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ScienceDirect
Energy Procedia 48 (2014) 1449 – 1458
Energy Procedia

SHC 2013, International Conference on Solar Heating and Cooling for Buildings and Industry
September 23-25, 2013, Freiburg, Germany

Research of economic sustainability of different energy refurbishment strategies for an apartment block building

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Abstract

May energy saving derived from the retrofit of a building be able to pay its costs? The paper wants to answer to this simple question, reporting a research started with a simple case study (an Italian social housing quarter, served by a district heating system, which needs – as many others in many other countries – a reasonable refurbishment). The economic sustainability of different retrofitting strategies has been studied: a method to evaluate the costs of refurbishment interventions has been developed through a detailed design of interventions, identifying construction costs thanks to the contribution of a group of selected contractors which gave us reasonable prices representative of a real services offers and assessing the cost-optimal energy levels leading the building towards the energy labels B and A. Both envelope and systems refurbishment works have been investigated. The adopted method allows to chose among different refurbishment options, evaluating them as elementary cases and whole interventions, considering their efficiency by means of the Cost of Conserved Energy (CCE) method and the pay-back of the investments (ROI) by the cash-flow method, analysing different funding systems and incentives.

Keywords: Building refurbishment; thermal bridges; economical optimization; net present value; cost of conserved energy

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Selection and peer review by the scientific conference committee of SHC 2013 under responsibility of PSE AG
doi:10.1016/j.egypro.2014.02.164

1. Introduction

Since the publication of the European directive EPDB/2010/EU [1] and its Regulation 2012/244/EU [2], cost-optimal levels analyses for energy refurbishment of existing buildings have become one of the most investigated topics in Italian and international congresses [4-6].

The cost-optimal energy level is defined as the energy performance level that leads to the lowest cost during the estimated economic life cycle of building, taking into account the initial cost of the investment for refurbishment works, costs of maintenance and use of building and systems components, costs and savings of energy and the real rate of interest (discount rate, energy price percentage growth). An intervention may be considered cost-efficient if the cost of conserved energy (as defined by [3] and applied by [5] and many other Authors) is lower than the price of energy. During the design phase of a refurbishment analysis, the cost-optimal energy level has been assessed on a real case study: a social housing apartments block building located in Brescia (northern Italy), built in the sixties before energy saving standards applications. The building, characterized by a compactness ratio equal to 0.46 m^{-1} and an average U-value for the envelope equal to 1.46 $W/(m^2K)$, is served by a district heating system (Case 1), with a conversion factor f_P=0.85, except for domestic hot water (DHW) that is still provided by individual electrical boiler (not considered in the analyses). In order to evaluate and to optimize different retrofit interventions on the existing building, the best energy retrofit strategies have been identified in a Pareto Optimal space representing Heating Energy demand (Primary Energy for heating) and Retrofitting Costs, per unit of conditioned Area (A_C).

Table 1. Geometrical features of the building.

Conditioned Area (internal dimensions)	2'046	[m^2]
Conditioned volume (external dimensions)	7'984	[m^3]
Compactness ratio (Thermal Envelope area/Conditioned vol.)	0.461	[m^{-1}]
Thermal envelope area (opaque)	3'335	[m^2]
Windows surface area:	351	[m^2]
Average U-value (of whole building envelope)	1.46	[$W/(m^2K)$]

