BSA 2022 Building Simulation Applications
5th IBPSA-Italy Conference
Bozen-Bolzano 29.6.2022 – 1.7.2022

IBPSA Italy
International Building Performance Simulation Association

e-SAFE

BSA 2022 - Building Simulation Applications
5th IBPSA-Italy Conference, Bozen-Bolzano 29.6.2022 – 1.7.2022

Heat and mass transfer modelling for moisture-related risks in walls retrofitted by timber materials

Università di Catania

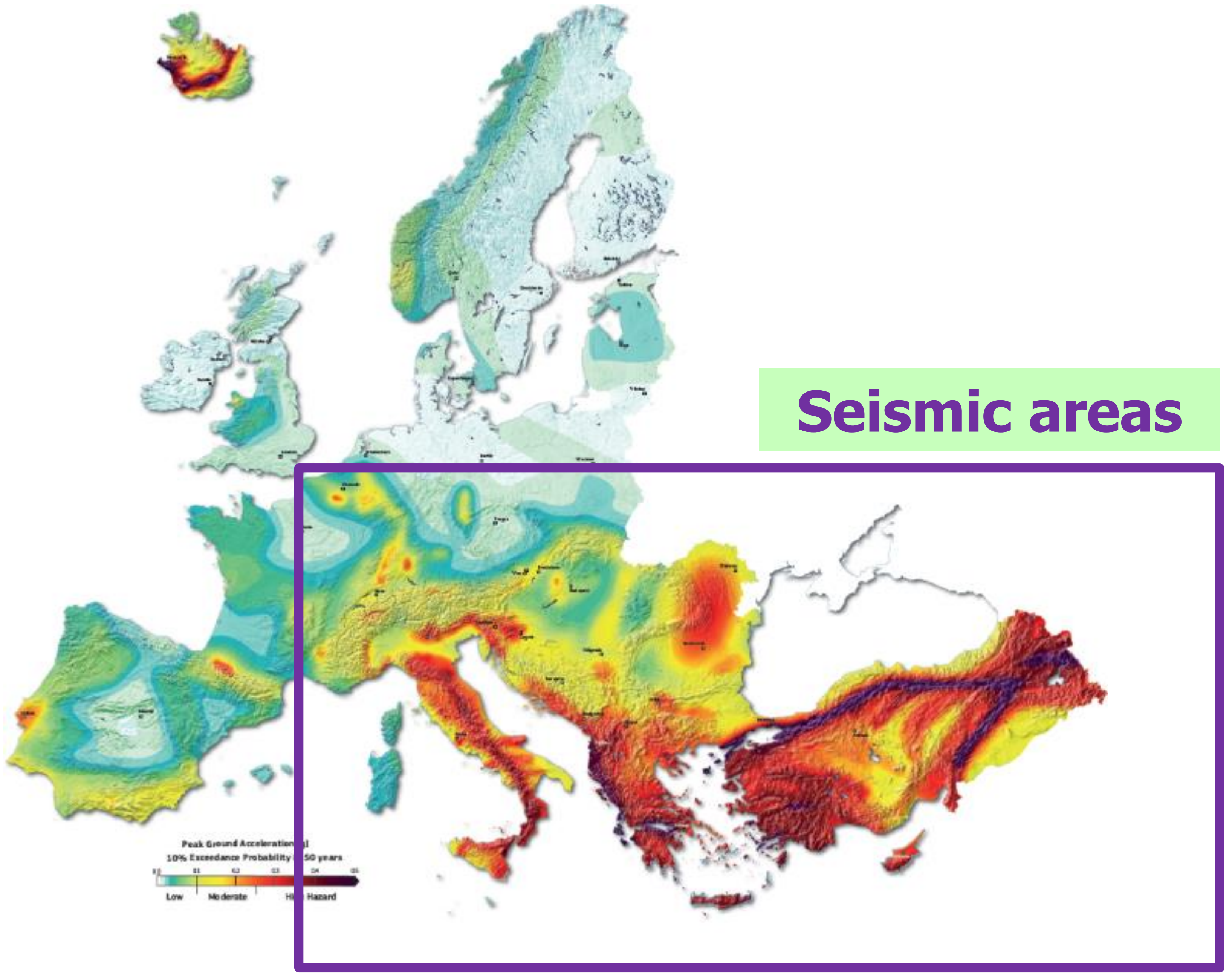
Gianpiero EVOLA, Alessandra URSO, Vincenzo COSTANZO, Francesco NOCERA, Luigi MARLETTA

University of Catania, Italy

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

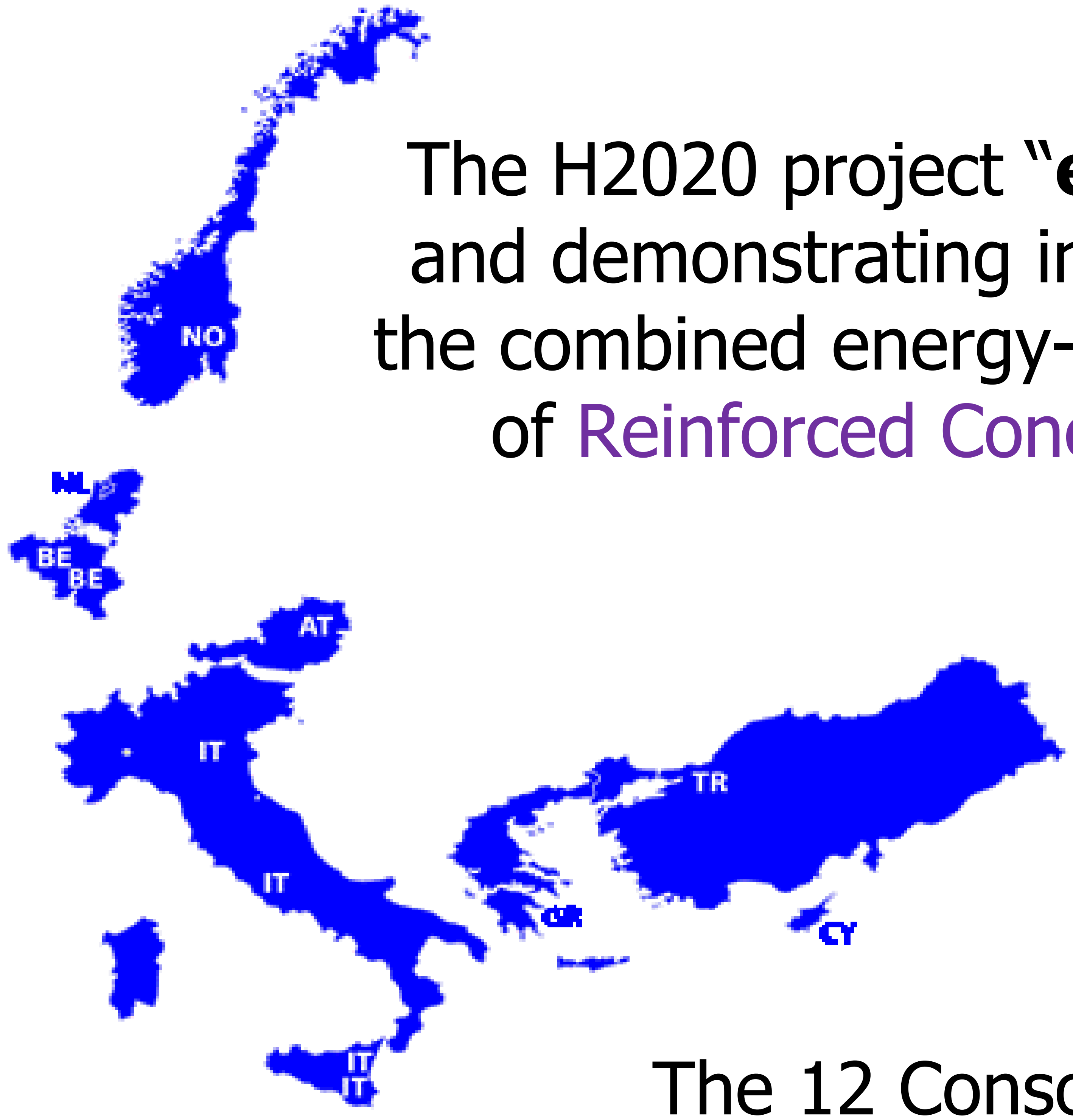
Introduction

Energy and seismic retrofit of the existing buildings



Energy inefficiency is not the only problem faced by the European building stock: about 50% of the European territory is earthquake-prone

