Simulation Application for the Assessment of the Energy Performance of a Building Renovated Using I-BEST System (Innovative Building Envelope through Smart Technology)

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Abstract

Energy renovation of existing buildings represents a fundamental action for achieving the objectives aimed at overcoming the climate crisis. However, several difficulties are encountered in building refurbishment. Among these are the high costs and long construction times, the invasiveness of interventions, which often prevent the usability of the building, and the impossibility of providing maintenance and verifying degradation of the underlying layers of the envelope. Regarding the systems, retrofit often causes substantial alterations to the building aesthetics, affecting its original character and defacing the surrounding environment. Furthermore, the integration of renewable sources is often hard to implement. The I-BEST system (Innovative Building Envelope through Smart Technology) is an innovative multifunction façade system for the redevelopment of the existing building stock, which aims to overcome these limits by offering a valid response to the growing demand for building "recladding". The system consists of sliding, modular and multi-functional panels, supported by a metal and light load-bearing structure fixed on the external wall and spaced from it to create a suitable cavity for containing plant ducts. The purpose of the present work is to evaluate, through dynamic simulation, the energy performance of a building renovated with the I-BEST system.

1. Introduction

Based on the Green Deal objectives, the European Union (EU) will have to achieve zero climate impact by 2050 (EU Commission). In the energy transition, a significant role is played by decarbonisation of the building stock, which accounts for 36 % of EU CO_2 emissions (United Nations Environment Programme, 2021). The European Commission has outlined a long-term restructuring strategy, using primarily the principle of energy efficiency, as well as evaluating the use of renewable energy. Consistently, each Member State has developed an Integrated National Plan for Energy and Climate to support the renovation of existing residential and non-residential buildings, both public and private, into nearly zero energy buildings, promoting cost-effective strategies. The renovation of buildings, which should take place at an average rate of 3 % per year, will make it possible to progressively increase the EU's energy independence, considering that each percentage point of increase in energy savings corresponds to a reduction in gas imports of 2.6 % (Directive (EU) 2018/844). In addition to energy inefficiency, existing buildings frequently show physical and formal degradation, which significantly alters the quality of the urban environment. Renovation actions often entail a series of problems that make it difficult to implement restructuring plans. The most common problems include: high costs and long construction times; the invasiveness of the interventions that usually require occupancy and work activities to be suspended; in the case of the application of external thermal insulation, the impossibility of periodic maintenance of the underlying elements and the inability to identify any cracks caused by earthquakes; the difficulty of integrating systems for the

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production of energy from renewable sources; in the hypothesis of replacing the heating and cooling systems, the presence of pipes on the external façades that disfigure the appearance of the building. A potential solution to the aforementioned problems consists of the renovation of the building through systems that involve the application of a second skin from the outside. This technical solution has been proposed and analysed in various forms, characterized by different configurations and operating principles, and which have different effects on the energy performance of the buildings that they are applied to (Pomponi et al., 2016; Shameri et al., 2011). Generally, in the literature, the addition of a second layer on the external surface of the walls is defined as a "double skin" or, more properly when speaking of interventions on existing buildings, "recladding", meaning a coating with elements that can also be opaque. As stated by (Alberto et al., 2017), the double-skin system is strongly influenced by climatic conditions and the location of the building. The authors of this study developed a parametric analysis based on numerical simulation to evaluate the im-pact on the building's energy performance, of geometry, airflow path, cavity depth, openings area and type of glazing. The results showed that the most efficient solution leads to a 30 % saving in energy demand in a temperate climate and that the orientation of the façade (North or South) produces a difference in the results of 40 %. (Hamza, 2008) explored the possibilities of using the double façade in a hot and arid climate; in particular, the cooling loads were compared for a single skin base case against three possible changes to the physical properties of the external layer of the double skin façade. The simulation results showed that a reflective double façade can achieve higher energy savings than a reflective single façade. The research conducted by (Blanco et al., 2016) concerned the evaluation and optimization of perforated metal sheet double skin façades for a case study in Spain. Through simulation, the influence of different configurations on heating, cooling and artificial lighting loads was evaluated, and a methodology aimed at the optimization of design sustainability based on minimum energy consumption was developed. (Jankovic & Goia, 2021) presented a literature review on experimental and numerical studies of double-skin façades that investigates and evaluates the cause-and-effect connection between the construction characteristics and the thermo-physical phenomena occurring in the system. Simple links between construction properties and performance have been identified, but only when one parameter is analyzed at a time. However, the authors highlighted that the complex interaction between multiple variables is rarely investigated. The study developed by (Tao et al., 2021) proposes two new analytical models to determine the ventilation rate inside naturally ventilated double façades, depending on various factors and using simple in-puts. An adjustable double-skin façade mock-up placed into a climate simulator was used by (Jankovic et al., 2022), to investigate different double-skin façade configurations in combination with a wide range of boundary conditions. The authors provided an overview of several methods based on different types of experimental investigations with various levels of complexity to assess how different constructive features and boundary conditions affect the performance of double-skin façades. Recently, more advanced double-skin façade solutions have been tested. For example, (Alqaed, 2022) examined the use of different types of façades (simple façade, double-skin façade and double-skin façade filled with phase changing materials) based on different climatic conditions in Saudi Arabia. The results proved that the use of phase change materials in the double skin façade significantly reduces the energy demand for both heating and cooling. (Pérez et al., 2021) focused on the development of a method for creating the 3D characterization of an experi-mental double-skin green façade, using LiDAR technologies. The proposed methodology enabled the 3D reconstruction of the green façade's outer envelope, also allowing an evaluation of the temperature reduction obtainable on the external sur-face of the building and providing a 3D object to be used in Building Information Modeling (BIM).

