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ScienceDirect

Energy Procedia 62 (2014) 62 – 71

Energy Procedia

6th International Conference on Sustainability in Energy and Buildings, SEB-14

Deploy energy-efficient technologies in the restoration of a traditional building in the historical center of Catania (Italy).

Gagliano[a] A.*, Nocera[a] F., Patania[a] F., Detomaso[a] M., Sapienza[b] V.

[a] *Department of Industrial Engineering and Architecture - University of Catania, viale Andrea Doria, 6 95125, Italy.*
[b] *Department of Civil Engineering and Architecture - University of Catania, viale Andrea Doria, 6 95125, Italy.*

Abstract

The policy about energy efficiency of buildings, including minimum energy requirements and energy performance certificate (EPC), have to be also applied to existing buildings in the case of energy retrofit. In this paper, the possible strategies that can be used to reduce the energy needs of traditional massive buildings, that are widespread in the old town of the Mediterranean cities, have been investigated. To this aim, this study evaluates the energy consumption of a massive building placed in Catania city, called "La Casa del Portuale", which was recently refurbished with the aim to host two local administrative centers. The energy needs of this building was evaluated through computer simulation both in the heating and cooling period, on a yearly basis. The activities research were developed analyzing different refurbishment solutions suitable to improve the thermal performance of most traditional buildings without adversely affecting their fabric and character. Therefore, the feasibility comparison has been performed between the examined refurbishment solutions. The results of the proposed research , considering the diffusion of this typology of buildings, could be assumed as reference to a significant portion of the traditional real estate.

Selection and peer-review under responsibility of KES International

Keywords: energy –efficient technologies, traditional massive building

1. Introduction

The BLUE Map scenario is predicated on strong policies to accelerate energy R&D, deploy energy efficient and low/zero-carbon energy technologies and put a value on CO_2 abatement.

Fifty percent of the buildings sector energy savings in the BLUE Map scenario [1] come from space and water heating, cooling and ventilation. Most buildings have long life spans, meaning that more than half of the current global building stock will still be standing in 2050. In this context, it is fundamental identify practical solutions for energy efficiency renovation of historic and traditional building stock. Historic buildings are the trademark of numerous European cities, historic centers are a living symbol of the rich cultural heritage of our cities. Thereby, they are precious and need to be protected. Restoration projects have to allow the buildings to continue to function in terms of maintaining ventilation and moisture permeability, whilst retaining historic character and minimizing the visual impact of the changes. Therefore

* Corresponding author. Tel.: +39-095-7382453; fax: +39-095-7382496.
E-mail address: agagliano@dii.unict.it

Selection and peer-review under responsibility of KES International
doi:10.1016/j.egypro.2014.12.367

a restoration project must be seen as an opportunity to make use of traditional construction systems as a tool for revitalizing and conserving historical city centers, and for promoting a new building model with sustainability as the centerpiece of architectural restoration [2]. The criterion of sustainability, as part of the restoration project should be pursued with moderation and prudence, to avoid excessive invasiveness. Therefore, it is appropriate to proceed with broad freedom in the replacement and renovation of the building elements, while more caution should be given when the modification of the elements of the factory as a whole and in the morphology of the spaces. Anyway, freedom of expression should be commensurate both with the needs dependent on the intended use and the other to the aesthetic, which must always be at the center of the design.

Mediterranean traditional building envelopes have good thermal inertia, but given their poor thermal insulation, they are usually exhibit high thermal losses. Several studies have investigated the energy performance of heritage building [3], [4]. Reducing buildings' energy consumptions is a task that has guided several researchers for continuously improve the energy refurbishment strategies and to develop adequate simulation tools [5], [6]. Other interesting theme is the exploitation of renewable energy sources (RES) in the built environment [7], [8] and their building integration. In this study, two targeted actions were evaluated: one action on the building envelope and the other one focused on the air conditioning system. The first action is focused on the upgrade of the thermal insulation of the building envelope with the aim to reduce both of the energy demand for heating and cooling. The second action is based on the renovation and the optimizations of the current energy production systems with the goal to increase its overall efficiency. Subsequently the financial analysis of the technological solutions designed was evaluated in order to assess which of them is the most effective.