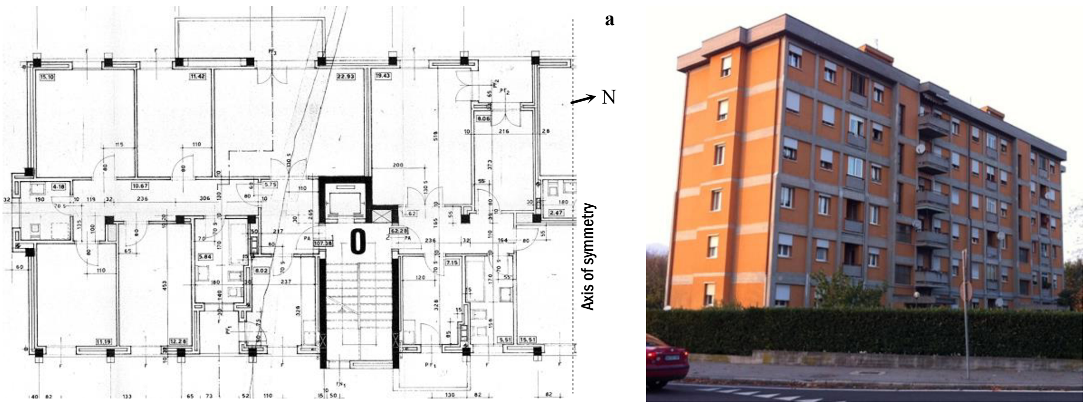

Fig. 1. (a) Plan of the building and (b) side view (south-east).

2. Heating energy need

The heating energy need in the winter season has been evaluated for the "asset rating", with reference to the quasi-steady state calculation method standardized by ISO 13790 [7]. Considering the efficiency of the system and a conversion factor for the electricity equal to 2.18, a primary energy need for heating (EP_H) of 176 $kWh/(m^2y)$ has been calculated. The same building has been also simulated (Case 2) as served by a traditional multi-stage gas heat generator (250 kWp) and with single glazing windows (U_w = 5 W/(m^2K) instead of double glazing ones (considered in the case 1). In this case, the calculated energy rating leads to a EP_H of 246 kWh/(m^2y).

Energy bills of the last three years gave us the real heating costs and let us to obtain a tailored analysis. The total cost for heating is about 920 €/year for the average size apartment (which is approximately 85 m^2), related to a heating energy consumption of about 118 kWh/(m^2y). It has been necessary to apply a correction factor C_f (equal to 0.7) to obtain real energy needs from calculated ones. In the case without district heating system, the heating cost for the average size apartment is equal to 1'170 €/year.

The detailed calculation of thermal bridges effects can be considered the first optimization step: moving from simplified linear transmittance of thermal bridges (as proposed by ISO 14683 [8]) to a detailed calculation with a 2D finite element software (THERM [9]), based on an analytical method in agreement with ISO 10211 [10], the EP_H is equal to 169 kWh/(m^2y). Different elementary retrofitting (more than 30) works have been analyzed: wall insulation technologies, roof and suspended floor insulation, windows or glazing substitution. Then, these cases have been combined, in order to identify best retrofitting solutions and to reach the following energy efficiency objectives: an advanced, "fiscal incentivized", *B-Class* scenario (Case 1.1 and 2.1), characterized by $EP_H \leq 49$ kWh/(m^2y), and the *A-Class* scenario (case 1.2), with $EP_H \leq 29$ kWh/(m^2y), according to local regulations. Fig. 2 represents the seasonal energy balance with reference to Case 1 and Case 2, both in the existing scenarios and retrofitted ones. Fig. 3 represents the values of the linear transmittance of eight different thermal bridges, with reference to ISO 14683 and to values obtained with the Finite Element analysis.

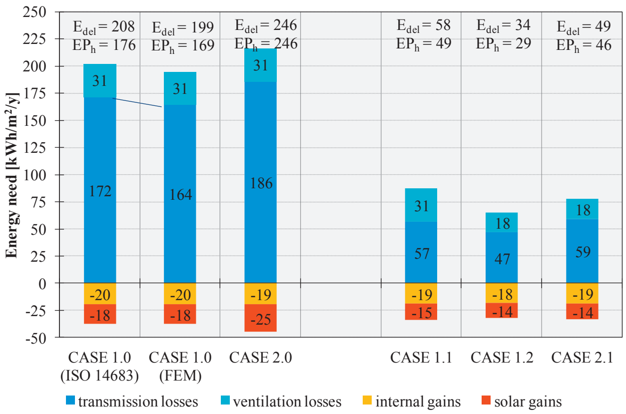

Fig. 2 Energy balance of base and retrofitted solutions.

