Cost-effective energy savings potential of Italian residential building stock

Francesco Madonna
RSE SpA
Via Rubattino, 54
IT-20134 Milano
Italy
francesco.madonna@rse-web.it

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Abstract

Deep renovation of existing building stock is the key action in order to significantly reduce building sector energy consumption. Furthermore, it cannot only contribute in reaching European energy targets but also in helping economic growth.

This paper shows that cost-effective renovations could be implemented in the 59 % of the Italian building stock. The corresponding potential energy savings amounts to 8 Mtoe (i.e. 26 % of households actual consumption) and overall investment costs would be €137 G. Incentives play a key role: if the rate of tax credit will decrease, potential energy savings would reduce down to 3 Mtoe.

The adopted methodology is founded on the creation of a database of the Italian residential building stock, linking the data of the last household census with buildings "archetypes", i.e. a set of 140 buildings representative of the Italian stock (classified according size, age and climate zone). This database is coupled with a tool able to evaluate energetically and economically different energy efficiency measures, including wall and roof thermal insulation, double and triple glazing, shading devices, condensing boilers, thermostatic valves and thermal solar collectors. Building energy performance is calculated via a dynamic simulation, while the cost data are based both on national price lists and recent construction projects. Then, using a cost-optimal approach complying with Directive 2010/31 and Delegated Regulation 244/2012, the best renovation packages are selected for each building in order to quantify the cost-effective savings potential of the building stock. Furthermore, the methodology includes a sensitivity analysis on the amount of incentives (tax credit covering a percentage of investment) as well as the possibility to impose constraints on investment profitability (payback period).

Introduction

Reduction of energy consumption in the buildings sector constitutes an important action needed to reduce European Union's greenhouse gas emissions and energy dependency. Residential buildings still offer the opportunity to realize substantial energy savings since reliable and innovative solutions are available both for building envelopes and for technical systems (especially heating systems). Under the decisive stimulus of European and Italian legislation, over the years, good results have been reached for new buildings and, in the near future, construction industry is ready for nearly zero energy buildings. However, in Italy, the annual rate of new houses is just over 1%. Therefore, actions focused on significantly reducing energy consumptions in existing buildings are essential. In this segment, potential energy savings seem to be extremely high as 73 % of the Italian houses were built before the entry into force of the first law on the energy performance of buildings (1976) and, consequently, are poorly insulated and, in short, energetically inefficient. However, the current rate of major renovations is quite low: according to CRESME, in 2013, investments in energy renovation were about €4 G (CRESME 2014). Moreover, according to ENEA (Nocera 2014), these renovations are, generally, light ones: in 2012, 64 % refer to glazing systems, 25 % to heating systems, 9 % to thermal solar systems, 2 % to thermal insulation of walls or roofs. Renovations involving both building envelope and technical systems were very few: 1,200 in the whole country (less than 0,5 %).

The aim of this paper is to demonstrate that, from a cost-benefit point of view, it is possible to implement more and deeper energy renovations than those currently implemented. With this goal, we estimate the fraction of the residential building stock where energy renovations are already cost-effective and we evaluate the corresponding potential energy savings. Using a metaphor, we are interested in quantifying the size of an energy reservoir (renovation of residential buildings) exploitable in a cost-effective way with current technologies and conditions. Particularly we are interested in understanding how incentives affect this potential. This step is fundamental to set reasonable short- and medium-term goals and to formulate a strategy to enhance the major renovation rate.

Methodology

The evaluation of the cost-effective energy savings potential of the whole residential building stock is performed using a bottom-up approach described in Figure 1. According to Swan et al. classification (Swan 2009), the proposed methodology is an "engineering" method based on the definition of archetypes, i.e. reference buildings representative of the whole stock. These archetypes are coupled with the data of the housing census in order to create a database of the residential sector. This database is linked to a simulation tool in order to evaluate the energy performance of each building before and after a renovation. The same tool is able to perform a cost analysis in such a way to evaluate the cost-effectiveness of a set of renovation options and then to select the cost-optimal one, if any. In such a way it is possible to estimate the actual fraction of the building stock where energy renovations are cost-effective and the corresponding potential energy savings and investment costs.