2. Methodology

The energy uses that have to be considered in assessing the energy performance of the building are those related to heating (H), cooling (C), production of hot water (W), ventilation (V) and lighting (L). Electricity for household appliances is not included in the current scope of the EPDB [9].

The energy consumption will be normalized with reference to the net surface or the net volume of the building; a year is the period of time to be used to make all the energy balances. As concerns renewable energy sources (RE), only on-site contributions can be considered.

Finally, specific primary energy (PE) is the indicator used for making the balance between energy uses and renewable energy production.

As a consequence, the following expression holds:

$$PE = \sum_{year}(PE_H + PE_W + PE_C + PE_V - PE_{RE}) \quad (1)$$

The result of Equation (1) shall not be positive in order to center the target of Net-ZEB buildings. PE can be expressed both in ($kWh{\cdot}m^{-3}{\cdot}y^{-1}$) or ($kWh{\cdot}m^{-2}{\cdot}y^{-1}$), if the net heating volume (V_n) or the net heated surface is used (S_n). Q_H and Q_W are the annual thermal energy demand respectively for space heating and heat water production (kWh) while Q_C is the annual cooling energy demand (kWh).

The other terms are calculated as follows:

$$PE_H = Q_H/\eta_H \cdot V_n \quad (2)$$

$$PE_W = Q_W/\eta_W \cdot V_n \quad (3)$$

$$PE_C = Q_C/V_n \quad (4)$$

η_H = annual fuel utilization efficiency of the thermal energy plant for space heating (%)

η_W = annual fuel utilization efficiency of the thermal energy plant for heat water production (%)

Specifically, η_H and η_W are respectively the ratio of the annual thermal energy demand for space heating or for heat water production, compared to the total annual fossil fuel energy consumed by a furnace or boiler. These efficiencies include the heat losses of the following different sub-systems: emission, control, storage, distribution and generation.

The specific primary energy for winter heating and heat water production were calculated through the software Master Clima [10]. The software Master Clima is based on a simplified steady-state model in accordance with EN 15316 and UNITS 11300-2, which is a technical specification for the nationwide application of EN 15316. With reference to the internal gains (associated with people, artificial lighting and electric appliances), conventional values are used, suggested by the National Regulation for the calculation of building thermal energy needs UNITS 11300-1. Such values change according to the type of room and to the time interval, ranging from 1.0 $W{\cdot}m^{-2}$ (bedroom, from 07:00 to 23:00) to 20.0 $W{\cdot}m^{-2}$ (kitchen and dining room, from 17:00 to 23:00).

3. Case Study

The neighborhood of Civita is the beating heart of the Catania, a medium city of the eastern Sicily. It is located between the elegant road of the historical city and the harbor area (Fig. 1). Seafarers (fishermen, maritime, porters,) and artisans live there in small homes on a very dense net of road. In San Francesco di Paola square, an open space facing the port structures, there is the “Casa del Portuale” of Catania (the roustabouts home).

Figure 1: Neighborhood of Civita (photo above), the south façade (left side), the east façade (right side).

The building is part of a large construction program, in the main Italian maritime cities (Livorno, Napoli, Salerno, Bari), that was realized by the Fascist Administration for the Roustabouts Company of each city. These Companies were founded in 1929, as corporations of workers, and the Roustabouts Homes were built at that time. However in Catania it was built later, in fact it was designed in 1948 by the Sicilian Regional Authority, together with other buildings in Palermo, Messina, Siracusa and Marsala, and it was finished only in 1957. The façade is inspired to the Late Rationalism (Fig. 1). The regular volumes are juxtaposed in a simply and linear way; the prevalent color is white; there are not mouldings or other ornamental elements; an airy portico is located over the main door. On the side facing the marina, the façade is animated by a revival of Littorio's Style, with a series of essential pilaster that surround the windows of the front.

The plan of the "Casa del Portuale" has approximately a C form; it is articulated around a patio, closed on one side by some older buildings. The central core is located on the square, there you have the hall; the north wing has a number of rooms, on two lines, that in the original state were used as service rooms (as changing rooms, showers, warehouses, …). The other wing was occupied by a single very large room: the refectory. In the upper floor, on the northern wing, there are the rooms used as admin offices, while in the other wing the surface there is only the meeting hall.

