e-SAFE: energy and seismic affordable renovation solutions for the decarbonisation and seismic safety of the EU building stock

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ABSTRACT

This paper aims at showing the concept, the scope and the main challenges of the four-year innovation project e-SAFE, started in October 2020 and funded by the EU in the framework of the H2020 Programme. e-SAFE aims to develop a new deep renovation system for non-historical reinforced concrete (RC) framed buildings, which combines energy efficiency and anti-seismic retrofitting actions with a series of further advantages including affordability, improved architectural image and reduced implementation time, costs and occupants' disruption. e-SAFE will also address strategies to activate new value chains to boost the deep renovation market throughout Europe, including financial and social aspects. The paper will also present some preliminary results about the expected energy and carbon reduction ensured by the e-SAFE solutions.

KEYWORDS

Deep renovation, EU buildings, energy savings, seismic resistance, decarbonization

INTRODUCTION

Recent data from the EU building stock observatory highlight that around 90% of the current European buildings was built before 1990, and that around one third was built before 1970 [1], when in general no regulations concerning energy efficiency in buildings were in force.

Now, the EU has set ambitious targets regarding primary energy savings and decarbonisation within 2030 and 2050 [2]: the above-mentioned data suggest that reaching these targets implies a massive energy renovation of the European building stock, and for this reason the EU strives to reach as soon as possible an annual renovation rate of 3%. However, the current yearly renovation rates for existing buildings hardly exceed 1.2% in the main European countries; furthermore, considering the low yearly rate of construction of new buildings, between 75% and 85% of the existing buildings would still be in use in 2050 [3].

Finally, one must not forget that energy efficiency is not the only issue concerning the European building stock. Indeed, almost half the European territory is earthquake-prone, even if with different levels of seismicity: in highly seismic countries, such as Albania, Greece, Turkey, Italy, Croatia and Romania, a destructive earthquake would make whatever energy saving solution for buildings unsustainable from a social, economic and environmental point of view [4]. In these countries, energy renovation actions must then be coupled with seismic upgrade.

In this framework, e-SAFE aims to develop and demonstrate new technical solutions to integrate energy efficiency and seismic safety in the deep renovation of non-historic buildings (i.e. built after 1950). The proposed solutions can be easily adapted to specific climatic conditions, seismicity levels and other boundary conditions, and will be demonstrated in one real pilot building in Italy, plus two virtual pilots that will be selected through a call for expression of interest in other EU countries.

However, e-SAFE encompasses not only technological and functional issues, but also other relevant architectural, methodological, financial and social aspects that might hinder full exploitation and market uptake, thus trying to overcome the most significant barriers faced by deep renovation in EU today. For instance, the proposed deep renovation solutions are conceived to minimize disturbance for occupants and the time needed onsite for the construction works, as well as to reduce installation and operation costs. Moreover, e-SAFE innovation includes a systematic engagement of stakeholders in co-design and mutual learning, thus contributing to the extensive social acceptance of retrofitting activities. Finally, e-SAFE will develop reliable innovative business models and financial tools, able to spur investments in deep renovation especially for low-income residents. The development of the

e-SAFE system is also accompanied by the training of a wide variety of actors in the deep renovation market, with a focus on professionals and builders, with the aim of enhancing their capacity to address complex energy and seismic design issues in a timely and costly manner.
Through such a multi-facet approach, e-SAFE is expected to significantly contribute to the decarbonisation of the EU building stock, while also reducing the effects of seismic events and, at the same time, improving the quality of life in existing dwellings.
The paper will present the different "souls" of the project, by also resuming the main technological and social challenges towards a full market uptake. Every chapter will deal with a specific issue, starting from technological aspects concerning the building skin, the energy systems and the implementation of ICT solution, and then addressing social issues, financial issues and demonstration activities.

