RESEARCH

ENERGY RETROFIT OF HISTORICAL BUILDINGS: AN ITALIAN CASE STUDY

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ABSTRACT

The most suitable intervention for energy rehabilitation of historical buildings has to reach both the goal of the optimization of the energy saving and the preservation of the original characteristics of the building. The present work is related to refurbishment and energy rehabilitation of an historical building dating back to 15th century. The building complex under study is an ancient residential courtyard building located in Northern Italy near Verona. The strategies have been focused on the building envelope and energy supply systems respecting both the regulatory constraints imposed by preservation of historical buildings and, where possible, the current national legislation about the building energy efficiency. This result was achieved only through the identification of best solutions based on mutual compatibility and optimization of the performance of the building envelope and the HVAC systems.

In the design phase, the thermal performance of the building for both winter and summer periods have been evaluated by dynamic computer simulations. It has been shown that adequate interventions focused on the building envelope and HVAC systems reduces the energy consumption in a significant way. Further, it has been shown through economical analysis that extra-costs for energy retrofit measures paid back quickly during the life span of the building. Historical buildings are characterized by unique and specific characters that could be preserved, also upgrading them to modern requirements. This study demonstrates how it is possible to intervene effectively (and correctly by the historical and architectural point of view) on the energy performance of ancient buildings. By applying innovative techniques and technologies, in fact, it is possible to achieve high energy efficiency levels, without affecting the original architectural appearance and value. The methodology presented can be an interesting case study for all those building interventions where energy, cultural and historical issues intersect.

KEYWORDS

energy retrofit; historical buildings; case study building; energy performance; economical evaluations

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1. INTRODUCTION

According to the EU Directives on the energy performance of buildings, buildings of residential and commercial sectors account for 40% of total energy consumption in the European Union (EPBD 2002; EPBD 2010). The final energy consumption in Italy for the civil sector absorbs more than 31% of total energy produced (ENEA 2008). The residential sector alone covers about 21% of total national energy consumption (Balaras et al. 2007) and in particular in this sector, heating covers about 70% of total consumption (ENEA 2007).

The average annual energy consumption of residential building for heating in the EU varies from 150 to 230 kWh/m^2 (47 to 73 kBtu/h ft^2) according to different climatic zones (Balaras et al. 2000). A recent study (Cantin et al. 2010) shows that the annual heating energy consumption of existing dwellings in France varies from 196 to 210 kWh/m^2 (62 to 66 kBtu/h ft^2). The annual energy consumption for heating in Italian residential buildings can be estimated about 120–130 kWh/m^2 (38–41 kBtu/h ft^2), while for Northern Italy this value, corresponding to existing national building stock (ENEA 2008; Regione Lombardia 2008; Politecnico di Torino 2009), can be considered about 170–180 kWh/m^2 (54–57 kBtu/h ft^2). Considering an average efficiency of the HVAC system equal to 75–80%, it can be estimated that the annual energy demand in Northern Italy (AIPE 2009) is around 130–140 kWh/m^2 (41–44 kBtu/h ft^2). In addition, within buildings, one of the fastest growing sources of new energy demand is for cooling, however, there are no reliable data available in this respect. This growth is especially fast in Southern European countries, but is significant also in the Central European ones.

In order to meet the targets of the 'Kyoto Protocol' and the successive action 'Climate and Energy 20-20-20', established by European Council in 2007 for the reduction of energy consumption, increase of energy efficiency and use of renewable sources in the building sector, it is necessary to increase significantly the energy performance of new buildings, and at the same time to rehabilitate the existing stock. It should be mentioned that in Italy new houses built each year represent less than 2% of the total national housing stock (ISTAT 2001).

The EPBD recast (EPBD 2010) notes that energy performance requirements of buildings should be set with a view to achieving the cost-optimal balance between the investments involved and the energy costs saved throughout the lifecycle of the building. Furthermore, in consideration of the long renovation cycle for existing buildings, the directive prescribes that existing buildings that are subject to major renovation, should meet minimum energy performance requirements.

The intervention on existing buildings certainly implies careful considerations, in particular the historical ones, which have unique and specific characters that must be preserved. In this regard, it should be noted that almost 20% of Italian buildings were built before 1919,

Nomenclature

U — Thermal transmittance (W/m^{2}K)
M_f — Superficial thermal mass (kg/m^2)
f — Decrement factor (-)
ϕ — Time lag (h)
Y_{ie} — Periodic thermal transmittance (W/m^{2}K)
g — Solar heat gain coefficient (SHGC)

and today more than 30% of the buildings are aged 50 years and above (ISTAT 2001). The first Italian law on energy savings in buildings was established in 1976 (Law 373 1976). The premises built before that date are generally characterized by low energy performance levels and represent more than 64% of all Italian buildings (ISTAT 2001).

According to the Italian law, a building can be considered an historical construction after 50 years of existence (D.Lgs. 490 1999). In particular, if the building represents an historical evidence of the human civilization, can fall in the category of cultural heritage and landscape and therefore is subject to preservation. In general, the constraints regard exterior appearance and morphology of the building, preservation of original envelope openings (doors and windows) and materials, maintaining artistic and decorative elements (cornices, friezes, etc.). These items could be in conflict with energy retrofit measures, such as insulation of walls, double glazing windows, innovative HVAC systems etc. Therefore, until today, the energy saving has been slow to appear in the subject area of restoration.

The present work is related to energy rehabilitation of an historical building dating back to the 15th century. The building complex under study is a residential courtyard and is located in Northern Italy near Verona. The strategies have been focused on the building envelope and energy supply systems respecting the regulatory constraints imposed by preservation of historical buildings and referring, even if not mandatory, to the current national legislation about the building energy efficiency. The thermal performance of building for both winter and summer periods have been evaluated by dynamic computer simulations. It has been shown that appropriate and targeted interventions focused on the building envelope and HVAC systems of an ancient historical building could enhance its energy performance, also operating compatibly with strong preservation constraints.

2. BUILDING ENERGY PERFORMANCE STANDARDS

Italian laws regarding the energy efficiency for buildings are very similar to the standards of other EU countries and basically define the limits to primary energy consumption for winter heating and some requirements to limit overheating in summer. Those limits for winter heating are referred to the building envelope and HVAC systems efficiency and their compliance have to be guaranteed through the application of steady state calculation methods. The designers have also to consider additional parameters like maximum U-value of opaque and glazed surfaces and the average global seasonal efficiency of the thermal system. More recent law amendments in Italy, derived from the implementation of the EU Directive, extends the national regulation to summer cooling and promote the use of renewable energy sources.