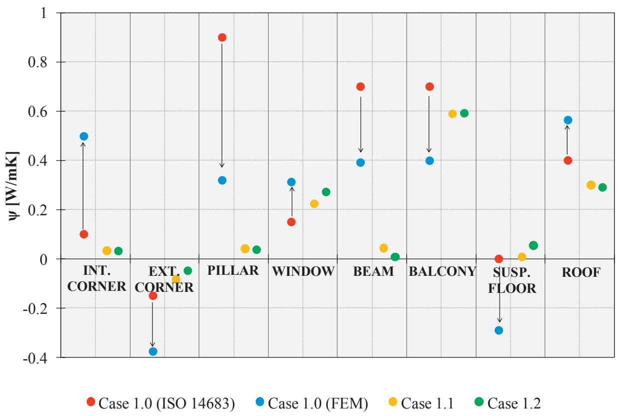

Fig. 3 Linear transmittance of thermal bridges in base and retrofitted solutions.

3. Costs estimation

Construction costs (represented per unit of A_C, with reference to the overall conditioned Area) have been estimated for each elementary work. They have been defined on the basis of a detailed design of the different working options and the average of the prices proposed by a series of selected builders. Quantities have been calculated following the gross surface rule (excluding voids greater than 1.0 m^2), accounting the extension of each detail (windows, beams and pillars).

The cost of the site has been assessed in a roughly way (actually a detailed project of the site has not been analyzed) and it has been included for each elementary work. For combined works, the cost of the site has been considered the same for each intervention (equal to 55'000 €, including the scaffolding, energy use and other temporary works) so the addition of different elementary works could differ from the total cost.

All costs include thermal bridge corrections, safety and overheads (+14%), company's profit (+10%), design costs (+8%), taxes (IVA +11% for refurbishment works) and discounts (-20%). These costs have been reported in Table 2.

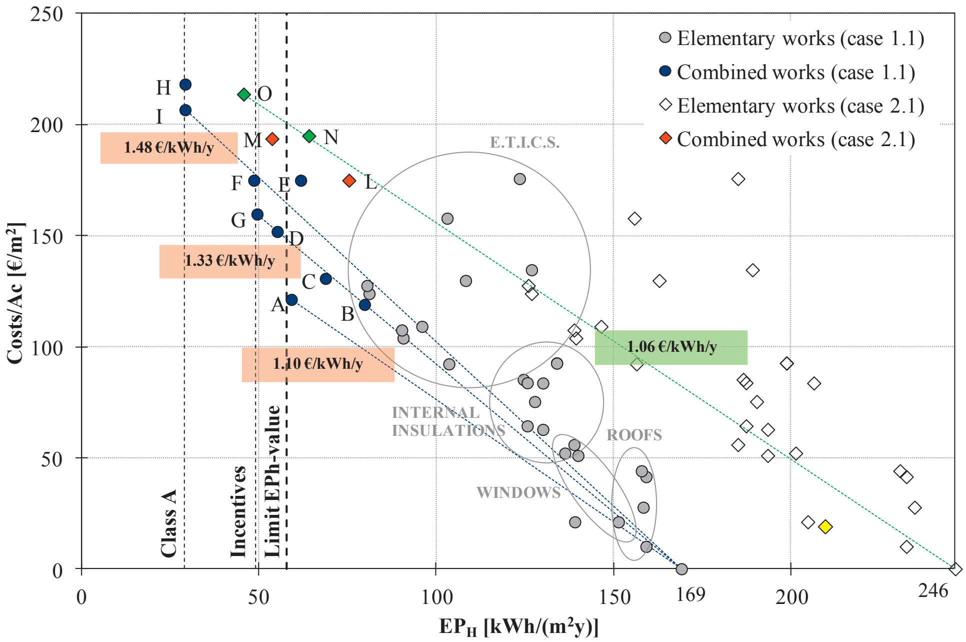

Fig. 4. Costs of retrofit works and primary energy (heating) achieved in cases with and without the district heating.