The H2020 project "**e-SAFE**" is developing and demonstrating innovative solutions for the combined energy-and-seismic renovation of Reinforced Concrete (RC) buildings

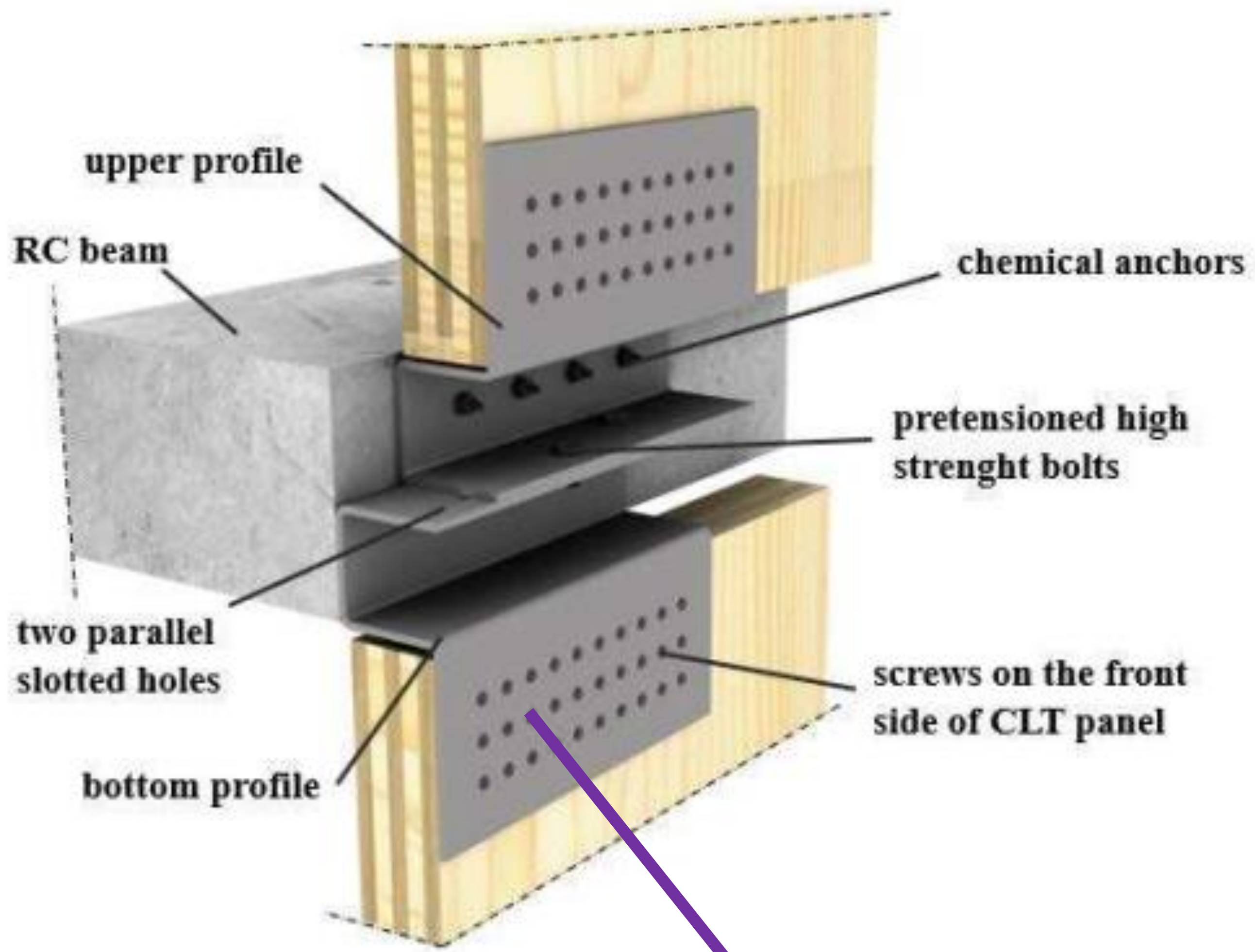


The 12 Consortium partners are from 8 EU Countries with different climate, including highly seismic regions

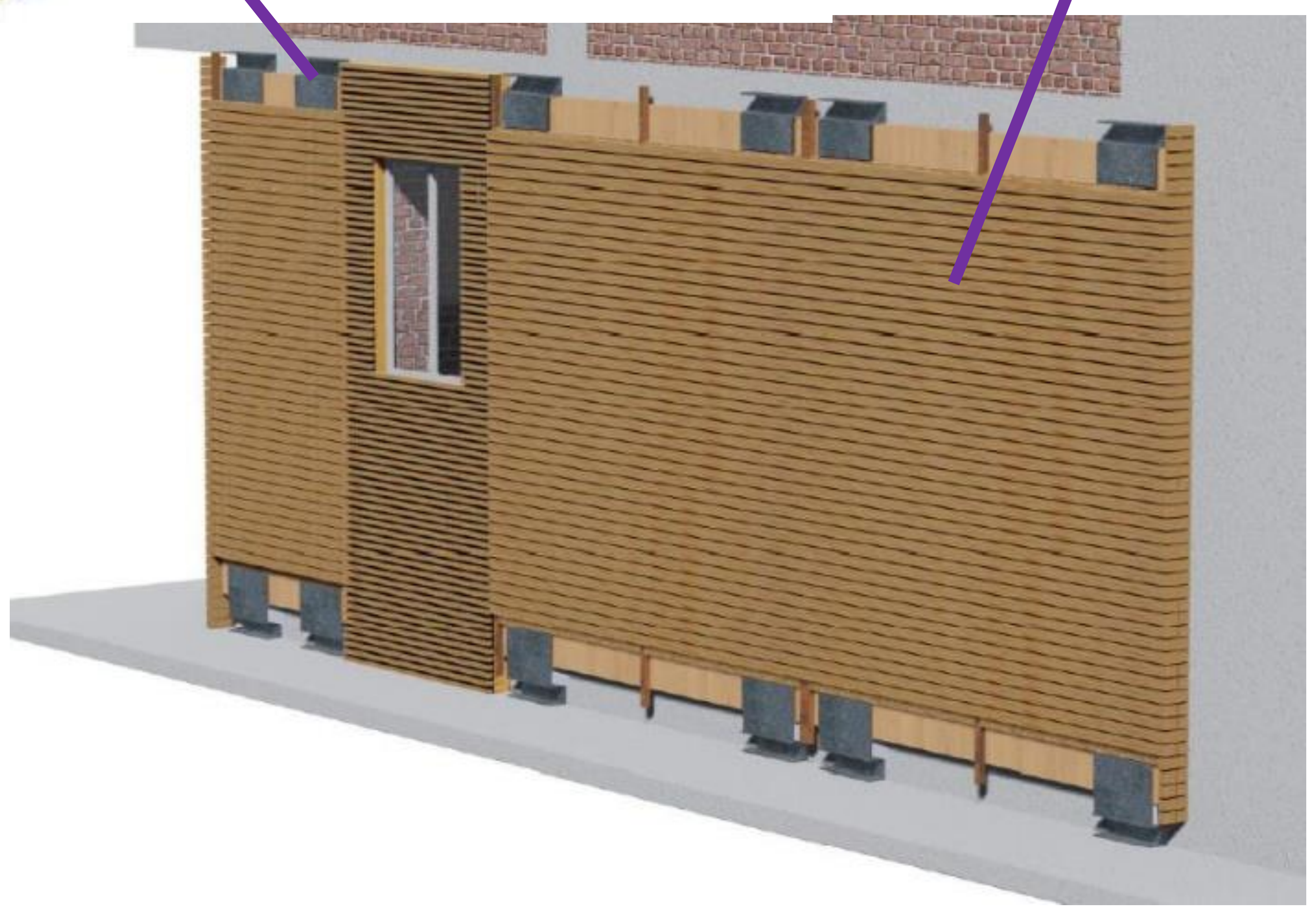
e-SAFE has received funding from the European Union's Horizon 2020. Coordination and support action programme under grant agreement No 893135.

Introduction

Energy and seismic retrofit of the existing buildings



Cross Laminated Timber (CLT) panels applied to the existing walls, including outer timber-based insulation



Pilot building (renovated in 2023)

Problem:
timber-based components are prone to moisture storage due to their cellular structure and – being wood an organic material – they are more sensitive to decay caused e.g. by mold.