Further, it should be noted that for the estimation of summer cooling demand, the steady state methods are not reliable and therefore it is more useful to carry out the analysis through the instruments using dynamic simulation methods. These instruments are capable of predicting more accurately the effect of thermal mass of building envelope on the energy demand, an important aspect for the summer cooling demand. It should be further mentioned that the Italian legislation on energy saving in buildings provides the possibility to perform the calculation of thermal energy requirements for heating and cooling by detailed simulation methods, which allow to take proper account of the dynamic phenomena. The use of these methods is always possible and sometimes preferable provided that hourly climate data of the specific site are available (UNI-TS 11300 2008).

FIGURE 1. Refurbished case study building.

The Italian basic building energy efficiency Law (Law 10 1991) was supplemented by the implementation of the national transposition of EBPD in 2005 and revisions in 2007 (D.Lgs. 192 2005; D.Lgs. 311 2006) and in 2009 (DPR 59 2009). The current law on energy saving in buildings defines new prescriptive and performance requirements in relation to the specific climatic conditions and building morphology. These requirements do not apply to buildings that fall under protected historical or cultural buildings where requirements compliance would lead to an unacceptable alteration of their original character or appearance with particular reference to historic and artistic character (D.Lgs. 311 2006).

It should be noted that in many cases, exclusion from obligation is disingenuously exploited to reduce intervention costs. However, by adopting the most appropriate solutions, through an accurate analysis and design process, it is still possible to act effectively even on the energy performance of ancient buildings, without compromising their historical significance and appearance. In this work a representative case history is explained. Figure 1 shows the refurbished case study building.

3. CASE STUDY BUILDING COMPLEX

The analyzed building complex is an example of the Venetian court (Fig. 2). The building is located in Sona, near Verona (latitude 45° 26' N, longitude 10° 49' E and altitude 169 m). The complex, known as "*Corte Montresora*", is a cluster of buildings that grew in different time periods in the past related to the needs of life and work (Gragnato 2003)

The rehabilitation project was commissioned by the society Cormorano91 S.r.l, and was realized by the collaboration among the architect Carlo Pession from Pession Associate Studio for architecture design, Politecnico di Milano for the energy and environmental design, and Detraco Engineering for HVAC system design.

The limit values by law for primary energy consumption for winter heating (EP_i), the average global seasonal efficiency of the thermal system (η_g), U-value of opaque and glazed surfaces for a building similar to the case study is located in Climatic Zone E are shown in Table 1.

For a proper building design, one should also pay attention to the control of summer comfort conditions and efforts should be made to reduce the energy requirements during the

FIGURE 2. Corte Montresora aerial view: before (left) and after intervention (right).

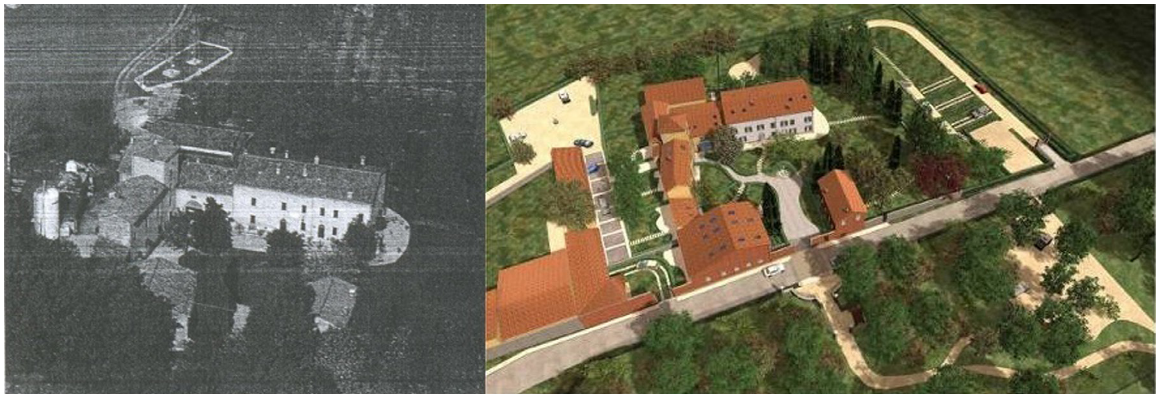


TABLE 1. The limit values for Climatic Zone E (D.Lgs. 311 2006).

EP_i (kWh/m^{2}year)	44.8
η_g (%)	74.4
U-value limits (W/m^{2}K)	
• External wall	0.37
• Roof (flat or sloped)	0.32
• Floor exposed to outside air or to non-heated zone	0.38
• Windows	2.4

hottest months of the year, which strongly impacts the total consumption of the building sector. In this analysis, however, this issue was not found critical since the external walls are of considerable thickness and thermal mass leads to lower summer cooling demand. In fact, the high thermal inertia tends to keep the indoor climate at relatively constant temperature, and avoid extreme temperature changes that can be recorded outside.

However, the new legislation includes the introduction of shading elements for glazed surfaces and the use of thermal mass structures not only for vertical but also horizontal surfaces. In relation to the latter issue, the law provides for compliance with a minimum value of surface mass of 230 kg/m^2 irrespective of the type of surface. This requirement only applies to the climatic zones characterized by an average irradiance on the horizontal plane higher than or equal to 290 W/m^2 corresponding to the month of maximum solar radiation, and therefore does not apply to our case study, where the corresponding value is lower. However, in the present study, the factors affecting the summer comfort are considered, in order to further increase the overall energy performance.

Moreover, the law foresees the use of renewable energy sources to produce heat and electricity for all categories of buildings. For new buildings or renovation of existing HVAC systems, at least 50% of domestic hot water should be produced from renewable sources.

The new rehabilitation project is an articulated building with ten residential units characterized by different distribution and orientation and organized on one or more levels. The

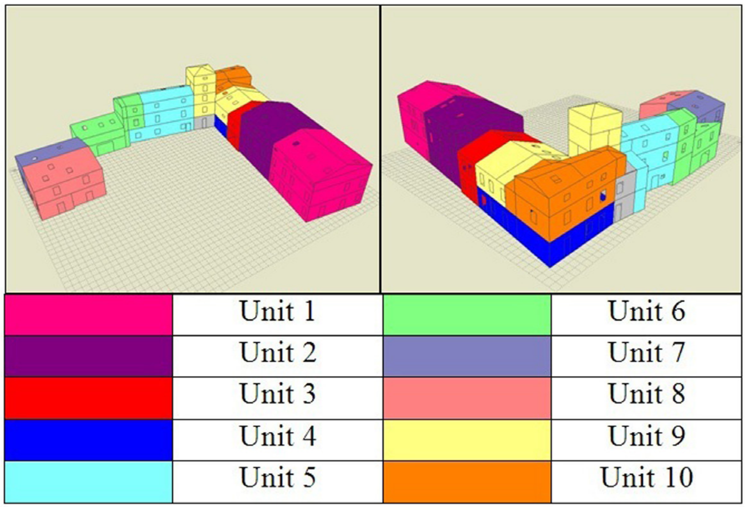


FIGURE 3. Identification of residential units.

units are distributed to form a "C", there is one arm extended to north with six residential units and another arm extended to south with two other units. The connection structure is oriented from north to south and includes an additional 2 units. Figure 3 shows the location of various residential units, according to a scheme by different color scale identification.