BUILDING SKIN: ENERGY, SEISMIC AND ARCHITECTURAL RENOVATION

From the skin to the architectural bark

The concept of architectural skin often offers a reductive interpretation since the building skin is considered the most superficial component of a building. It is in fact, by epidermal definition, the outermost part, the so-called envelope. The image of the building and its external perception are therefore assigned to the skin [5]. Although this is not always the case, designers often tend to treat the skin as a separate element from the rest of the construction, intending it either as a mask or a cover [6]. The interior of the building, apparently separated and dissociated from the skin, in the contemporary era seems to be able to respond to rules different from those of the envelope [7].
This concept of architectural skin is contrasted by the construction concreteness of architecture. Some scholars instead, including architect Helio Piñon, propose a paradigm shift: replacing the concept of skin with that of *bark* [8]. The bark – like the skin – covers and protects the interior of the building, but – unlike the skin, which does not influence the shape of the building – has an autonomous and substantial structure. In fact, the building bark, as the cortex with respect to its trunk, has relationships with the body it protects in terms of thickness, image, color, texture and specific structure. Although the skin has also its own structure, however, unlike the bark, it is a continuous component with an elasticity that allows it to replicate or reshape the form of the underlying body, indifferently. The elasticity of the skin gives it autonomy with respect to the building shape so as to allow the architectural body to be broken down into components that may not even be related to each other, i.e. the current concept of architectural skin may not affect the interior space nor could it be conditioned by it. In other words, the misunderstanding about the current concept of architectural skin leads to the separation, also in constructive and technological terms, of the interior space from its envelope.
In this sense, the envelope solutions developed within the e-SAFE project are closer to the concept of bark than that of skin. In fact, in the design of these solutions, the need of covering and protecting the interiors meet and combine together, both in terms of energy efficiency, seismic resistance and architectural image. The architectural interior is not independent from the external envelope because the indoor comfort and the seismic safety depend on the latter, while the architectural perception is provided by chameleonic possibilities of finishing, freely adaptable in terms of materials, textures and colors.

The e-SAFE technological bark

According to the previous section, e-SAFE proposes three technological components – namely e-PANEL, e-CLT and e-EXOS – that, adequately combined, constitute the new multifunctional bark of the renovated building.

The e-PANELs are prefabricated plug-and-play modules made of a timber-framed structure combined with local bio-based recyclable/recycled insulating materials (hemp, cork, wood fiber, cellulose fiber, sheep wool, etc.) and finished by the desired cladding material (e.g. ceramic, stone, porcelain stoneware, metal, glass, wood, wood-plastic composites, etc.). These panels integrate other functional layers (breathable waterproof membrane, vapor screen/barrier, etc.) and an air cavity between the insulation and the cladding, as well as high-performing windows and sun shading devices, which will replace the existing ones. By selecting suitable materials and systems, the e-PANELs can meet the thermal and acoustic requirements for deep renovation in most European countries [9]. Of course, e-PANELs are intended to cover the entire vertical envelope of the building.

In earthquake-prone countries, the e-PANELs will be applied on the walls that include openings, while the blind walls will be covered by another kind of plug-and-play panels with structural properties, called e-CLT (Figure 1). The e-CLT panel is made of prefabricated Cross Laminated Timber (CLT) boards equipped with seismic energy dissipation devices (dampers). The CLT panel is connected to the beams of two consecutive floors through new and innovative friction dampers and provides additional lateral stiffness, strength and energy dissipation capacity to the existing structure, thus reducing the story drift demand in case of earthquake. The additional stiffness can be controlled by modulating the thickness of the CLT panel. Instead, activation force and number of dampers determine the additional strength and energy dissipation capacity provided by the system to the building. The activation force of the dampers is also set below the maximum force the CLT panel can sustain in compliance with the capacity design principle. This allows the CLT panels to remain in their elastic range of behavior even in occurrence of strong ground motions, while the nonlinear response is restricted to the dampers, which are specifically conceived to tolerate nonlinear response and dissipate input seismic energy. Like the e-PANEL, the e-CLT panel is also externally coupled with a bio-based insulation and the desired finishing material in order to meet thermal and acoustic requirements.

