[Article] Retrofit scenarios and economic sustainability. A case-study in the Italian context

Original Citation:
Fregonara, Elena; Lo Verso, V.R.M.; Lisa, Matteo; Callegari, Guido (2017). *Retrofit scenarios and economic sustainability. A case-study in the Italian context.* In: ENERGY PROCEDIA, vol. 111C, pp. 245-255. - ISSN 1876-6102

Availability:
This version is available at : `http://porto.polito.it/2650116/` since: September 2016

Publisher:
Elsevier

Published version:
DOI:10.1016/j.egypro.2017.03.026

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 00 (2016) 000–000

Energy Procedia

www.elsevier.com/locate/procedia

8th International Conference on Sustainability in Energy and Buildings, SEB-16, 11-13 September 2016, Turin, ITALY

Retrofit Scenarios and Economic Sustainability. A Case-study in the Italian Context.

Elena Fregonara[a]*, Valerio R.M. Lo Verso[b], Matteo Lisa[c], Guido Callegari[a]

[a]*DAD – Politecnico di Torino, Viale Mattioli 39, Torino 10125, Italy*
[b]*Energy Department, Politecnico di Torino, TEBE Research Group, corso Duca degli Abruzzi 24, 10129,Turin, Italy*
[c] *WoodLab Student Group, Politecnico di Torino, Viale Mattioli 39, Torino 10125, Italy*

Abstract

The aim of this paper is to highlight the potentialities for supporting the decision making process and design activities, for the case of retrofit projects with alternative technological solutions to compare. A multidisciplinary approach was adopted, involving the contribution of Real Estate Market and Economic Evaluation of Project, Architectural Technology and Building Physics. A simplified application of the Life Cycle Costing methodology was used, in synergy with energy analyses, to select, among different scenarios, the most viable solution for the retrofitting project of a single house in Northern Italy.

Commento [S1]: Elsevier to update with copyright entity, year, copyright company Elsevier Ltd./B.V./Inc. and the conference organizer name.

Keywords: Energy Retrofit, Energy Efficiency Scenarios, Economic Sustainability, Life Cycle Costing, Global Cost

---

1. Introduction

The building and the construction sector, and consequently the real estate market, have been largely impacted by the economic-financial crisis effects over the last years. In fact, the collapse of permits for the construction of new buildings has been about 80% in Italy. On the contrary, interventions of restoration and energy requalification of the built heritage has shown a positive trend. As a result, the energy requalification of the built heritage represents an opportunity for construction enterprises to get over the crisis. This condition is of particular interest in Italy: over

---

* Corresponding author. Tel.: +39-011-090-6432; fax: +39-011-090-4374.
E-mail address: elena.fregonara@polito.it

half of buildings were erected before the Seventies, and currently they need strong and possibly low costs interventions aimed at architectural and technological improvements, in an energy requalification perspective. Furthermore, the Italian governance policies have been moving toward regulations that limit the use of Greenfield for new constructions, strengthening the interest of operators and practitioners for the restoration of the built heritage.

The energy requalification of the built heritage can generate positive effects not only from an economic viewpoint, but also in environmental terms. It is well known that the construction sector is one of the major responsible for the global pollution and CO_2 emissions. The annual energy use in the construction sector in Italy is almost half of the entire national consumption, with values higher than what recorded for the transportation and industrial sectors. Both economic and environmental reasons have led the research toward highly efficient buildings, able to limit the use of energy resources and polluting emissions, while reducing the ground consumption. The objective to "*rethink the built*" can be pursued through punctual interventions on buildings, which are aimed at optimizing the global energy efficiency and at creating enlargements and elevations of buildings, with an impact on their architectonical quality and usability.

Within this context, the paper deals with the topic of the energy requalification of buildings, focusing on the typology of single houses. About 85% of the Italian built heritage includes residential buildings, and about three quarters of this share consists of single or double family houses. For these reasons, the following aims are assumed as fundamental:

- to define sustainability strategies to address interventions on the built heritage, with special attention to the typology of residential single houses. This typology is particularly suitable for enlargement, considering that the increase in the volume could be coupled with an increase in the energy efficiency
- to define a methodological framework concerned with retrofitting of existing buildings, especially when in the presence of alternative technological solutions. Such framework should assist practitioners and administrators in defining, evaluating and selecting the optimal scenario, from both an economic and an environmental viewpoint

The goal of this paper is to explore the application of a multidisciplinary approach to a real case-study (a double-family single house located in a municipality near Turin, Northern Italy), taking advantage of the contribution of three disciplines: Architectural Technology, Real Estate Appraisal and Economic Evaluation of Project, and Building Physics [1,2]. The contribution of these disciplines is finalized to define a methodology simple and easy to be replicated, also considering the general difficulty – particularly in Italy – in data collecting. Specifically, the Life Cycle Costing approach, well known and extensively investigated in the international context but not so commonly treated in Italy [3], is here adapted and applied to a case-study. A simplified modality of the classic Global Cost calculation is proposed.