The gross volume of living space is about 6,687 m^3, with a total loss surface area approximately of 3,200 m^2 and a S/V ratio equal to 0.47. The net volume of living space is approximately 4,796 m^3 and the total useful surface area of the complex is approximately 1,648 m^2. The geometrical data of building complex is shown in Table 2.

It is assumed that the space will be occupied by about 44 people. The apartments feature double-facing exposition and the openings are not too large (Fig. 4), the ratio between transparent and opaque surface of the facade is about 12%.

The complex is included in the list of environmental heritage of the territory of Verona. Therefore, its rehabilitation shall be characterized by several restrictions on the possibilities of interventions. In general, it could be said that these limits affect in particular the building envelope but not the HVAC system choices, if these do not interfere significantly with architectural characters. The evaluation and design process, described in the paper, have been developed under these assumptions.

TABLE 2. Geometrical data of building.

Total loss surface area	3,200 m^2
Total windows surface area	188 m^2
Floor area (gross)	2,200 m^2
Floor area (net)	1,648 m^2
Gross thermal zone volume	6,687 m^3
Net thermal zone volume	4,796 m^3
Surface to volume ratio (S/V)	0.47

FIGURE 4. Architectural plan type.

4. EVALUATION METHODOLOGY

With the aim of optimum energy intervention, a first analysis was carried out on the old structure to identify briefly the main design considerations and possible interventions and quantify the benefits in terms of achievable energy savings. To achieve a high level of performance, it was decided to focus on the building envelope as well as HVAC systems in an holistic and systemic manner.

The work was carried out using innovative design methodology based on integrated building design, a process of design in which multiple disciplines and seemingly unrelated aspects of design are integrated in a manner that permits synergistic benefits to be realized. The goal is to achieve high performance and multiple benefits at a lower cost than the total for all the components combined. A key to successful integrated building design is a multidisciplinary approach.

Conventional building design tends to be linear (Fig. 5) with little interaction among the different designers/experts involved in the project. The design process proceeds when the architect creates a design and hands it off to the engineers who design the systems (sometimes independent of each other), and then pass the design off to the contractor. This approach fails because it is unable to deliver "high performance" buildings—ones that optimize energy efficiency, incorporate appropriate security measures, and achieve peak occupant productivity—all within the prescribed budget. Employing conventional design can also result in poor energy performance, harmful environmental impact, and higher operating maintenance costs.

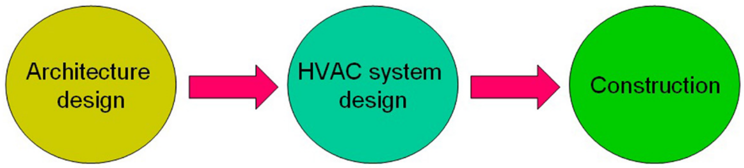


FIGURE 5. Conventional building design process.

Integrated Building Design is a holistic approach to the design of the built environment. It is driven by collaboration between specialized professionals in fields such as architecture, lighting, HVAC, power distribution, interior design, acoustics, landscape design, structures, and construction. Integrated Building Design projects may be large or small, new construction or renovation, and of any architectural style.

The design process of high performance building is not linear, but circular and iterative (Fig. 6). The proposal for architectural design is evaluated using simulation models, which provide detailed indications on the performance of the building envelope and HVAC systems, intended as a single system. From the results the energy expert extracts data that allow architect as well as the HVAC system engineer to formulate corrective or alternative proposals adapted to their needs. This circular process is repeated till a satisfactory solution in terms of aesthetic, functional, energy and cost is achieved. A solution that will inevitably be tied to specific climatic conditions and natural resources (Butera 2008).

In this specific case, the energy performance analysis was carried out according to the following evaluation methodology:

- analysis of the existing building structure;
- selection of possible interventions on building envelope;
- selection of possible interventions on HVAC systems;
- assessment of energy performance for different scenarios;
- selection of the optimized solution.

The analyzed building is not subject to energy performance law requirements as it falls under the category of protected historical or cultural buildings. With the objective to achieve high standards for energy-environmental construction, however, the requirements specified by the law, wherever possible, have been adopted as reference.

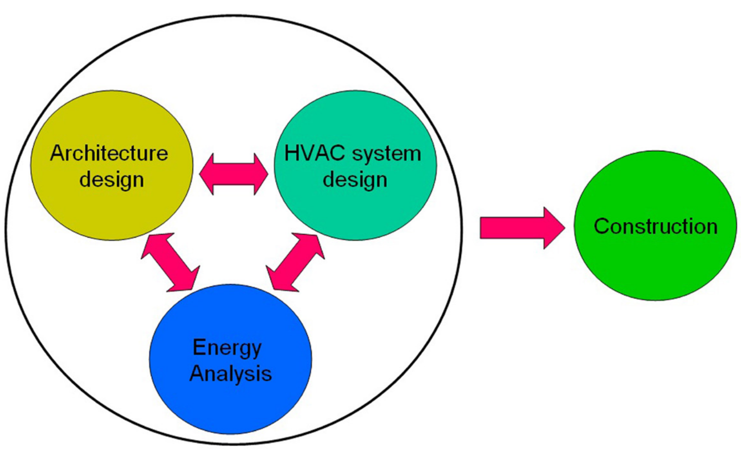


FIGURE 6. Integrated building design methodology (Butera 2008).

To improve the energy performance, a detailed assessment on the building performance has been carried out by identifying some scenarios related to different technological solutions applicable to the existing structure. The pre-existence of walls, floors, roofs and other structures imposes constructive and operative constraints.

The original historical structure of the building (Fig. 7) was characterized by mixed stone and brick walls of different thicknesses and wooden floors and a wooden beam roof with tile like finishing. For the building envelope, the analyzed interventions for the reduction of energy consumption in the winter and summer periods can be identified by the following points:

- valorizing existing thermal mass of building envelope;
- increasing thermal resistance of opaque components;
- use of high performance glazing (double or triple glazing, low-e coatings, gas cavity);
- use of thermal-break and high performance windows.