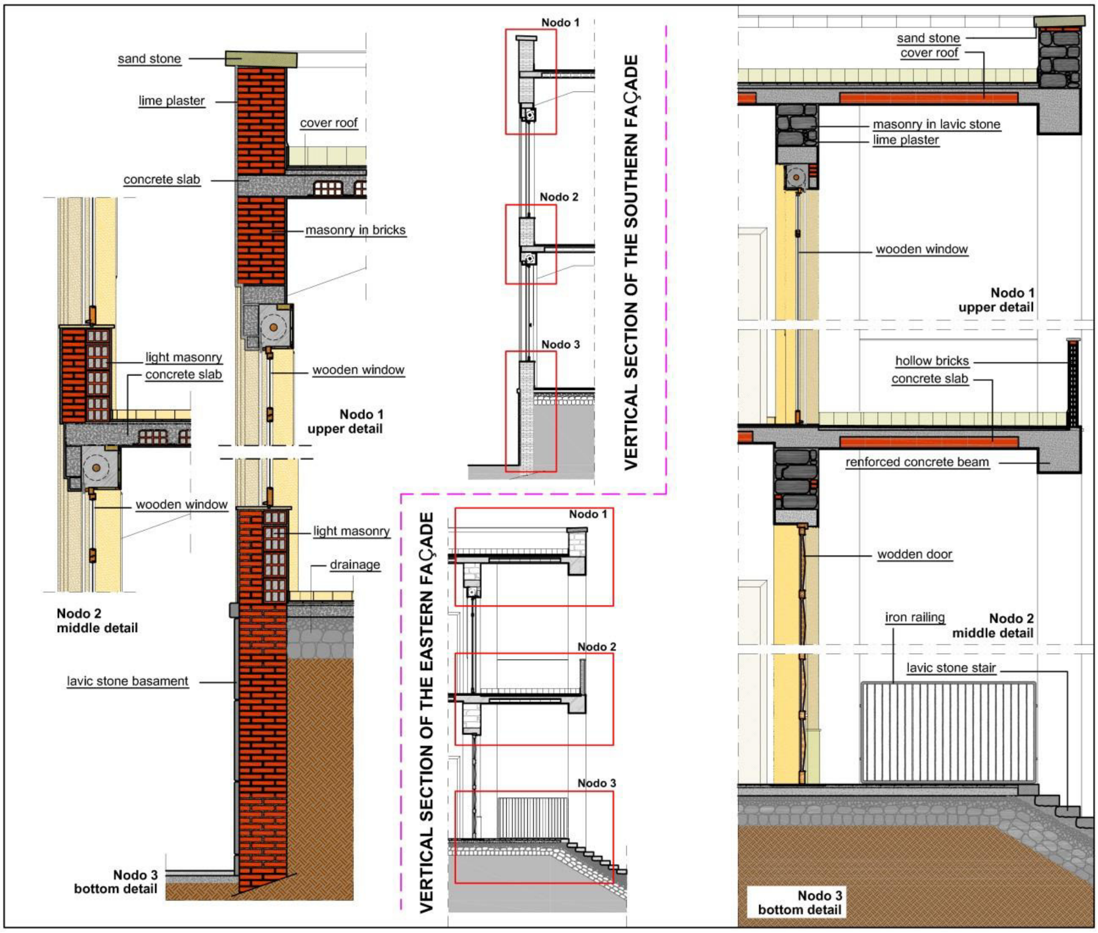

Figure 2. Vertical section of the south façade (left side); vertical section of the east façade (right-side).

During the years, the number of the sea workers has had a gradual reduction; moreover, the roustabout companies were abolished in 1993, in all parts of Italy, to contrast their monopoly. Therefore, the "Casa del Portuale" of Catania, like in the other cities, was unused for several years, and it was struck by various pathologies that are typical of this kind of constrictions: humidity infiltrations, oxidation of the steel rods, detachment of the plasters, aging of the windows, and, of course, obsolescence.

Since this building is always attractive thanks to its large interior spaces and closeness to the city centre, the Sicilian Regional Authority, few years ago, has decided to plan its refurbishment to host two different administrative services: the UREGA (office for invitation to tender) at ground floor and upstairs the Maritime Domain. Thereby an efficient and elegant little center that hosts the above mentioned administrative offices was created. The architectonic project was accompanied by an energy requalification, to be carried out in gradual steps and according to the financings resources.