The value of the gradient, from one point to another, represents the cost per saved kWh, for each heating season [€/kWh/y] and it may be used to compare different retrofit solutions. The lower is the gradient, the greater is the advantage: costs will be lower or energy savings will be greater.

Points with higher gradient will be excluded and only the better ones will be considered realizable. Each best point can be linked to the previous one drawing a parable that represents the cumulative interventions. The ratio between such a value and the cost of the used energy (expressed in €/kWh) has the dimension of time and we will refer to it as "simplified" Pay-Back Time.

Case 1 building may reach the "advanced *B-Class*" limit (and profit for actual local incentives) with either option G or F. The *A-class* limit may be reached with option H, i.e. applying an EPS ETICS 16 cm thick (instead of 12) on walls and suspended floor. For what concerns attic ceiling, 20 cm thick cellulose insulation give the same result of the application of a 12 cm PUR sandwich panel on the roof, but it costs 25'000 € less (see point I and H in Fig. 4).

The intervention includes the changing of windows (U_w=1.25 W/(m^{2}K)). Simple *B-Class* limit (which is in this case very close to the EP_H limit value) may be reached also with an internal insulation of the walls, with about 8 cm (option A, in Fig. 4).

In all cases, it is useful to improve the heating control subsystem. Thermostatic valves on existing radiators cost about 1'000 €/flat and give the same result of glazing substitution (solution C compared to D), that costs about three time more.

To achieve greater energy efficiency, more efforts are needed and we can compare solution G (ETICS thickness growth) with solution E (frame and glazing substitution) or F (the same, expecting a consistent reduction in the average natural ventilation rate). The first option has a lower gradient and is less expensive than the other two, so it has to be considered a priority action.

With same interventions, the **Case 2** building (without district heating) may not reach *A-Class* rating and it is necessary to substitute the heat generator in order to reach the "advanced *B-Class*" label. Nevertheless, this case has a higher refurbishment potential, as its savings are greater and costs are comparable to the case with district heating system (see Fig. 4).

Table 2: Combined retrofit options for Case 1 (A-I) and Case 2 (L-O) building.

Description of global interventions		Total cost (€)	Cost/Ac (€/m^2)	EP_H (kWh/m^2/y)	Gradient (€/kWh/y)
A	Walls: internal insulation 8cm; attic ceiling: blown cell. ceiling insulation, 20 cm; suspended floor ETICS: 8 cm; new glazing; thermostatic valves.	247'842	121	59.3	1.10
B	Walls and suspended floor: ETICS EPS 8cm; balcony slabs: ETICS 4cm; attic ceiling: blown cellulose ceiling insulation, 20 cm.	243'483	119	79.8	1.33
C	B + thermostatic valves	267'459	131	68.8	1.30
D	B + thermostatic valves + new glazing	310'669	152	55.2	1.33
E	B + new windows (n=0.5 h-1)	357'867	175	61.8	1.63
F	B + new windows (n=0.3 h-1)	357'867		48.6	1.45
G	D but walls and suspended floor: ETICS EPS 12 cm.	326'779	160	49.0	1.33
H	Walls and suspended floor: ETICS EPS 16 cm; balcony slabs: ETICS 4cm; roof insulation: PU 20 cm; new windows; thermostatic valves.	357'867	218	29.2	1.56
I	H but blown cellulose ceiling insulation. 20 cm	396'228	207	29.2	1.48
L	B + new windows	398'847	175	75.4	1.02
M	L + condensing heat generator + thermostatic valves	437'209	194	53.7	1.00
N	Walls and suspended floor: ETICS EPS 16 cm; balcony slabs: ETICS 4cm; roof insulation: PU 20 cm; new windows.	422'823	195	64.1	1.07
O	N + condensing heat generator + thermostatic valves	446'452	214	45.7	1.06

In addition, costs of different heating systems have been assessed, considering the change of heat gas generator with a new condensing one, the change of radiators, the realization of a radiant floor and of a new DHW plant.

The size of heat generator has been calculated according to UNI EN 12831 [11], considering heat transfer coefficients for transmission and ventilation and an external design temperature of -7°C. The cost of heat generator is depending on its size, as stated in the Table 3.