The result is a continuous bark applied over the envelope of the existing building that simultaneously increases its energy efficiency, seismic resistance and architectural image.

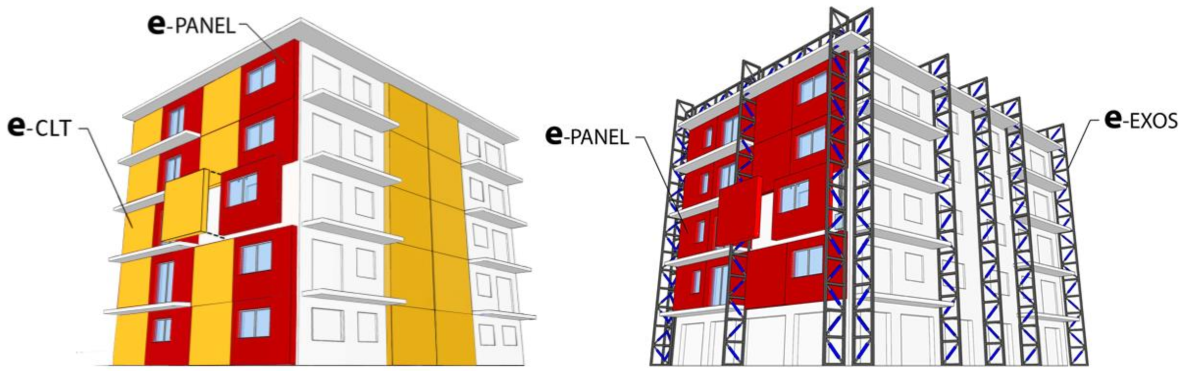

Figure 1. The e-SAFE solutions for the energy and seismic upgrade of the envelope

Always in seismic areas, in addition to or in place of e-CLT, the e-SAFE envelope system includes the e-EXOS, which is an ensemble of external metal bracings equipped with seismic dampers (Figure 1). The bracings are placed with their plane oriented orthogonal to the facade of the existing building and are connected to its perimeter beams. The dampers can be part of the bracings or can be located in the connections between bracings and building structure. The application of the e-EXOS to the building can reduce the story drifts demanded by the earthquake below the capacity. Indeed, the exoskeleton increases lateral stiffness and strength of the building structure. In addition, the it acts like a continuous beam pinned to the bottom and to the top of the building, thus avoiding the formation of the single-storey collapse mechanism, which is the main reason of the poor behaviour of existing buildings. Finally, since the exoskeleton can be equipped with dampers, it can further reduce the seismic response by dissipating part of the seismic input energy. The e-EXOS is installed on the outside of the existing building and does not interrupt the continuous bark realized by e-CLTs and/or e-PANELs.

The proposed anti-seismic, energy efficient, architectural bark offers the following four main advantages: (i) reduced occupants' disruption, since it is made of prefabricated components installed only on the outside of the buildings; (ii) low environmental impact, since the involved materials are recycled and/or recyclable and with a low carbon footprint; (iii) easy and quick installation, since its BIM-designed components can be dry assembled through mobile cranes and aerial platforms, avoiding traditional scaffoldings; (iv) cost-effectiveness, in comparison with traditional anti-seismic renovation solutions that require invasive interventions on the entire building structure.

TECHNICAL SYSTEMS

The e-SAFE project will also introduce thermal systems in the proposed renovation solution, according to a specific architecture named e-THERM, to replace the existing inefficient thermal systems with high-performance centralized electricity-driven heat pumps in order to satisfy both space heating/cooling needs and Domestic Hot Water (DHW) production.

In particular, the proposed e-THERM solution will take advantage from high performance air-to-water electric heat pumps (A2W EHP) coupled to insulated water tanks to store thermal energy. Air-to-water heat pumps are preferred to avoid excessive upfront investments, unless local conditions will make it possible to conveniently install water-source or ground-source heat pumps.

