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Costs assessment for building renovation cost-optimal analysis

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Abstract

In the frame of the IEA-EBC project "Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation", the Politecnico di Milano research group elaborated the information required to perform the renovation measures cost-optimal analysis of two case study buildings, representative of the most common ones of the Italian residential stock. Renovation costs have been composed accurately and, additionally, an analysis of several references has been accomplished for collecting national energy consumptions and GHG emissions values, current and projected, and energy career indexes. Adopted approach can provide insights for analogous researches and outcomes can be considered for similar retrofit cases in Italy.

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Keywords: building renovation costs; energy efficiency measures; common residential buildings; national energy-emissions indexes; cost-optimal analysis.

1. Introduction

The aim of the project "Cost-Effective Energy and Carbon Emissions Optimization in Building Renovation (Annex 56)" implemented by IEA-EBC (International Energy Agency – Energy in Buildings and Communities Programme) is to develop a new methodology, which is able to serve as basis for future standards, enabling cost effective renovation of existing buildings while optimizing energy consumption and carbon emissions reduction [1]. In this frame, a WP (Work Package) deals with the assessment of cost effective combinations of renovation measures, which optimize energy and carbon emissions savings. The Politecnico di Milano research group contributed in defining Italian case studies, a single-family and a multi-family house (SFH-MFH), representative of the most common residential

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buildings of the national stock. For this goal, data on geometrical, thermo-physical, systems/equipment characteristics and energy needs have been assessed, as well as a set of renovation measures with related costs. Concerning renovations, different levels of interventions have been considered, starting from the conventional maintenances as base cases implementable with energy improving measures widely adoptable. These ones foresaw two increasing levels of insulation for the envelope, the adoption of new HVAC (heating, ventilation and air-conditioning) systems, solar thermal and PV (photovoltaic) systems. Moreover, consistently with the methodological issues of the WP [2], proper national values referred to primary energy conversion factors, current and projected shares of energy consumption, GHG (green-house gas) emissions and prices of energy carriers have been provided.

2. Definition of Italian case studies

The selected SFH-MFH building typologies refer to solutions built between 50s and 70s (the period responsible of more than 1/3 of the Italian existing stock, affected by the worst energy performances [3]). In order to take into account the wide national climatic variability (in Italy the Heating Degree Days values range goes from less than 600, in the national climatic zone A, to over 3000, in the zone F), two opposite climatic contexts, in which buildings are numerically significant, have been considered: Milano and Palermo (placed in zone E and B, respectively). Hence, four cases are presented, whose nomenclatures are: MFH-E, SFH-E, MFH-B, SFH-B. For assessing the buildings characteristics, data have been defined with reference to literature and standards [3]-[9]. MFH (Fig. 1a) is a building with five heated floors, each one having four apartments, while SFH (Fig. 1b) is a detached building with two heated floors. Both buildings have unheated basement (garages, cellars), reinforced concrete structure with hollow clay bricks, uninsulated envelope (opaque elements with U values comprised between 1.15-1.57 W/m2K), wooden frame windows with double panes glazing in zone E and with single glass in zone B. Furthermore, among the most common ones, the following existing HVAC installations have been assumed: in MFH, heating system is centralized and gas-based while DHW (domestic hot water) is individual (gas-based or electric) and, in SFH, DHW systems (gas-based or electric) are considered as separate from the space heating system, except from zone E where can also be combined (gas-based). Finally, because widely diffused in southern Italy, existing splits or multisplits for space cooling are considered in SFH-B.

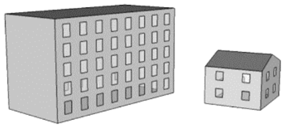

Fig. 1. (a) MFH sketch; (b) SFH sketch.

3. Renovation measures

3.1. Costs assessment

Consistently with the real building practice, each work cost has been composed comprising all the additional charges that are necessary for the supply and installation of the completed intervention, including removal of old components and management of waste materials, work safety equipments, auxiliary temporary structures (e.g. construction site equipments, scaffolds rental, etc.), overhead and profit for the construction company. For this scope, the detailed Milano Municipality building price-list for public works [10] has been adopted. With this regards, it should be noted that its prices are mainly taken as a reference for public tenders (involving large size works), allowing decreases during the offer phase of the competition (in some case also up to 20-25%). In the present study, because of the private perspective, for taking in account, in first analysis, other owner’s additional expenses (design, construction supervision, administrative procedures, etc., that usually correspond to at least the 10% of the work costs), the reduction of the prices was limited to the following specifications. In zone E (northern Italy), only for the MFH measures a 10% of reduction has been considered, while for the SFH ones the prices are maintained as they are, in order to consider the economies of scale (small size). In zone B (southern Italy), in order to consider the different (lower) costs of labor, an overall reduction of 10% has been assumed (that consequently corresponds to the 20% for the MFH and to the 10% for the SFH). These criteria have been applied only to the envelope renovation measures, the ones that are strictly affected by the economy of scale and by the share of labor.

