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Retrofit of an historical building toward NZEB

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Abstract

The European Directive on Energy Efficiency in Buildings (Directive 2010/31/EU) has introduced the need to transform buildings to nearly zero energy (NZEB) by 2020. Existing buildings represent the major part of the building stock and an interesting challenge is to transfer it toward NZEB. Energy retrofit is even more significant in Italy, where existing buildings stock (mainly residential) is also historic, so it's subject to environmental constraints or architectural-artistic value, and it's influenced by specific regulations and methods of intervention for refurbishment. In this case, the challenge becomes even more important and concerns both the building shell and the systems: retrofitting introduces not originally present in the complex; retrofit is not covered in the maintenance, since it represents an upgrade, an adaptation of the building, specifically in relation to energy efficiency, but also, by extension, other functions / features pertaining to the environment and sustainability. A case study of a radical refurbishment of an historical building is Ca' S. Orsola in Treviso. It is ruled by the Historical and Architectural Veneto Regional Authority. The building has been transformed into a prestigious residential complex by a major renovation that was aimed primarily seismic and energy upgrading. The energy and environmental performance of building have been analyzed by numerical simulation and experimental measurement in the EBC IEA Annex 56 [1] context with the aim to verify that intervention strategies respect to the reduction of energy consumption, the minimization of CO_2 emissions and maximizing the use of sources of renewable energy.

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1. The case study

Caô S. Orsola is located in the historic center of Treviso, in North East of Italy, very close to the city Cathedral. The building was the old seat of Polish Institute and now it is a listed building by Historical and Architectural Heritage Superintendence of Veneto Region. Originally it was a convent and it And it was inhabited for 40 years until 2000 and during the time it keep intact the original structure and architectural distribution. Then it was bought in 2007 for acting a deeply renovation and converting it in a prestigious residential building; The whole building (Fig. 1) is a gross volume of 6300 m^3 and it consists of an area of 4500 m^2.

Fig. 1 General view of the building a) before and b) after the intervention.

At the beginning of construction phase the structure revealed a quite ruined state of conservation: walls are crooked and presented different solutions, moisture affected wooden elements in the floors and in the roof. There was a heritage architectural restriction about the external envelope. Specific goals of renovation project were:

- to achieve the A class energy classification according to Italian regulations;
- to consolidate and to reinforce the building structure;
- to improve the indoor thermal and acoustic quality;
- to transform it in a prestigious residence with all comforts.

The building refurbishment was developed with a particular regards on thermal insulation of the building envelope and special attention has been paid to the mechanical ventilation and the renewable energy utilization (both solar thermal and photovoltaic system).

2. Building envelope, heating, ventilation, cooling systems before the energy renovation.

Building envelope before renovation presented a traditional construction system, based on bearing masonry with covered solid bricks. The floor had a wooden structure, while the ground floor leaned directly on soil. The roof is made of hollow tiles sheets with a wooden structure and a lightweight ceiling slab (Fig. 2).

Fig. 2 Building envelope before renovation: a) crooked walls; b) demolished partition walls left and used as a substrate; c) beam support in the perimeter wall.

The windows frames were made of wood and the windows used to have a single glass. There is no insulation in the external walls, roof and floors (Table 1).

Table 1 Thermal characteristics of the building elements.

Element	Area *(m^2)*	U-value before renovation *($W\ m^{-2}K^{-1}$)*	U-value after renovation *($W\ m^{-2}K^{-1}$)*
Facade	1300	0.90	0,18
Ceiling	508	1,65	0,788
Windows, doors	140	2,70	1,948-2,035
Roof	508	1,09	0,158

Heating or cooling system was not installed. Heating was provided by a fireplace, also used for cooking, occasionally an electric heater or portable fan coils was placed in any room. The domestic hot water was supplied by electric heaters with storage tank; there wasn't a ventilation system, so ventilation was made by natural means.

3. Energy renovation features.

The restructuring aims not only to heal a property that was under the limit of sustainability from the structural point of view, but especially to retrain in terms of energy and acoustic complex.

Technologies measures aimed to achieve A energy class; several design topics were adopted among which high insulated windows, high level of opaque walls insulation, mechanical ventilation system with heat recovery, solar thermal panels and PV systems, water to water heat pumps and chillers.

The first step has been taken the measures to consolidate the building structure. Subsequently a detailed study on thermal and acoustic bridges has been developed with the aim to improve the indoor thermal and acoustic quality.

In the external walls the insulation is placed on the inner part (Fig. 3) and this solution meet the requirements of the Superintendence of Veneto Region, preserving the existing materials and the external architectural identity of the building. Specifically, two types of insulating are used: an expanded polystyrene (EPS) foam, placed directly on masonry, and a rigid mineral wool panel with a plasterboard cover. Roof was replaced with a new wooden structure and it was insulated with wood fiber and water tight covering. All existing windows are replaced with a low-energy double layer ones within wooden frames.

Fig. 3 Insulation on a) internal and b) external walls.