The new generation of medium-size A2W EHPs for residential applications offers many advantages, such as high COP values (COP > 4), use of new refrigerants with low Greenhouse Gas (GHG) emission and reduced noise emission. The idea consists in adopting heat pumps for outdoor installation, equipped with Full DC Inverter technology and capacity of modulation from 30% to 100%. The preferred refrigerant gas at this stage is R32, which is A2L class (low flammability) and presents an Ozone Depletion Potential equal to zero and a Global Warming Potential GWP = 675. The efficiency of the chosen EHP must comply with no less than A++ class according to EU Regulation 811/2013 [10], when working at low water temperature (LWT 35 °C). The expected seasonal heating performance (SCOP) is higher than four, while the desired seasonal cooling Energy Efficiency ratio (SEER) is higher than five. Fan coils will be used as indoor units, fed at medium temperature (45 °C).

Storage systems also play an important role in e-SAFE in order to reduce peak energy demand and increase the efficiency of the whole energy production systems. For this reason, the e-THERM concept also appoints a central role to heat storage systems by deploying innovative integrated technologies that enable effective integration and communication with the heat production devices. A first storage level is provided by large centralized underground water tanks (see Figure 2a): the heat pump will be equipped with a programmable control system in order to optimize energy performance for different thermal loads and outdoor climate conditions, while using the water tanks as a buffer to make the heat pump operate in the most convenient conditions (e.g. when PV electricity is available, or the outdoor air temperature exceeds a minimum threshold).

The water content of the storage tank will be determined to provide a certain degree of autonomy to the heat pumps while also keeping the tank at a reasonable size. The best set-up of operational water temperatures and control logics will be defined through the help of dynamic thermal simulations in TRNSYS, and afterwards tuned in real operational conditions with the e-BEMS system developed within the e-SAFE project.

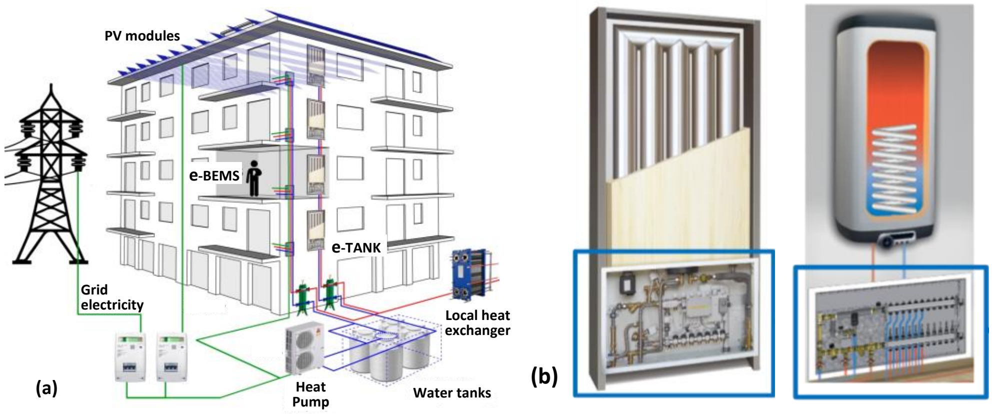

Figure 2. The e-THERM concept (a) and the e-TANK storage tanks (b)

A second level of energy storage is provided by small-size decentralized tanks named e-TANK, primarily devoted to DHW storage for every dwelling renovated through e-SAFE and implemented via a two-pipe network, which is very easy and inexpensive to install. As part of the e-SAFE project, two different types of modular decentralized water storage tanks will be developed (see Figure 2b):

- the first type is a storage tank with a very flat design that allows direct integration into (or at least tight fitted to) the walls of a dwelling. Despite the reduced size of the storage tank ($1.75 \times 0.82 \times 0.25$ m^3), the volume capacity amounts to 140 litres and is deemed sufficient to reliably supply the dwelling with the amount of hot water needed by a typical family of four people.
- the second type is a conventional cylindrical storage tank of size $1.23 \times 0.52 \times 0.55$ m^3, resulting in a volume capacity of 150 liters. This solution comes with the advantage of lower production costs if compared to the flat version, while retaining the same operation mode. In case there is enough space for integration in the renovated dwelling, this storage variant would be then preferred to the flat one.