Table 3: Costs for a new condensing heat generator for case study 2.1 (without district heating).

EP_H (kWh/m^2/y)	$Q_{H, GEN}$ (kW)	Cost (€)	Notes
209.0	222	25'000	From the starting point
53.7	80	8'000	Point M
45.7	72	8'000	Point O

Different scenarios of system improvement have been analyzed and represented in a graph (Fig. 5) considering an additional cost starting from initial points (with reference to Case 2) reached with envelope interventions M and O (Table 4).

On the best scenario (point O), it has been tested the change of the existing heat gas power plant with an heat pump with a nominal COP=3.5 that allows to reach a primary energy for heating value of about 32 kWh/m^2/y.

It has to be considered the replacement of DHW system (in cases *c*, *e* and *Hp.b*) allows to reduce the EP_W from 65 to 24 kWh/m^2/y (this is not represented in the graph, since on the x-axis is the primary energy for heating only).

Lastly a photovoltaic plant has been added in order to reach a zero EPH-value: assuming an energy production of 1000 kWh/kW$_p$ and a cost of realization of 2'200 €/kW$_p$, it would be necessary to realize about 195 m^2 and 30 kW$_p$ of photovoltaic roof surface, considering a surface of 6.5 m^2/kW$_p$.

Table 4: Costs for different scenarios of systems improvement.

Case	Scenario	Cost (€)	Case	Scenario	Cost (€)
a	Thermal power plant	49'384	Hp	Heat pump (COP=3.5)	48'131
b	a + radiator	79'888	Hp.a	O.f + radiant floor	289'991
c	b + DHW power plant	268'940	Hp.b	O.g + DHW power plant	358'067
d	a + radiant floor	127'202			
e	d + DHW power plant	336'360			

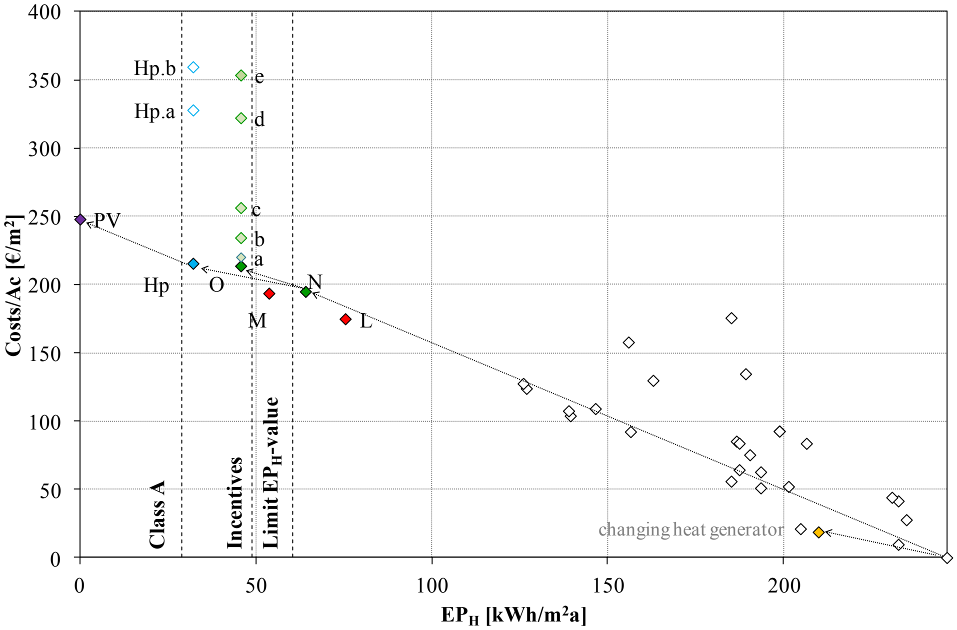

Fig. 5. Costs [€/m^2] and primary energy (heating) [kWh/m^2/y] in case 2.1 for systems retrofit works.