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

Paper outline

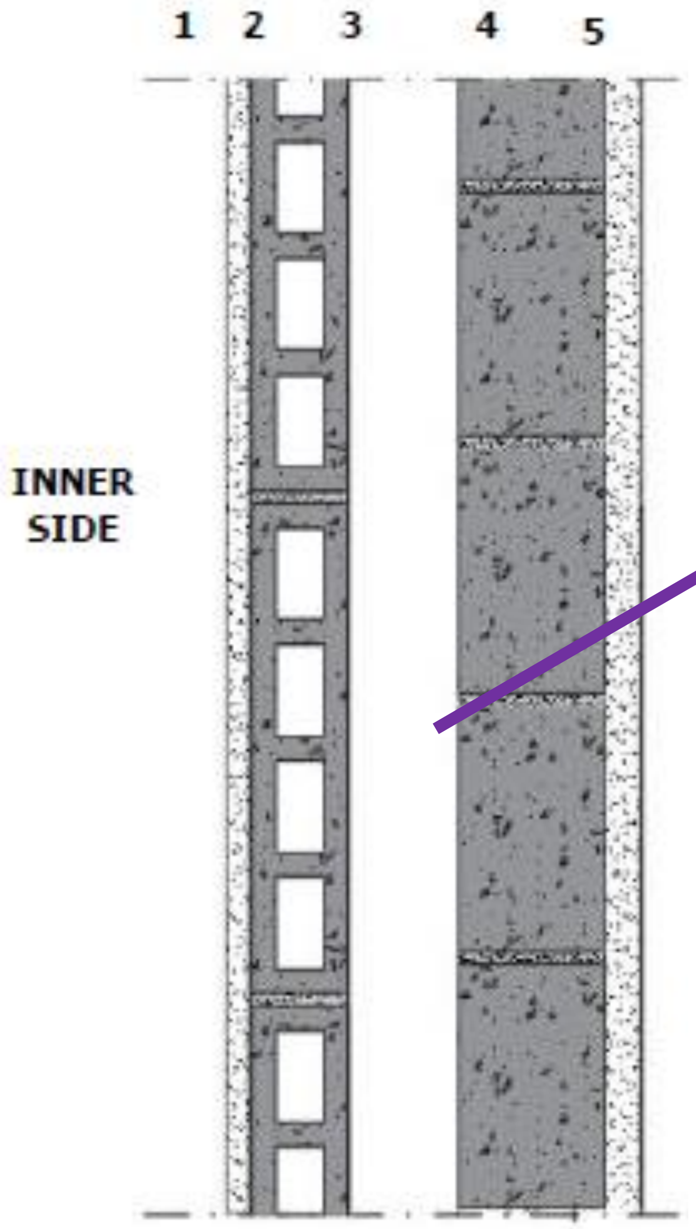
Main scopes and objectives

- Investigating moisture-related risks in the proposed retrofit solution, based on transient HAMT (Heat and Moisture Transport) simulations with the software **Delphin 6.1.3** (according to EN 15026:2007)
- Assessing the dispersion in the available values for the hygrothermal properties of CLT, and the sensitivity of the results to their inaccuracy
- Assessing the effects of using different available weather files for the same location

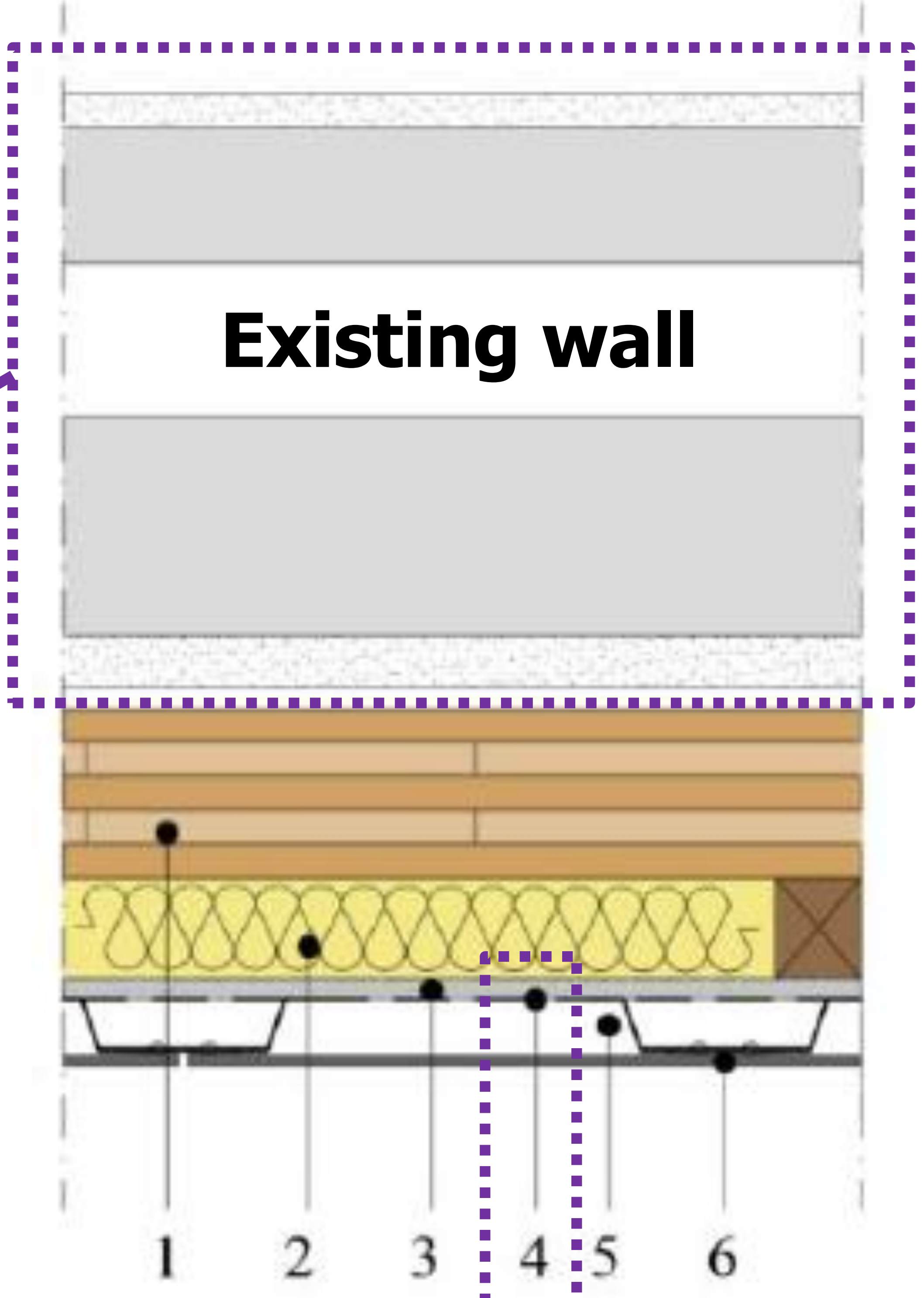
e-SAFE has received funding from the European Union’s Horizon 2020. Coordination and support action programme under grant agreement No 893135.

The e-CLT solution

Energy and seismic retrofit of the existing buildings



1. Internal plaster
2. Hollow concrete block
3. Air cavity
4. Hollow concrete block
5. External plaster



1. CLT panel (100 mm)
2. Wood fiber (60 mm)
3. Cement-based board (12.5 mm)
4. Waterproof vapor-open membrane (thickness = 0.8 mm, μ = 50)

Hygrothermal properties:

- μ: vapour resistance factor (-)
- A: water uptake coefficient
- θ_{80}: moisture content at RH = 80%
- θ_{eff}: moisture at effective saturation

id	Material	μ -	A $g \cdot m^{-2} \cdot s^{-0.5}$	θ_{80} $kg \cdot m^{-3}$	θ_{eff} $kg \cdot m^{-3}$
242	Plaster	33	30	40.7	430.0
508	Hollow blocks (80 mm)	15	177	11.4	319.4
15	Non-ventilated air gap	1	-	-	-
508	Hollow blocks (120 mm)	15	177	11.4	319.4
712	CLT	186	2 - 5 - 12*	59.8	728.1
1762	Wood fiber	1.1	5	12.7	590.3
15	Scarcely-ventilated air gap	1	-	-	-
654	Fiber cement cladding	26	14	70.9	283.6