Both devices include plug-and-play hydraulic connections and integrated electronic control that reduce the number of hydraulic components located inside each dwelling.

In order to manage also the hot water supply for space heating, as well as the fresh water supply for domestic purposes and space cooling, a prefabricated hydraulic module is installed as part of the e-TANK system. In the case of the flat storage tank, this hydraulic module can be installed directly below the storage tank, while the hydraulic unit for the cylindrical tank can be installed in a flush-mounted cabinet below the storage tank (Figure 2b).

The distribution network is operated at a low temperature level during heating operation, and the temperature of the feed line is only briefly raised to a higher level while the hot water storage tank is being charged. This results in low heat losses in the pipes, and creates ideal conditions for efficient operation of low-temperature heat sources such as heat pumps.

Finally, e-SAFE envisages the installation of PV panels for on-site electricity generation. Indeed, the most important advantage is that electricity-driven heat pumps can make full profit of PV-based electricity production, thus increasing the self-consumption rate. As a first option, PV modules will be placed on sloped roofs since the surface of PV modules that can be installed on suitably oriented pitches is sufficient in many cases to produce enough electric energy to cover a high share of the electricity bill. If needed, additional PV modules can be either integrated in the new skin – such as e-PANEL or e-CLT – and/or placed in a dedicated photovoltaic shelter (in case of flat roofs). In addition, the possibility of adopting an electric storage device to partially support thermal storage will be considered. For instance, in the renovated building (see the dedicated following section) a 10 kWh battery will be included.

ICT AND BUILDING ENERGY MANAGEMENT

The e-SAFE project also aims to develop a Decision Support System (e-DSS) for designers and stakeholders involved in the deep renovation process. The e-DSS will guide through a decision-making process during which interested parties (designers, investors, owners and occupants) will iteratively provide inputs and evaluate different alternatives. The tool will have a user-friendly graphical interface and will implement a well-defined set of simplified algorithms that, properly coded, will enable to rank the solutions proposed by the designer.

The e-DSS will allow the designer to select amongst several different renovation alternatives that, applied to the initial state of a building, will be evaluated through a wide set of sustainability criteria. Many outputs are expected but, among them, specific relevance will be given to primary energy consumption and CO_2 emissions, renovation duration and costs, energy savings and expected time of return. In this stage, the inputs will also come from users (e.g. owners or occupants), such as the selected type of finishing, sun shading, balcony additions or enlargements.

The DSS solution proposed by the project is a pragmatic alternative to highly complex simulation-based software platforms. Indeed, in the initial definition of candidate solutions e-DSS will rely on the expertise and technical skills of the designer and will consider constraints (e.g. when proposed interventions cannot be applied to the existing building) and financial opportunities (e.g. the availability of public or fiscal incentives, sources of funds etc.). Feedback from the local stakeholders is then used to steer the search process in subsequent iterations. The e-DSS will also interact with available databases of local suppliers that can provide those materials and services needed to implement the e-SAFE system.

e-SAFE will also ensure energy performance monitoring and control via its Building Energy Management System (e-BEMS). The role of e-BEMS is essential to optimize the energy and economic performance of the e-SAFE package. Moreover, it allows reducing the gap between actual and expected performance, which is key issue to further enhance occupants' confidence and motivation.

