Outer facade retrofitting through precast insulation panels: method and planning tool applied to an Italian residential building

Graziano Salvalai*, Giuliana Iannaccone, Marta Maria Sesana, Emilio Pizzi

Highlights

The EASEE project developed an outer solution for envelope retrofitting that allow superior insulating characteristics, installation procedure without fixed scaffoldings, minimization of occupants’ discomforts as well as the duration of the intervention. An experimental characterization of a new composite insulation panels was performed in laboratories from structural, hygrothermal and building physical point of view.

Abstract

Developing a more energy efficient building stock is the focus of the European energy policies. Much of the required reduction in energy consumption needs to be achieved through the renovation of existing buildings. To this topic, the work presents all the research steps from the design process, through the experimental characterization in laboratory to the final on-site construction with respective monitoring campaign for the envelope retrofitting of an Italian residential building. The developed system, result of a European founded project EASEE is a prefabricated composite panel that integrate both thermal insulation and exterior finishing.

Keywords

Building retrofitting, Precast solution, Insulation panels, Retrofitting tool

1. INTRODUCTION

According to the World Business Council for Sustainable Development (WBCSD), more than half of the European Building stock are dated between 1925 and 1975, for more than 80 Million buildings. Residential buildings represent about one third of these, 10 millions of them being multi-storey buildings, with distributed ownership. This type of buildings are widely diffused in the European cities centres and present common features from the architectural and structural point of view. They often have a linear façade finished with plaster covering or with bricks, with some three-dimensional architectural elements as well as hydraulic/gas piping or electrical cabling fixed on it. According to the JRC publication [1] a large part of this European existing building stock still needs to be insulated and there is a lack of practical
technical solutions in this area excluding the ETICS insulation practice. When it comes to the building physics, heat losses through building components are proportional to their heat transfer coefficient and to their surface area. Insulating the largest surfaces with the highest heat transfer coefficient is therefore the most efficient in terms of cost-benefit point of view. Multi-storey buildings share a common roof, which reduces its importance and makes the vertical envelope the main issue. Statistical studies show that nearly 76% of Italian dwellings were built before 1981 and 49% have more than 50 years old; with an average annual increase in new dwellings in the 1981–2011 period was only 1%. In Northern Italy, the energy consumption of existing buildings has been estimated, on average, around 18-20 litres of oil fuel per square meter per annum. Buildings dated between 1925 and 1975 were constructed in an era where there was little or no consciousness of the need to design for energy efficient performance and therefore have the largest energy demand. A common feature of these buildings is that they are usually not forced by specific regulatory constraints for their refurbishment, differently from historical buildings, although the original appearance of the façade needs in general to be kept. In this scenario, the project EASEE (Envelope Approach to improve Sustainability and Energy efficiency in Existing multi-storey residential buildings multi-owner), funded by the European Union under the Seventh Framework Programme for Research and Development, lead to the development of a new holistic approach to energy efficient envelope retrofitting of multi-storey and multi-owner buildings which preserves the original appearing of the façade through a combination of modular pre-fabricated components and scaffolding-free installation. The expected and reached outputs were: EASEE methodology and EASEE Toolkit, which integrate affordable solutions and guidelines that construction SMEs, can apply to reduce energy demand while minimising the impact on occupants during retrofitting and EASEE retrofitting planner. The EASEE Toolkit derived from the deep analyses on the three main components of the envelope that influence the energy performance of multi-storey buildings, namely the outer façade, the cavity walls and the inner envelope. For each of these envelope parts, a novel solution have been developed within the project, which combined according to the characteristics of the building to be retrofitted as well as to other non-technical parameters as for example cost and location of the building. In particular, this paper describes the results of the demonstration activities for the outer solution being the focus of the authors, belonging to the project team. The implementation of an overall envelope retrofitting of a residential building with a modular pre-fabricated façade system composed
by a core of EPS and two layers of textile reinforced concrete and applied to the existing structure by means of mechanical anchoring is described from the design phase to the installation procedure onsite for an Italian residential case study. A typical multi-storey residential building built in the 1971 has been selected - with the support of the Lombardy Region - as a demonstration building for the EASEE outer solution. The residential building has four storeys with the ground floor used for parking and storage spaces (Figure 1). The gross floor area for each floor is about 281.0 square meters with an internal height of 3.0 meters; the total area of the building envelope is about 900.0 square meters. From the technological point of view, the envelope is characterized by a cavity wall with an outer steel reinforced concrete layer of 20.0 cm, 2.0 cm of air gap, 3.0 cm of polystyrene and an inner hollow brick layer of 8.0cm with additional 10.0 mm of cementitious plaster. The windows are characterized by an iron frame and a single glass with a thermal transmittance of 6.0 W/m²K.