In the present study, an innovative double-façade model, designed for the renovation of existing buildings, is presented and its effectiveness in reducing the heating energy demand is evaluated for a selected case study, with reference to Mediterranean climatic conditions. The proposed system differs from the solutions currently available and discussed in the literature because: a) the façade is made up of opaque panels; b) the cavity of the double envelope is not ventilated; c) the system is multifunctional, in the sense that it is possible to adapt the cladding panels to different functions, according to the specific needs of the case in hand.

2. Methodology

2.1 Description of the I-BEST System (Innovative Building Envelope through Smart Technology)

I-BEST (Innovative Building Envelope through Smart Technology) is an innovative multifunction façade system developed for the refurbishment of existing buildings. This system is designed to implement integrated energy efficiency both in envelope and plant performance. Using the I-BEST system, in fact, it is possible to do the following: improve the energy efficiency of the building; enhance the aesthetic quality of the building and therefore of the surrounding urban environment; avoid the degradation phenomena affecting the materials of the building envelope; implement non-invasive interventions for the occupants of the building, who can continue to use the interior even during the renovation works. The I-BEST technology consists of a system of sliding, modular and multifunctional panels, supported by a metal and light load-bearing structure, which is fixed to the existing building from the outside, without structurally weighing on it. The application of the double skin creates a cavity that can be used to install plant ducts (air conditioning, electrical, water systems and the collection and drainage of rainwater). The design solution meets the growing demand from the recladding sector, which requires the replacement of façades, claddings and openings of aged buildings with new, modern, functional and high-performance components. Furthermore, the system offers a high potential in the construction market, thanks to its modularity, adaptability to different building types, and replicability in various climatic contexts, while maintaining low costs and reduced construction times. The main strength of the I-BEST system is its high flexibility. The multifunctional module-panels, in fact, can be used as a simple coating (also customizable on the surface), or they can include a layer of thermal insulation that varies according to the climate, incorporate solar modules for the production of renewable energy, integrate layers with vegetation to create green surfaces.

2.2 Presentation of the Case Study

For the evaluation of the I-BEST performance, its application to a building identified as a case study is considered. The building is part of the residential centre of the University of Calabria Campus. The location is characterized by a Mediterranean climate. The building consists of two adjacent blocks, slightly staggered in plan and two floors high. Each block includes two residential units, one on the ground floor and one on the first floor, with a net surface area of about 65.5 m^2. Overall, the building includes four apartments, with a total net area of 262.0 m^2. Fig. 1 shows the floor plan of the building. As regards the construction characteristics of the building, the external walls are made with a double layer of perforated bricks and a central cavity with thermal insulation, with thermal transmittance of 0.52 W/(m^2 K). Fig. 2 depicts the detailed stratigraphy of the external wall. The roof is flat, not insulated, with thermal transmittance equal to 1.35 W/(m^2 K).

