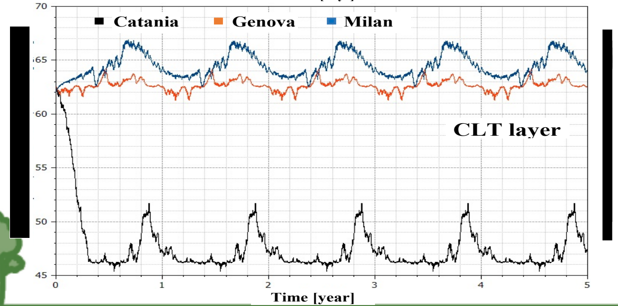
- Temperature (°C) and relative humidity (%) values at CLT and thermal insulation layers



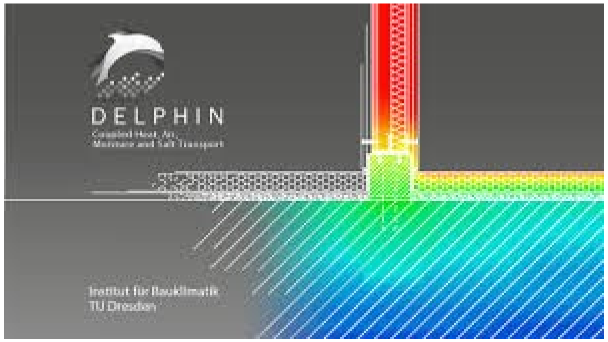
- Mould Index (-) values at CLT and thermal insulation layers



- Total Water Content ($kg \cdot m^{-3}$) values at CLT and thermal insulation layers



METHODOLOGY: *simulations in Delphin 6.1*



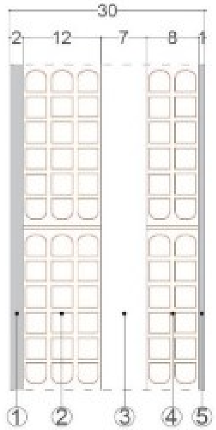
DELPHIN 6.1 is a software tool developed at University of Dresden that allows a detailed 2-D numerical study of the dynamic heat and mass transfer phenomena inside building components, including **vapour diffusion, vapour and liquid sorption and capillary suction**

A rich database is available, where **materials are characterized through their relevant hygrothermal properties**, including experimentally measured sorption curves and moisture-dependent thermal conductivity

However, **sorption curves do not take into account hysteresis**, which implies a slight deviation between adsorption and desorption processes. This feature is actually common to most HAMT tools, and in case of wooden materials this might imply a slight inaccuracy

METHODOLOGY: *wall assembly*

The hygrothermal performance of the e-CLT solution is investigated by supposing its application to a wall assembly that is quite traditional for the residential building stock built in Southern Europe between the 1960s and the 1980s: **infill walls** with a double layer of hollow clay bricks and an intermediate air cavity ($U = 1\ W \cdot m^{-2} \cdot K^{-1}$)



Starting from this wall configuration, **further layers are applied on the outer side** according to the e-CLT solution ($U = 0.28\ W \cdot m^{-2} \cdot K^{-1}$):

- a 3-ply 10-cm CLT panel
- a layer of wooden fibre (6.5 cm)
- a vapour-open water-proof membrane (vapour resistance μ = 50) is applied on the outer surface of the insulation to protect the wall from rain and wind
- a thin air-gap (2 cm)
- a final finishing wooden layer (2 cm)

	s [m]	λ [$W \cdot m^{-1} \cdot K^{-1}$]	C_p [$J \cdot kg^{-1} \cdot K^{-1}$]	ρ [$kg \cdot m^{-3}$]	μ [-]	w_{80} [$kg \cdot m^{-3}$]	w_{sat} [$kg \cdot m^{-3}$]
Internal plaster	0.02	0.7	800	1500	9.3	34.2	430
Hollow clay brick	0.08	0.35	1000	720	10	11.4	319.4
Non-ventilated air cavity	0.05	*	1000	1.2	1.0	-	-
Hollow clay brick	0.12	0.35	1000	720	10	11.4	319.4
External plaster	0.03	0.70	1000	1600	11	25.2	250
Cross Laminated Timber	0.10	0.13	1600	440	50	62.6	445.1
Wooden fibre	0.065	0.04	2000	50	1.1	12.7	590.3
Water-proof membrane	$18 \cdot 10^{-4}$	0.23	1000	180	50	0.3	345.1
Slightly ventilated air cavity	0.02	**	1000	1.2	1	-	-
Wooden staves	0.02	0.13	1880	630	1	-	-

