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Energy refurbishment of historical buildings with public function: pilot case study

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Abstract

In the last few decades, an increasing attention has been paid to the enhancement of energy performance and indoor comfort conditions of historical buildings, where the architectural heritage and artistic value do not allow typical retrofit intervention. The need to enhance the energy efficiency and environmental sustainability of historic buildings is addressed in this paper, through energy modeling and dynamic simulation of a real building with the integration of renewable energy plants for building heating and cooling. The pilot case study is "Palazzo Gallenga Stuart", a historical university building located in Perugia, Italy. The energy performance of the building has been evaluated in order to reduce the building energy demand through the implementation of high-efficiency technologies in historic buildings. The increase of the energy efficiency of the building has been pursued through the improvement of the actual energy plants' technology by introducing a more effective heat pump plant, in order to prevent the use of visually impacting external units on building historic façade.

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Keywords: Historic buildings; Dynamic simulation; Post-occupancy assessment; Energy efficiency; Energy saving; Energy retrofitting.

1. Research background and motivation

Buildings in EU account for almost 40% of the global energy demand and of all the materials entering the global economy, and also generate 40-50% of the total output of greenhouse gases [1-2]. These data demonstrate the urgent need for the development of innovative strategies for the enhancement of buildings energy efficiency and sustainability [3], especially with reference to the new European and international construction policies [4]. Buildings represent indeed long-lasting products that could significantly affect the quality and the comfort level of both the indoor and outdoor environment. To this aim, several methodologies for the performance assessment and optimization of existing buildings have been proposed

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[5]. Additionally, many design options and multiple energy retrofit measures for heritage historical buildings have been detected [8], for both improving the energy efficiency and reducing buildings' operational costs [9]. In particular, heat use is responsible for almost 80% of the energy demand in houses and utility buildings for space heating and hot water generation, whereas the energy demand for cooling is growing year after year. Efforts have been made in order to establish installation standards and to develop design methods for high-efficiency geothermal systems such as ground source heat pumps [10], which have the potential to reduce cooling energy by 30-50% and heating energy by 20-40%, and are able to reduce the amount of greenhouse gases emissions in the atmosphere.

In this scenario, the purpose of the present work is to define an integrated methodology for the enhancement of the energy efficiency and sustainability of historic buildings, through energy modeling and dynamic simulation [15-16] of a real historic university building selected as "pilot case study". Therefore, the main objective is to reduce the building's energy requirement for heating and cooling through the implementation of specific solutions to be integrated into historic buildings' structure, by taking into account all the constraints related to the high historical and artistic value of the existing building and its content.

2. Description of the case study

The selected building is "Palazzo Gallenga Stuart", a four story university building situated in the city center of Perugia, Italy (see Figure 1). The structure is composed of two underground levels (professors' offices, classrooms, cafeteria), and four floors above ground (reception hall, classrooms, laboratories, dean's office, conference room) for a total gross building area of about 7000 m^2 and total height of about 25 m. The opaque envelope is composed of bearing stone blocks masonry, brickwork finishing and internal cement plasterboard. Calculated thermal transmittance of the wall corresponds to 2.2 W/m^2K, and thermal transmittance of the unoccupied clay-tile sloping roof is 2.8 W/m^2K.

The current energy plants of the building include a hot water radiator distribution for heating powered by a traditional methane boiler, and condensing external units with fan-coils for cooling. The cooling system operates in the period June 1st – September 30th. The heating system operates in the period October 1st – April 30th. Therefore, the plants operate every day from Monday to Friday, from 8:00 a.m. to 7:00 p.m. The occupancy level of the case study building is about 0.5 people per m^2 in every classroom. This density is lower in the other spaces, e.g. toilet, reception, offices, i.e. 0.1 people per m^2.

Fig. 1. Palazzo Gallenga Stuart (XVII-XVIII cent.), Piazza Grimana, Perugia (Italy).

