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The e-SAFE energy and seismic renovation solutions for the European building stock: main features and requirements

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Abstract. In the framework of the ongoing four-year 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 European countries are going to be developed and demonstrated. These solutions address both the energy performance of the building envelope and the heating and cooling of the indoor spaces, and aim to be prefabricated, customizable, low-disruptive and sustainable in order to boost the decarbonisation of the largely inefficient European building stock. This paper presents the main features of the e-SAFE solutions and the results of a preliminary analysis to verify their effectiveness and compliance with European legislation and standards. The outcomes will be useful for the design and demonstration stage, by identifying issues that need to be tackled.

1. Introduction

According to the EU building stock observatory, around 90% of the entire EU building stock (and 78% of the only residential buildings) were built before 1990 [1]. Furthermore, about 35% of the EU buildings are more than 50 years old: in order to reach the targets set by EU for 2030 and 2050, the deep renovation of the existing building stock is then a key issue [2]. Indeed, the EU strives to reach as soon as possible the ambitious annual renovation rate of 3%, while current yearly rates only range between 0.1% and 2.0% in the main European countries (being around 1.2% in Italy). This means that between 75% and 85% of the existing buildings would still be in use in 2050 [3].

Energy efficiency is not the only problem faced by the European building stock. Nearly 50% of the European territory is earthquake-prone with different levels of seismicity: in seismic countries, such as Albania, Greece, Turkey, Italy, Croatia and Romania, in case of destructive earthquake any solution for decarbonisation alone will turn out to be unsustainable from a social, economic and environmental point of view [4]. In these countries, energy renovation actions must combine with seismic upgrade.

2. The e-SAFE solutions

In order to ensure energy and seismic retrofit of the existing RC-framed buildings, e-SAFE will make use of: (i) timber-based energy efficient panels (e-PANEL), including a wood-based insulating material, (ii) structural panels made of Cross Laminated Timber (e-CLT) that increase seismic performance through their connection to the existing RC beams with specifically designed friction dampers. The CLT panels make available additional lateral stiffness, while the dampers dissipate seismic energy in case of moderate or strong ground motions. The e-CLT will also include an outer insulation, with a lower thickness than in the e-PANEL in order to get the same thermal transmittance.

The two types of panels will externally clad the existing walls in a way that allows reaching the desired energy and seismic resistance. As a general rule, the e-PANEL will be applied on those walls including openings, where e-CLT would not be effective (see Figure 1.a). Both panels are customizable (in terms of size, thermal transmittance and finishing material) and will be prefabricated through BIM-based design procedures. The e-SAFE project envisages the possibility of applying also a metallic exoskeleton (e-EXOS) made of bi-dimensional bracings equipped with dampers and connected to the existing RC frame. Moreover, e-SAFE will deal with heating and cooling of the indoor spaces by installing centralized PV-fed reversible air-to-water heat pumps, and by relying on thermal energy storage to decouple energy production and demand, while also shaving the peaks in the energy demand. Innovative slim decentralized modular plug-and-play tanks to store Domestic Hot Water (called e-TANK) will also be installed (see Figure 1.b).

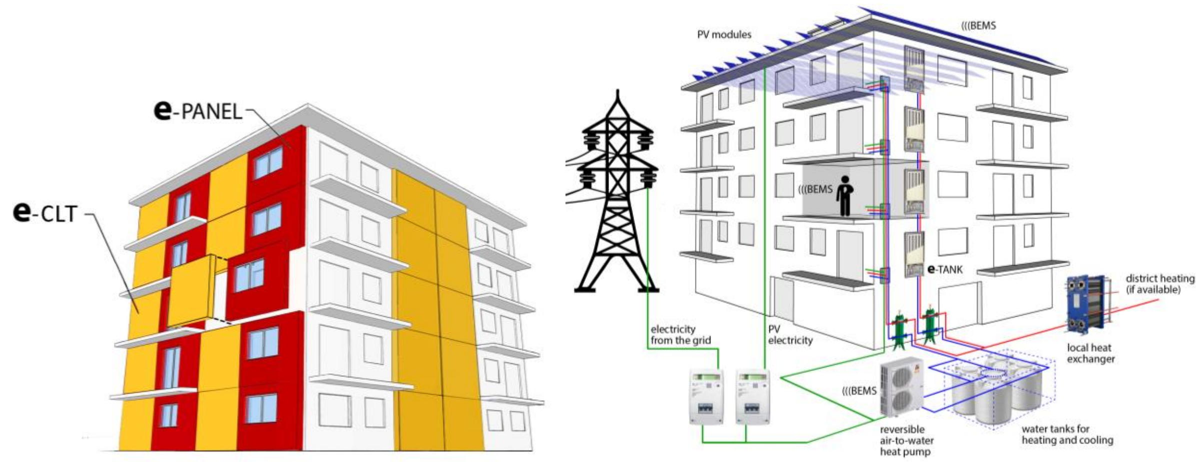

Figure 1. e-SAFE solutions for the energy upgrade of envelope (a) and technical systems (b).