* Thermal resistance $R = 0.18\ m^2 \cdot K/W$ ** Thermal resistance $R = 0.09\ m^2 \cdot K/W$

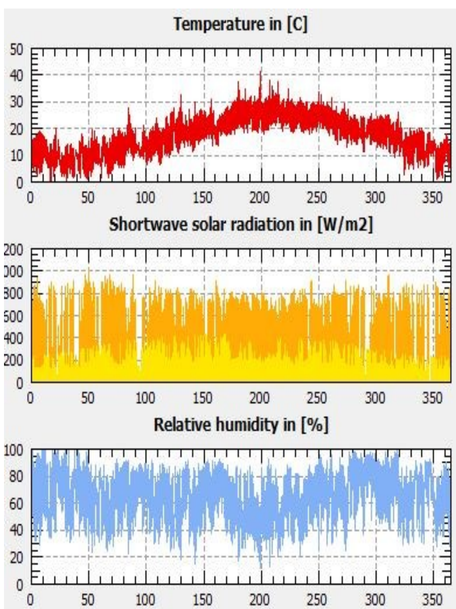
METHODOLOGY: *CLT panels*

The **CLT panels** chosen **are made of three separate layers**, alternating transverse and longitudinal fibres: in principle, longitudinal fibres imply higher water absorption coefficient ($A = 0.012\ kg \cdot m^{-2} \cdot s^{-0.5}$) than transverse fibres ($A = 0.002\ kg \cdot m^{-2} \cdot s^{-0.5}$)

In this research, **the entire CLT panel is characterized through longitudinal fibres**; further analyses about the role of fibre orientation on the hygrothermal performance will be discussed in a following study

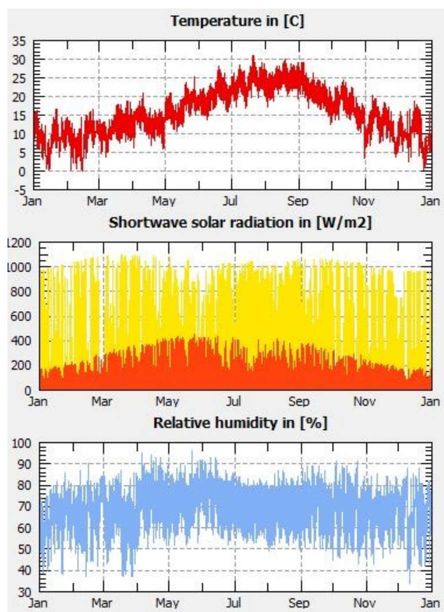
METHODOLOGY: *climate and boundary conditions*

The simulations for e-CLT are run for **three different climatic conditions in Italy**, namely those of Catania, Genova and Milan, making use of the weather data available in the DELPHIN database