Various possible interventions were evaluated by defining different scenarios by combining and modifying in various ways the plasters and the insulation material type, thermo-physical performance and thickness, type of windows with different materials for both the opaque and transparent component, and thermo physical-performance. In addition to the envelope, the HVAC system was also evaluated to create a correct formulation of the building-plant system.

After the comparison of the achievable results related to the different scenarios analyzed, two main cases have been considered:

- Base Case, which represents a basic rehabilitation project without specific energy retrofit measures;
- Improved Case, which represents the optimal energy retrofit solution among the different alternatives considered.

The choice of the new envelope solutions was based on the intention to minimize heat losses through the envelope and to exploit effectively its thermal mass. The importance of

FIGURE 7. The building before refurbishment.

thermal mass is well evident in the literature (Balaras 1996; Roucoult et al. 1999). In fact, during the summer period, thermal inertia makes it possible to obtain a shift of the temperature, between indoor and outdoor, which can last several hours. In winter, a high thermal inertia allows the mass to store solar and internal gains during the day. Thus, the building components release stored energy with a delay of several hours. This delay makes it possible to reduce the heating period and to preserve a comfortable temperature during the night. With numerous sunny days in spring and in autumn, the thermal inertia make it also possible to reduce the heating period. Consequently, the use of high thermal inertia walls in buildings usually results in a reduction of energy requirements both for heating and cooling. Furthermore, the thermal inertia becomes more important when the inertia is coupled with other energy savings measures, and with an efficient and rational use of the building (Aste et al. 2009).

In general, the improved case is obtained by introducing an insulating layer on the inside or outside of the walls, a layer of plaster with high thermal performance inside of the walls, and high-performance transparent elements. But considering the variability of envelope and the preservation constraints, different choices have been made on different portions of the complex, such as structures located outside of the splint facing north-south and placed further north and in the tower. It was not possible to obtain permission from heritage authorities and then the only possibility of intervention possible was to add insulation to the inside portion of the building. For the rest of the complex, it was possible to intervene from the outside but with limitation on the thickness of insulating material to be applied, so as not to affect the aesthetic appearance of the facades by including the frames of the opening to the outside to align with the new wire wall. In addition, HVAC systems have been designed to exploit better the energy performance of the building envelope with high efficiency systems.

5. BUILDING ENVELOPE SPECIFICATIONS

In this section, the building envelope specifications for two cases are described. The first one (Base Case) is merely hypothetical, while the second one (Improved Case) corresponds to the real building designed and realized on the basis of the findings of the present study.

5.1 Base Case

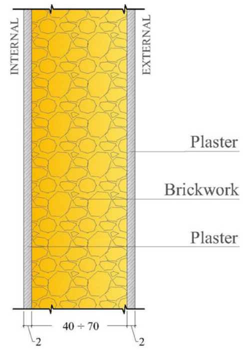
In the basic version of design, the roof and floors were completely renovated, thus eliminating the previous deteriorating structure.

In particular, the final layer of roof coverage was maintained. Since the building is subject to preservation constraints, the external, originals walls, which are in good condition, are maintained. These elements are characterized by a certain variability of thickness. The estimated thermo-physical parameters for vertical walls are shown in Fig. 8.

In Fig. 9, one can see the non-uniformity of the wall thickness, either due to particular construction technologies, but also the development of the complex *Corte Montresora* over time. The different colours indicate the different thickness of the wall, and in particular starting from a darker colour with the thickness of 70 cm to the lighter colour with a minimum wall thickness of 40 cm.

The details on the horizontal structures like roof and floors along with the estimated thermo-physical parameters are shown in Figs.10 and 11.

FIGURE 8. Building elements of vertical walls (Base Case).



Thickness (cm)	40–70
U (W/m^{2}K)	2.16–1.56
M_f (kg/m^2)	976–1666
f (-)	0.21–0.0502
ϕ (h)	10.17–16.89
Y_{ie} (W/m^{2}K)	0.46–0.0786

FIGURE 9. Vertical wall building elements.

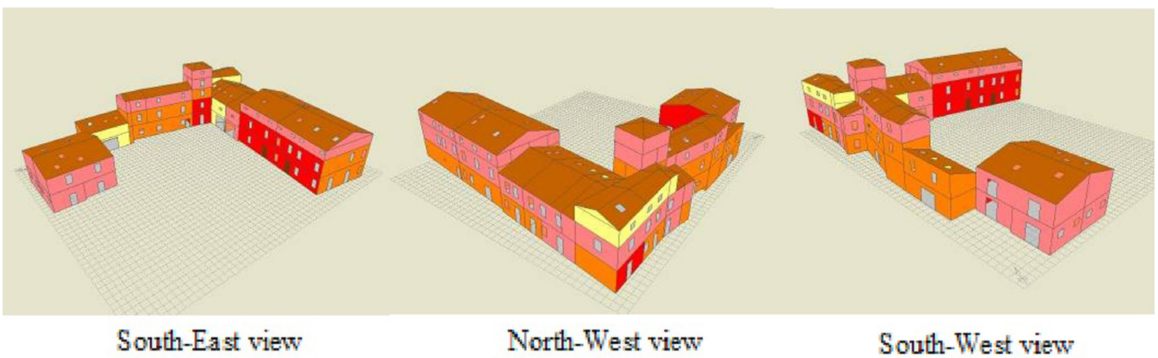
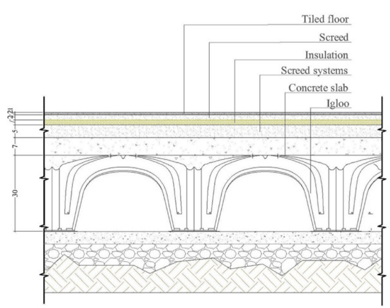
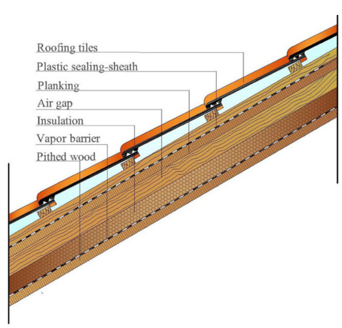


FIGURE 10. Building elements of horizontal structures: ground floor (Base Case).



Thickness (cm)	57
U (W/m^{2}K)	0.65
M_f (kg/m^2)	943.6
f (-)	0.0234
ϕ (h)	20.0
Y_{ie} (W/m^{2}K)	0.0153

FIGURE 11. Building elements of horizontal structures: roof (Base Case).