e-BEMS will measure indoor temperature, CO_2 concentration, indoor humidity, electricity consumption and production in real-time: this is a necessary step to collect information about the real performance of the e-SAFE concept, and to quantify the actual benefits in terms of comfort, indoor air quality and energy savings. Real-time data will be also available to the occupants through tailored application software available on their smartphones, which will also suggest in real-time the best options to improve indoor comfort and environmental quality and to reduce energy demand also through load management. For instance, the app will notify them to open windows in order to get suitable air change (when CO_2 levels are too high) and to operate the external blinds to improve visual comfort or reduce overheating. The direct involvement of the users is an essential step to increase their degree of acceptance, understanding and confidence in the e-SAFE concept. Finally, data coming from monitoring activities, performed by the e-BEMS, will be used to fine tuning the parameters of the algorithms executed by the e-DSS.

e-BEMS is expected to provide scalability, robustness, open protocol, interoperability, cost-effectiveness, as well as local and remote monitoring, allowing it to work with load control devices from different manufacturers that operate on different communication technologies and protocols like Ethernet (IEEE 802.3), Serial (RS- 485), ZigBee (IEEE 802.15.4) and Wi-Fi (IEEE 802.11).

SOCIAL ISSUES

A project like e-SAFE, aimed at pushing buildings' deep-renovation forward, has several social benefits for all people whose daily quality of life is strictly connected with buildings' ability to provide safe, comfortable, and welcoming spaces for all kinds of human activities (housing, offices, schools, public services, production, commerce, etc.). e-SAFE adds to this set of benefits at least two additional ones, related to two different aspects.

First, e-SAFE encompasses an innovative method to pursue such benefits, which is based on the co-design paradigm. Since the first pioneering experiences in the 1960s and 1970s [11], the co-design paradigm challenges designers to abandon traditional top-down approaches, based on the idea that formal, functional, structural, material and technological choices can be made by the experts solely on the base of theories, established design procedures, and/or empirical-ergonomic data [12]. Instead, such a paradigm requires designers to share their design expertise collaboratively with all those who are or can be potentially impacted by the design [13]. This is not only a way to make sure that the final design takes full consideration of stakeholders' preferences: collaboration requires stakeholders to go beyond their traditional role of "survey respondents," engaging in processes through which they become active and develop new awareness while enhancing their ability to change unsustainable living habits and constructively relate with new technologies. To this end, a multi-scale Stakeholders Forum (e-SAFE Stakeholder community) is being developed, engaging not only experts but all other types of interested actors. The technological and methodological innovations of the project will be the outcome of a systematic engagement of the stakeholders, which also increases deep renovation's social acceptance and public awareness. Stakeholders at EU and local levels will be actively engaged throughout the project's lifetime for developing and testing a co-design protocol to be to be included in the e-SAFE implementation guidelines. This aims at making e-SAFE design solutions always inclusive of user's knowledge.

A second innovative aspect is related to the strong connection between the social and the financial issues. e-SAFE has the ambition to be a "deep renovation system" that is able to "uptake" the renovation market, dealing with the fact that major obstacles are not of technological nature but rather financial, normative, and/or procedural. Thus, e-SAFE intends to be effective also in the face of significant socio-cultural obstacles, both at the individual and the organizational level. Many individual owners not only lack money and/or basic financial literacy (e.g. the ability to access eventual financial incentives) but also hold a socio-cultural status connected with life priorities that are not inclusive of deep renovation. The challenge is even bigger in the context of condominiums with vacant and/or delinquent apartments. At the organizational level, there are many "broken" and/or "highly dysfunctional" public housing authorities and/or social housing organizations, which are unable to perform any level of action even in the face of adequate housing policies. As a matter of fact, most of these buildings are located in distressed neighbourhoods lacking reasonable real estate investment return prospects, no matter how "good" the financial deal on the table is (reduced costs, fiscal benefits, etc.). This perspective makes "deep renovation" an 'urban' challenge that can only be addressed through strategies that uptake the urban scale, significantly enhancing the urban real estate market while addressing urban socio-cultural gaps. e-SAFE uptakes this challenge through the establishment of local urban platforms and the use of collaborative urban mapping techniques [14], providing inputs for the establishment of an ad-hoc entity (the e-FOUNDATION). Such organization is designed to be able to unfold a complex set of socio-cultural and financial strategies to apply e-SAFE even in the face of the most desperate "regeneration scenarios".