Starting from the Standard ISO 15686:2008 - part 5, and from the Global Cost calculation as defined in Standard EN 15459:2007, the Life Cycle Costing methodology was used in synergy with an energy evaluation procedure to compare different technological solutions for the considered case-study, so as to define the most viable solution not only in technological and energy terms, but also from an economical viewpoint.

2. Methodology

In this work, a 'simplified' application of the LCC methodology was used to identify the optimal scenario among a set of different technological solutions aimed at reducing the energy requirements for heating and at including the use of renewable energy sources. The Standard ISO 15686–5:2008 - Buildings and constructed assets – Service-life planning (prepared by Technical Committee ISO/TC 59, Building construction, Subcommittee SC 14, Design life), specifically the Part 5: Life Cycle Costing, was used as the methodological reference [4].

LCC is an approach for quantifying costs and benefits, with a special attention to the relevant costs along the whole life cycle [5,6]. This approach is used for supporting decisions among alternative design solutions, or components, or single materials, on the base of efficiency and effective criteria. Furthermore, it is a technique for economic evaluation of a project in the case of new projects or retrofitting of existing buildings: it allows considering individual products or components, or an entire building systems (e.g. HVAC and lighting systems), as well as immediate and/or long term costs and benefits (usually savings). The approach can be applied with different purposes: to compare alternative technical solutions to assess the relative difference in terms of their life cycle costs;

to define a ranking among alternative projects, focusing on the benefits which can be obtained by investments with limited resources; to assess the budget of a selected project for a predetermined lifespan. The results are expressed through quantitative indicators (Net Present Value, Net Present Cost, Net Savings, Discounted Pay Back Period etc.), starting from input data on costs, cost profiles of each option considered, and financial input data.

The Global Cost concept is the basis of LCC. It is defined in the Standard EN 15459:2007 [7] and specified in the Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 [8], which followed the Directive 2010/31/EU – EPBD recast [9]. The Standard EN 15459 aims at harmonizing the methodology for the calculation of the energy performance of a building at an European level and at representing the methodological base for the Global Cost calculation. It relies on two approaches: the global cost method and the annuity method. The global cost method considers the initial investment and the sum of annual and disposal costs. The residual value of the components with a life-cycle longer than the building lifetime must be deducted, as shown in Equation (1):

$$C_G(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau}\left(C_{a,i}(j)\cdot R_d(i)\right) - V_{f,\tau}(j)\right] \tag{1}$$

where: $C_G(\tau)$ = global cost (referred to starting year τ_0); C_I = initial investment costs; $C_{a,i}(j)$ = annual cost during year i of component j, which includes annual running costs (energy costs, operational costs, maintenance costs) and periodic replacement costs; $R_d(i)$ = discount rate during year i; $V_{f,\tau}(j)$ = residual value of the component j at the end of the calculation period, referred to the starting year.

Input data related to costs are usually based on market analyses (e.g. comparison with recent and similar building projects, market-based databases, market prices defined by the operators). Normally, running costs and residual values of building elements must be considered for the whole calculation period. For this reason, the choice of an appropriate calculation period is a crucial step. Usually, it is determined with regard to the estimated life-cycle of a building and its technological components, accounting for the guidelines provided in the Commission Delegated Regulation (EU) No 244/2012 concerning the time period for the calculation, and the values set in European Standard EN 15459:2007 (Annex A) concerning the lifetime of the elements of the building envelope and systems.

The costs over the calculation period must be discounted, through the discount factor R_d:

$$R_d(p) = \left(\frac{1}{1+\frac{r}{100}}\right)^p \tag{2}$$

where: p is the number of years starting from the initial time and r is the real discount rate, which is defined according to the country in which the analysis is conducted. The distribution of the costs along the life cycle phases in the construction sector is presented in Fig. 1. The relevant costs related to each phase are identified according to the definition in [5]. The costs occurring in phases 1 to 4 are not discounted, assuming that the preliminary-executive process is usually shorter when compared to the management phase. This latter, in fact, is discounted at the present time. The same applies to end of life/disposal costs.