$\lambda = 0.12\ W/(m \cdot K)$

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

Hygrothermal properties

CLT: data from literature and Delphin database

Source	Material	ρ $kg \cdot m^{-3}$	μ -	A $g \cdot m^{-2} \cdot s^{-0.5}$
DELPHIN Database	Spruce (radial) – TU Dresden	395	186	12
	Spruce (tangential) – TU Dresden	395	488	5
	Spruce (longitudinal) – TU Dresden	395	5	12
EN ISO 10456	Timber	450	50	-
Lapage (2012)	CLT, Eastern SPF	486	-	4 – 7
	CLT, Western SPF	500	-	12
	CLT, European softwood	340	-	10 – 11
	CLT, Him-Fir	522	-	14
Alsayeg (2012)	CLT, Eastern SPF	370	328	2.0
	CLT, Western SPF	440	456	1.9
	CLT, European softwood	340	311	1.6
	CLT, Him-Fir	380	277	2.5
Cho et al. (2019)	CLT	602	630	-
Kordziel et al. (2020)	CLT, SPF + Douglas Fir	423	-	2.5 – 2.8
	SPF without adhesive	426	146	2.8
	SPF with adhesive	426	168	2.4
Raina (2021)	CLT, European spruce	-	-	1.9 – 3.6
	CLT, European spruce – without covered edges	-	-	7.0 – 12.0
Chang et al. (2020)	Larch (radial)	570	75	-
	Larch (tangential)	570	109	-
	Larch (longitudinal)	570	5	-
	CLT, larch and plywood	600	79	-

The Delphin database does not include CLT properties, but reports a series of wood types with different fiber orientation: some of them have been tested at TU Dresden.

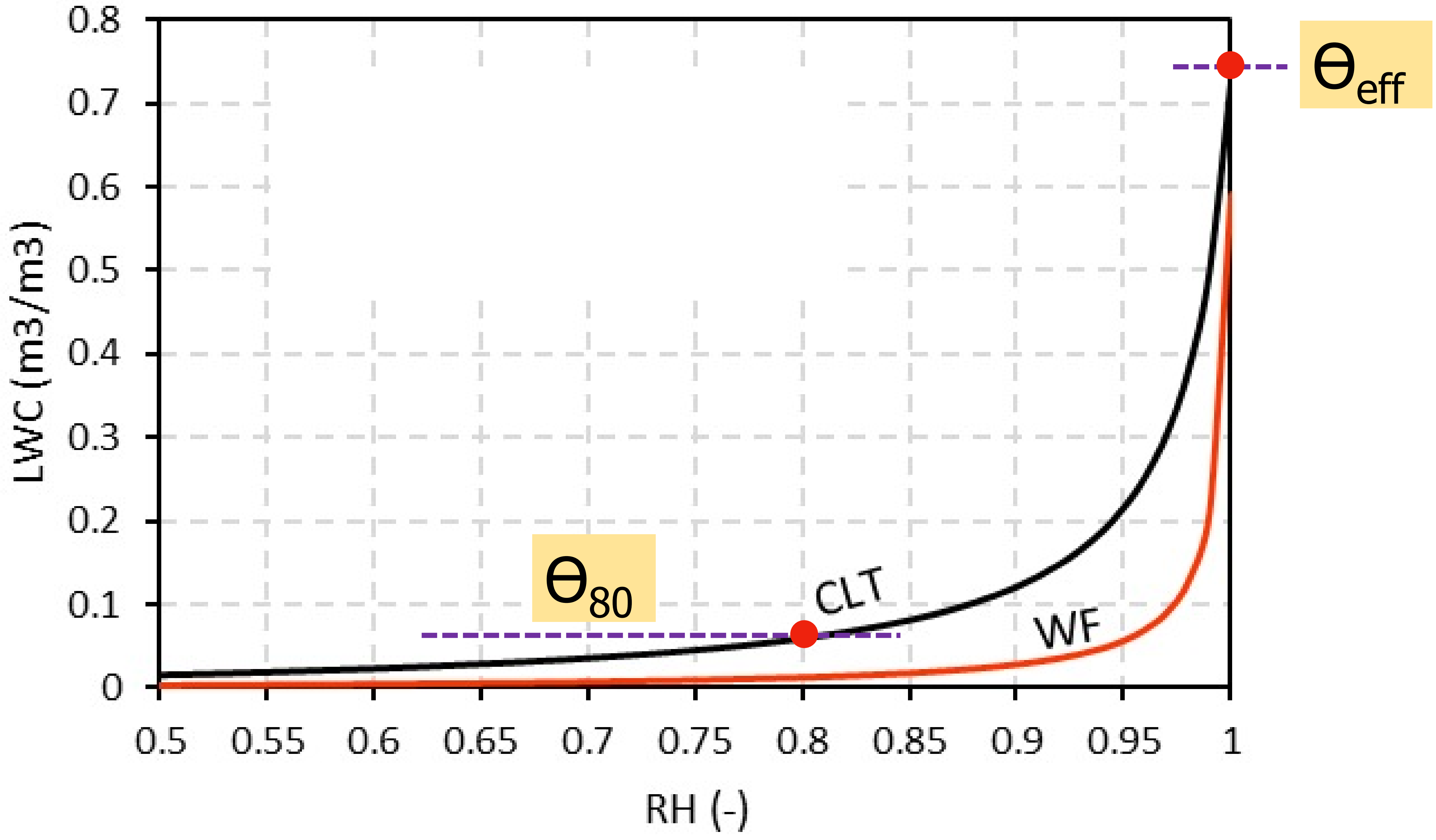
Based on experimental data from the literature, CLT has:

- μ-value: slightly higher than just wood (due to the glue layers). Very low in case of longitudinal fibers.
- Density: ranging from 350 to 600 kg/m^3 (we used 450 kg/m^3, based on manufacturers' technical sheets)
- Water uptake coefficient (A): ranging from 2 to 12 $g/(m^2\ s^{0.5})$

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

Hygrothermal properties

Sorption curves



- The sorption curve should be defined experimentally (ISO 12571:2013)
- Otherwise, by setting Θ_{80} and Θ_{eff} Delphin can build a sorption curve (based on models)
- No dependence of the sorption curve from temperature
- Desorption/sorption curves are not the same: however, Delphin does not consider hysteresis

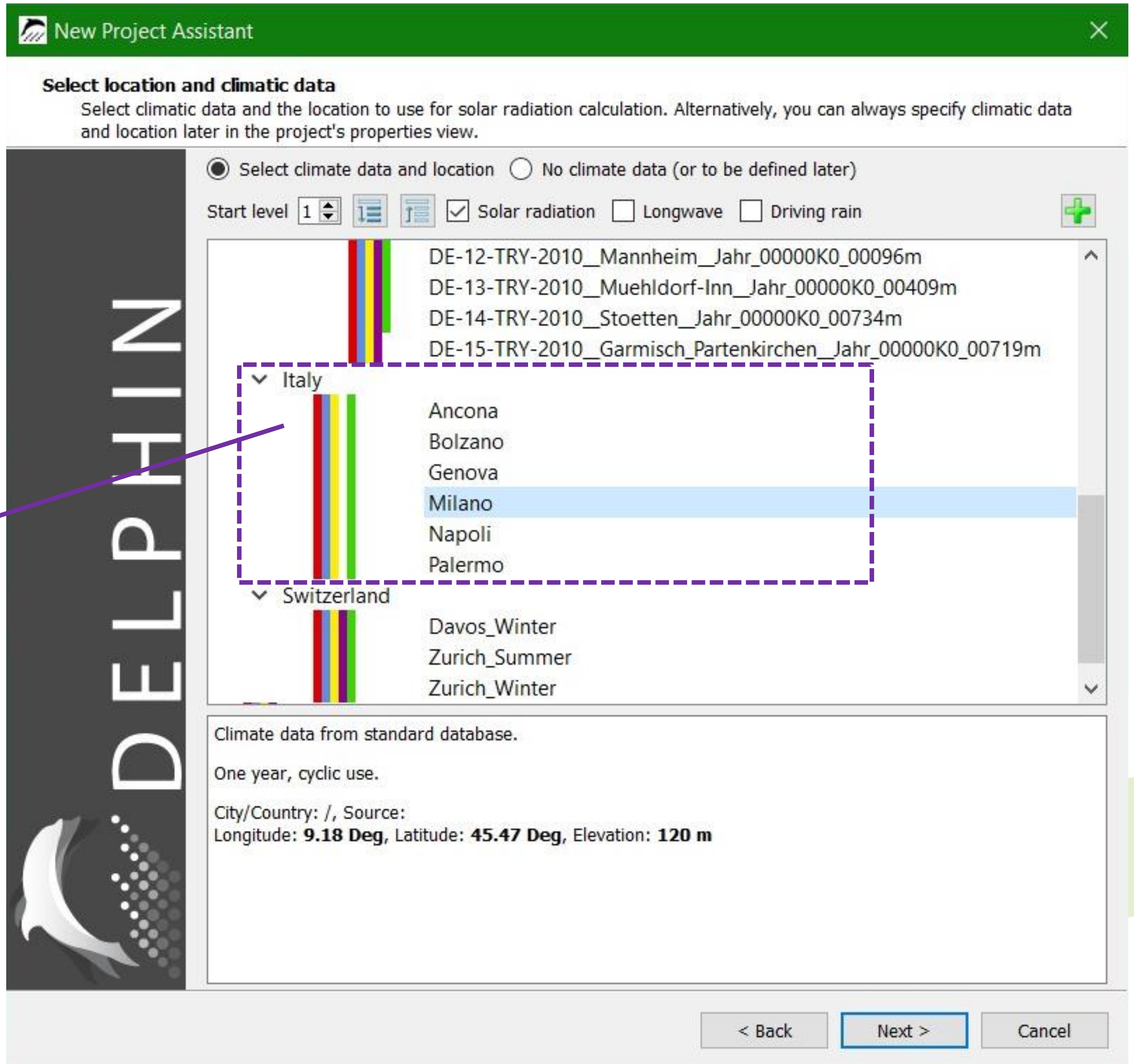
e-SAFE has received funding from the European Union's Horizon 2020. Coordination and support action programme under grant agreement No 893135.