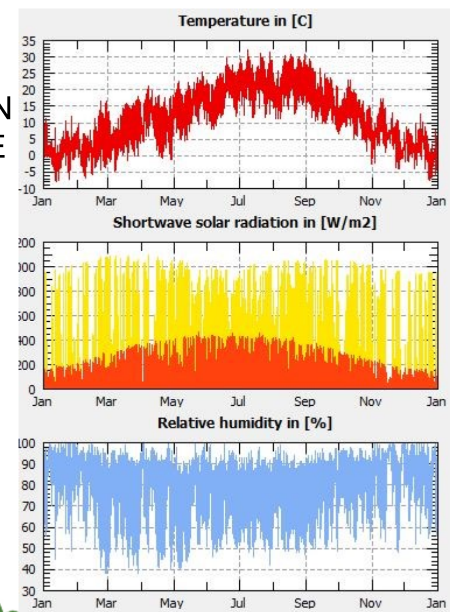
CATANIA

LAT. 37. N
LON. 15 E
Alt. 10 m



GENOVA

LAT. 44.4 N
LON. 8.9 E
Alt. 20 m

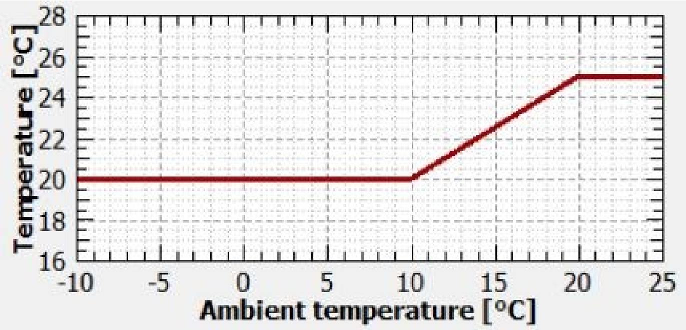


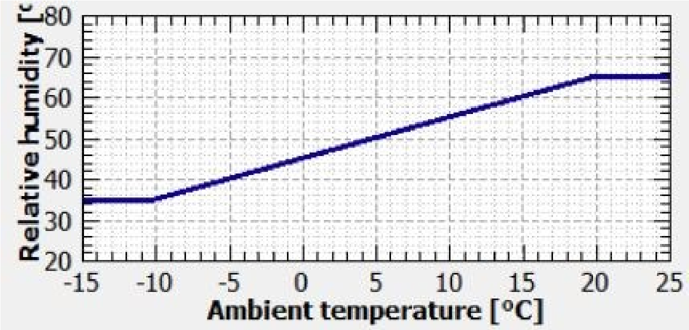
MILAN

LAT. 45.4 N
LON. 9.1 E
Alt. 120 m

METHODOLOGY: *climate and boundary conditions*

Indoor conditions change as a function of outdoor temperature, **according to EN ISO 15026:2007 Standard**: indoor air temperature ranges between 20 °C and 25 °C, while relative humidity ranges between 35% and 65% (normal internal moisture load)

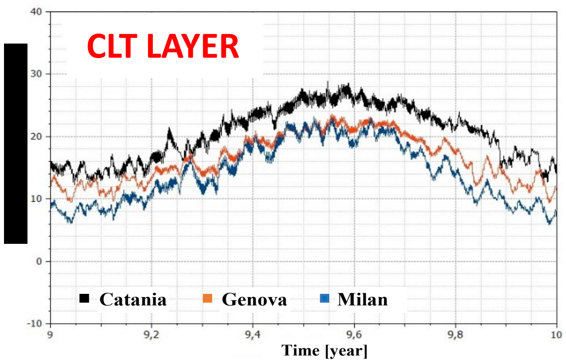


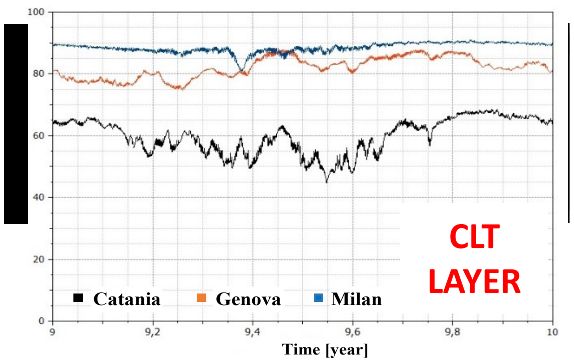


OTHER SETTINGS

- The **simulations are performed over a 10-year-long period**, in order to get a stabilized behaviour, while initial conditions correspond to 80% relative humidity for all materials
- The investigated **wall is oriented facing north**, in order to exclude the drying effect of direct solar radiation
- The effect of **wind driven rain is not considered.** However, preliminary simulations accounting for rain revealed negligible influence because of the water proof membrane