FINANCIAL ISSUES

In order to maximize market uptake, e-SAFE will provide customers (either intermediate or end-user) with a one-stop-shop experience. Insofar as possible, and depending on the characteristics of each project, e-SAFE will aim to alleviate customers of relevant concerns (e.g. cash-flow matters) and/or risks (e.g. credit/default risk).

A business model will be developed that will consider the generation of a new complex of three actors aimed at managing all economic, commercial and financial aspects needed to support the development, use and sustainability of the e-SAFE system, during and beyond the project's lifetime, as follows:

- e-NABLE: an e-SAFE expert working group acting, during the project, as an enabling actor, to formulate suitable exploitation strategies. More specifically, it will undertake the research, testing, implementation, reporting and all other activities necessary to develop, enable and maintain the financing schemes/tools that will underpin e-SAFE implementation. e-NABLE will also undertake policy engagement activities to promote the introduction of energy-efficient and anti-seismic renovation governmental incentives (fiscal and other). e-NABLE's core functions will be absorbed by the entities described below, to ensure that the exploitation strategy remains up-to-date;
- e-IPR, an entity charged with ownership and management of the e-SAFE intellectual property rights. e-IPR's income will be invested, at agreed proportions, into e-FOUNDATION (see below). Also, part of the profits made by e-SAFE partners from the sale of the various e-SAFE components will be allocated to e-IPR;
- e-FOUNDATION, an entity envisaged as a social enterprise that will be charged with the provision and/or facilitation of affordable and tailored financing to e-SAFE end-users.

e-FOUNDATION will create its cash pool pairing the licence/royalty income received by e-IPR with a variety of capital raised through financing tools such as:

- Crowdfunding, both through existing platforms and a new dedicated platform for e-SAFE projects only;
- Peer-to-peer lending whereby investors contributing to specific e-SAFE projects can have a lien over the property and benefit from a fixed amount of interest income;
- Energy trading via smart contracts via blockchain technology, where building owners implementing e-SAFE may sell excess energy produced to interested buyers (including energy suppliers) in an automatic manner;
- Green bonds, issued for large-scale projects.

In turn, a variety of financing instruments will be used by e-FOUNDATION to finance building owners under preferential terms, e.g. low-interest loans, ESCO model financing through energy savings, recurring funds etc. The potential financial schemes will be matched with prioritised market segments, determined according to a market segmentation analysis, considering firmographic, geographic and socioeconomic circumstances in terms of strengths, weaknesses, opportunities and threats (SWOT).

DEMONSTRATION AND EXPECTED IMPACT

Application of the previously discussed aspects on the real and the virtual pilots should reveal the actual performance and effectiveness of the e-SAFE solutions. In fact, implementation and demonstration activities play a key role to provide visibility to the project, to overcome the lack of confidence from the users and to establish possible improvements to the concept. They will provide the possibility to test e-SAFE concept on field (in the real pilot building), and monitor the performance for at least one year, while also identifying and tackling potential drawbacks arising during co-design, installation, operation, energy production and maintenance.

The Italian pilot is an RC framed apartment block belonging to a public housing compound located in Via Acquicella Porto (Figure 3), in Catania, a city characterized by a high seismic risk. The pilot was built in 1964 by the Istituto Autonomo Case Popolari (IACP) of Catania – which is a partner of the project – and has five stories, 10 apartments and an overall gross floor area around 1180 m^2. This pilot is representative of the building stock erected in Italy between the 1950s and the 1980s, before the issue of the most recent and restrictive national regulations on seismic resistance and energy efficiency.

Figure 3. The pilot building in Catania, owned by IACP.

The external infill walls are made of two leaves of hollow clay bricks (8-cm and 12-cm thick, internally and externally respectively) with an intermediate 10-cm thick layer (9-cm thick air cavity, plus 1 cm cement plaster on the inner face of the outer leaf). The current U-value for these external walls is $U = 1.1\ W/(m^2 \cdot K)$.