COST-BENEFIT ANALYSIS

Investment costs

Investment costs are evaluated adopting a full cost approach. It allows not only to compare different solutions in order to assess the cost-optimal one, but also to evaluate the actual cost of a renovation. The main sources used to gather cost data are national price lists (DEI 2011) (DEI 2012), but we also analyze recent renovation projects (Zanetta 2014) in order to integrate and validate data.

Energy performance calculation

The calculation of energy need for space heating is performed with the hourly dynamic calculation method described in ISO standard 13790; an analysis of this method is proposed in (Millet J.-R., 2007) and a comparison with monthly methods is presented in (Van Dijk H.A.L. et al., 2004). The main assumptions in our calculations are: a single thermal zone per building, air infiltration rate equals to 0,3 vol/h, operative temperature set to 20 °C during heating hours and night time operative temperature set to 17 °C. The length of heating season is different for each climate zone reflecting Italian legislation as well as the maximum heating hour per day. Heating systems efficiencies are estimated on a seasonal basis, via UNI/TS 11300-2 (Italian standard). Using an hourly model requires weather data in the form of a typical year: for this purpose we use the IWEC files (International Weather for Energy Calculation) (ASHRAE 2011) that are based on historical data. A calibration of resulting energy use for space heating is done on the actual consumption of a year (2006) chosen as representative of average climatic conditions (Apadula 2009). As a further check, we compare the calculated energy use with the real consumption of over 200 existing buildings, and, using a smaller sample (18 buildings), we also compare energy performance both before and after a renovation (Zanetta 2014).

Global cost and cost-optimal renovation

The cost-optimal renovation is selected using the global cost methodology described in Delegated Regulation N° 244/2012 supplementing Directive 2010/31/EU by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for buildings and building elements. We follow EN 15459 for the calculation of global cost considering initial investment, running costs and the final value as well as disposal costs if appropriate, all with reference to the starting year. The residual values of equipment are also taken into account and the calculation period is set to 30 years. We assume a discount rate, in real terms, of 4 % and we adopt the financial calculation.

We carry out cost-benefit analyses considering incentives and evaluating their impact. The main state incentive to promote energy efficiency in residential sector is tax credit. Currently the 65 % of investment is reimbursed by tax credit over 10 years, beginning with the completion of work. For instance, assuming a major renovation with an investment cost of €100 k, it means that is possible to have a tax credit of €6,5 k per year for a period of 10 years. There are upper limits on the amount of costs reimbursed and, in order to access to this incentive, requirements on energy performance of building or building elements must be fulfilled. To be noted that is also possible to access to an alternative state incentive mechanism: white certificate scheme. However white certificate scheme is less favorable than tax credit (Capozza 2014) and currently it is used mainly by industry (80 %). Another incentive system is "conto termico" but, concerning energy efficiency measures, it is dedicated only to public sector.

Payback period

In addition to the global cost calculation used to define the cost-optimal renovation, we also evaluate payback periods (PBP), i.e. the period of time required to recoup the funds expended in an investment (assuming discounted cash flows). This evaluation is replicated in two circumstances: comparing the energy renovation with "doing nothing" (i.e. just considering maintenance) and with a basic refurbishment (e.g. façade repair, simple double glazing, non-condensing boiler).

Building stock and archetypes

THE ITALIAN RESIDENTIAL BUILDING STOCK

According to 2011 Housing Census (ISTAT 2011), there are 12 millions of residential buildings in Italy, containing 31 millions of housing units, including unoccupied, temporary occu-