3.1. Building features and weather data

The main geometric feature sand the thermal transmittance (U-value) of the main elements of the building envelope are shown in Table 1. The external walls are based on rock lava brick, which are most widespread in traditional building. The overall thickness, including inner and outer plaster, is 70 cm. The windows have an aluminum frame without thermal break and a single 4-mm glazing.

Table 1. Geometric features and U-value of the building envelope at the initial state.

Geometric feature	Dimension	Building element	U-value [W $m^{-2}K^{-1}$]
Heated gross-volume	V =7287.70 m^3	*External walls*	*2.50*
Surface that enclose the heated volume	S =1524.87 m^2	*Flat roof*	*1.90*
Shape factor	S/V =0.209	*Inner floors*	*1.70*
Net floor area	S_n=1139.12 m^2	*Floor on the ground*	*1.90*
Transparent surface / Net floor area	Sv/Sn= 0.187	*Windows*	*4.50*

The main weather data for the site (lat, 37°37', long, 15°, degree day 833) are shown in Figure 3.

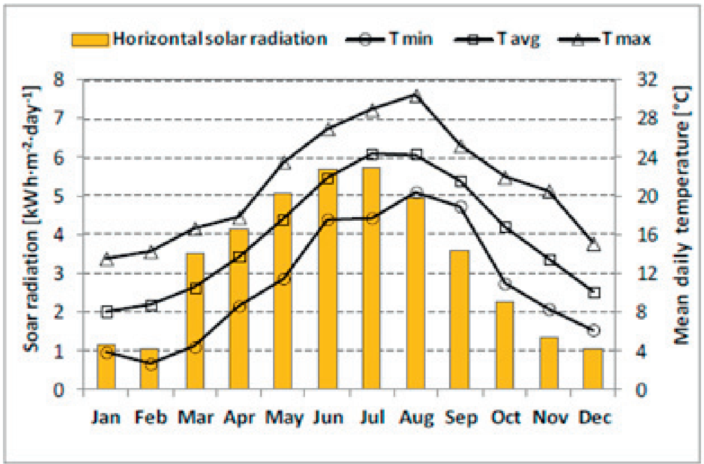

Figure 3. Weather data for the site considered in the study.

The heating system is constituted by a centralized gas-fired systems, hydronic distribution systems, centralized control system and hot water radiators.

The following assumption have been assumed:

- internal design temperature is assumed 20°C in heating period and 26°C in cooling period.

- heating period (N_H) from 1th December to 31th March,
- cooling period (N_C) from 1th April to 30th November.

Conventionally, a ventilation rate as high as 0.5 and 0.3 air changes per hour (ACH) have been taken into account in the cooling and the heating season, respectively; these ventilation rate includes the air infiltration through leaks. The energy consumption and the main energy performance parameters are summarized in table 2.

Table 2 – energy consumption and the building's rating

Annual energy demand (kWh)		Specific Energy demand ($kWh \cdot m^{-3} \cdot y^{-1}$)	
Energy for space heating, (Q_{PH})	406640.35	(PE_H)	56.15
Energy for DHW production (Q_W)	2279.70	(PE_W)	1.052
Energy demand for cooling (Q_c)	76506.89	($PE_{C,}$)	10498

The energy needs result from simulations indicate that the specific energy demand for space heating is enormous if compared to the threshold value allowed by the Italian rule, that is eight times lower (7,328 , ($kWh \cdot m^{-3} \cdot y^{-1}$)). Instead, the specific energy demand for cooling is even lower than the threshold value that is 14.00 ($kWh \cdot m^{-3} \cdot y^{-1}$).

The building is rated in G class, for the heating energy needs, and in class V for the cooling energy need, that are the worse classification foreseen by the Italian rules on the energy performance certification of buildings. The large energy demand for space heating depends both by the poor thermal insulation of the building envelope and by the awful global efficiency of the heating system, which results only of 40.54%. More specifically, the inefficiencies are due to the insufficient and inaccurate thermal regulation system, the low efficiency of the boiler (75%) and the not adequate typology of the indoor heating system. Indeed, the radiators give a not uniform distribution of the emitted heat within rooms with height higher than 3.00 m.