Thickness (cm)	20
U (W/m^{2}K)	0.5
M_f (kg/m^2)	22.14
f (-)	0.9236
ϕ (h)	2.57
Y_{ie} (W/m^{2}K)	0.4691

TABLE 3. Transparent building elements (Base Case).

Building elements	Position	Layers	U-value (W/m^{2}K)
Glass	Whole building	Double glass (g-value = 0.747)	3.00
Frame		Wood frame	1.80
Window		-	2.50

TABLE 4. Other building elements (Base Case).

Building elements	Position	Layers (from internal to external)	U-value (W/m^{2}K)
Intermediate floor	Inside the building	Tiled floor (1 cm) Screed systems (5 cm) Layer wood-Planking (3 cm)	2.0
Partition 25 cm	Partitions inside the units	Plaster (1.5 cm) Brick (25 cm) Plaster (1.5 cm)	1.32
Vertical wall 60 cm	Partitions between different units	Plaster (1.5 cm) Brick (60 cm) Plaster (1.5 cm)	1.56

The glazed elements of the building are characterized by double glass with wooden frame. The estimated U-value of these elements are shown in Table 3.

The details on additional components of building envelope are shown in Table 4.

5.2 Improved Case

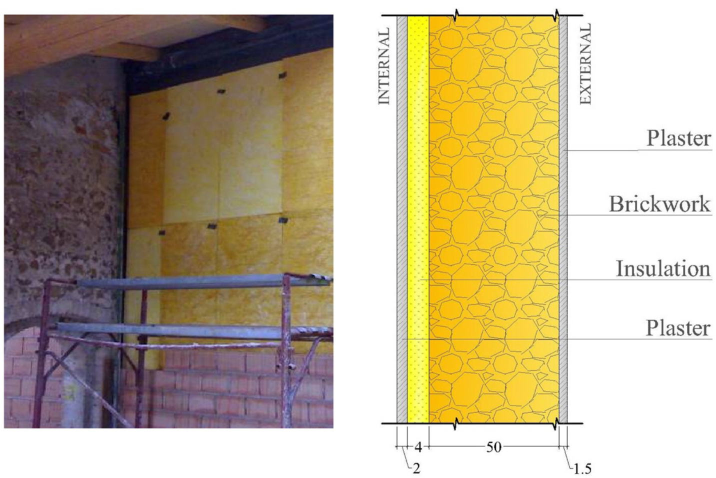
At the initial stage of defining energy rehabilitation strategies, verifications had been made from the cultural heritage department regarding the possibilities of intervention on the building and accordingly the more appropriate solutions were considered. With respect to Improved Case, the intervention on the exterior vertical walls of the Units 3, 4, 5, 6, 7, 8, 9 has been considered by introducing an additional layer of external insulation with the thickness of 8 cm and a traditional plaster finish with a thickness of 1.5 cm. The finish is made with 2 cm of plaster. This solution (Type A) was adopted for the part of envelope that is not subject to special restrictions.

For the walls of Units 1 and 2, being subject to special restrictions, it was not possible to intervene on the external part of envelope. It was suggested to apply an internal insulation layer of 4 cm, a brick layer of 8 cm and a layer of traditional plaster of 2 cm at both internal and external walls (Type C). The existent wall of Unit 10 is covered externally with 8 cm of insulation, except for two local places of the tower, where the intervention is assumed by adding 4 cm of plaster insulation on the inside walls of the perimeter (Type B). Figs. 12–14 show the typologies and estimated thermo-physical parameters for the vertical walls corresponding to the Improved Case.

FIGURE 12. Building elements of vertical wall: Type A (Improved Case).

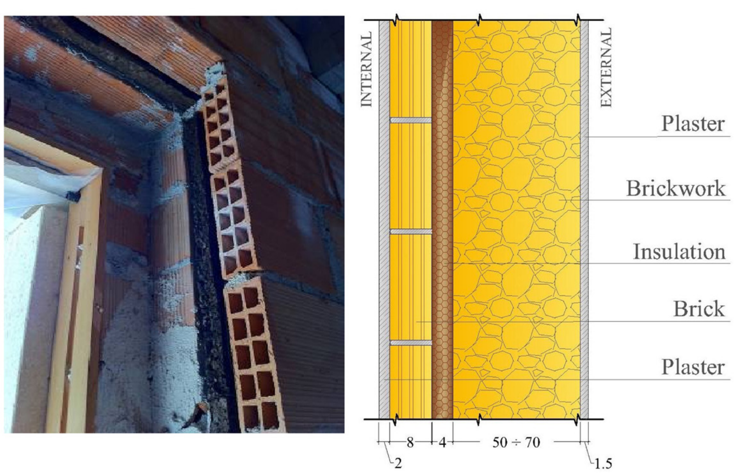
Thickness of wall (cm)	40–70
U (W/m^{2}K)	0.40–0.38
M_f (kg/m^2)	978.6–1668.6
f (-)	0.0657–0.0121
ϕ (h)	13.27–20.01
Y_{ie} (W/m^{2}K)	0.0267–0.0046

FIGURE 13. Building elements of vertical wall: Type B (Improved Case).



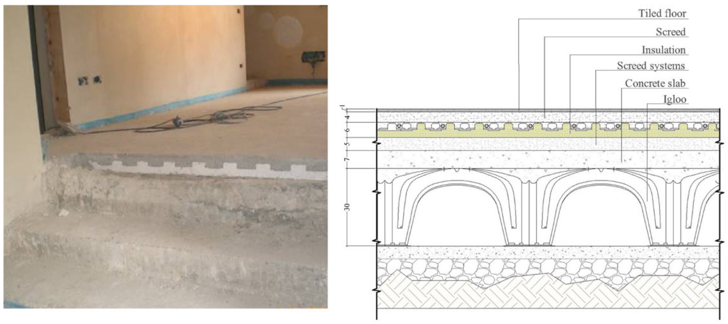
Thickness of wall (cm)	50
U (W/m^{2}K)	0.7
M_f (kg/m^2)	1214
f (-)	0.0659
ϕ (h)	15.10
Y_{ie} (W/m^{2}K)	0.046

FIGURE 14. Building elements of vertical wall: Type C (Improved Case).