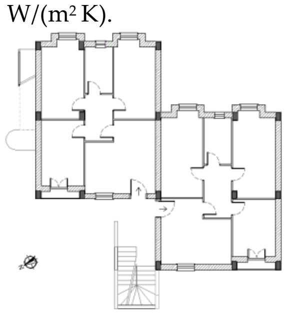

Fig. 1 – Floor plan of the case study building

The ground floor slab, also not insulated, is characterized by a U value of 1.55 W/(m^2 K). The windows have single glazing (U_{glass}=5.7 W/(m^2 K) and aluminum frames without thermal break (U_{frame}=5.9 W/(m^2 K)). Each apartment is equipped with a gas boiler for heating and DHW production.

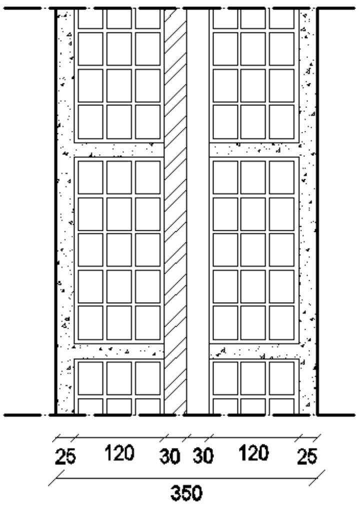

Fig. 2 – Stratigraphy of the external wall before renovation

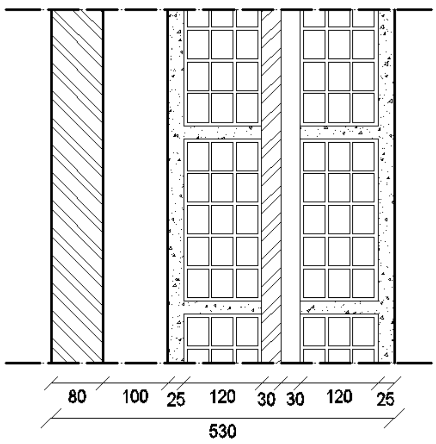

Fig. 2 – Stratigraphy of the external wall after renovation with the I-BEST system

2.3 Calculation Assumptions

In order to conduct a preliminary analysis, the energy model of the building was created using DesignBuilder software (DesignBuilder Software Ltd), a graphical interface of EnergyPlus (Energy Plus). The model was used to perform dynamic simulations and evaluate the effect of the introduction of the I-BEST system in the building, estimating the energy demand for heating before and after the installation of the double façade. The building was actually selected as a test building for the research project within which the innovative I-BEST system was developed, and it will therefore be renovated through the installation of the I-BEST modules on the external façades, in order to experimentally evaluate the performance of the proposed system. In this study, the effectiveness of the I-BEST system is evaluated exclusively by simulation and is limited to the analysis of the solution relating to the use of the I-BEST panel containing a layer of thermal insulation. Future studies will be aimed at exploring the effect produced by other solutions associated with the multi-functionality of the panel (integration of solar panels and green surfaces). Fig. 3 shows the stratigraphy of the external wall following the application of the I-BEST modules. Assuming the non-ventilated cavity, the thermal transmittance of the wall after the energy renovation with I-BEST is equal to 0.20 W/(m^2 K), complying with the minimum requirements set by law (D.M. 26 June 2015).

Hourly weather data provided by the Italian Thermotechnical Committee (CTI - Comitato Termotecnico Italiano) were used in the simulation. The location is classified within the climatic zone D (D.P.R. 412/93), with the heating period running from 1 November to 15 April. The heating setpoint temperature is set at 20 °C. Since no specific information on the occupancy is available, the internal gains have been quantified following the standard (UNI/TS 11300–1) and amount to 5.68 W/m2. Similarly, the natural ventilation rate has been estimated based on technical specification (UNI/TS 11300–1) and is equal to 0.3 ach. Dynamic simulation was conducted on an hourly basis in order to predict the thermal needs for heating and the primary energy required by the building at the current state and after the I-BEST renovation.

3. Results and Discussion

Fig. 3 shows the thermal heating requirement on a monthly basis, at present and after renovation with the I-BEST system. The results refer exclusively to the intervention on the external walls, in order to evaluate the impact of the proposed double façade system. For the purposes of this study, no other envelope efficiency measures were considered that would in any case be required to meet regulatory constraints (e.g., insulation of the roof and ground floor slab, replacement of the windows).