About technical systems, the HVAC generation system is a water to water centralized heat pump/chiller. The underlying well is the hot/cold water source and internal comfort is achieved exploiting a radiant system (Fig. 4) installed in the floor together with a dehumidification system for the summer period.

Fig. 4 Radiant system: a) collectors and b) TNT underflooring above system.

For heating and cooling the system adopted is a 32 kW heat pump with a distribution by radiant floor system; another heat pump (20 kW) is installed for domestic hot water requirement (DHW); mechanical ventilation (Fig. 5) is provided by a system with heat recovery box (95% efficiency).

Fig. 5 Mechanical ventilation system.

Renewable energy systems have been installed after renovation: thermal solar panels for DHW production (20 m^2) are located in vertical position and a photovoltaic power plant (18,85 m^2) producing 3300 kWh of total annual energy. These panels are installed on the roof and oriented to the south.

4. Achieved energy savings, CO_2 reductions and costs.

Energy needs values before renovation are calculated by a simulation and they are presented for comparing thermal comfort conditions after retrofit measures. It should be stressed that values for DHW need already include the solar thermal contribution and also that the amount of renewable energy was zero before renovation (Table 2).

Table 2 Energy savings and CO_2 reduction

Energy need		**Before renovation**	**After renovation**	**Saving**
Heating	$kWh\ m^{-2}a^{-1}$	342,7	42,3	88%
DHW	$kWh\ m^{-2}a^{-1}$	44,4	33,6	24%
Electricity	$kWh\ m^{-2}a^{-1}$	45,0	20,0	56%
Total	$kWh\ m^{-2}a^{-1}$	432,1	95,9	92,5%
Energy label		G	A+	
Carbon emissions	$kg\ CO_{2Eq}\ m^{-2}a^{-1}$	29,8	5,8	81%

Construction cost about renovation (Table 3) excludes the costs for heating and DHW, so costs related to the purchase of the area, charges, interest, taxes.

Table 3 Renovation costs

Costs	**EUR**	**EUR m^{-2}**
Craftsmen	2.94 million	1463,41
Consultants	130.000,00	64,71
Electrical and Plumbing	700.000,00	348,43
Total construction	3.77 million	1876,56
Thermal solar and PV system	32.000,00	15,92
NPV	13 Years	

The contribution of renewable energy resources is given in 6,56 kWh/m^{2}a: calculation and monitoring gives a production of about 3300 kWh for photovoltaic system and 8500 kWh for solar thermal.

5. Overall improvements

The major benefit given by renovation measures is the energy saving of 336,2 kWh m^{-2}a^{-1}, including heating, DHW, ventilation systems.

The indoor climate was improved due to the upgrade of the building energy performance and the control of indoor temperature and humidity without relevant energy costs. The standard energy performance for new buildings in Italy has been achieved by several factors such as the reduction of losses through the insulation on walls, roof and the installation of new window; the reduction of the thermal bridges allow to eliminate related condensation problems and also the mechanical ventilation is balanced with heat recovery and with a carefully adjusted supply temperature. From economic point of view, renovation of existing buildings, especially if listed, is too much expensive than standard, because it need specialized operations and the preliminary count evaluation is upset during the construction phase. After intervention, however, market value increased for this property and also for the surrounding area: in this case study all apartments have been sold by the end of the construction phase (Fig. 6).

About decision process during building phases, the investment costs were incurred by the contractor, that is also the owner: in this particular situation themes such as sustainability and energy retrofitting were understood and applied. The major overcome barriers were essentially related with the bureaucracy for obtaining the permission by Historical and Architectural Heritage Superintendence of Veneto.

Fig. 6 The residence after intervention: a) Courtyard from west perspective; b) Typical living room in a dwelling.

After the retrofit intervention itôs possible to underline also non-energy benefits, rather factors that can be brought back to social and economic aspects in the long term; for example this radical renovation transformed a historic building in a prestigious and comfortable residence; then a better living conditions is enriched with more qualified living spaces and privacy to the occupants are ensured by a reached acoustic first class according to national standard UNI 11367; the improved structural conditions in an uninhabited and listed building implemented a seismic consolidation and an aesthetical improvement returned the identity of the original building and increased the market value.

6. Final remarks

Ca' S.Orsola is a listed building completely renovated and converted into a residential building, with offices and shops at floor plan and dwellings above. Renovation aimed not only to restore the structure, but also to redefine the both energy and acoustic target maintaining an high indoor comfort level. The building structures are certified by seismic point of view and each apartment of the block is certified in A Class; low-e energy glasses high performance insulating layer, the installation of a mechanical ventilation system with heat recovery, the integration of solar panels for DHW are the main facilities adopted for achieving an high level of certification. Living environmental quality is assured by the use of indoor materials with low harmfulness and because of the installation of underfloor winter heating and summer cooling with humidity control. Renovation measures decreased global energy consumption, reducing up to 90%; solar and photovoltaic system contributed to minimized energy consumption.

A prestigious location, a renovated historic building with the most innovative technical solutions made a safe and long-lasting investment.

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