4. Cost of conserved energy: efficiency of interventions

The cost of conserved energy (CCE) here presented shows the mutual convenience between different refurbishment works and the efficacy of each work compared to the cost of fuel used for the heating service.

It considers the ratio *t* between the reference calculation period n_r (assumed of 20 years) and the life cycle period of a building component (walls, windows, heat generating systems, ventilation system, etc.) of a building n_u

(assumed equal to 50 years), the real interest rate d (equal to 0.98% dependent on nominal rate 3% and inflation 2%), the cost of initial interventions I_m, the real annual delivered energy conserved ΔE_y multiplied the factor B_x (price dynamic factor as stated in the standard EN 15459 [12]), which includes the energy price percentage growth.

Costs of maintenance of building parts and components ΔM_y have been not considered in this analysis.

$$CCE = \frac{a(n_r, d) \cdot I_m}{\Delta E_y \cdot B_x} \tag{1}$$

Some options result convenient as their CCE values are lower than the average energy price in the reference period (equal to 0.08 €/kWh). If the reference period would be 30 years instead of 20 years, CCE values would be lower (interventions would be more convenient). In case with heat pump the CCE should be compared with the price of electricity (about 0.20 €/kWh).

It is however necessary to point out that the CCE has been calculated referring to the delivered energy saving. The efficiency is higher in cases with higher initial energy consumptions, such as the cases without the district heating, class B cases and generally for global interventions instead of simple works on building elements.

In case of which the existing heat generator has been replaced with a electric heat pump (also served by photovoltaic panels) the real electric energy consumption has been related to the real thermal energy one using the Equation (2). The thermal energy B_x factor will be used to project the energy savings in the reference period.

$$\Delta E_y = \frac{\left(E_{del,0} \cdot C_f \cdot P_{gas} - E_{del,1} \cdot C_f \cdot P_{el}\right)}{P_{gas}} \tag{2}$$

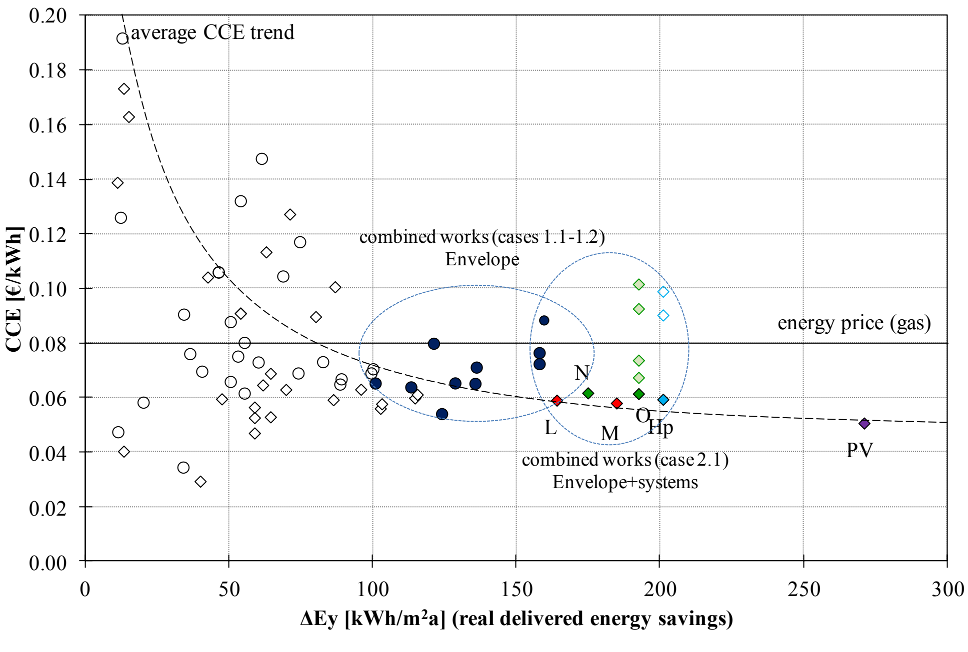

Fig. 6. Costs of conserved energy and saved energy for each retrofit work.