Weather data

Comparison between TMY and Delphin database

Simulations are based on weather data for Milan (Italy):

1) the TMY weather file from Linate (2004 – 2018) downloaded from the website Climate.OneBuilding.org
2) the weather file from the Delphin database



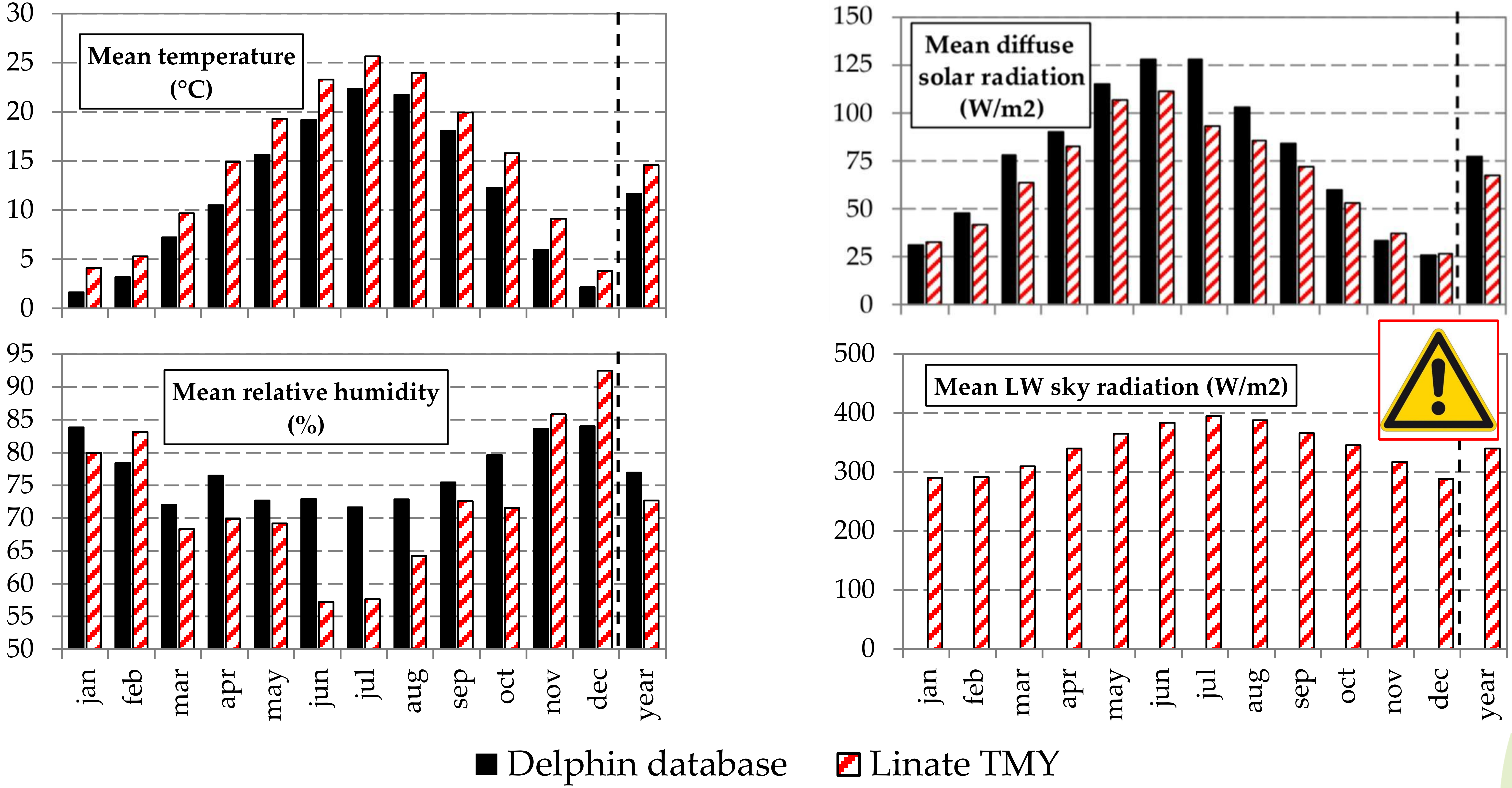
Limitations:

- Just 6 Italian cities
- No reference about the methodology used for building the weather file (TMY? EWY? MRY?)
- No data about longwave sky irradiance available !!

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

Weather data

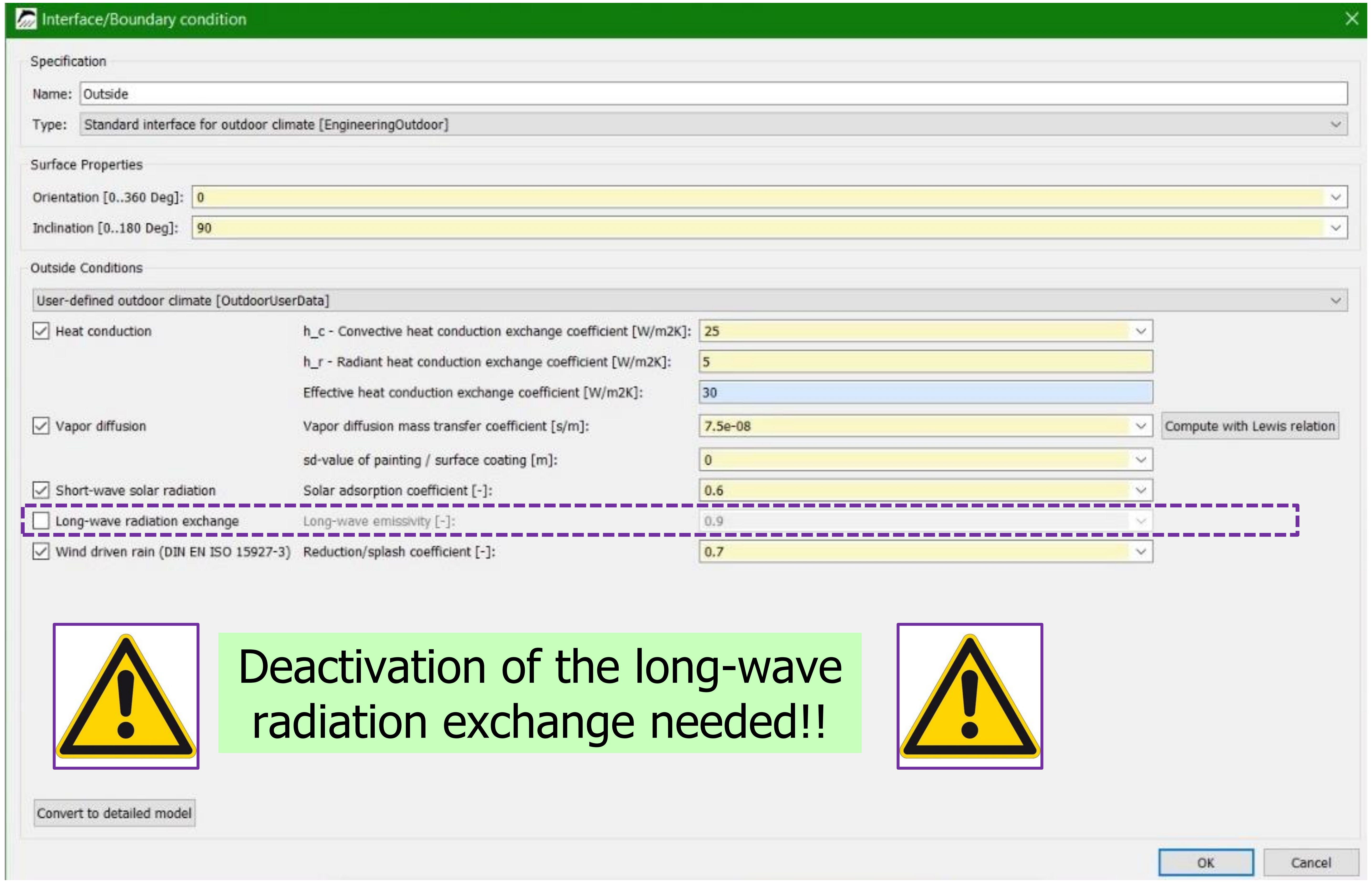
Comparison between TMY and Delphin database