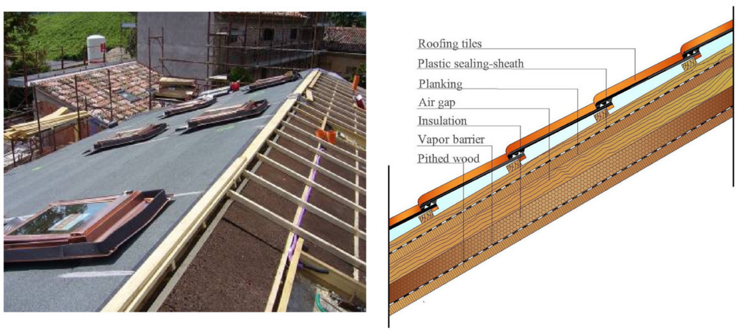
Thickness of wall (cm)	50–70
U (W/m^{2}K)	0.54–0.535
M_f (kg/m^2)	1245–1706
f (-)	0.0514–0.017
ϕ (h)	16.62–21.11
Y_{ie} (W/m^{2}K)	0.0294–0.0091

FIGURE 15. Building elements of horizontal structures: ground floor (Improved Case).



Thickness (cm)	63
U (W/m²K)	0.391
M_f (kg/m²)	976.8
f (-)	0.0136
ϕ (h)	21.63
Y_{ie} (W/m²K)	0.0053

FIGURE 16. Building elements of horizontal structures: roof (Improved Case).



Thickness (cm)	24
U (W/m²K)	0.33
M_f (kg/m²)	27.9
f (-)	0.7814
ϕ (h)	4.69
Y_{ie} (W/m²K)	0.2586

The details on the horizontal structures like roof and floors along with the estimated thermo-physical parameters are shown in Figure 15 and 16.

The glazed elements of the building are characterized by double glass with wooden frame. The estimated U-value of these elements are shown in Table 5.

The details on additional components of building envelope are shown in Table 6.

For solar control, use of the external louver shutters equipped with adjustable slots have been installed to control the solar radiation entering as well as the illumination level inside.

6. HVAC SYSTEM SPECIFICATIONS

The energy performance analysis considers two different HVAC system typologies to evaluate primary energy consumption corresponding to a Base Case and Improved Case. For the Base Case, the hypothesis on heating system makes provision only for a conventional system (gas boiler) with radiators because it is not suitable to install a high performance HVAC system in a building characterized by a low envelope performance. According to the same criteria, multi-split air conditioners are considered for cooling. For the Improved Case, the new intervention assumes the use of a HVAC system to serve the complex with two ground source water-water multi-stage heat pumps integrated with a radiant floor panel system providing heating in winter as well as cooling during summer period. A dehumidification system for humidity control in the summer period is also present. A general scheme of the HVAC system for Base Case and Improved Case is shown in Fig. 17.

The HVAC system characteristics for both cases are shown in Table 7.

TABLE 5. Transparent building elements (Improved Case).

Building elements	Position	Layers	U-value (W/m^{2}K)
Glass	Whole building	Selective double glass (g-value =0.594)	1.10
Frame		Wood frame	1.80
Window		-	1.50

TABLE 6. Other building elements (Improved Case).

Building elements	Position	Layers (from internal to external)	U-value (W/m^{2}K)
Intermediate floor	Whole building	Tiled floor (1 cm) Under floor heating (10 cm) Screed systems (5 cm) Wood layer (3 cm)	0.47
Partition 25 cm	Partitions inside the units	Plaster (1.5 cm) Brick (25 cm) Plaster (1.5 cm)	1.32
Vertical wall 60cm	Partitions between different units	Plaster (1.5 cm) Brick (60 cm) Plaster (1.5 cm)	1.56

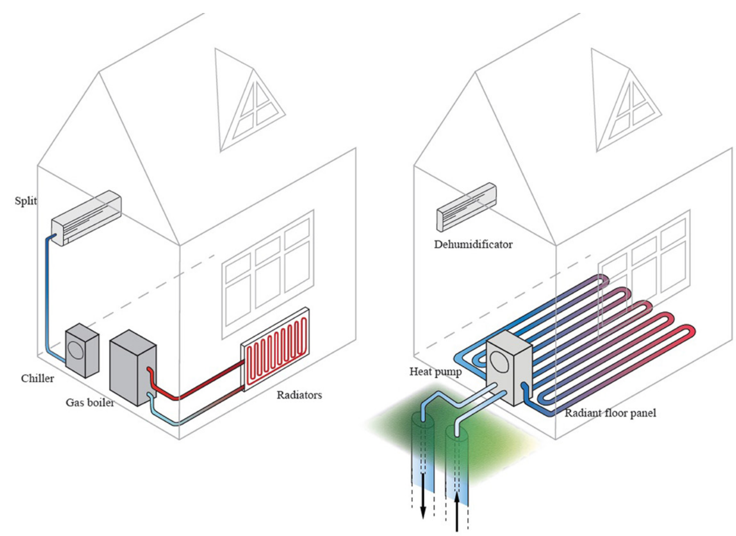


FIGURE 17. Scheme of the HVAC system for Base Case (on the left) and Improved Case (on the right).

TABLE 7. HVAC system specifications.

Case	HVAC system		Supply terminal	Nominal efficiency/COP/EER
Base Case	Heating Cooling	Gas boiler Multi-split Room A/C	Radiators	0.8 2.6
Improved Case	Heating Cooling	Ground source heat pump	Radiant floor	3.2 4.0

7. ENERGY PERFORMANCE EVALUATION

A comparative analysis has been carried out regarding the energy performance of the Base Case and Improved Case. To verify the assumptions made and to guide and support subsequent design choices for improvements in building energy performance, dynamic energy simulations have been carried out through *EnergyPlus* program (DOE 2008; Crawley et al. 2004; Crawley et al. 2001). The climatic hourly data used for simulation corresponds to a typical meteorological year (TMY) for the location of reference (Verona).

The input data used for the analysis consist in the different building envelope characteristics and HVAC specifications corresponding to the Base Case and Improved Case. The analysis assumes common standard parameters adopted according to the functional destination of the building (UNI 10399 1995) and are reported in Table 8. The HVAC systems during mid seasons (15 April – 30 May and 1 September – 14 October) are not in function.

For the Improved Case, the provisions for solar control and the night ventilation have been considered during the summer period. To simulate the solar control, it has been assumed that if the global solar radiation incident on the windows exceeds 300 W/m^2, the shading device is active. For night ventilation, the air-change rate during night time is assumed equal to 3 V/h (Santamouris et al. 2000). The above hypotheses considered for simulating the solar control and night ventilation are reasonable and are expected to calculate the values of energy savings quite well.

7.1 Energy demand

The calculated annual building energy demand for heating and cooling corresponding to the Base Case and Improved Case are shown in Fig. 18. The cooling demands includes the sensible as well as the latent energy demand.