![Figure 1. a) Italian demo building typical plan and b) Italian demo building South façade before the retrofitting.](image)

2. STATE OF THE ART

Energy renovation is playing a strong role as a stabilizer of the building sector and consequently of the European economy in the period since the financial crisis. Estimates of the energy renovation market was of the order of EUR 109 billion in 2015 in the EU and created 882,900 jobs with the French, German and Italian energy renovation markets that alone accounted for almost half of the EU energy renovation market. Buildings account for around 40% of the total energy consumption and 36% of the CO₂ emissions in Europe and possess the biggest untapped mitigation potential. Increasing the size of the energy renovation market would unleash the fourth industrial revolution in Europe. The industrial renaissance would require however intervent ed a toolkit in grado, da un lato, di pianificare il processo di riqualificazione e, dall’altro, di indirizzare e facilitare la scelta verso soluzioni tecnologiche appropriate con processi caratterizzati da un minimo impatto sugli occupanti. Il toolkit sviluppato all’interno del progetto considera tre diverse possibili modalità di riqualificazione dell’involvero edilizio: l’isolamento esterno, l’isolamento in cavità e l’isolamento sul lato interno. Per ogni soluzione è stata studiata, sviluppata ed installata una soluzione tecnologica innovativa, la cui scelta applicativa varia in funzione delle caratteristiche dell’edificio da riqualificare e dall’analisi costo-beneficio. In particolare, il seguente lavoro descrive il metodo ed il risultato ottenuto dall’attività dimostrativa condotta attraverso l’uso di sistemi prefabbricati applicati sul lato esterno dell’involvero. Le attività sono state eseguite su un intero edificio residenziale attraverso l’utilizzo di un innovativo sistema modulare di facciata prefabbricato composto da un nucleo centrale in EPS contenuto tra due layer di cemento fibrinforzato e applicato alla struttura esistente mediante sistemi meccanici puntuali.

L’edificio dimostrativo è un edificio residenziale a più piani costruito nel 1971 scelto, in accordo con Regione Lombardia, all’interno del parco edilizio di ALER Milano. L’edificio si caratterizza per la presenza di quattro piani fuori terra con il piano terra utilizzato per gli spazi di parcheggio e di stoccaggio (Figura 1). La superficie lorda di ogni piano è pari a circa 281.0 metri quadrati con un’altezza interna di 3.0 metri; la superficie totale dell’involvero opaco verticale è pari a circa 900.0 metri quadrati. Dal punto di vista tecnologico si caratterizza per la presenza di una parete a cassa vuota e dall’esterno verso l’interno da uno strato di cemento armato di 20.0 cm, 2.0 cm di spazio d’aria, 3.0 cm di polistirene e una parete di tamponamento in lattezio forato da 8.0 cm finito, verso l’interno, con circa 1.0 cm di intonaco di cemento. La trasmissione termica misurata è pari a 0.85 W/m²K. Le finestre sono, invece, caratterizzate da un telaio in ferro con vetro singolo dalla trasmissione...
different innovation: to move from the current step-by-step component-based energy renovation to an overall approach to the building; to develop an holistic prefabricated zero energy kits to transform the EU buildings from being passive consumers into being active prosumers; modern methods and methodologies to gather data and analyse them. The roll-out of smart-meters, as now required by directives on the internal market in electricity and gas and the energy efficiency directive, needs to be combined with energy models based on Geographical Information Systems (GIS), the use of drones for inspections and auditing, and well-designed mandatory reporting templates to close the data gap [2]. Considering the construction processes, multi-storey and multi-owner buildings are normally refurbished by construction SMEs, normally with low-skilled work force. This means that new approaches in energy retrofitting should require fault tolerant and simplified procedures as well as easiness of application to reach the expected improvement. Moreover referring to the impact of the retrofitting process on the life of the occupants, traditional approaches need scaffolding on the outer façade for very long times (on average between 12 and 24 months for a seven storey building due to the heavy removal of materials and the wet processes involved), requiring occupants to seal the windows and introducing safety issues. Dust and noise add to these discomforts. Furthermore, scaffolding creates burden to the traffic and to the people walking by, apart being an additional cost as normally local taxes to occupy the ground are to be paid. In this framework, there is the strong need for the development of new modular and fault tolerant solutions for the envelope retrofitting in multi-storey and multi-owner buildings, ensuring an important reduction of building energy demand through off-site prefabricated components and simplified dry construction processes and installation procedures, while at the same time reproducing the original façade and reducing at minimum the discomforts for the occupants. Any novel approach that would also foster the introduction of multi-functionality in the façade system, like for instance integration of piping systems for solar thermal, natural ventilation or hydronics as well as sensors to acquire key physical parameters, would definitely concur to increase the overall cost-effectiveness while introducing more systemic designs interfacing HVAC and energy management.