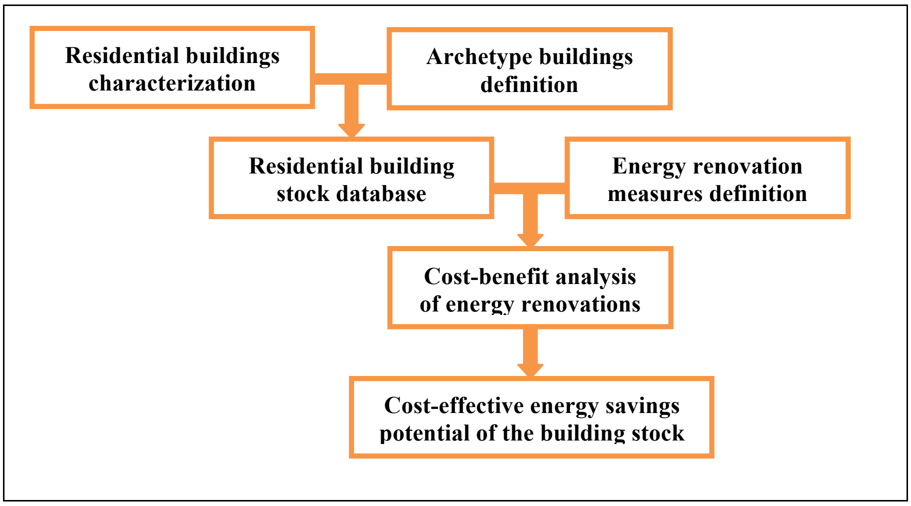

Figure 1. Schematic representation of the methodology.

Table 1. Percentage of buildings and dwellings per number of dwellings in the building.

	Number of dwellings in the building					
	1	2	3–4	5–8	9–15	≥ 16
Residential buildings	62 %	20 %	9 %	5 %	2 %	2 %
Dwellings	21 %	18 %	15 %	14 %	12 %	20 %
Occupied dwellings	19 %	17 %	15 %	14 %	13 %	22 %

pied and second home. The housing units occupied by resident persons are 24 million and have a total floor area of 2,397 million of square meters.

Over the 60 % of the buildings are single-family ones. However, although large multi-family buildings are less than 2 %, dwellings in such buildings are more than 20 %. (Table 1). In Figure 2 the number of buildings and dwellings as a function of the year of construction is shown: it could be noted that dwellings built between 1945 and 1981 represent the 52 % and that older buildings generally have less housing units. Concerning climate conditions, Italy is split into six climate zones, ranging from A (warmer) to F (colder) according to the heating degree days of each municipality. As shown in Table 2, buildings and dwellings located in climate zone E are the majority, while very few are situated in "extreme" climate zone (A, B and F).

The final energy consumption of the residential sector is 31 Mtoe (EUROSTAT 2014). Natural gas is by far the most used energy product (57 %), followed by electricity (19 %), renewable energy (12 %), petroleum products (10 %) and derived heat (2 %). Space heating is the most energy-intensive service and, actually, is responsible for the 68 % of this amount (ENEA 2013). On average, the final energy consumption for space heating is 102 kWh/m^{2}year, corresponding to 0,88 toe per dwelling. Space cooling service is growing continuously, but current consumption is only the 6 % of electricity consumption (Vitale 2012), i.e. about the 1 % of the final energy use of residential buildings.

ARCHETYPE BUILDINGS

A common approach in describing a building stock is the definition of archetypes, i.e. reference buildings representative of the entire building stock. Actually, the energy consumption of a building is a function of its geometric and thermal characteristics, its equipment and technical systems, operating and boundary conditions (end-users behaviours, climate, temperature set-points, adjacent buildings, etc. …). However building characteristics are correlated to certain parameters in such a way that, those features known, it is possible to quickly estimate the energy performance of a buildings portfolio. Such approach is quite common and different authors often use the same criteria to classify a building stock (Balaras 2007; Ballarini 2011; Clarke 2004; Mata 2011; Medina 2011). All the cited authors use "type of building" as first category and "climate zone" and "age of construction" are often considered too. Finally, some authors also introduce a segmentation for the heating system.

In this study, we use the 140 archetypes defined by V. Corrado et al. (Corrado 2014), on the basis of statistical analysis and experts' experience. The segmentation is based on size (building typology), period of construction and climate zone. The heating system typology is implicitly considered in the period of construction.

Particularly, four typologies are considered[1]:

1. This choice is mainly driven by the availability of detailed data concerning the heated useful floor area of dwellings. However, this segmentation is reasonable considering the dwelling distribution shown in Table 1.