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

Weather data

Inconsistency with LWR data



Deactivation of the long-wave radiation exchange needed!!

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

Methodology

Some settings for the simulations

- The simulations are performed over a 10-year-long period, in order to get a stabilized behaviour
- The initial conditions correspond to T = 20 °C and RH = 80% for all materials
- The investigated wall is oriented facing North, thus excluding the drying effect of direct solar radiation.
- Wind driven rain on the wall surface is calculated according to EN ISO 15927-3 (rain reduction coefficient = 0.7)
- A water source (1% of the incident rain flux) is imposed to the outer surface of the water-proof membrane, to simulate possible leakage from the cladding

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

Methodology

Criteria for risk assessment

- **Liquid Water Content (LWC)** in the materials ($m^3 \cdot m^{-3}$)

  This output influences the thermal conductivity of the various materials and – in turn – the thermal transmittance (U-value) of the wall.

$$\lambda(LWC) = \lambda_{dry} + 0.56 \cdot LWC$$

$$U(LWC) = \left[\frac{1}{h_{0,e}} + \sum_{i=1}^{n} \frac{s_i}{\lambda_i(LWC)} + \frac{1}{h_{0,i}} \right]^{-1}$$

- **Mould Index (MI)** , according to the model elaborated by Viitanen and Ojanen (2009)

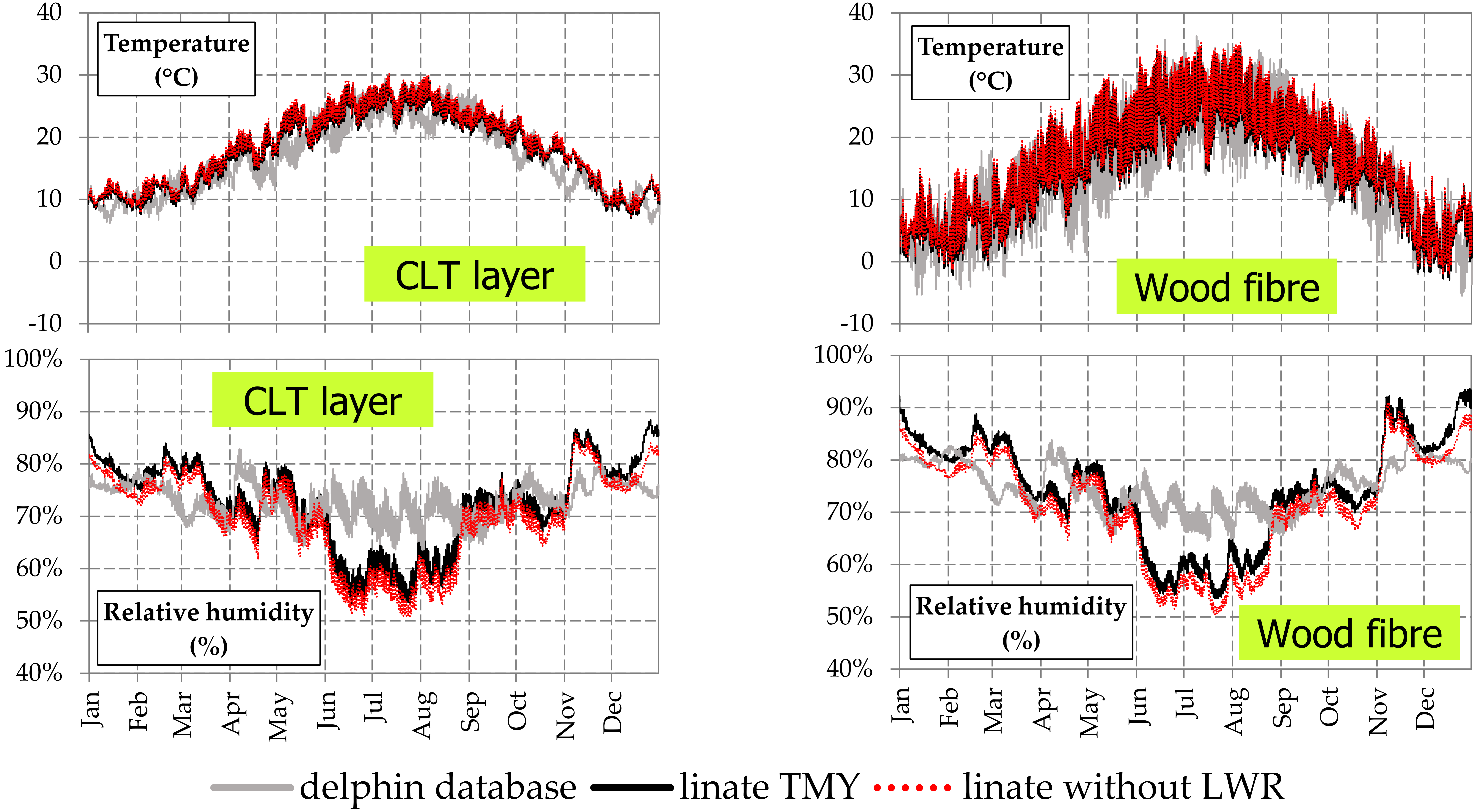
M = 0	M = 1	M = 2	M = 3	M = 4	M = 5	M = 6
No mould growth	Small amounts of mould on surface	Several local colonies of mould on surface	Visual findings of mould on surface (< 10%)	Visual findings of mould on surface (< 50%)	Plenty of mould growth on surface (> 50%)	Very heavy and tight mould growth

Unacceptable conditions !! (M = 3 to M = 6)