5. Index of energy present value

By the Discount cash-flow method it has been possible to calculate the actualized net present value of investment (NPV), the Internal Rate of Return (IRR) and the Profitability Index (PI) after 20 years.

The nominal increasing of energy cost p has been considered equal to 5%, corresponding to a real energy cost increasing equal to 2.94%, (source: Italian Authority of electricity and gas), the nominal Minimum Attractive Rate of Return (MARR) r is equal to 3% and the builder's discount are equal to 20%. It has been assumed that the quantity of energy saved each year Q_S is equal over all the investment period.

The incentives I_i (given for refurbishment works) have been considered equal to 65% in accordance with a recent Italian law [13]. These incentives have been investigated for building envelope refurbishment case.

It is necessary to point out that the maximum incentivized cost is equal to 100'000 € for works in common parts of buildings or 60'000 for each apartment. Incentives are given as a tax relief, over a period of 10 years.

In the following are presented the results of financial analyses (Fig. 7) with own capital and with a 10 years loan with an interest rate equal to 4%. All scenarios have been considered both with and without 65% incentives using the Equation (3). Lastly a sensitivity analysis (Fig. 8) has been performed, pointing out the increasing of energy cost and the reference period are the most sensitive parameters.

$$NPV = \sum_{S=1}^{M} Q_S \cdot \sum_{t=0}^{N} \frac{P \cdot (1+p)}{(1+r)^t} + \sum_{i=0}^{10} \frac{I_i}{10 \cdot (1+r)^i} \qquad (3)$$

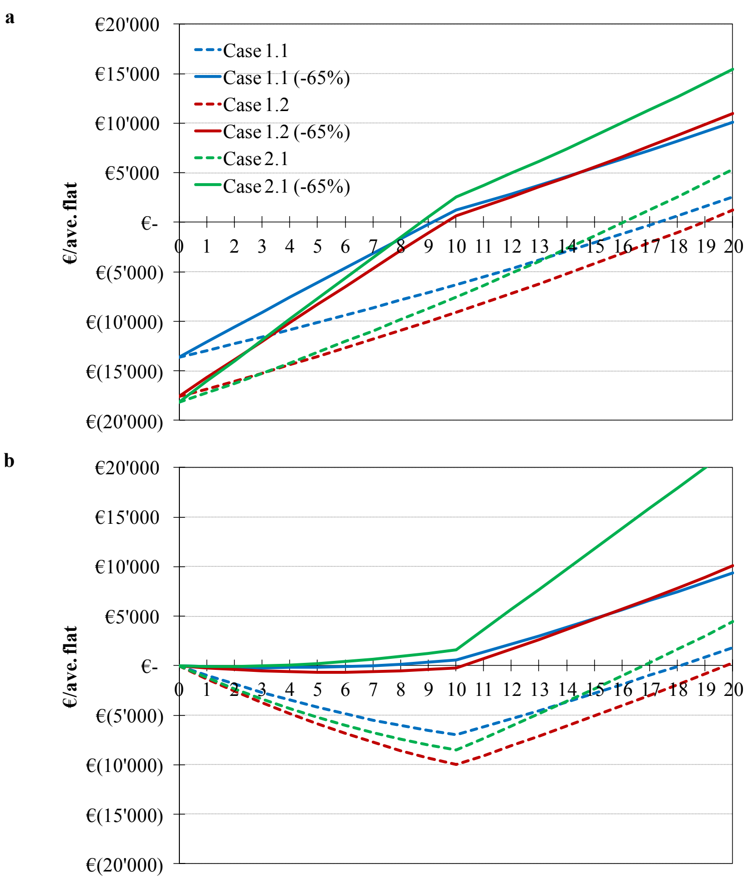

Fig.7. Graphs of discount Cash-flow (a) with an own capital and (b) with a 10 years loan.