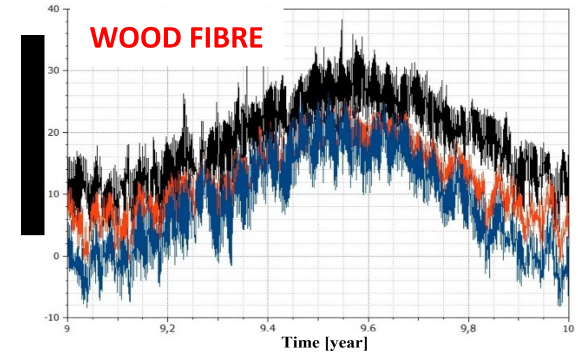
RESULTS: *temperature and relative humidity*

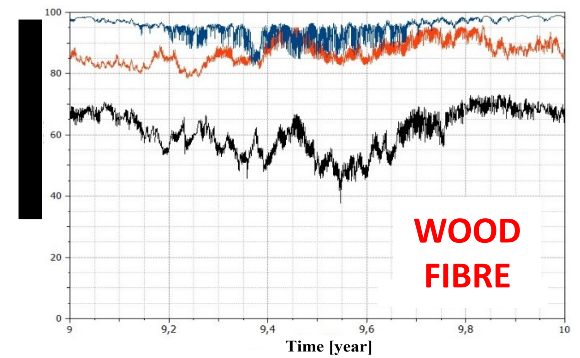




- There is **a remarkable difference amongst the selected climates**, especially when looking at relative humidity values (RH) occurring inside the wooden materials (CLT and fibre)

- These **differences are apparent and of the same magnitude in both CLT and wood fibre layers** (values are referred to the outermost material's surface)



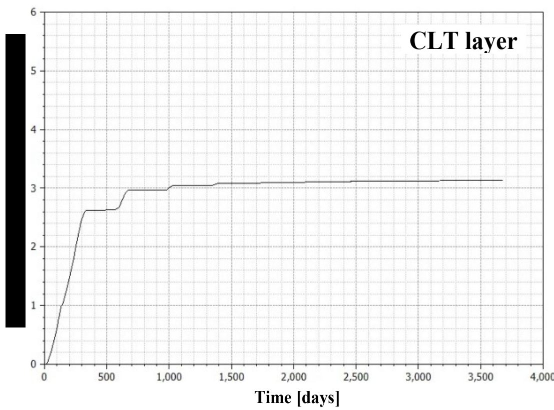


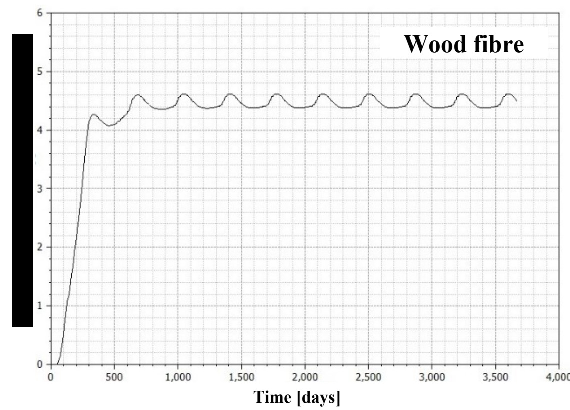
- In Milan RH keeps constantly ≥ 90% both in the CLT and in the wood fibre, while in Catania it ranges between 40% and 70%