In this study, a ‘simplified’ Global Cost calculation was used, according to the following assumptions:

- the “global cost method” was adopted as an alternative to the annuity method
- the initial investment costs, which include the specific technological solutions, were related to heating, cooling, electric lighting and DHW systems
- the relevant costs considered the operational costs and the maintenance costs
- the residual value of asset or materials or components and disposal costs were not considered

Consequently, the LCC approach was resolved according to equation (3):

$$LCC = C_i + \sum_{t=0}^{N} \frac{C_0 + C_m}{(1+r)^t} \tag{3}$$

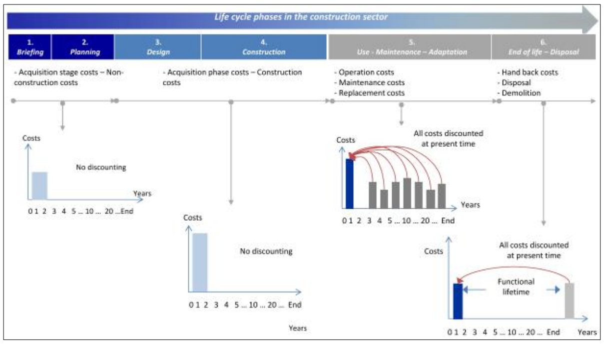


Fig. 1. Relevant costs during life cycle phases and discounting for Global Cost calculation (elaboration from: D. Langdon, Life Cycle Costing (LCC) as a contribution to sustainable construction: a common methodology – Final methodology, 2007, p. 52).

where: *LCC* is the Life Cycle Cost; C_I the investment costs; C_o the operational and energy costs and C_m the maintenance costs; *t* the year in which the cost occurred and *N* the number of years of the entire period considered for the analysis; *r* the discount rate. The residual value of asset or materials or components, as well as the end of life costs, were not considered in the calculation.

For the LCC calculation, it is necessary to know data on the energy performance of the building, related to a set of technological scenarios with different costs and performances, among which to select the most viable one both in economic and in energy performance terms. For this reason, the calculation of the energy use of the considered building was carried out as a key analysis of the work, using the software Termolog Epix 6 (licensed by Logical Soft). The calculation was carried out in accordance with the latest regulations issued in Italy following the European Building Performance Directives EPBD [10]. The global energy performance index of the building used as case-study was determined through the calculation of the following indices [11]:

$$Ep_{gl} = Ep_h + Ep_{dhw} + Ep_c + Ep_i \tag{4}$$

where: Ep_h, Ep_{dhw}, Ep_c, and Ep_l are the building energy performance indices for space heating, domestic hot water DHW production, space cooling, and electric lighting, respectively (in (kWh/m^2/a) for residential buildings). All indices account for the amount of primary energy consumed to provide a certain energy need for the building as well as for the auxiliary energy provided by the systems to produce energy from different sources. They need to be calculated on a monthly basis, assuming a quasi-steady state, according to the procedures specified in the UNI-TS 11300-1 technical standards [12,13], on the basis of the methodology adopted in EN 13790 [14]. Termolog allows the energy performance indices to be calculated according to these specifications set by Italian standards.

The ‘simplified’ LCC methodology used in this study was applied through a two-phase approach:

1) energy evaluation, which consisted of the following steps:
- definition of the energy efficiency solutions, regarding the improvement of the energy performance of the building envelop and the exploitation of renewable energies
- definition of different scenarios on the basis of different combinations of technological solutions
- calculation of the primary energy consumptions for each scenario. At this stage of the research, the analysis was limited to the calculation of the energy performance indices for heating and for DHW from renewable sources (EP_h and EP_{dhw} in equation (4))

2) economic evaluation, which consisted of the following steps:
- calculation of the life cycle cost for each scenario, referred to the whole building life cycle (Global Cost)
- calculation of economic performance indexes through a ‘simplified’ Life Cycle Costing approach
- comparison of the economic indexes with respect to a base-case scenario
- identification of the most viable solution from both an energy and an economic viewpoint