- Single-family house (abbreviated in SF).
- Terraced house and small multi-family house (less than 9 housing units) (abbreviated in TH).
- Medium size multi-family house (between 9 and 16 housing units) (abbreviated in MM).
- Large size multi-family house (more than 16 housing units) (abbreviated in LM).

This classification implicitly takes into account the compactness ratio. The year of construction is strongly correlated to energy performance because of the evolution of energy conservation requirements in building codes. Moreover, the age is also linked to construction techniques, building materials, inter-floor height and heating system typology. The considered classes are the following:

- Houses built before 1918 (V1).
- Houses built between 1919 and 1945 (V2).
- Houses built between 1946 and 1960 (V3).
- Houses built between 1961 and 1980 (V4).
- Houses built between 1981 and 1990 (V5).
- Houses built between 1991 and 2006 (V6).
- Houses built after 2007 (V7).

The last axis is the location (climate zone). Actually, energy performance is directly influenced by the climate and building techniques differ locally reflecting both climate and the availability of materials. Furthermore, for recent buildings, energy efficiency requirements depend on climate zone. So the choice of locations was made in order to cover all climate zones except climate zone A (only two municipalities belong to this zone and less than 0,05 % of the building stock is located in this zone).

We resume some characteristics of these building in Table 3. Concerning technical system, in multi-family buildings built before 1990 (i.e. from V1 to V5), the assumption is: central space heating systems and point-of-use water heaters for DHW. For V6 buildings, each dwelling is equipped with a boiler that provide both space heating and domestic hot water. On the contrary, the newest buildings (V7) have a centralized system that provide both space heating and domestic hot water. The emission systems are based on traditional radiators with the only exception of V7 archetypes that have a floor heating systems. For a full description of these archetypes we recommend to look at the original source.

Archetypes energy performance for space heating is resumed in Table 4. Combining these values with the data of the 2011 housing census Figure 4 is obtained. It could be observed that houses built between 1946 and 1981 are responsible for 60 % of the final energy consumptions for space heating of the whole building stock.

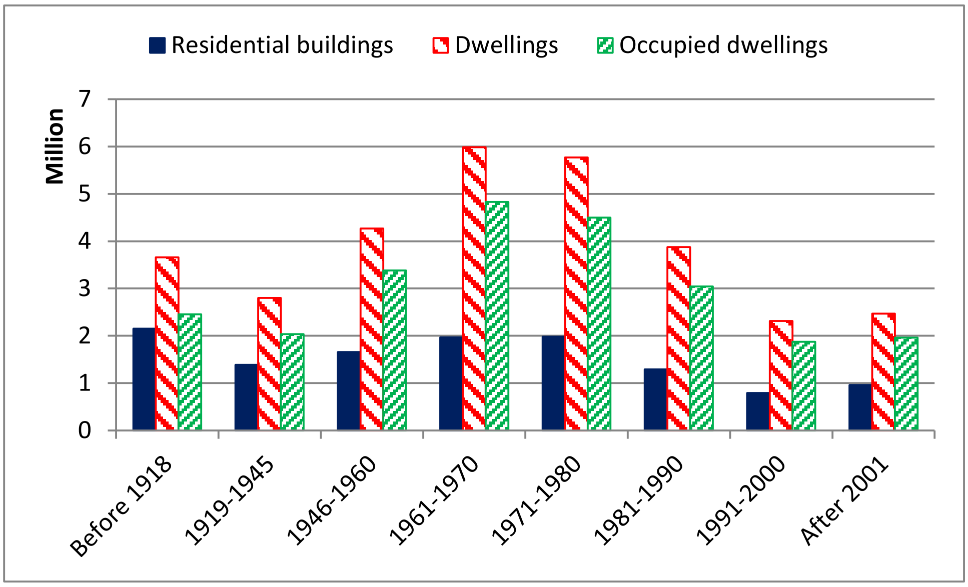

Figure 2. Number of residential buildings and dwellings by construction period.

Table 2. Percentage of buildings and dwellings per climate zone.