4. Proposed Refurbishment Techniques

Two targeted actions were evaluated: one action on the building envelope and the other one on the energy production systems. The restoration project identifies four different elements for upgrading the thermal performance of the building's envelope that are walls, windows and doors, roofs/attics.

The balance between advanced envelopes and advanced equipment needs to be established at the regional or local level while considering product availability, cost, climatic conditions and energy prices.

4.1. Opaque vertical envelope

Currently the thermal transmittance of the vertical opaque walls is on the order of 2.50 $W \cdot m^{-2} \cdot K^{-1}$, therefore , usually the upgrade of the thermal insulation assume a central role in the restoration projects of the historical buildings. Preliminarily, it is necessary to underline that is not mandatory satisfy the threshold transmittance values imposed by current Italian regulations [11]. This enables of choose refurbishment interventions that can safeguard the historical instance that characterizes many historical buildings. The peculiarity of the historic buildings suggests, to not altering their architectural appearance that would be appropriate to discard the interventions, which modify the external coating of the facade, e.g. the Exterior Thermal Insulation Coating system (ETICs). Thereby, an insulated plasterboard with a thermal conductivity $\lambda = 0{,}055\ W \cdot m^{-1} \cdot K^{-1}$, has been chosen for upgrading the thermal insulation of the external walls. The thermal insulation has a thickness of just 3.5 cm. The choice of a so small thickness is due to the consideration that adding most thickness thermal insulation has a smaller effect on energy savings than installing insulation initially [1].

4.2. Transparent vertical envelope

The windows of historical building are still only single-glazed, with clear glass and poorly insulated frames. These have U-values of approximately from 4.5 $W{\cdot}m^{-2}{\cdot}K^{-1}$ to 5.6 $W{\cdot}m^{-2}{\cdot}K^{-1}$.

Therefore, the replacement of windows is usually required because, beyond the considerations on the thermal transmittance of frames and glazing, dated doors and windows have often problems of water and airtightness. In addition, windows and doors, with the passage of time, easily lose their mechanical functionality. When windows are renovated it is necessary to evaluate all their components: framing materials, glazing, coatings, spacers between panes of glass and low thermal conductivity inert gases to reduce heat transfer within cavities, thermal breaks and operating hardware. The choice of wood frames seems the most compatible with the architecture of the traditional buildings. However, their actual performance is entrusted to their laying, taking care to ensure the correct coupling frame / masonry.

High-performance windows with low thermal transmittance for the entire assembly (including frames and edge seals) and climate-appropriate solar heat gain coefficients (SHGC) have been chosen (see table2). Technological solutions more advanced than double-glazed, low-e windows can be less cost-effective because additional energy savings are lower. Within the Mediterranean region, characterized by a high solar radiation, it is necessary to dispose a shadow system. If it is not allowed by the architectonical design, it is possible to foresee a solar control glass.

4.3. Roof plan

The re-roofing is probably the maintenance operation that is repeated with greater frequency during the life of a building, to restore its water tightness. Therefore, during the maintenance of the roof, since the thermal resistance of the roof surface is usually not sufficient to satisfy the threshold value, the designers, should foresee the installation of a thermal insulating material with definite advantages in the energy balance of the building. In this case a thickness of 8.00 cm of thermal insulation panel with thermal conductivity $\lambda = 0.05\ W{\cdot}m^{-1}{\cdot}K^{-1}$, has been chosen.

4.4. Heating system efficiency

One cause of the high-energy consumption of traditional buildings is the low efficiency of the completely heating system: boiler, distribution, control and emission system. Older furnace and boiler systems had efficiencies in the range of 56% to 70% [12], and the overall efficiency can easily drop down 50%.Therefore boilers can be retrofitted to increase their efficiency. As well known the greatest energy efficiency benefits are obtained from installing condensing boilers.

Installing effective controls can also give a significant impact on the energy consumption of heating and hot water systems. Effective controls allow both increasing the efficiencies of the heating system and providing the opportunity to minimize energy consumption by ensuring that the right comfort temperatures can be maintained and reducing overheating phenomena. Thermostatic radiator valves (TRVs) are used to limit the temperature in individual rooms. In addition, they reduce the overheating phenomena caused by solar and other incidental gains. In this way, they allow to cut down unnecessary energy consumptions. Another cause of inefficiency is the airflow circulation originated by the conventional radiator emitters within rooms with height more than 4.00 m. Indeed, conventional heating system warms up the air in the room that goes up to underneath the ceiling. On the walls, the air cools down again and sinks to the floor. This means essentially high temperature differences between floor and ceiling (cold feet - warm head).