3. The case-study

As shown in Fig. 2, the case-study consists of a two-storey family residential building, located in the municipality of Carmagnola (South area of Turin, Northern Italy). The district has a high number of single family or family houses, many of which are currently being retrofitted using traditional technologies. The reference building is therefore representative of the main building typology in this area, which is nevertheless largely diffused across the Italian territory, especially in small town and villages. The building, erected in 1963, has a rectangular plan and includes two flats, for a total floor area of 204 m^2. As far as the envelope technologies are concerned, the thermal transmittance of existing walls was assumed to be 0.9 W/m^2K, while the windows have a single pane glazing with frames (see Fig. 3). As far as the HVAC technologies are concerned, the independent heating system consists of a natural gas unit, while two condensing boilers were installed in 2002 to serve the two residential units, providing heating and DHW. Based on current conditions, the building was classified in Energy Class E (Ep_{gl} = 118 $kWh/m^2/a$) and the annual energy cost (heating gas consumptions, DHW and electricity for the two apartments) is 3024 € (taken from the bills paid by the occupants). As part of the study, a vertical enlargement was designed to obtain a third apartment on the roof of the existing building; furthermore, a side enlargement was also designed to extend the existing flats. Besides, a retrofit intervention was defined (and calculated) to enhance the energy performances of the envelope and of the systems, as described in section 4.1.

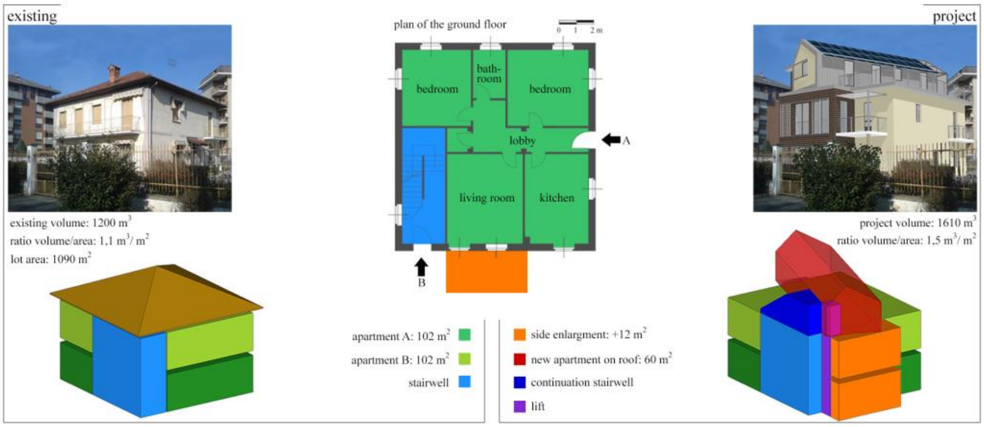


Fig. 2. The residential building used as case-study: existing and project schemes (the second floor having the same layout of ground floor).

At the time of the study, these surface and volume enlargements were allowed by regional regulations (Piedmont Region Housing Plan), provided that the final volume of the enlarged building is within +135% of the existing building. The volume/area ratio meets the limits imposed by the master plan of Carmagnola.

4. Energy evaluation

4.1 Energy Efficiency scenarios

Following the EPBD guidelines, various energy efficiency solutions were defined and applied to the case-study. These can be summarized into two main groups:

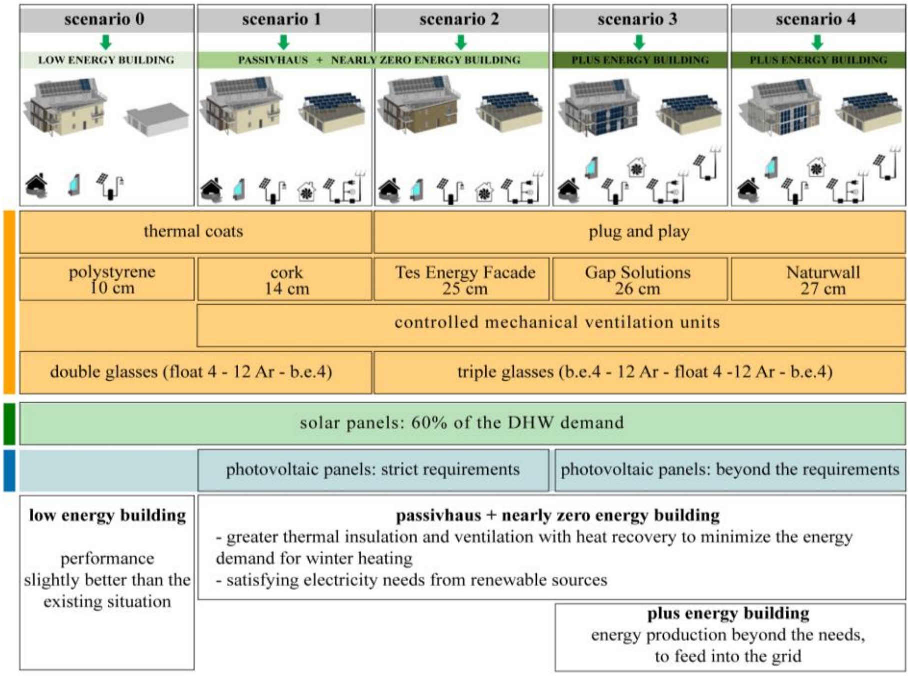
a) solutions to allow a reduction of the energy requirement for heating, concerning:

- the external thermal insulation of opaque walls
- the replacement of existing windows with highly insulating packages

- installation of decentralized controlled mechanical ventilation units, dual-flow with heat recovery system

b) solutions to exploit the renewable energy sources, concerning:

- the installation of solar panels for the production of at least 60% of the DHW demand (consistently with local regulations issued in the Piedmont Region)
- the installation of photovoltaic panels for the production of electric energy



low energy building

performance slightly better than the existing situation

passivhaus + nearly zero energy building

- greater thermal insulation and ventilation with heat recovery to minimize the energy demand for winter heating
- satisfying electricity needs from renewable sources

plus energy building

energy production beyond the needs, to feed into the grid

Fig. 3. Summary of different energy efficiency measures.

The different solutions which were identified were combined to create five scenarios with different performances in terms of energy consumption and costs. The energy consumption includes gas, which is used both for heating and for production of DHW, and electricity. The use of thermal and prefabricated façade coating panels (plug and play components) was adopted and the integration of these with windows and technical systems was addressed. For all scenarios, the installation of a solar thermal system for the production of DHW was assumed. This system consisted of two collectors Beretta SC-F20, with a storage tank of 120 liters (installed with a tilt angle of 30°, facing south).

A baseline scenario 0 was assumed as reference case: traditional technologies were used to achieve a low energy building (with an energy performance slightly better than the existing situation). The alternative scenarios were based on innovative technologies: the greater wrap thermal insulation and the ventilation with heat recovery allow the energy requirement for heating to be minimized and this reduced energy requirement was coupled with the installation of two photovoltaic systems to balance the electricity use (each system consisting of monocrystalline silicon panels Solon Black 230/07, with a power installed for each system of 3 kW (tilt angle of 30°, facing south). These systems were positioned on the flat roof of the garage. In this way, the innovative scenarios were configured in accordance with the ‘passivhaus’ and nearly zero energy building criteria. Furthermore, innovative scenarios 3 and 4 were integrated with an additional photovoltaic system on the south-facing façade (26 Monocrystalline silicon panels Solon Black 230/07, installed power: 6 kW, tilt: 90°, azimuth: 18° off south). This system allows an extra production of electricity, with a surplus compared to the electricity use in the house. As a result, this extra energy produced is fed into the grid, with a gain, thus configuring two ‘plus energy building’ scenarios. The characteristics of the various energy scenarios are summarized in Fig. 3.

4.2 Simulation assumptions

The energy evaluation was conducted with the following aims: *i*) to calculate the thermal transmittance U and the periodic thermal transmittance Y_{IE} of the envelope (walls and roof); *ii*) to calculate the energy consumption for heating and DHW, and then the primary annual energy Ep of the various scenarios, as well as the Energy Performances Class EPC (according to Law 90/2013); *iii*) to quantify the effect of the renewable energy systems on the energy consumption, also calculating the annual energy cost; *iv*) to verify to what extent the different scenarios were able to comply with the limit values set by the Italian technical-regulatory framework (see Fig. 4).

	existing	scenario 0	scenario 1	scenario 2	scenario 3	scenario 4
stratigraphy opaque wall						
thickness [cm]	38	48	52	66.2	63.8	65.8
transmittance U [W/m^2K]	0.9	0.25	0.23	0.14	0.16	0.13
periodic thermal transmittance Y_{IE}[W/m^2K]	0.26	0.015	0.011	0.004	0.003	0.001
glass	single float 4	double float 4 - 12 Ar - b.e.4		triple b.e.4 - 12 Ar - float 4 -12 Ar - b.e.4		
transmittance Ug [W/m^2K]	5.7	1.5	1.5	0.9	0.9	0.9
transmittance Uw [W/m^2K]	2.9	1.3	1.3	0.7	0.7	0.7
mechanical ventilation	✗	✗	✓	✓	✓	✓
Ep [kWh/m^2year]	118	42	21	15.7	15.2	15.3
energetic class	E	A2	A3	A4	A4	A4

Fig. 4. Summary of transmittance and primary energy consumptions.