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

Results

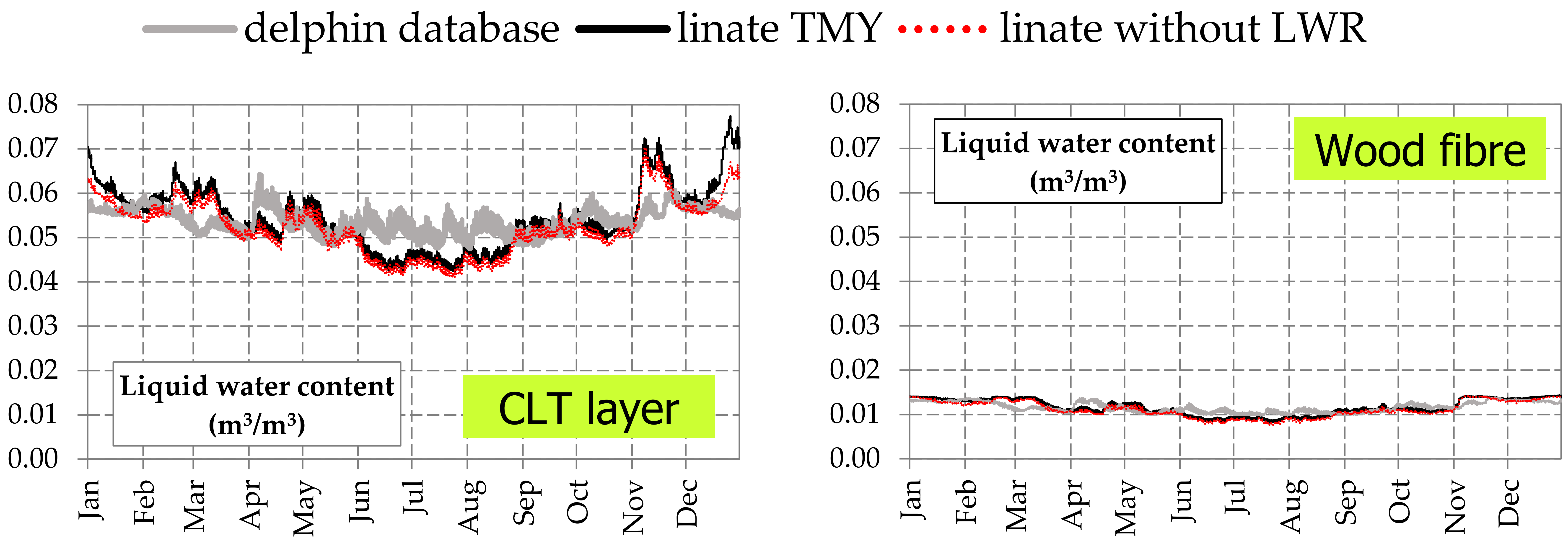
Temperature and Relative Humidity



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

Results

Liquid Water Content (LWC)



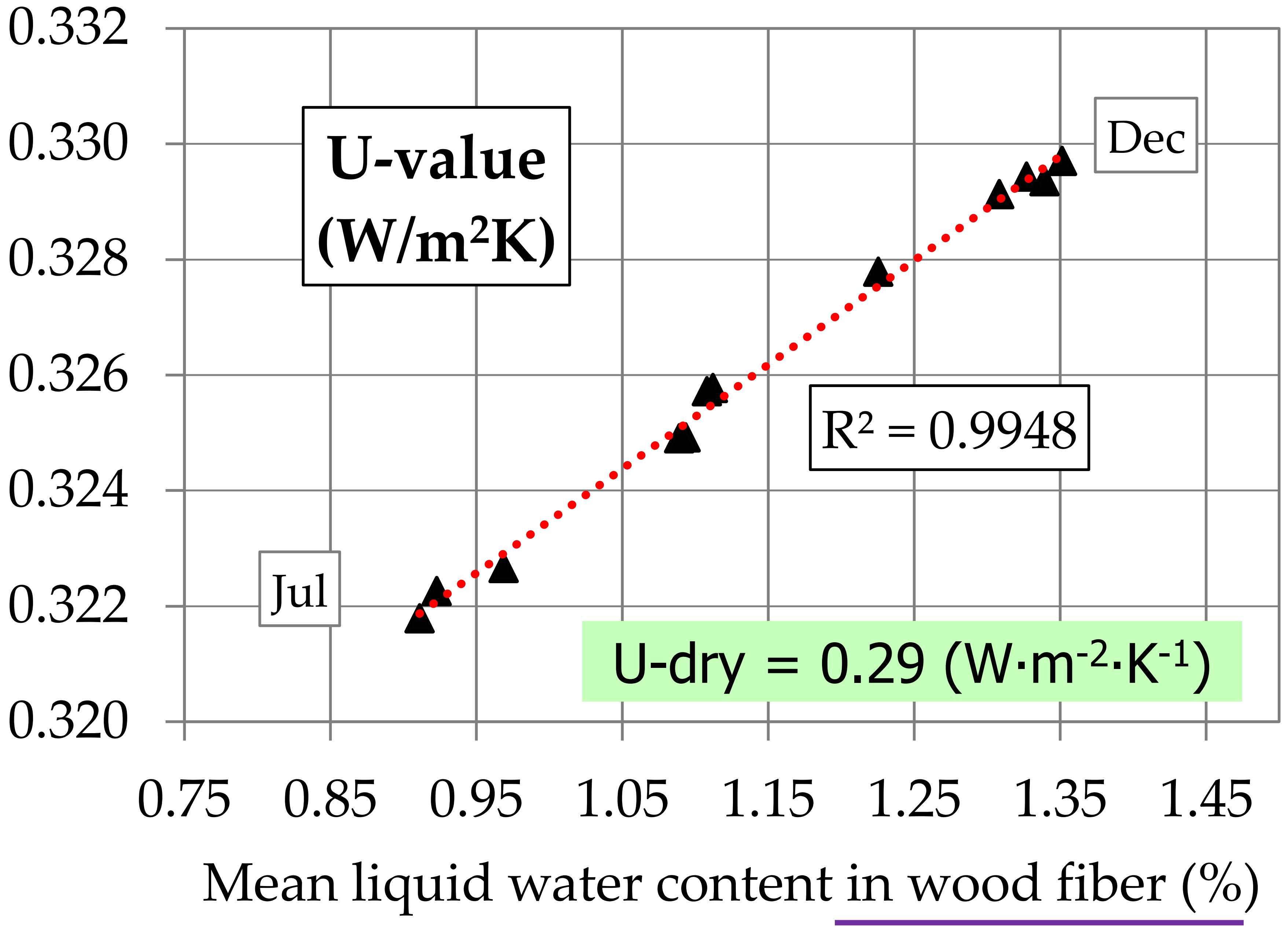
- The Liquid Water Content (LWC) in the CLT is 5 to 6 times higher than in the wood fibre, due to its high sorption capacity
- Neglecting the Longwave Radiation (LWR) exchange means reducing the LWC by around 4%, in both the CLT and the wood fibre

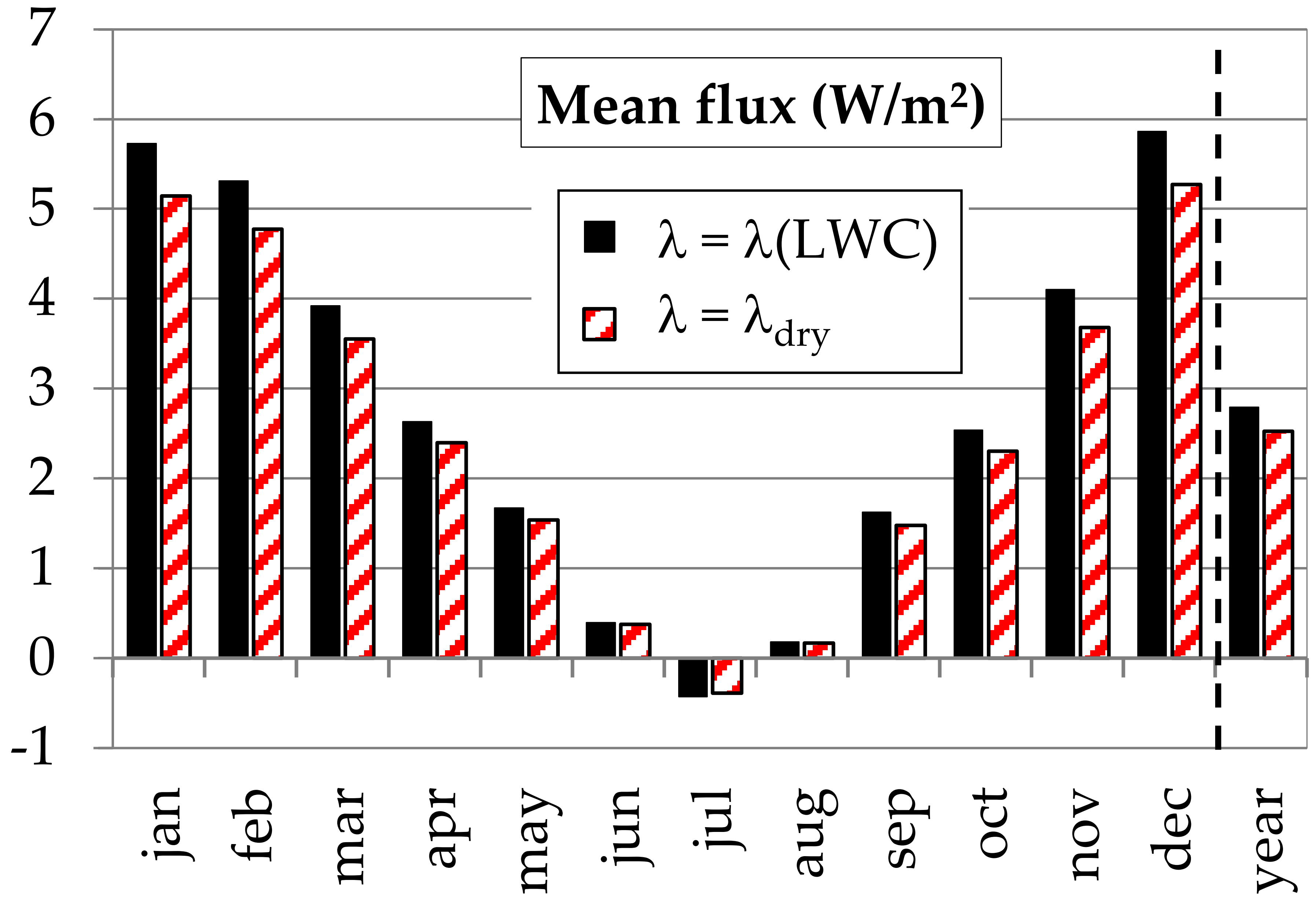
e-SAFE has received funding from the European Union's Horizon 2020. Coordination and support action programme under grant agreement No 893135.