For Base Case, the estimated annual heating demand is about 132 kWh/m^2 (42 kBtu/h ft^2), however, the calculated demand for Improved Case is amount to 45 kWh/m^2 (14 kBtu/h ft^2) year which is about 66% lower than the Base Case. The annual energy demand for cooling for Base Case and Improved Case is estimated as 19 kWh/m^2 (6 kBtu/h ft^2) and 10 kWh/m^2 (3 kBtu/h ft^2) respectively. For Improved Case a reduction in cooling energy demand of about 48% is obtained.

The results of the simulations for monthly energy demands corresponding to winter and summer periods have been shown in Fig. 19. As said before, the calculations for summer energy demand is based on the sensible and latent energy loads.

TABLE 8. Description of simulation parameters.

	Base Case	Improved Case
Internal gain (people, artificial illumination, equipments)	5 W/m^2	5 W/m^2
Ventilation	0.5 V/h	Winter-0.5 V/h Summer-0.5 V/h (7:00 a.m. to 10:00 p.m.) Summer-3.0 V/h (10:00 p.m. to 7:00 a.m.)
Solar control	No	Winter-No Summer- Yes
Heating period Set point throughout the day	October 15 – April 14 20°C and 50% RH	October 15 – April 14 20°C and 50% RH
Cooling period Set point throughout the day	June 1 – August 31 26°C and 50% RH	June 1 – August 31 26°C and 50% RH

FIGURE 18. Annual heating and cooling energy demand for Base Case and Improved Case.

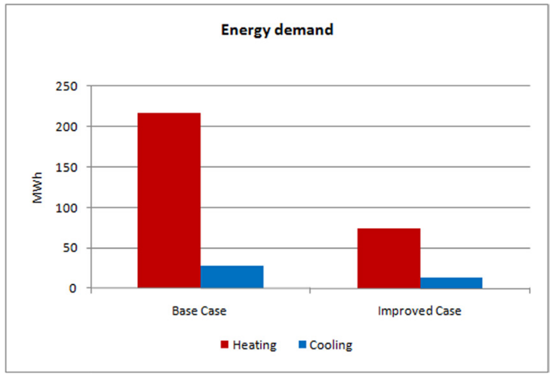


FIGURE 19. Monthly heating and cooling energy demand.

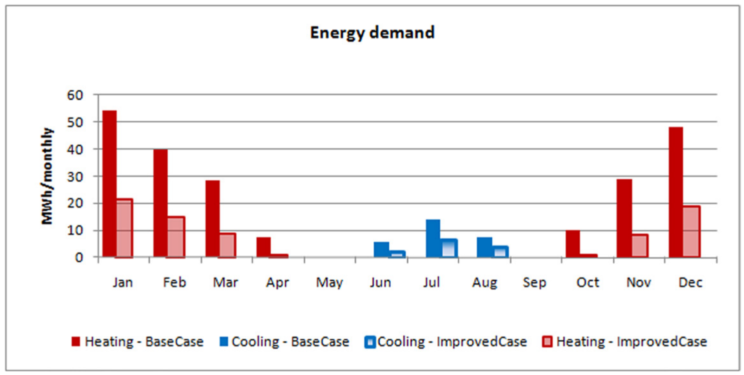
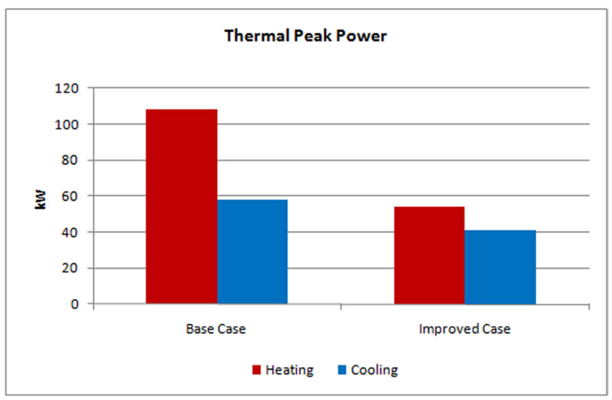


FIGURE 20. Estimated thermal peak power for heating and cooling.



The thermal peak power for heating and cooling corresponding to two cases is shown in Fig. 20. It can be observed that for a better energy performance envelope (Improved Case), the required thermal peak power is much reduced in comparison to Base Case. This, in turns, directly affects the sizing of the HVAC systems. The thermal peak power for heating is estimated as 108 kW (66 W/m^2) and 54 kW (33 W/m^2) for Base Case and Improved Case respectively (–50%). Moreover, for cooling the thermal peak power corresponding to Base Case is estimated as 58 kW (35 W/m^2) and is reduced to 41 kW (25 W/m^2) for Improved Case (–30%).

7.2 Primary Energy consumption

The annual primary energy consumption for both the cases are shown in Fig. 21. The energy consumption for cooling also includes the energy consumed for dehumidification.

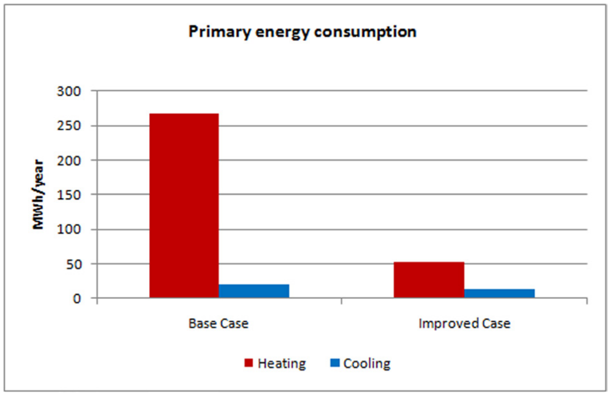


FIGURE 21. Estimated annual primary energy consumption.

It is clear from the results that the combination of better envelope and high efficiency HVAC systems (Improved Case) leads to low annual primary energy consumption of 40 kWh/m^2 (13 kBtu/h ft^2), which corresponds to 32 kWh/m^2 (10 kBtu/h ft^2) for heating and 8 kWh/m^2 (2.5 kBtu/h ft^2) year for cooling. The estimated annual primary energy consumption (heating and cooling) for the Base Case are 163 kWh/m^2 (52 kBtu/h ft^2) and 13 kWh/m^2 year (4 kBtu/h ft^2) respectively. This results in an overall decrease of 75% in the primary energy consumption in favor of the Improved Case. It has to be noted that the conversion factor between electricity and primary energy is equal to 2.17 kWh/kWh$_e$ (Delibera EEN 3 2008), which corresponds to the typical fuel mix system for electricity production in Italy.

The estimated seasonal COP of GSHP system for heating and cooling are 4.2 and 5.2, respectively.