Table 1. Summary table of consumptions and costs of two apartments.

			existing	scenario 0	scenario 1	scenario 2	scenario 3	scenario 4
A	gas for heating	consumption (kWh/m^2 yr)	97	35	14	8.5	8.0	8.1
		saving (%)	-	60	84	90	91	91
		cost (€/year)	-1656	-622	-263	-162	-153	-155
B	gas for DHW	consumption (kWh/m^2 yr)	21	7.2	7.2	7.2	7.2	7.2
		saving (%)	-	61	61	61	61	61
		cost (€/year)	-356	-138	-138	-138	-138	-138
C	electric energy	consumption (kWh/m^2 yr)	29	29	0	0	0	0
		saving (%)	-	-	100	100	100	100
		surplus (kWh/yr)	-	-	3180	3180	9540	9540
		cost (€/yr)	-1012	-1012	+350	+350	+1040	+1040
energy costs (A + B + C)			-3024	-1812	-51	+50	+749	+747
operating costs			-	-	-70	-70	-140	-140
C_G (energy costs + operating costs)			-3024	-1812	-121	-20	+609	+607
C_m (maintenance costs)			/	-	-220	-220	-370	-370
C_S (replacement costs of façade insulation, 20° yr)			/	-22842	-25772	-	-	-
C_I (initial investment costs)			/	-206219	-236220	-242109	-326849	-301680

For the energy simulations with Termolog, two thermal zones were defined, one per each of the two housing units. The heating system was assumed to be active October 15th through April 15th, consistently with the prescriptions of the Italian regulations for the climate zone E (2714 Degree Days).

The results which were obtained for the different scenarios are summarized in Table 1: the scenario 0 presents an annual cost slightly lower than the existing building. Scenarios 1 and 2 present a cost close to 0, scenarios 3 and 4 present energy gains, rather than costs. The percentage of saving is calculated with respect to the existing condition.

5. Economic analysis

In the second phase of the study, the economic analysis was carried out. The LCC was applied using equation (3), with the support of a specifically built Microsoft Excel® sheet. The following set of input data was assumed:

- financial data: the lifespan for the calculation, which corresponds to the technological life of the less durable element used in the retrofitting (photovoltaic/solar systems); the discount rate, set as a function of the investment risk (lowered to account for the potential savings generated by the retrofitting, tax reduction, enhancement of the asset value, enlargement of the house etc.)
- the initial investment costs C_I, assumed at the year 0, which include:
    - construction costs, quantified considering the enlargement and retrofit costs separately. The enlargement cost was calculated through the application of a “mixed comparative-analytics procedure”, while the retrofit costs were calculated using the price lists of companies
    - non-construction costs, i.e. infrastructure costs (derived from the local municipality) and design costs (calculated as 5% of construction costs)
- the annual costs during the holding period C_t:
    - operational costs C_o, the most relevant being the energy costs (related to gas consumptions for heating and DHW and electricity consumptions, which were obtained from the simulation results) and the operating costs (related to net energy metering of photovoltaic electricity, considering the annual cost for the service)
    - maintenance costs C_m, including the ordinary maintenance costs (efficiency maintenance and systems’ cleaning, from price lists of companies) and extraordinary maintenance costs (components replacement)

As a consequence, the Net Present Value (NPV) was calculated with respect to the starting year τ_0 considering the costs for a lifespan of 30 years, with a discount rate of 2.5%. The initial investment costs were referred to the year 0, taking the reduced construction period due to the use of prefabricated technologies into consideration. The annual costs C_t were discounted at the year 0 and then considered constant throughout the lifespan, except for the replacement costs. Among the maintenance costs, a replacement of the external wall insulation system after 20 years, in line with is usually requested for this kind of systems, was assumed.

The NPV was calculated for every scenario, while other economic indicators – Net Savings (NS), Discounted Pay Back Period (DPB), Saving to Investment Ratio (SIR), Adjusted Internal Rate of Return (AIRR), Simple Pay Back Period (SPB) were calculated only for the alternative scenarios, compared to the base case 0.