As consequence the warmth spreads unevenly within the room envelope, this air circulation aids the formation of mold. If the radiators cannot be replaced a most common expedient is the apposition of a suspended ceiling to reduce the internal height of the rooms.

Therefore, the internal height has been reduced to 3.00 m introducing a false ceiling realized with plasterboard panels. Consequently, the emission efficiency of the radiators increases from 0.75 to 0.85.

It is necessary point out that the false ceiling alters the formal perception of the interior spaces especially in two large rooms, the past refectory and the past-meeting hall, where the ceiling hides the massive beams that mark the soffit of the slab, giving rhythm to the volume of these rooms.

An architectonic solution can be obtained realizing the workstations by means of glass or Plexiglas box that allows continuing to grasp the environment in its entirety, as depicted in figure 4.

Figure 4. The main room with the workstations realized as transparent boxes.

The thermal transmittances of the components after the upgrading are summarized in Table 3.

Table 3. Thermal transmittances of the components of the building envelope after the upgrading..

U-value [W m^{-2} K^{-1}]			
External walls	Roof	Floor on the ground	Windows
1.00	0.46	1.90	2.10

5. Energy needs after refurbishment.

The energy needs and the new rating of the building after the interventions of renovation are summarized in table 4.

Table 4. Energy needs and the new rating of the building after the interventions

Intervention of refurbishment	Energy needs for Cooling		Energy needs for Space Heating			Specific Energy needs (Heating+ DHW) [kWhm^{-3}K^{-1}]	
	Q_c kWh	PE_C kWhm^{-2}K^{-1}	Q_H kWh	η_H (%)	QP_H kWh	PE_H	PE_{gl} /rating
a) Roof	52907	7.26	145723	40.54	359809.8	49.32	50.38 /G
b)Walls	80329	11.03	107281	40.54	264891.3	32.71	33.76/G
c) Windows	72621	9.96	154065	40.54	380407.4	52.58	53.63/G
d) Heating system	76506	10.45	164852.4	80.00	206065.5	28.27	29.32/G
Total (a+b+c+d)	53148	7.29	77499	80.00	96873.7	13.29	14.34/D

The energy savings achieved is due in large part to the upgrading of the wall insulation (34.85%), the replacement of windows and the upgrading of the roof insulation that diminish the energy consumption of 6.45% and 11% respectively. Anyway, the most remarkable contribution is obtained increasing the efficiency of the heating plant decreasing the height of the rooms and upgrading the gas boiler, which give a reduction of the energy needs of 52%. Globally, the summation of the refurbishment intervention reduce the specific energy needs for space heating, EP_H, from 406.6 MWh/a to 96.87 MWh/a that is the 24% of the original energy demand. Once the renovation the building moves from the energy class G to D. The improvement of the energetic class from G to D, that a superficial lecture might appreciate as unsatisfactory is due to the current rules on the energy efficiency of buildings [13]. This rule requires performance particularly severe in climatic zones A and B, in order to achieve the most virtuous energy class (A), that is achieve values of EP_H lower than 3.00 $kWhm^{-3}K^{-1}$. This objective would require interventions of energy upgrade incompatible with the historic factories, as well as the extra costs that could be not be justified in terms of benefits obtained. The interventions of energy refurbishment give different contributions to the reduction of energy needs during the cooling season. The roof insulation gives rise to a significant reduction of the energy needs of about 30.8%, whereas the replacement of fixtures produces a reduction of energy needs of only 5%. Instead, the upgrading of the thermal insulation of the walls produces an increase of 5% of the requirements as a result of the reduction of the free cooling during the periods when the outdoor temperatures are lower than the indoor temperature.

5.1. Renewable energy source

Upgrading the building envelope and improve energy efficiency of the heating system, as seen so far, although allows achieving significant energy savings, are not sufficient to achieve the target of buildings with energy balance of zero (or almost zero), the so-called NZEB. This ambitious target can only be achieved by introducing both more efficient energy production systems and renewable energy sources.