	Climate zone					
	A	B	C	D	E	F
Residential buildings	0,04 %	6 %	22 %	23 %	43 %	6 %
Occupied dwellings	0,03 %	5 %	20 %	25 %	47 %	3 %

Table 3. External wall U-value of archetype buildings [kWh/m²year].

Climate zone	Building typology	Age classes						
		V1	V2	V3	V4	V5	V6	V7
B	SF	2,20	2,20	2,41	1,40	0,90	0,57	0,48
	TH	2,21	2,22	2,42	1,18	0,91	0,59	0,48
	MM	2,19	2,19	2,40	1,38	0,89	0,56	0,48
	LM	2,19	2,19	2,40	1,38	0,89	0,56	0,48
C	SF	1,57	1,35	1,35	1,77	1,11	0,77	0,40
	TH	1,60	1,80	1,55	1,83	1,12	0,78	0,40
	MM	1,07	1,34	1,34	1,76	1,10	0,79	0,40
	LM	1,31	1,17	1,50	1,34	1,10	0,77	0,40
D	SF	1,63	1,50	1,50	1,28	0,77	0,60	0,36
	TH	1,65	2,04	1,21	1,58	0,78	0,62	0,36
	MM	1,19	1,48	1,48	1,15	0,80	0,59	0,36
	LM	1,31	1,08	1,15	1,10	0,76	0,59	0,36
E	SF	2,59	1,35	1,35	1,16	0,68	0,60	0,34
	TH	2,59	1,80	1,36	1,21	0,70	0,62	0,34
	MM	1,67	1,34	1,34	1,14	0,67	0,60	0,34
	LM	2,35	1,73	1,06	1,02	0,67	0,59	0,34
F	SF	2,20	2,20	2,41	1,40	0,90	0,57	0,33
	TH	2,21	2,22	2,42	1,18	0,91	0,59	0,33
	MM	2,19	2,19	2,40	1,38	0,89	0,56	0,33
	LM	2,19	2,19	2,40	1,38	0,89	0,56	0,33

Table 4. Space heating energy use (final energy)[kWh/m²year].

Climate zone	Building typology	Age classes						
		V1	V2	V3	V4	V5	V6	V7
B	SF	54	52	49	36	23	18	9
	TH	33	31	37	32	15	15	3
	MM	28	34	36	32	19	11	1
	LM	26	34	36	20	12	6	1
C	SF	100	97	93	70	47	35	19
	TH	67	63	74	65	32	30	9
	MM	56	70	72	64	38	24	6
	LM	55	69	72	42	25	16	4
D	SF	165	133	123	139	101	80	37
	TH	134	110	117	150	78	50	21
	MM	117	123	104	130	89	45	17
	LM	95	105	107	85	57	40	14
E	SF	250	227	195	184	120	84	59
	TH	201	197	165	210	92	65	34
	MM	178	186	164	163	104	60	31
	LM	145	157	156	119	69	56	24
F	SF	291	254	218	207	135	100	70
	TH	231	218	198	227	104	78	43
	MM	213	218	184	182	112	74	40
	LM	230	208	168	131	82	71	31