3. METHODOLOGY

Several research works deal with the energy retrofitting methodology [3][4][5], presenting the impact of different energy conservation measures carried out on building stocks on the reduction of greenhouse gas emissions. According
to literature on the topic, there are a large number of methodologies available for improving the energy performance of existing buildings, but often they are too complicated or they requested too detailed data often not available for existing building or too sectorial, considering only one aspect per time (i.e. technic, economic, aesthetic, historical and cultural aspects) without considering them together as a whole. As mentioned in the introduction, to address the issue of energy efficiency retrofitting facades of existing buildings, the EASEE project aims to be an integrated design process, combining advanced analysis of the building stock with the development of innovative strategies, for the final goal of reducing the energy required by the building occupants. This section describes and explains the EASEE methodology defined and then applied and verify within the project on demonstrative building case study. The new approach to envelope retrofitting proposed by EASEE is schematically depicted in Figure 2. Being the EASEE retrofitting method based on a high level of prefabrication with components which have the final appearance without additional finishing on site, accurate measuring information of the building envelope are required. The first step of the retrofitting process consist therefore in a careful assessment of the envelope both from structural and energetic point of view, as well as in terms of other non-technical parameters and indicators that will be useful for the planning of the retrofitting intervention. These analyses have been carried out starting from technical drawings of the buildings that will serve as a guide for a deeper assessment of the envelope characteristics and conditions. In this respect, it is worth noticing that in some cases and depending form the Country, drawings were not available for buildings built before 1950. In this case, more accurate non-destructive techniques were used, as for example flux meters, to have detailed information of the envelope structure. More in detail, the structural and physical conditions of the demo building have been evaluated through state of the art non-destructive technologies: 3D laser scanning, infrared (IR) imaging. These techniques has allowed to acquire three-dimensional morphological data, temperature maps (to evidence thermal bridges or heat losses), plaster stability and other building data as for example wall thickness and characteristics of the critical points as windows and balconies.