5.1 Results of economic evaluation

Table 2 shows the values of the economic indicators which were calculated for each scenario: Net Present Costs (NPC), Net Savings (NS), Savings to Investment Ratio (SIR), Adjusted Internal Rate of Return (AIRR), Simple Pay Back Period (SPB), Discounted Pay Back Period (DPB). Scenario 0 presents initial investment costs much lower than all the other scenarios; nevertheless, it is worth stressing, based on the results of all the economic indicators, that scenario 1 is comparable to scenario 0 while scenario 2 appears to be preferable: in spite of the higher initial investment, they actually allow a reduction of the costs during the holding phase. A little difference in terms of NPC was observed between scenarios 0 and 1, nevertheless the scenario 1 is preferable because it has nearly zero energy costs; instead the scenario 0 presents energy costs, although better than the existing situation, but still high.

The initial investment of the scenarios 3 and 4 was found to be very high, for two reasons: the use of more expensive envelope technologies; the installation of a photovoltaic system for the selling of electricity. High initial costs affect negatively on economic indicators. Scenarios 3 and 4 present longer Pay Back Periods, but this should not influence their final selection: in fact, these include envelop technologies which are expected to be more durable over time, and for which high replacement costs are not necessary, unlike scenarios 0 and 1.

Adopting the approach ‘Plus Energy Building’ may be questionable for such a small building. In fact, production and selling of electricity from renewable sources partially balances the costs; this strategy could be more profitable in the case of photovoltaic systems of large size, taking advantage of tax incentives. From a residential building’s owner point of view, it is advantageous to adopt systems based on renewable sources only to strictly cover the own building energy consumption.

Table 2. Summary table of results of economic evaluation

	NPC (Global Cost)	NS	SIR	AIRR	SPB	DPB
Acceptability conditions:	as low as possible	acceptable > 0 not accept. < 0	acceptable > 1 not accept. < 1	acceptable > 2,5 not accept. < 2,5	as low as possible	
Scenario_0	265869	-	-	-	-	-
Scenario_1	265321	548	1.02	2.6	10	13.2
Scenario_2	253539	12330	1.3	3.5	10.7	14.6
Scenario_3	328044	-62175	0.5	0.1	19.5	>30
Scenario_4	302920	-37052	0.6	0.8	19	21.5

Finally, it is worth stressing that the enlargement-retrofit intervention allows the asset to be enhanced, increasing its market value. Globally speaking, the increasing in market value is due to a combination of factors, such as the refurbishment of the asset, the increasing in the surface, and, particularly, to the Energy Class shift. Undoubtedly, as shown in some recent studies related to the Italian real estate market [15,16], this latter characteristic is able to influence the assets market value, even if at the time being it is not possible to quantify the relative marginal price.

6. Discussion

According to the Authors, the research presented in this study has the main merit to have developed a multidisciplinary methodology which combined different expertises such as the Real Estate Market and Economic Evaluation of Project, Architectural Technology and Building Physics. Such an approach showed for the case-study which was analyzed, how energy and economic analyses can be fruitfully used in synergy when addressing different possible retrofitting strategies. In this regard, the best performing solution in energy terms does not correspond to the best performing solution from the economic indicators viewpoint. Also the opposite applies, which show that the best solution is a trade-off which does not limit the analysis to a strict fulfilment of energy requirements, but also investigate the global cost of each intervention over time. Secondly, the methodology can be generalized and applied to other building typologies, as it represents a supporting tool to orient designers and practitioners in the early design phase, decision makers in the decision processes, public authorities in governance activities and in defining territorial policies. Furthermore, it can be used for both new and existing buildings, including the case of cultural heritage and public properties. For instance, the procedure shows the maximum initial cost, beyond which the investment convenience decreases.

Beside the potentials, there are also some limits which need to be highlighted: for instance, the difficulty in defining a lifespan for envelope elements of external wall insulation system or the variability of energy prices in the long period may influence the result of the analyses and the conclusions which are drawn. Similarly, the simulation tool which was used for the energy analyses (Termolog) is an important tool that may impact on the final results. Actually, Termolog uses a quasi-steady procedure, consistently with the Italian regulations for the energy certification process [12-13]. If other tools were used, which allow dynamic simulations to be run, the results of the analyses would change accordingly. On the other hand, it is also true that a dynamic analysis is particularly important for the cooling period, which was not addressed in the analysis carried out in the present study: this was actually limited to the heating season (including the production of DHW).