3. Energy and acoustic performance of the e-SAFE solutions: preliminary analysis

This paper mainly deals with the thermal and acoustic performance of the e-SAFE solutions devoted to the energy and seismic renovation of the building envelope, that is to say e-CLT and e-PANEL.

On the one hand, e-CLT consists in superposing to the existing wall a CLT panel ($\lambda = 0.12$ W·m^{-1}·K^{-1}, $\rho = 420$ kg·m^{-3}) which integrates a layer of wooden fibre ($\lambda = 0.038$ W·m^{-1}·K^{-1}, $\rho = 50$ kg·m^{-3}) or other similar bio-based insulating materials, and the final finishing (e.g. ceramic, porcelain stoneware, glass, metal, wood) according to the desired architectural image and the local availability of materials. A thin air-gap (2 cm) will be left between the insulation and the cladding, and a vapour-open water-proof membrane (6 mm, with equivalent air layer thickness Sd = 0.30 m) on the outer surface of the insulation will protect the wall from rain and wind. On the other hand, the e-PANEL just includes a thicker layer of insulation and the cladding, but with a greater air gap in order to get the same overall thickness as for the e-CLT. Table 1 reports the main thermal and acoustic performance parameters obtained by adding either e-CLT or e-PANEL to two traditional wall structures that are very common in many European countries, especially in buildings built before 1990s that are in need of energy and seismic upgrade. The parameters include thermal transmittance (U), periodic thermal transmittance

(Y_{IE}), phase shift (φ) and internal areal heat capacity (κ_i), as well as the weighted sound reduction index (R_W). The results apply if the CLT thickness is 10 cm (Sd = 6 m), whereas the insulation thickness is 6 cm (Sd = 0.06 m) in the e-CLT and 9 cm in the e-PANEL (Sd = 0.09 m).

Table 1. Thermal and acoustic performance for two traditional walls upgraded with e-SAFE solutions.

Original wall structure	Renovation solution	U [$W \cdot m^{-2} \cdot K^{-1}$]	Y_{IE} [$W \cdot m^{-2} \cdot K^{-1}$]	φ [h]	κ_i [$kJ \cdot m^{-2} \cdot K^{-1}$]	R_w [dB]
Double-leaf hollow clay bricks with non-insulated air gap (overall 30 cm)	e-CLT	0.28	0.02	15.3	47.4	58.0
	e-PANEL	0.28	0.06	12.0	48.3	56.0
Non-insulated solid brick wall (overall 28 cm)	e-CLT	0.31	0.01	17.5	64.1	60.0
	e-PANEL	0.31	0.03	13.3	64.3	59.0

All values reported in Table 1 are satisfying, if compared with national and international regulations. On the one hand, the thermal transmittance complies with all regulations in force in Southern European countries (e.g. Greece, Italy, Turkey), while at least 4 more cm of insulation would be necessary e.g. in Central and Northern Europe. On the other hand, Y_{IE} is well below 0.10 $W \cdot m^{-2} \cdot K^{-1}$, as required by national regulations in Italy when more than 50% of the building envelope is renovated. As for the phase shift, all proposed solutions show excellent dynamic thermal performance ($\varphi \geq 12$ h); the internal areal heat capacity – i.e. the ability of a wall to accumulate heat when a periodic heat wave acts on its inner side – is always $\kappa_i > 40$ $kJ \cdot m^{-2} \cdot K^{-1}$ and thus complies with a recent Italian regulation for public buildings. Furthermore, according to the method described in the EN Standard 13788:2013, no internal or surface condensation occurs in Southern Europe. In cold climates, a vapour barrier must be placed on the inner side of the insulation, since condensation occurring in the winter does not entirely evaporate in warm months.

Finally, the acoustic performance of building façades is commonly regulated either through their apparent weighted sound reduction index (R'_w), which includes the effect of glazed openings and lateral transmission, or through the weighted standardized level difference ($D_{2m,nT,w}$). If double glazing windows with different glazing thickness are installed (e.g. 6-10-12), the weighted sound reduction index presented in Table 1 ensures that $D_{2m,nT,w}$ keeps between 42 dB and 46 dB, which is largely sufficient to comply with various national regulations, especially for residential buildings. No further improvement in the acoustic performance stems from an increased thickness of insulation.

This paper has shortly presented the main results of the Task “Preliminary definition of the e-SAFE requirements” of the e-SAFE project. Further in-depth studies, including dynamic heat-and-moisture transfer in the walls, will be described in upcoming papers.

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