3.2. Envelope renovation measures

Common maintenance envelope measures, whose costs are shown in Table 1, can be summarized as follows. For both MFH and SFH, substitution of deteriorate external plaster of walls, within 30% of the overall surface, including final painting; general repair of windows, including repair/replacement of damaged wooden elements and metal ware, wooden sanding, filling and final painting. For MFH flat roof, installation of an additional waterproof covering, consisting of a double elastomeric bituminous membrane with an upper slated finishing and reinforced with polyester layer. For SFH pitched roof, general repair of roof covering, within 30% of the overall surface, is considered including substitution of damaged elements and repositioning of tiles.

Table 1. Specific costs of envelope maintenance renovation measures [€/m^2].

	MFH-E	MFH-B	SFH-E	SFH-B
Walls	55	50	38	34
Roof	27	25	26	24
Windows	90	81	100	90

Energy improving measures for the envelope have been defined based on two different increasing levels of insulation, as required by the WP methodology. For this purpose, two national targets of thermal transmittance have been considered: as a “standard” level, the U values target corresponds to the limits in force [11] and, as an “advanced” level, the U values target is in accordance with stricter limits that allow accessing to tax deductions [12]. Foreseen measures, whose related costs are shown in Table 2, are following described[1].

For both typologies:

- external insulation of walls through EPS (expanded polystyrene) layer/s equipped with cement plaster (including fixing metal ware, adaptations to the new thickness of the windowsill, balcony joints, etc., and final painting);
- insulation of the ceiling of the basement through EPS layer/s finished with cement plaster (including fixing metal ware, metal or fiberglass reinforcement mesh gripping the cement plaster finishing);
- substitution of existing windows with new ones equipped with: double glazing in the standard case of the zone B, with additional low-e (low emissivity) coating in the advanced case; low-e double glazing in the standard case of the zone E, improved with argon in the advanced case.

For MFH flat roof, overlaying of EPS walkable panel/s and installation of a new waterproof covering as described for maintenance measures; for SFH pitched roof, installation of sandwich panels EPS aluminum cladded cant strips equipped (cost includes removal and repositioning of tiles with substitution of the damaged ones, removal of the existing wood cant strips).

Table 2. Specific costs of envelope energy renovation measures [€/m^2].

	STANDARD MEASURES				ADVANCED MEASURES			
	MFH-E	MFH-B	SFH-E	SFH-B	MFH-E	MFH-B	SFH-E	SFH-B
Walls	135	117	130	111	141	120	136	113
Roof	47	38	84	70	51	41	90	73
First heated floor	31	23	35	26	32	24	36	27
Windows	284	249	315	277	288	255	320	284

[1] Concerning the insulating layers, the overall thickness of the EPS varies between 4 and 12 cm, depending on the envelope element, on the considered case (standard or advanced) and on the Italian climate zone.

3.3. HVAC systems measures

Several options of HVAC systems[2] substitutions, whose costs are shown in Table 3, have been provided and can be summarized as follows.

With reference to MFH, the solutions for the heating system are:

- condensing boiler, with three-pass smoke furnace stainless steel and two-stage or modulating gas burners;
- reversible air-to-water heat pump with centrifugal fans (the cost includes adaptation of heating room needed for the air issue);
- ground water heat pump, including heat exchanger (indirect circulation), drilling of boreholes (length of each pipe considered within 30 m, with reference to aquifer level) and adaptations of heating room equipments.

For the cooling system, a multisplit with 12 internal units per floor (3 per flat) coupled with three alternative configurations of external units: one unit (serving four flats), two units (each one serving two flats) and four units (one per flat, which is the most common solution allowing individual electricity bills). For DHW, the options of individual water heaters, wall-mounted with 100 l tank, are: electric, gas-based and, as an advanced alternative, air-to-water heat pump (the cost of the latter, not included in the adopted building price-list, has been assessed based on the recent market deals and by considering the additional components that are necessary for retrofit adaptations).

With reference to SFH, the heating systems options are: two alternative condensing boilers (a compact wall mounted or an aluminum floor-standing with modulating gas burner) and a reversible air-to-water heat pump, connected with existing distribution system (also the DHW-combined options are considered). The latter, coupled with the substitution of the existing radiators with new fan-coils (estimated cost 6 k€ per 10 units, including electricity connections and the realization of pipes to collect condensing water) can also provide cooling. Otherwise, as common cooling system, a multisplit is foreseen (in the southern zone B, this could be used also for heating and, in this case, related costs should obviously not be considered twice). DHW systems options are: two wall mounted electric water heaters (one each floor) with 100 l tank or, with a tank of 250 l, one floor-standing gas-based and, as an advanced alternative, one floor-standing air-to-water heat pump.

Table 3. Costs of building HVAC systems [k€].