3. Methodology

The main methodology steps are the following: (i) Elaboration of the energy model of the building by means of the Energy Plus tool [17], by considering the current status of the structure, both in terms of architectural and technical elements; (ii) simulation of the year-round energy performance of the building in terms of heating and cooling primary energy requirements, before the energy retrofit. (iii) P

(iii) Proposal of a new integrated configuration of the energy systems, by taking into account all the architectural and technical constraints due to the historical value of the pilot case study building. The retrofit strategy proposed for the building consisted of: (i) the disposal of the outdoor condensing units and the maintenance of the existing radiators; (ii) the substitution of the old methane boiler with a more performing and effective ground-source heat pump plant, with the consequent recovery of the preexisting technical rooms; (iii) the installation at the building's second basement of a system for the heat storage. In particular, the system consists of 10 tank modules (12 m^3/each) for a total number of 36 vertical underground heat exchangers (34 m length/each) positioned in the vertexes and in the center of the tank base surface. The total provided thermal power corresponds to 170 kW_t, consistent with the predicted required power calculated in Section 5. The heat pump, the boreholes' length and the tank's volume were determined based on the peak heating consumption.
(iv) Simulation of the building energy performance after the energy retrofit, in order to evaluate the heat pump energy consumption over a year of operation. The calculated annual energy consumption was therefore compared to the consumption of the building before the energy retrofit.

4. Discussion of the results

4.1. Year-round energy assessment before and after the energy retrofit

Figure 2 shows the comparison of the annual profiles of the primary energy requirement for heating and cooling of the case study building, before and after the energy retrofit.

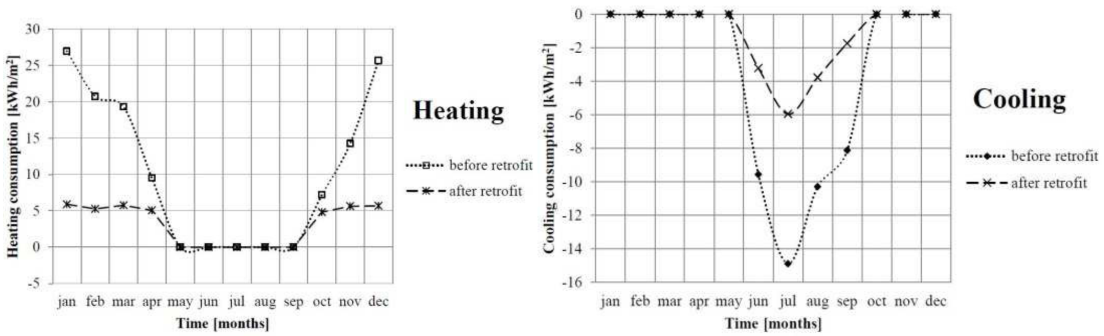

Fig. 2. Annual profile of the primary energy requirement for heating and cooling of "Palazzo Gallenga" (a) before the energy retrofit and (b) after the energy retrofit.

According to these results, the total building requirement for heating and cooling before the energy retrofit (Figure 3a) are about 69 kWh/m^2 per year. After the implementation of the more effective ground heat pump system with additional storage tanks (Figure 3b), the buildings' requirement for heating and cooling are almost 30 kWh/m^2 over a year of operation.

5. Conclusions

This paper showed how the application of specific action for the energy retrofit of existing buildings could decrease the annual energy requirement for heating and cooling, without compromising the artistic and historical value of the building. A more effective and sustainable plant was selected for the pilot case study building, consisting of a ground heat pump coupled with water storage tanks, each one connected with underground vertical boreholes as heat exchangers. The system was designed and optimized in order to combine several modules (tank and boreholes) and provide a more versatile technology to be implemented in historic buildings with low invasive contribution in the underground floors. In fact, such under-ground spaces were usually used as archives when paper documents were required to be preserved for years. Therefore, no useful function was assigned to those spaces, which could be provided by the energy storage function of the proposed system. Finally, a total building energy saving of more than 50% was achieved, by taking into account all the architectural and environmental constraints.

6. Future developments

Further research should focus on the analysis of the impact at urban scale of the energy retrofit of historic buildings, in terms of economic costs/management, and environmental/architectural impact. Additionally, parametric and replicable methodologies for the optimization of energy retrofit actions of historic buildings could be defined.

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Biography

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