7. Conclusions

The retrofitting of a double-family house was addressed in this paper through a combined analysis based on both energy efficiency and the related costs. A real case-study was investigated, analzying two types of interventions: on an enlargement of the volume and energy solutions on the envelop components (using high-insulating prefabricated panels) and implementing some mechanical and solar systems (condensation heating unit with heat recovery, solar and photovoltaic panels). All the interventions resulted in an Energy Performance Class A (in some cases also meeting the passivhaus and NZEB criteria). But the economic analysis, carried out using a ‘simplified’ LCC technique, showed a different cost for each solution. The most viable trade-off between energy and economic constraints was the scenario 2, which presented the lowest NPC. On the contrary, scenarios 3 and 4, even in the presence of operating costs clearly lower compared to the scenario 2, need higher initial investments due to a supplementary photovoltaic system for electricity production and to more expensive envelope solutions. The energy saving through the envelop is the priority in interventions on existing assets, rather than the production of energy surplus through new systems. The envelope is a lasting component, which does not decreases in performances, does not require operational or maintenance costs during life cycle. The situation is different for energy production from renewable sources: these requires maintenance costs, are subject to reductions in productivity (today rather small), and it is not certain the durability and disposal.

In conclusion, it is worth stressing that the aim of the work is not to find an exemplar project, but to delineate a tool to support design activities. The innovative scenarios presented permit to test a working approach useful for interventions on built assets, and specifically on residential single houses, which at the time being represent three-quarters of Italian buildings. Furthermore, it is important to highlight that the real estate market is deeply influenced by energy performance and operating costs of the assets; in the meanwhile, the environmental matters have deeply influenced the technologies and, consequently, the production in the building sector.

References

[1] Fregonara E, Curto R, Grosso M, Mellano P, Rolando D, Tulliani JM. Environmental Technology, Materials Science, Architectural Design, and Real Estate Market Evaluation: A Multidisciplinary Approach for Energy-Efficient Buildings. J Urban Technol 2013; 20:57-80.
[2] Becchio C, Ferrando D, Fregonara E, Milani N, Quercia C, Serra V. The cost optimal methodology for evaluating the energy retrofit of an ex-industrial building in Turin. Energy Build 2016; 127:590-602.
[3] Fregonara E. Valutazione sostenibilità progetto. Life Cycle Thinking e indirizzi internazionali. Milano: Franco Angeli; 2015.
[4] ISO 15686:2008. Buildings and constructed assets – Service-life planning – Part 5:Life Cycle Costing, ISO/TC 59/CS 14; 2008.
[5] Langdon D. Life Cycle Costing (LCC) as a contribution to sustainable construction: a common methodology – Final methodology, 2007. Available online: http://ec.europa.eu/enterprise/sectors/construction/studies/life-cycle-costing_en.htm.
[6] König H, Kohler N, Kreissig J, Lützkendorf T. A life cycle approach to buildings. Principles, Calculations, Design tools. Regensburg: Detail Green Books; 2010.
[7] European Committee for Standardization (CEN). Standard EN ISO 15459:2007. Energy performance of buildings - Economic evaluation procedure for energy systems in buildings. Brussels: Belgium; 2007.
[8] European Parliament. Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU. Brussels: Belgium; 2012.
[9] European Parliament. Directive 2010/31/EU of the European Parliament and of Council of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union. Brussels: Belgium; 2010.
[10] Presidential Decree 59, Decree of the President of the Italian Republic DPR 59, 2009, Regulations for the application of the article 4, comma 1, letters a) e b), of the Legislative Decree 19 August 2005, no. 192, concerned with the application of the directive 2002/91/CE on energy efficiency of buildings (in Italian), In: Gazzetta Ufficiale della Repubblica Italiana n° 132, June 10; 2009.
[11] Decree, National guide lines for building energy certification (in Italian), Italian Ministry for the economic development, in: Gazzetta Ufficiale della Repubblica Italiana no. 158, July 10; 2009.
[12] UNI/TS 11300–1. Building energy performance – Part 1: Evaluation of the energy need for space heating and cooling (in Italian). 2014.
[13] UNI/TS 11300–2. Building energy performance – Part 2: Evaluation of the primary energy need and of system efficiencies for space heating and domestic hot water production (in Italian). 2014.
[14] European Standard EN 13790. Thermal performance of buildings - Calculation of energy use for space heating. Distributed through the Comité Européen de Normalisation (International Committee on Standardization), Brussels; 2005.
[15] Fregonara E, Rolando D, Semeraro P, Vella M. The impact of Energy Performance Certificate level on house listing prices. First evidence from Italian real estate. Aestimum 2014; 65:143-163.
[16] Curto R, Fregonara E, Semeraro P. Listing behaviour in the Italian real estate market. Int J Hous Markets Anal 2015; 8:97-117.