By combining both geometrical and stratigraphic information, a Building Information Model (BIM) of the demonstrative building has been generated, also taking into consideration the different structural elements following the constructive logic of the building: elements of the cover, walls, insulation, panels, roof, pillars and beams (object oriented approach to the design). The data analyses based on the input and model derived from the first steps of the envelope retro fitting process consist therefore in a careful assessment of the envelope characteristics and conditions. Inoltre al per determinare la composizione dell’involucro esistente, possono avere sulla riduzione delle emissioni di CO$_2$ [3][4][5]. In letteratura sono disponibili svaretate metodologie proposte e illustrate nello schema energetica degli edifici esistenti, ma a volte sono troppo complicate o altre volte richiedono dati troppo dettagliati, spesso non disponibili per gli edifici esistenti o troppo settoriali, perché si focalizzano esclusivamente su una tipologia di parametri, nonché tecniche avanzate, porti alla riduzione del consumi energetici come richiesti dagli utenti stessi. Questo paragrafo descrive la metodologia EASEE, sviluppata e verificata nel corso del progetto su edifici impianti dimostratervi. Il nuovo approccio di riqualificazione dell’involucro proposto è illustrato nello schema di Figura 2. Essendo la metodologia EASEE basata su un elevato livello di prefabbricazione con componenti che presentano già la finitura completa al momento dell’installazione in cantiere senza necessità di ulteriori operi di intervento, è stato proposto un accurato rilievo geometrico dell’edificio. La prima fase del processo di adeguamento consiste quindi in un’attenta valutazione dell’involucro sia dal punto di vista strutturale che energetico, nonché in termini di parametri e indicatori non strettamente tecnologicisti, utili alla completa pianificazione dell’intervento di recupero. Queste analisi sono state eseguite partendo dalla documentazione esistente dell’edificio, input iniziale per una valutazione più approfondita delle caratteristiche e delle condizioni attuali dell’involucro. A questo proposito, è importante sottolineare come in alcuni casi e per certe nazioni, la documentazione tecnica non fosse disponibile per gli edifici costruiti prima del 1950. In questo caso, sono state utilizzate tecniche più precise non distruttive, come ad esempio termo flusimetri, per rilevare informazioni il più dettagliate possibili per determinare la composizione dell’involucro esistente. Inoltre, è stato proposto un accurato rilievo geometrico dell’edificio. La prima fase del processo di adeguamento consiste quindi in un’attenta valutazione dell’involucro sia dal punto di vista strutturale che energetico, nonché in termini di parametri e indicatori non strettamente tecnologicisti.}

3. METODOLOGIA

Molte sono le ricerche condotte sui metodi di risguagliamento energetico che hanno studiato e valutato l’impatto che, differenti misure di risparmio energetico applicate al patrimonio edilizio esistente, possono avere sulla riduzione delle emissioni di CO$_2$ [3][4][5]. In letteratura sono disponibili svaretate metodologie proposte e illustrate nello schema energetica degli edifici esistenti, ma a volte sono troppo complicate o altre volte richiedono dati troppo dettagliati, spesso non disponibili per gli edifici esistenti o troppo settoriali, perché si focalizzano esclusivamente su una tipologia di parametri, nonché tecniche avanzate, porti alla riduzione dei consumi energetici come richiesti dagli utenti stessi. Questo paragrafo descrive la metodologia EASEE, sviluppata e verificata nel corso del progetto su edifici impianti dimostratervi. Il nuovo approccio di riqualificazione dell’involucro proposto è illustrato nello schema di Figura 2. Essendo la metodologia EASEE basata su un elevato livello di prefabbricazione con componenti che presentano già la finitura completa al momento dell’installazione in cantiere senza necessità di ulteriori operi di intervento, è stato proposto un accurato rilievo geometrico dell’edificio. La prima fase del processo di adeguamento consiste quindi in un’attenta valutazione dell’involucro sia dal punto di vista strutturale che energetico, nonché in termini di parametri e indicatori non strettamente tecnologicisti, utili alla completa pianificazione dell’intervento di recupero. Queste analisi sono state eseguite partendo dalla documentazione esistente dell’edificio, input iniziale per una valutazione più approfondita delle caratteristiche e delle condizioni attuali dell’involucro. A questo proposito, è importante sottolineare come in alcuni casi e per certe nazioni, la documentazione tecnica non fosse disponibile per gli edifici costruiti prima del 1950. In questo caso, sono state utilizzate tecniche più precise non distruttive, come ad esempio termo flusimetri, per rilevare informazioni il più dettagliate possibili per determinare la composizione dell’involucro esistente. Inoltre, è stato proposto un accurato rilievo geometrico dell’edificio. La prima fase del processo di adeguamento consiste quindi in un’attenta valutazione dell’involucro sia dal punto di vista strutturale che energetico, nonché in termini di parametri e indicatori non strettamente tecnologicisti, utili alla completa pianificazione dell’intervento di recupero. Queste analisi sono state eseguite partendo dalla documentazione esistente dell’edificio, input iniziale per una valutazione più approfondita delle caratteristiche e delle condizioni attuali dell’involucro. A questo proposito, è importante sottolineare come in alcuni casi e per certe nazioni, la documentazione tecnica non fosse disponibile per gli edifici costruiti prima del 1950. In questo caso, sono state utilizzate tecniche più precise non distruttive, come ad esempio termo flusimetri, per rilevare informazioni il più dettagliate possibili per determinare la composizione dell’involucro esistente. Inoltre, è stato proposto un accurato rilievo geometrico dell’edificio. La prima fase del processo di adeguamento consiste quindi in un’attenta valutazione dell’involucro sia dal punto di vista strutturale che energetico, nonché in termini di parametri e indicatori non strettamente tecnologicisti, utili alla completa pianificazione dell’intervento di recupero. Queste analisi sono state eseguite partendo dalla documentazione esistente dell’edificio, input iniziale per una valutazione più approfondita delle caratteristiche e delle condizioni attuali dell’involucro.
allow identifying within the EASEE approach the most suitable solution (outer, inner, internal) for envelope retrofitting. The final phase concerns the retrofitting process from building design to construction site coupled with monitoring campaign.