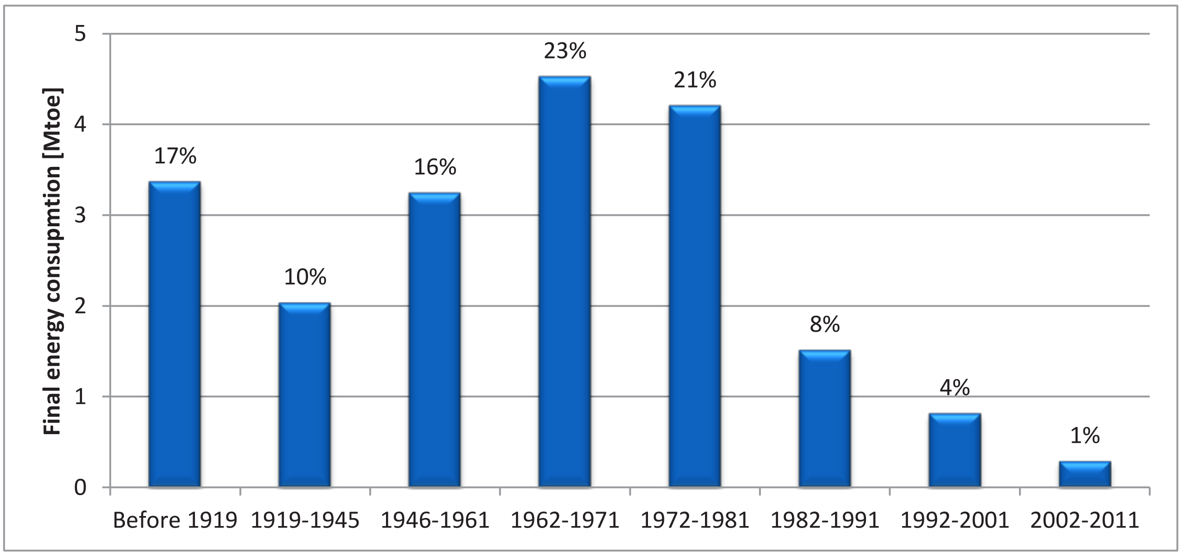

Figure 3. Final energy consumption for space heating sorted by building construction periods.

Energy renovations

ENERGY EFFICIENCY MEASURES

We analyze measures that are already widespread and we focus on measures oriented to reduce energy use for space heating and domestic hot water. We avoid those related to space cooling because, currently, only 30 % of dwellings are equipped with a cooling system (including portable appliances) and such systems are used occasionally and just in some rooms (ISTAT 2014). We also avoid renovations requiring a radical modification of distribution and emission systems because too invasive. All these hypothesis bring to a conservative estimation of potential energy savings and an exclusion of the most innovative solutions such as heat pump, combined heat and power, biomass boiler[2] and mechanical ventilation. Finally, we identify four packages:

A. Opaque envelope thermal insulation. The renovation involves external walls, roof and floor thermal insulation (when possible). The target U-values are shown in Table 5[3] as a function of climate zone. The material used for external insulation is extruded polystyrene (thermal conductivity 0,034 W/m·K).

B. Glazing systems and shading devices. The target U values are shown in Table 5.

C. Condensing boiler and thermostatic valves. We assume a 97 % efficiency at nominal output and at an average boiler-water temperature of 70 °C. In order to install the condensing boiler a chimney flue retrofit or a new chimney flue are considered. In single-family buildings and in multi-family buildings with autonomous heating systems, the same system provides both space heating and domestic hot water[4].

D. Glazed flat-plate collectors with selective absorber surfaces. This measure is evaluated only in single-family houses and the system is design in order to cover the 60 % of the energy need for domestic hot water.

Furthermore, we also tested the combination of some of these packages, namely A+B, A+B+C and A+B+C+D. To be noted these measures represent about 97 % of current energy renovations (ENEA 2014).

INVESTMENT COSTS

In order to effectively present investment costs for such a huge number of cases (660 considering all buildings and measures) we decide to show results only for single measures and in form averages over buildings located in different climate zone and built in different periods (Table 6). It appears that the cheapest solution is the renovation of the heating system (condensing boiler and thermostatic valves). Within this category, we note a higher cost in multi-family buildings with autonomous systems: it is due to the number of generators and the necessity of a new chimney. The following solutions are solar thermal systems and, then, glazing system (comprehensive of shading devices). The cost of the latter solution could vary up to 20 % depending on the location, because more insulating systems (triple gazing, low-emissivity coating, gas filling) are required in colder climate zone in order to attain the U-values illustrated in Table 5. Finally, the most expensive solution is the opaque envelope thermal insulation. To be noted that renovation cost is little affected by insulating layer thickness and that higher costs result in single-family buildings because of a greater compactness ratio (more envelope related to useful floor area).

2. The use of wood biomass is prohibited in many locations for air quality concerns.

3. Target values are set in order to have access to tax credit incentive mechanism. To be noted that these values are very similar and sometimes lower (up to 15 %) than those obtained in the cost-optimal methodology required by Directive 2010/31/EU (Corrado 2013).

4. To be noted that, when the same system provides both space heating and domestic hot water, evaluation of energy savings and the cost-benefit analysis also include the energy need for domestic hot water. Otherwise they concern energy need for space heating only.