Table 5. Present value of works (own capital)

Case	NPV [€]	IRR [%]	PI [-]
Case 1.1	€ 2'547	4.64%	1.19
Case 1.1 (-65%)	€ 10'097	10.19%	1.74
Case 1.2	€ 10'978	9.25%	1.62
Case 1.2 (-65%)	€ 10'978	9.25%	1.62
Case 2.1	€ 5'375	5.51%	1.30
Case 2.1 (-65%)	€ 15'475	11.00%	1.85

Table 6. Present value of works (loan)

Case	NPV [€]	IRR [%]	PI [-]
Case 1.1	€ 1'843	5.25%	1.26
Case 1.1 (-65%)	€ 9'393	44.91%	48.31
Case 1.2	€ 299	3.28%	1.03
Case 1.2 (-65%)	€ 10'067	29.74%	16.40
Case 2.1	€ 4'433	7.05%	1.52
Case 2.1 (-65%)	€ 22'049	98.74%	370.19

Table 7. Summary of interventions costs and savings

Cases	Total costs [€]	Total costs [€/flat]	Initial cost for heating [€]	Saving [€]	Final cost for heating [€/flat]	Cost of interventions [€/m² of Ac]	EP_H [kWh/m²y]
1.1	326'800	13'617	921	656 (71%)	265	160	49
1.2	422'800	17'617	921	765 (83%)	157	207	29
2.1	437'200	18'217	1'170	958 (82%)	212	214	46

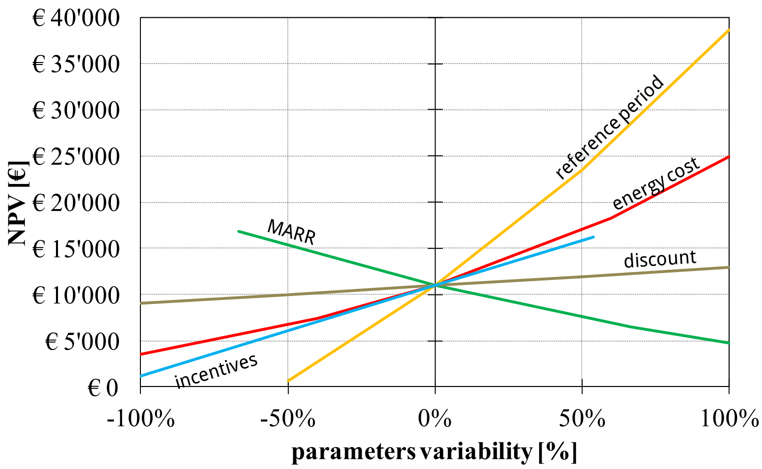

Fig.8. Sensitivity analysis for NPV for case 1.2 (Class A work) with 65% incentives.

6. Conclusions

Energy refurbishment requires a very detailed technical and economical analysis of possible interventions in order to pick out the cost-optimal solution (the higher energy saving at the lower cost).

Without any work on heating system, the costs of refurbishment interventions are in the range of 160-210 €/m² of conditioned area with an energy saving of about 70% and 80% respectively for the class B and the class A.

Considering also heating system interventions options, the use of a heat pump seems to be the optimal solution. In this case, costs are about equal to a new gas heat generator but energy savings are higher. The more COP is similar to the primary energy conversion factor for electricity (2.18 in Italy) the more a heat pump is inconvenient.

The cost of PV panels is continuously decreasing during recent years. This type of intervention is greatly performing, but it is important to consider the constraint of the availability of a receiving surface (usually, the roof) above all in apartment block buildings.

The method allows finding the cost-optimal solution for refurbishment designs. It is important to remember there could be some other constraints that could even address the choice in a different way respect to what energy and economic savings analysis show.

Receiving a grant (as incentives) results convenient and fundamental to keep the return of investment of retrofit options within a time that could be accepted as reasonable for an investor. From a strategic point of view, it is therefore necessary to prorogate the ends of grants.

To define the correct incentive policy, ROI should be analyzed considering the environmental (non renewable resources depletion) and the social impact (life quality) of retrofit options and not only the economic advantages achieved with these interventions, considering the broad refurbishment need of our existing building stock, as stated in [14].

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