- T and RH values in Genova are close to those of Milan

RESULTS: *Mould Index (MI)*

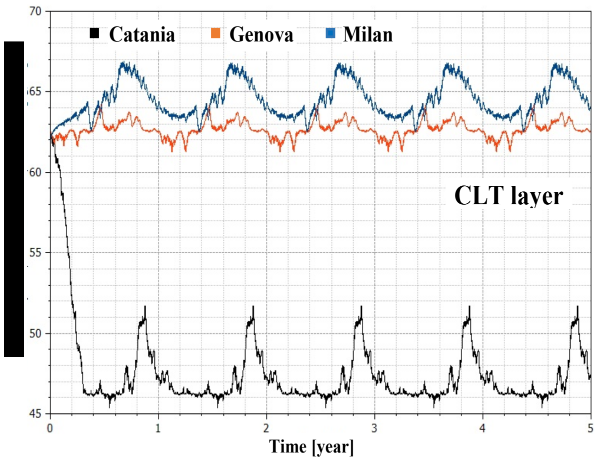
- Previous results suggest that mould formation issues are very likely in Milan and Genova, while being extremely unlikely in Catania
- In Milan, **after two years of simulations the Mould Index stabilizes** around MI = 3 and MI = 4.5 in the CLT and the wood fibre, respectively

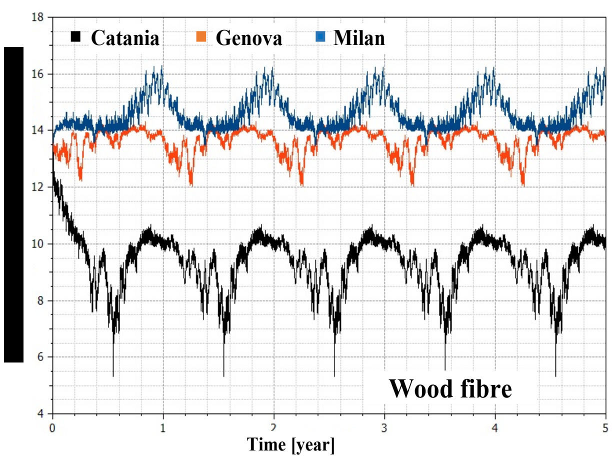




- According to the scale of MI introduced by the VTT model, **this corresponds to visually evident mould formation** on a significant portion of the material, which is not acceptable
- The Mould Index in Genova is slightly lower than in Milan, but this still implies mould growth issues in the wood fibre, that need to be solved. On the contrary, **no mould formation occurs in Catania** (MI = 0 in both layers)

RESULTS: *Total Water Content (TWC)*





- The **TWC in Catania is much lower than in the cold climates** for both layers. Catania is also the only context where the structures dry starting from their initial water content

- **The highest TWC competes to the CLT**, most likely because the wood fibre can more easily dry out through mass and heat transfer processes with the outdoors

- If compared with the saturation moisture content (w_{sat}), **the TWC in the CLT corresponds – in Genova and Milan – to slightly less than 15% of the maximum moisture content**, and slightly exceeds the w_{80}

CONCLUSIONS AND FUTURE DEVELOPMENTS

- **In warm climates** of coastal Southern Italy **the proposed solution does not show any hygrothermal issues**

- **In cold and humid climates** (Northern Italy), **visible mould formation** and the consequent wood decay is likely to occur, especially in the CLT layer

Criterion	Layer	CATANIA	GENOVA	MILANO
Total Water Content	CLT	52 kg/m^3	64 kg/m^3	67 kg/m^3
	Wood fibre	10.6 kg/m^3	14.2 kg/m^3	16.2 kg/m^3
Surface Condensation	Inner surface	NO	NO	NO
Mould Index (max)	CLT	0	1.8	3.2
	Wood fibre	0	3.8	4.6

- In the CLT layer, the maximum TWC reached during an annual wetting/drying cycle is slightly less than 15% of the maximum (saturation) moisture content in the material

- **Suitable adjustments** must then be envisaged for the proposed stratigraphy when it is adopted in cold climates, **such as adding a vapour barrier** on the inner side of the CLT or using a different kind of insulation with lower attitude to absorb vapour from the outdoors

CONCLUSIONS AND FUTURE DEVELOPMENTS

- These issues are currently being investigated in the framework of the e-SAFE innovation project, together with **the effects of driving rain** that have been neglected in this research

- Further ongoing studies are also addressing the possibility of **simulating the CLT panel through three separate layers with different fibre orientation**, and the increase in heat transfer due to the effects of humidity on thermal conductivity

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