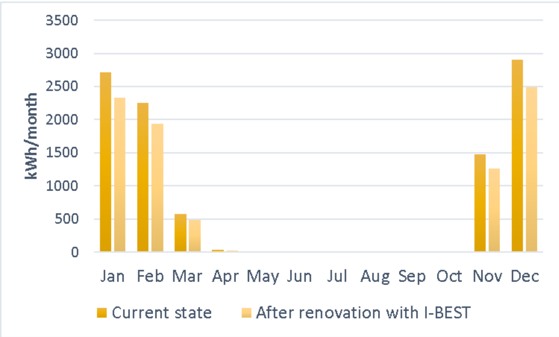

Fig. 3 – Thermal requirements for heating of the case study building before and after the renovation with I-BEST system

The installation of the I-BEST panels, including an appropriate layer of thermal insulation, allows a reduction in the monthly thermal requirement for heating varying from 14.0 % to 16.4 % to be obtained. Considering the whole heating season, the energy needs decrease from 38.08 kWh/(m²year) to 32.58 kWh/(m²year). The improvement in the energy performance of the external walls is also evident in the internal air temperature. Fig. 4 and Fig. 5 show the average daily air temperature corresponding to the coldest day of the year based on the weather file used, that is, February 2. On this day, the lowest outdoor air temperature occurs, equal to -2.8 °C.

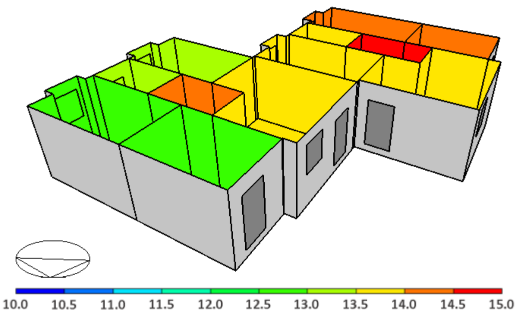

Fig. 4 – Average daily internal air temperature before renovation (free-floating simulation carried out for the coldest day of the year)

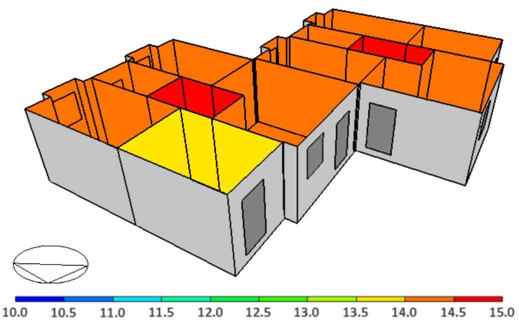

Fig. 5 – Average daily internal air temperature after renovation with I-BEST system (free-floating simulation carried out for the coldest day of the year)

The simulation is carried out in free-floating conditions, thus without considering the activation of the heating system. Therefore, the performance represented in the figures refers to the passive behavior of the envelope and only considers the energy efficiency measure applied on the external walls. The results are displayed based on a color graphic scale and are represented as an example for the ground floor of the building. From the figures, it can be noted that the use of the I-BEST modules produces an increase in the internal air temperature in all the areas of the housing units analyzed. This effect is due to the decrease in the thermal transmittance of the external walls after the addition of the I-BEST panels.

The assembly of the panels on the external façades allows a non-ventilated cavity, which acts as a thermal buffer between the internal and external environment, to be obtained. In fact, inside this cavity, the temperature values are higher than the external air temperature, creating a transition zone capable of mitigating heat dispersion. Fig. 6 shows the temperature trend for the coldest day (February 2), in free-floating operation. In particular, the external air temperature, the internal air temperature and the air temperature inside the cavity are displayed in the graph, with reference to a room on the ground floor.