4. RESULTS

The Italian demo building was targeted to validate the retrofitting approach on a large scale, from assessment of the starting conditions to the manufacturing and installation of the modular elements to the monitoring of performance after retrofitting. The demo building was selected among others in cooperation with ALER (Public Housing Agency of Lombardy Region) because it perfectly fulfilled the desired specifications towards the demonstration activities (multi-storey residential buildings built between 1925 and 1975 with cavity walls). Moreover, the information collected from the survey with a thermal imaging camera revealed and confirmed the needs to apply an energy retrofitting in order to solve the high-energy losses from the envelope. Among the other reasons, the retrofitting of the Italian demo building, being a public housing building, would strengthen the importance of replicability and impact of the EASEE approach for future improvement and applications. The building geometrical, structural and energetic analysis has been performed towards a complete evaluation of building boundary conditions and the validation di rilievo con una temocamera ad infrarossi. Queste tecniche hanno permesso di acquisire dettagliate informazioni tridimensionali, mappe di temperatura superficiali (per individuare eventuali punti termici), stabilità degli intonaci o altri elementi di finitura, oltre ad altri dati come ad

![EASEE methodology for envelope retrofitting.](image)

**Figure 2. EASEE methodology for envelope retrofitting.**
of the EASEE methodology. The geometrical and technological survey on the residential case study has been conducted in order to build a BIM model reproducing the real geometric irregularities of the fabric and to make a correct design of the new envelope panels (Figure 3).

Together with the 3D laser survey, an IR imagines campaign (Figure 4) has been conducted, allowing to perform a non-destructive investigation on the building, viewing in real time the heat map on the elevation, and measuring the facade surface temperature without contact (Figure 5). The survey revealed the critical points of the building, mainly thermal bridges (both structural and between windows and the opaque envelope).

Figure 3. EASEE Italian demo building model from survey and elaboration in a) Revit and in b) Rhino.

Figure 4. Italian demo building thermal imaging survey on North/East facade (Source: POLIMI Elaboration).

Figure 5. Temperature profile line of the thermal survey on North/East facade.
As described in the introduction, the EASEE project lead to the creation of three envelope retrofit solutions. Within the analyses of the data derived from the building assessment of first phase of EASEE methodology, the outer solution has been identified as the most suitable for the envelope retrofitting of the case study. The design of the outer solution has been conducted focusing on the main typological, morphological and technological features of a typical residential building and aiming at preserving the architectural features of the exterior building envelope or, wherever possible, at improving them with a reduced extra-load on the existing structure. Moreover, lightness and fast and easy assembly techniques were the major concern in parallel with the goal to install the solution without fixed scaffolds to reduce impact on inhabitants’ life. The solution obtained is a prefabricated insulation panel consists of a core of EPS, 100 mm thickness laminated to two outer layers of concrete, fibre-reinforced with polymer fibres (Textile Reinforced Concrete - TRC) of thickness equal to 10 mm. Excellent resistance to compression and a high tensile strength characterizes the system. Several tests in research laboratories at Politecnico di Milano - combined with dynamic simulations - have been conducted before starting the production of the panels in order to investigate mechanical [6], energetic and hygrothermal properties [7].