For historic buildings it is necessary to evaluate the possibility of building integration of the RES, considering both the cultural values of the buildings and the space available, shadows, wind velocity and so on [14]. The energy demand for producing DHW can be almost entirely satisfied installing a solar thermal system with a solar collector area of about 5.00 m^2. Moreover, on the roof terrace there is the possibility to install a photovoltaic plant system (PVs) having a nominal power of 15.0 kW. The chosen PV systems is constituted by crystalline silicon, and have the following performance. Average daily/monthly electricity production of 63.9/1,940 kWh; total yearly electricity production of 23,300 kWh. The performance of this PV plant have been calculated by means of the tools PV-GIS [15].

6. Financial analysis

The economic cost for increasing the energy performance, is one of the most interesting items for the designer because frequently (too much frequently) not sufficient analysis are executed. However, some of the interventions of energy refurbishment proposed in this case study must be realized to contrast typical pathology of traditional buildings. Starting from this consideration, the financial analysis has been developed considering only the extra costs specifically imputable only to the energy retrofit. Therefore, only the cost of the thermal insulation and its laying have been considered, without adding other additional costs, e.g. the cost of scaffolding for the facade insulation. Once the simple payback time both for each intervention and for the global intervention has been calculated (figure 5). It is possible to notice that the total cost of the proposed interventions is about of 154.159,00 € with a payback time less of 6 years. The worst performance emerges for the windows renovation, which has a payback time of about 9 years, while the renovation of the heating system shows the best payback time that is of about 3 years. This evaluations have been developed do not considering the eventuality of tax relief or other advantages not quantified in terms of energy savings (e.g., noise reduction and so on).

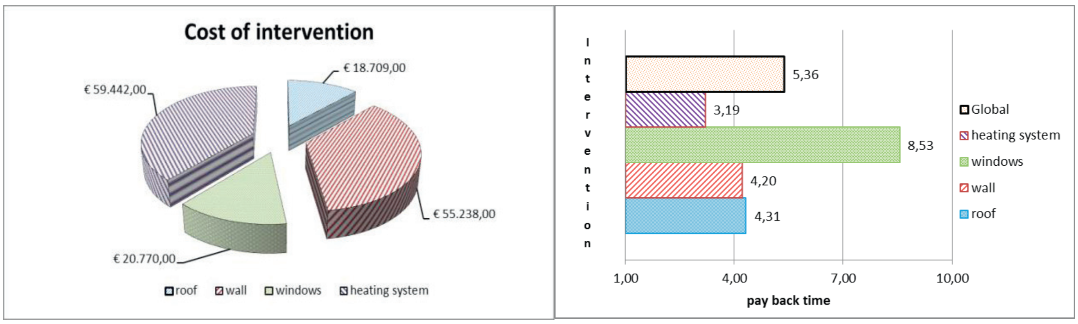

Figure 5. Costs of the energy upgrading and payback time.

Anyway, the financial analysis highlights that the substitution of the windows, which usually is one the more diffuse interventions in the context of energy renovations, has to be very carefully evaluated.

7. Conclusions

The study developed shows that upgrading both of the building envelope and the efficiency of the heating plant allows reducing significantly the energy needs of traditional buildings, about of 70%, with spending increases relatively content. The overall results demonstrate that in the case of buildings located in mild climates is not necessary to use thick layers of thermal insulation, since the reduction in energy consumption is very low. In addition, the risk to create overheating during summer period can occur.

Moreover, it is noteworthy highlight the reduction of the energy consumptions of about 50%, which has been achieved by improving the energy efficiency of the heating systems.

However, the refurbishment of traditional buildings, to reach the target of a building with energy balance close to zero, must will include the exploitation of renewable energy sources, preferably building integrated. Nowadays it should be an absolute priority transforming the classical interventions of refurbishment in an opportunity for deep reductions in energy consumption of traditional buildings.. Future developments of this research include the energy analysis under dynamic regime with the aim to evaluate the effects of high thermal inertia on the energy performance of massive traditional buildings.

Acknowledgements

We would like to express our very great appreciation to Eng. Davide Martello that has collaborated to the geometric and thermo-physic modelling of this building.

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