Results

Increased heat flux due to the Liquid Water Content

The mean monthly U-value is from 10% to 11.5% higher than the "dry" U-value



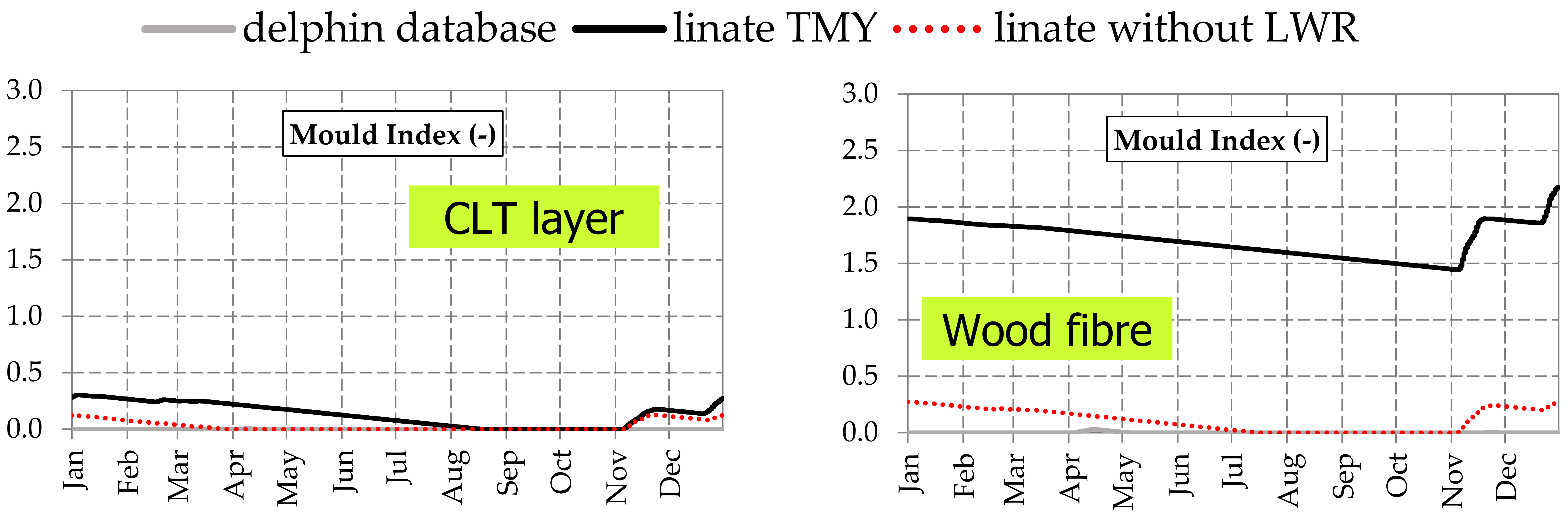


If one considers dry materials, heat losses are – on average – 9.7% lower than with wet materials.

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

Results

Mould Index (MI)

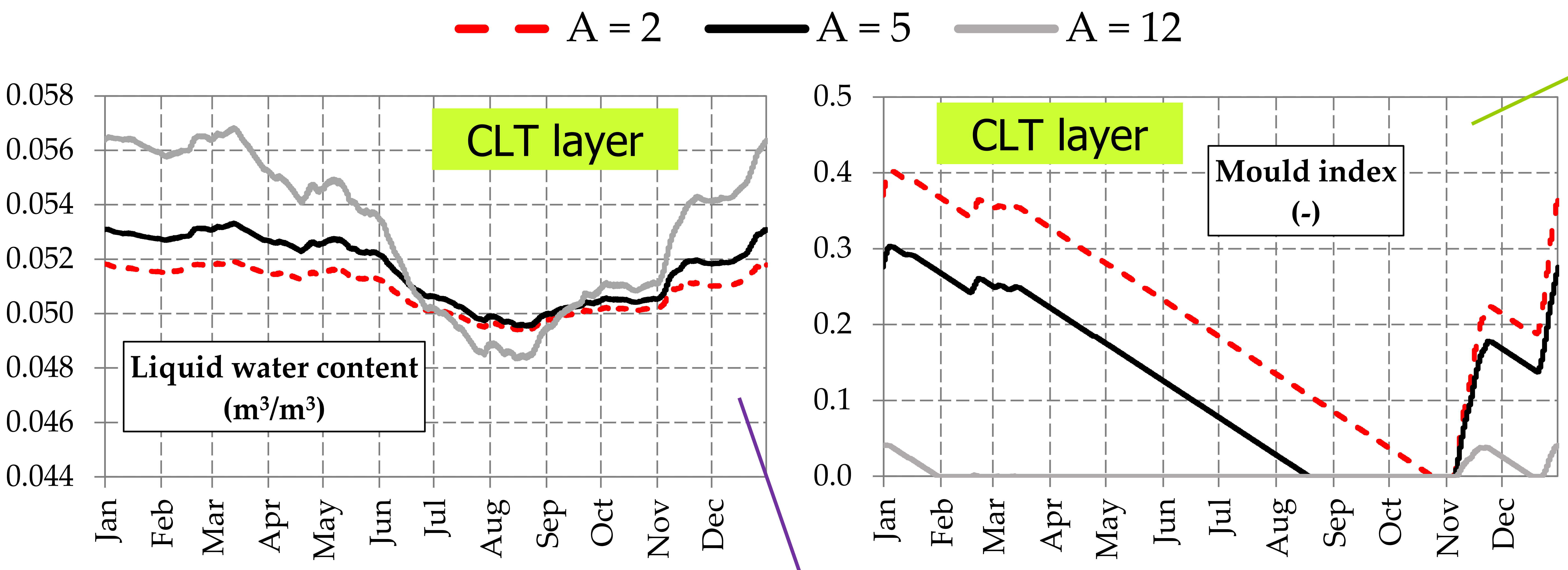


- The risk of mould growth is higher in the wood fibre (MI = 2 with TMY data)
- Neglecting LWR (Delphin data and Linate without LWR) significantly underestimates the risk of mould growth

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

Results

Sensitivity to the water uptake coefficient



In any case, the risk of mould growth in the outer side of the CLT remains negligible

Higher A-values imply higher LWC in winter, and more effective drying in summer. However, the mean yearly LWC varies by less than 4%, which does not imply variations in the heat losses

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

Conclusions

Critical issues and next steps

- In Milan, a moderate mould growth risk (MI = 1.5 – 2) occurs in the wood fibre, while MI << 1 in the CLT
- The liquid water (LWC) kept inside the wooden materials increases the U-value by around 10% if compared with dry materials
- Available weather data are not always reliable: lacking Longwave Radiation (LWR) data significantly lowers the simulated mould growth risks, but LWC varies only slightly
- The hygrothermal parameters for CLT should be attentively selected
- The inaccuracy on the A-value of CLT does not significantly impact on LWC and mould growth risk (MI) in the CLT

Next steps:

- Comparison with Moisture Reference Years and under several different climate zones
- Effect of position and type of membrane (vapour-open / vapour barrier)

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

Thank you

Prof. Ing. Gianpiero EVOLA
DIEEI – University of Catania
gevola@unict.it

STAY UPDATED WITH US

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