	MULTI-FAMILY HOUSE			**SINGLE-FAMILY HOUSE**	
HEATING	**100-150 kW (zone B)**		**200-250 kW (zone E)**	**15 kW (only heating)**	**25 kW (combined DHW)**
Wall-mounted condensing boiler	-		-	2.2	2.4
Floor-standing condensing boiler	13.2		17.7	4.4	4.5
Multisplits	-		-	14.1	-
Air-to-water heat pump	30.6		47.0	6.2	7.0
Ground water heat pump	35.1		42.2	-	-
COOLING	**23 kW (5 ext. units)**	**14 kW (10 ext. units)**	**5 kW (20 ext. units)**	**14 kW**	
Multisplits	108.5	126.0	130.0	14.1	
DHW	**wall mounted**			**floor standing (except electric one)**	
Electric water heater	5.8			0.6	
Gas-based water heater	21.0			2.1	
Heat pump water heater	28.0			3.3	

[2] Related efficiency values, required from the methodological issues of the WP, have been set with reference to the national literature [5], [24], [25].

3.4. Solar systems

Solar thermal system for contributing in 50% of DHW production has been included only for SFH, as a diffusible renovation measure (in MFH this measure would reasonably involve the evacuation of the entire building). The considered solution is a forced circulation system, with storey tank, expansion vessels, etc. Based on the different climatic conditions, 5 m^2 flat plate collectors are foreseen in zone E (cost of the system 4.5 k€) while 4 m^2 in zone B (4 k€).

Photovoltaic systems, grid-connected, are foreseen for both MFH and SFH typologies and related costs, defined for different size options, include all the proper equipments/devices and the required administrative procedures, documents, etc.: for 3 kWp 21 k€, for 8 kWp 49 k€, for 20 kWp 122 k€ and for 200 kWp 1090 k€.

4. National values

Consistently with the most updated available data, as required by the WP methodology, current and projected values of national final energy consumptions, and electrical and thermal shares, with related quotes of renewables also referred to the building stock (entire and residential one) have been provided, as well as the overall and the buildings related GHG emissions. The values (Table 4) have been set based on a proper analysis of several references [13]-[18], by selecting them directly or by crossing the different sources as in the following cases:

- current overall energy from RES (renewable energy sources), by crossing the RES share of the year 2012 (13.5%) reported in [13] with the total overall energy consumption value available for the same year in [14];
- current overall thermal energy from RES, by crossing the RES share of 2010 (10.7%) reported in [13] with the share of total overall thermal energy (45%) and with the total overall energy consumption value, both available for the same year in [15];
- current electricity from RES, in both the entire building stock and in residential one, by crossing the share of electricity from RES in 2010 (20.2%) reported in [13] with the share of electricity consumptions, in buildings and residential buildings (11% and 5% respectively), and with the total overall energy consumption value, available for the same year in [15];
- projected electricity from RES, in both the entire building stock and in residential one, by crossing the projected share of electricity from RES (38%) reported in [15] with the total electricity consumption values, for buildings and residential buildings, foreseen for the year 2022 in [16].

Table 4. National energy consumptions and GHG emissions.

	Current (2012)		Projected (2020)	
FINAL ENERGY CONSUMPTIONS [TJ/year]	**Total**	**From RES**	**Total**	**From RES**
Overall	5190739	700750	5274461	1002148
Overall electricity	1068087	294792	1269638	439538
Overall thermal	2401763*	256989*	2302344	460469
Building stock share	1978362	151662	1925597	-
Electricity in building stock	587098*	118594*	758518**	288237**
Residential building stock share	1311499	131401*	-	-
Electricity in residential building stock	266863*	53906*	277118**	105305**
NATIONAL GHG EMISSIONS [t CO_{2eq}]				
Overall	501000000		455000000***	
Building stock share	86100000		83200000	

* Referred to 2010. ** Referred to 2022. *** Effects of foreseen energy efficiency measures included.

In addition, other required values related to energy careers have been provided and are reported in Table 5, where the GHG production coefficients and the primary energy conversion factors refer to [19],[20] (the latter for the electricity career), while available energy prices refer to [21]-[22].

Table 5. National energy careers indexes.

	GHG PRODUCTION COEFFICIENT [t CO_{2eq}/GJ]	PRIMARY ENERGY CONVERSION FACTOR [GJ/GJ $_{final\ energy}$]	RETAIL PRICE [€/kWh] 2012	2020	2030
Natural gas	0.092	1.36	0.09	-	-
Oil	0.077	1.35	0.14	-	-
Wood pellets	0.001	1.06	-	-	-
Electricity	0.107	1.86	0.19	0.11	0.10

5. Conclusions

The definition of two case studies, representative of most common existing residential buildings in Italy, and of the data required from the Annex 56 methodology to assess the cost-effective combination of renovation measures has been described. The most relevant topic focused on the assessment of reliable renovation measures costs, based on a private perspective, by carefully taking into account all the additional building charges that, consistently with the whole retrofit process, contribute to define the actual overall final cost. Another subject concerned the collection of the national final energy consumptions and emissions values, current and projected, and energy career indexes, whose assessment is affected by data sources fragmentariness. For this purpose, an accurate analysis of references has been accomplished.

The approach adopted within this study can provide insights for other researches in these fields and, in particular, the outcomes can be taken into account in cost-effectiveness evaluations of similar retrofit cases in Italy.

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