8. ECONOMIC PERFORMANCE EVALUATION

The economic performance evaluation has been carried out based on the methodology developed by the authors (Aste et.al. 2010) in order to demonstrate the economic convenience of an energy efficient design. The analysis considers the cost of intervention, sub-divided into the main categories of interest relevant to present study: opaque envelope insulation, windows, HVAC systems and general item named ‘other works’, which includes all other architectural works not affecting the energy performance (finishing, painting, appliances etc.). The adopted cost parameters are in reference to the Italian listing price for building materials (Prezziario 2007) and for HVAC systems (Prezziario 2008), and also verified with similar real cases.

An estimation of the total investment costs was made for both the cases, Base and Improved, as shown in Table 9. The total cost for Base Case and Improved Case is estimated about € 5,400,000 and € 5,500,000 respectively. The extra cost for energy efficient building (Improved Case) is about 50 €/m^2 which is about 2% higher than the Base Case.

TABLE 9. Total building costs.

	Base Case (€)	Improved Case (€)
Envelope Insulation	7,300	80,600
Windows	47,500	66,500
HVAC Systems	111,800	105,000
Other works	5,233,400	5,247,900

TABLE 10. Useful life and substitution costs of HVAC systems.

HVAC components	Useful life span (Y_{rs})	Substitution cost (€)
Gas boiler	20	3,000
Multi-spilt A/C	15	108,800
Heat Pump	20	17,000

All assumptions made regarding the costs have been in facts confirmed afterwards by the actual realization of the Improved Case solution, which was suggested just by this evaluation.

The other cost parameters considered for the economical evaluations are as follow:

- refurbishment/maintenance cost through time for building envelope is considered same for both the cases and therefore not taken in account in the evaluation;
- substitution cost: it has been assumed that the generator of HVAC system (condensing boiler and multi-split A/C for Base Case and heat pump for Improved Case) are substituted during the life span of building, and the useful life of these components are taken from the European standard (prEN 15459 2006). The values of useful life and substitution costs are summarized in Table 10;
- cost of energy: the value attributed to the prevailing electricity and gas prices. The value estimated for electricity is 0.225 €/kWh and for gas 0.07 €/kWh (AEEG 2008).

From the literature (Mateus and Oliveira 2009; EC 2008) an estimate has been made regarding the increment in future energy prices and this value is considered 2% per year.

The maintenance costs for HVAC systems are considered the same for all the cases and therefore not taken into account in the evaluation. This hypothesis is highly conservative for the heat pump (HP), because it can be easily proven that HP yearly maintenance is cheaper than the one required for the gas boiler and multi-split A/C systems, according to the Italian law and standards.

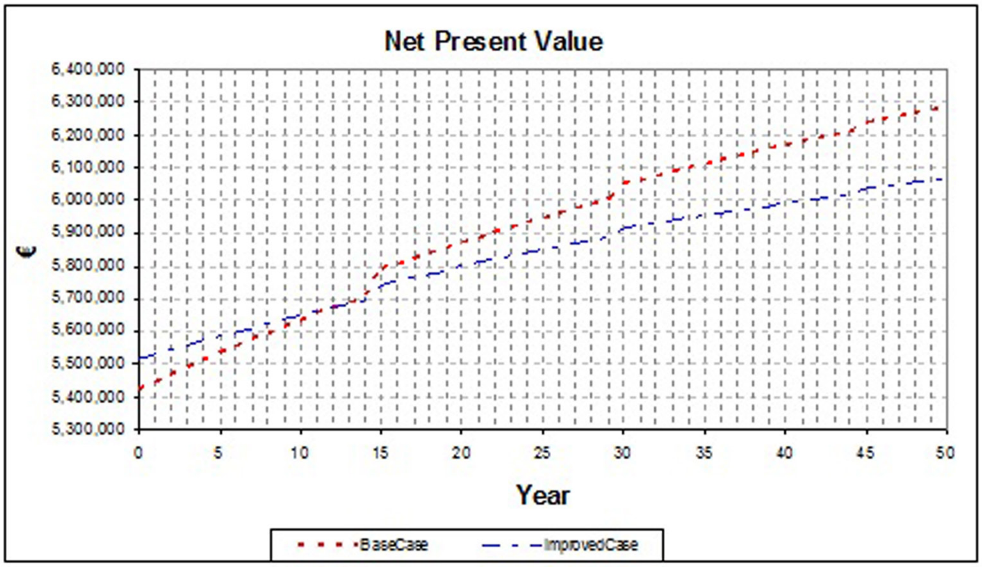
The economic evaluation was carried out with the estimation of total costs corresponding to Base Case and Improved Case (total initial investment cost and operating costs), considering a period of 50 years of building operation. The total cost, as an economic indicator related to these cases has been evaluated through the net present value (NPV) method. The annual discount rate considered for the analysis is 4%.

The NPV (Net Present Value) of the total cost (total initial investment cost and operating costs) for both cases during the life span of the building are shown in Fig. 22. It can be seen that higher initial investment for an energy efficient building becomes profitable during the life span of the building. The building with the energy retrofit (Improved Case) becomes profitable after 14 years with respect to one without energy retrofit (Base Case).

9. CONCLUSIONS

The present work discusses the strategies adopted for energy rehabilitation of an existing historical building and the optimization of energy consumption. In particular, it has been shown that adequate interventions focused on the building envelope and HVAC systems reduces the energy consumption in significant ways and also have positive effects on operating costs. In detail, it is highlighted how the difference in cost between a basic project and an effective energy retrofit could be very small (in this case only 2% higher). Faced with limited extra cost,

FIGURE 22. Net present value of total cost during the life span of 50 years.



however, it is possible to have significant energy benefits. This results in a significant reduction of energy requirements: in the presented case study the primary energy consumption is reduced by 75%. Also the sizing of the HVAC systems has an important role, with thermal powers reduced by 30% (cooling) and 50% (heating) for the energy efficient building.

Furthermore, it has been shown through economic analysis that the extra cost for energy retrofit measures paid back quickly during the life span of the building: the building with an energy retrofit becomes profitable after 14 years with respect to the basic one.

Based on the results of techno-economical analysis presented in this paper, the real building is constructed corresponding to Improved Case solution.

The theme of restoration of historical buildings has not yet fully addressed the issue of energy efficiency in context of built heritage. It might be helpful to address the energy issues by adjusting the current performance limits for the new building, and addressing the concept of performance improvement of existing buildings, if possible, in view of the synergies arising between past and present. Therefore, this paper presents an interesting case study, which demonstrates how to intervene effectively on historical buildings, and to obtain good results in terms of energy savings and cost effectiveness. At present, the project is in the construction phase, the monitoring of energy performance is foreseen for comparing the simulated results with the actual performance of these buildings.

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