During the demonstration activities, e-PANEL and e-CLT will be installed, lowering the thermal transmittance to $U = 0.28\ W/(m^2 \cdot K)$. The existing windows will be replaced by high-performance double-glazing windows with $U = 1.4\ W/(m^2 \cdot K)$, including integrated shutters.

The e-THERM concept for the technical systems will be implemented too, including the innovative e-TANK plug-and-play decentralized storage devices (one per dwelling) and an estimated 20 kW (peak) of crystalline PV modules. According to preliminary calculations carried out with the PV-GIS tool, the PV field will produce around 29000 kWh annually (i.e. slightly less than 3000 kWh per dwelling). Furthermore, preliminary simulations in Energy Plus and TRNSYS showed that the non-renewable primary energy demand of the pilot building will be reduced by around 85%, while also cutting down the greenhouse gas emissions by 88%.

Demonstration activities will include monitoring and displaying of real time energy performance. It is important to underline that IACP is the owner of a vast stock of residential buildings in Italy (around 700.000 dwellings), and that they are keen on replicating a successful experience to other buildings in need of renovation, thus generating a significant replication potential in Italy.

While the real pilot lies in Italy in an already identified location, the virtual pilots will be selected through a call for expression of interest for early adopters and will be used to further test the whole co-design approach, the e-EXOS and the inclusion of district heating systems.

In e-SAFE, both demonstration and stakeholders' engagement are key actions to ensure the replicability of the proposed solutions. The activities on the real pilot will also verify the occupants' degree of acceptance and their perception of disruption, as well as the time and

costs needed for the actual on-site implementation. The experience on the real pilot will allow refining the co-design approach, in order to make it more effective in meeting owners' and occupants' needs.
As concerns the other EU countries, replication is conveyed by the involvement of relevant stakeholders at EU scale (Climate Alliance, European Builders Confederation, EnEffect, Epta Prime, etc.), in the e-SAFE Advisory Board, and by the activities on the virtual pilots. Indeed, even if the project will not be responsible for the physical implementation of the executive designs developed through the virtual pilots, such designs will considerably help the buildings' owners in proceeding with actual implementation.
In addition, all three pilots – thanks to specific urban engagement activities – will also generate a geo-dataset of buildings that will be used for the investigation of e-SAFE adaptability and the wide replication in different urban contexts. The pilot's outcomes will be extensively disseminated across Europe.

CONCLUSIONS

This paper has presented the scopes and the main challenges of the four-year innovation project e-SAFE, started in October 2020 and funded by the EU in the framework of the H2020 Programme.
More specifically, the project is an Innovation Action that has been selected in the call H2020-LC-SC3-EE-1-2018-2019-2020, dealing with "Decarbonisation of the EU building stock: innovative approaches and affordable solutions changing the market for buildings renovation". The proposed e-SAFE technical solutions address the energy, seismic and architectural renovation of the existing non-historical EU building stock: for instance, in the Italian pilot the thermal transmittance of the opaque vertical surfaces can be reduced to 0.28 $W/(m^2 \cdot K)$ – or even less, according to the insulation thickness – and the resistance in case of earthquake can be highly improved. Preliminary investigations have also indicated that the proposed solutions may reduce the energy demand and the CO_2 emissions of the renovated building by around 85% and 88%, respectively, also thanks to a significant share of PV electricity (around 3000 kWh per dwelling, at least in the Italian pilot).
However, the market uptake is also a key result of the project, since it is the most effective way to ensure both full exploitation of the proposed technology and its significant contribution to the decarbonisation of the EU building stock. For this reason, technological development and implementation is just one of the "souls" of e-SAFE, despite the project already combines expertise belonging to several different technological fields (building technology, seismic safety, building physics, architecture). Indeed, the Consortium firmly believes that full market uptake must be favoured through suitable and innovative financial tools and socially oriented participatory actions, such as co-design and co-analysis.

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