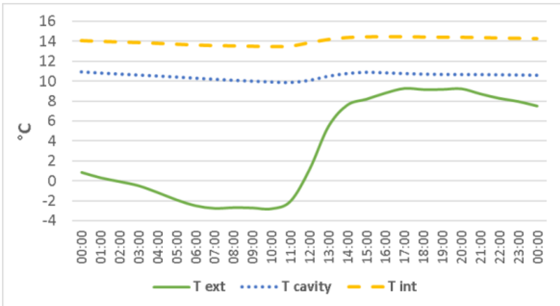

Fig. 6 – Hourly trend of the air temperature (external, internal and inside the cavity) obtained from simulation conducted in free-floating conditions for the coldest day of the year

However, the greatest potential of the I-BEST solution derives from the fact that it is an "integrated" renovation system which, in addition to improving the performance of the building envelope, allows renovation of the heating plant to be carried out easily and economically. The unvented cavity created by the installation of the double façade, in fact, can be used to conveniently place the pipes of the heating system. Consequently, it is possible to assume the replacement of the existing heating plant consisting of gas boilers and radiators, with a more efficient system including an air-water heat pump (SCOP=3.5) supplying fan coils. Furthermore, this solution would also allow cooling in the summer. Thanks to the I-BEST technology, the new heating plant can be fitted quickly, without demolition work and excavations for the passage of the pipes, and without interfering with the use of the internal environment. At present, a gas supply of 11703 kWh is required. Considering the integrated restructuring of the envelope and heating plant, which involves the installation of the I-BEST system and the replacement of the boilers with an electric heat pump, electricity consumption of 2439 kWh is predicted.

To make a comparison, the energy supplied is converted into primary energy using the non-renewable primary energy conversion factors provided by the law (D. M. 26 Giugno 2015). Fig. 7 presents the monthly values of primary energy demand before and after renovation. A saving of 61 % is achieved for the heating season, with a reduction from 46.90 kWh/(m²year) to 18.15 kWh/(m²year).

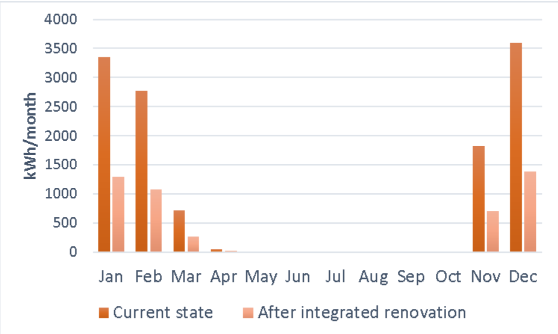

Fig. 7 – Comparison between the monthly primary energy demand for heating before and after integrated renovation, involving the installation of the I-BEST double façade and heat pump system

4. Conclusions

The analysis presented in this work concerned the evaluation using dynamic energy simulation of the energy performances offered by an innovative building renovation system, consisting of sliding and multifunctional modular panels (I-BEST system). The proposed technology allows for the creation of a double façade by realizing a non-ventilated cavity, which can be used to set up the pipes of the plants. This makes it possible to operate an integrated renovation of the building envelope and heating system in a short time, without demolition work and reducing costs. Since the I-BEST system is designed for the combined renovation of the heating system and external walls, its affordability is particularly evident when the following conditions occur: the need to install, complete or renovate the air conditioning system; the need to place scaffolding on public land to implement the work aimed at the thermal insulation of the envelope. In the first case, it would be very expensive to operate inside the house to build the air conditioning system, as this involves the demolition and reconstruction of the tracks where the pipes pass. With reference to the second hypothesis, the municipal charges to be paid for the occupation of public land are high, and a faster operation, such as that allowed by the I-BEST system can bring significant savings.

The modular and multifunction panels confer high flexibility to the system, in terms of adaptation to different contexts and functions performed (simple cladding, thermal insulation, solar façade, and green surfaces). In particular, the analysis developed in this study focused on the evaluation of the configuration designed for thermal insulation. A building was selected as a case study and the energy saving achievable following the integrated renovation was assessed, involving the application of the I-BEST system and the replacement of the heating plant. The results showed that the use of the I-BEST double façade allows for a reduction in the heating requirement of about 14 %. The enhanced performance of the walls allows an improvement of the internal conditions with regard to the passive behaviour of the envelope to be obtained, resulting in an increase in the internal air temperature. Considering the refurbishment of the heating system through the installation of a heat pump, it is possible to achieve a saving of 61 % in terms of primary energy. Future studies will be aimed at extending the analysis to evaluate the effect of the I-BEST technology also in the cooling period and to explore the other possible alternative configurations of the I-BEST system (solar façade and green façade). Moreover, the implementation of the system on the building selected as test-case for the research project will also allow experimental analyses to be performed.

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