The design of the prefabricated panels started from the following concepts:

- Energy performance improvement with the achievement of the thermal transmittance targets (in terms of U value);
- Installation time minimization and mistakes reduction for the building retrofitting, by performing an accurate survey of the building and by developing optimized prefabricated panels components;
- Availability of wide range of different finishing layers of the retrofitting panels;
- Easiness of local replacement in case of damage of a single panel;
- Possibility to retrofit the building without burdening occupants and users
as well as normal activities inside the building during the intervention. From the structural point of view the panels were connected with the existing façade by means of specific anchoring systems (developed by Halfen), which are connected with dedicated HPFRC (High Performance Fibre-Reinforced Concrete) boxes located in the four corners of the perimeter of the panel. Magnetti Building S.p.a. has produced the panels installed on the demonstrative building by means of the reconfigurable formwork designed by STAM and assembled at Magnetti premises. This formwork allows the realization of different types of panels finishes in terms of colours and texture. Indeed, pigments of colours can be add to the TRC before the concrete injection and a form liner can be applied to the internal side of the formwork in order to obtain the desired finishing. As already mentioned in the Methodology paragraph, BIM process was extensively used at supporting the building design of the Italian building retrofitting, towards the anchoring systems definition, check congruence with irregularities façade, indication for adjustment anchor and related tracking on site (Figure 7 and Figure 8). The BIM model become an input for the Retrofitting Planning tool (developed by IES within the project – as a partner of the consortium). Then the software analysed the model in order to identify panels dimension according to the façade and its technological and structural characteristics.

Figure 7. BIM approach at supporting retrofitting design.
The results is a file containing all the necessary manufacturing data directly provided to the project partner for the production of the different panels.

5. CONCLUSIONS

The Italian demo building of the EASEE project, concerning the design of the outer façade renovation solution and the EASEE methodology application, has been presented in the article. The EU project outputs demonstrated the effectiveness of an innovative modular prefabricated system for the outer envelope retrofitting characterized by good insulation performances ($U_w = 0.27$ W/m²K after the retrofitting) and durability and a wide variability of finishes for both colour and textures. The overall EASEE holistic retrofitting approach has been validated through the retrofitting of an entire building case study in Italy, where all technical details have been evaluated and put in place. During...
the building-retrofitting phase, the occupants have always expressed interest and very positive attitude towards the works and they have really appreciated the absence of scaffolding and the possibility to perform daily activities in full freedom. Moreover, they have also experienced the quick installation of the panels themselves that took 3 months for their completion. The widest façade of the building have been indeed retrofitted in approximately 10 days. Finally, building occupants will appreciate the benefits of the EASEE thermal solution not only in winter, but also in summer when they always complain about thermal discomfort inside their homes. The result of the building façade renovation is presented in Figure 10. The research leading to these results has received funding from the European Union 7th Framework Programme 2007-2013 under Grant Agreement n. EeB.NMP.2011-3-285540.

6. REFERENCES


In addition, the BIM model has provided data for the Retrofitting Planning Tool, developed by partner IES within the framework of the project. From the analysis of the model, the software has elaborated the construction of the innovative technological systems for the development of the facade and the implementation of a solution for the facade rehabilitation and the implementation of an innovative methodological approach to the rehabilitation. The results of the project have demonstrated the effectiveness of an innovative modular system prefabricated for the rehabilitation of the external facade of the building characterized by good prestations in terms of thermal insulation (U<sub>0</sub> = 0.27 W/ m²K after the intervention of recuperation) and durability and a wide variability of finishes, with a change in color and texture. L’approccio olistico, implementato nell’ambito di EASEE, è stato validato attraverso un intervento completo di recupero su un caso di studio in Italia, dove tutti gli aspetti tecnici sono stati valutati e messi in opera. Durante la fase di realizzazione dell’intervento di recupero, gli occupanti hanno sempre manifestato interesse ed una positiva predisposizione, apprezzando inoltre l’assenza di ponteggi che ha limitato i disagi nello svolgimento delle loro attività giornaliere. Inoltre hanno puntato testimoniare la rapida realizzazione dell’intervento.

Figure 10. View of the South-West Façade after the EASEE panels installation.