ENERGY SAVINGS

As for the previous section, in order to effectively present results for such a huge number of cases, it is necessary to aggregate results. So we decide to show averages over buildings built before 1980 (in more recent buildings energy savings are considerably less) differentiating between single-family and multi-family buildings (Table 7 and Table 8). To be noted that values shown refer to single measures and that, combining more measures, the resulting energy savings are not the sum of these values.

The renovation that generates more energy savings is the opaque envelope thermal insulation. Final energy use is about halved in multi-family buildings and savings could attain up to 70 % in single-family ones. Considering that according to the GBPN (Shnapp 2013) a deep renovation is defined as the one that reduces actual consumption at least by 75 %, opaque envelope thermal insulation is not sufficient to attain this ambitious target but it is necessary to combine it at least with another measure.

Heating system renovation (i.e. condensing boiler and thermostatic valves) reduces energy consumption by about 25 % in multi-family buildings and about 15 % in single-family ones. Glazing systems and shading devices are definitely less effective: savings are less than 15 %, further reduced in single-family buildings and in warm climate zone.

Finally it has to be noted that for solar thermal systems energy savings are almost constant in all buildings since systems are designed in order to cover the 60 % of energy need for domestic hot water. In relative terms, energy savings attain more than 15 % in warmer climate zone (i.e. more than the amount obtained with heating system renovation), while in climate zone F (the coldest) this solution is the least effective one.

COST-OPTIMAL RENOVATIONS

Applying the global cost calculation, we observe that, depending on building typology, construction period and location, the cost-optimal solution is the opaque envelope thermal insulation (36 % of archetype buildings, especially single-family and terraced houses) or the renovation of the heating system (25 %). None of the proposed measures (opaque envelope thermal insulation, new glazing systems, heating system renovation, solar

Table 5. Target U-values for opaque and transparent envelope and g-value of glazing systems. [W/m2K].

Climate zone	Target U-values				g-value	
	External walls	Roofs	Floors	Glazing systems	Without shading	With shading
B	0,41	0,32	0,46	2,4	0,67	0,23
C	0,34	0,32	0,40	2,1	0,67	0,23
D	0,29	0,26	0,34	2,0	0,67	0,23
E	0,27	0,24	0,30	1,8	0,50	0,18
F	0,26	0,23	0,28	1,6	0,50	0,18

Table 6. Investment costs of energy renovations. The values are expressed in euro per square meter of useful floor area (including VAT) [€/m²].

	Building typologies			
	SF	TH	MM	LM
Opaque envelope thermal insulation	€290/m²	€194/m²	€193/m²	€148/m²
Glazing systems and shading devices	€73/m²	€73/m²	€74/m²	€90/m²
Heating systems (single-family buildings)	€34/m²			
Heating systems (central heating)		€28/m²	€25/m²	€21/m²
Heating systems (autonomous heating)		€43/m²	€64/m²	€51/m²
Solar thermal systems	€41/m²			

Table 7. Energy savings in term of final energy use for space heating and DHW. Single family buildings build before 1980 [kWh/m2year and percentage].

	Climate zone									
	B		C		D		E		F	
Opaque envelope thermal insulation	37	58 %	70	66 %	101	64 %	155	67 %	172	66 %
Glazing systems and shading devices	1	2 %	3	3 %	7	5 %	8	4 %	12	5 %
Heating systems	9	15 %	15	16 %	23	16 %	35	16 %	39	16 %
Solar thermal systems	10	16 %	10	9 %	10	6 %	9	4 %	9	3 %

Table 8. Energy savings in term of final energy use for space heating and DHW. Medium and large multi-family buildings build before 1980 [kWh/m2year and percentage].

	Climate zone									
	B		C		D		E		F	
Opaque envelope thermal insulation	19	58 %	38	59 %	58	53 %	81	51 %	99	51 %
Glazing systems and shading devices	3	8 %	6	10 %	12	12 %	16	10 %	21	11 %
Heating systems	8	24 %	16	25 %	27	26 %	39	25 %	45	24 %

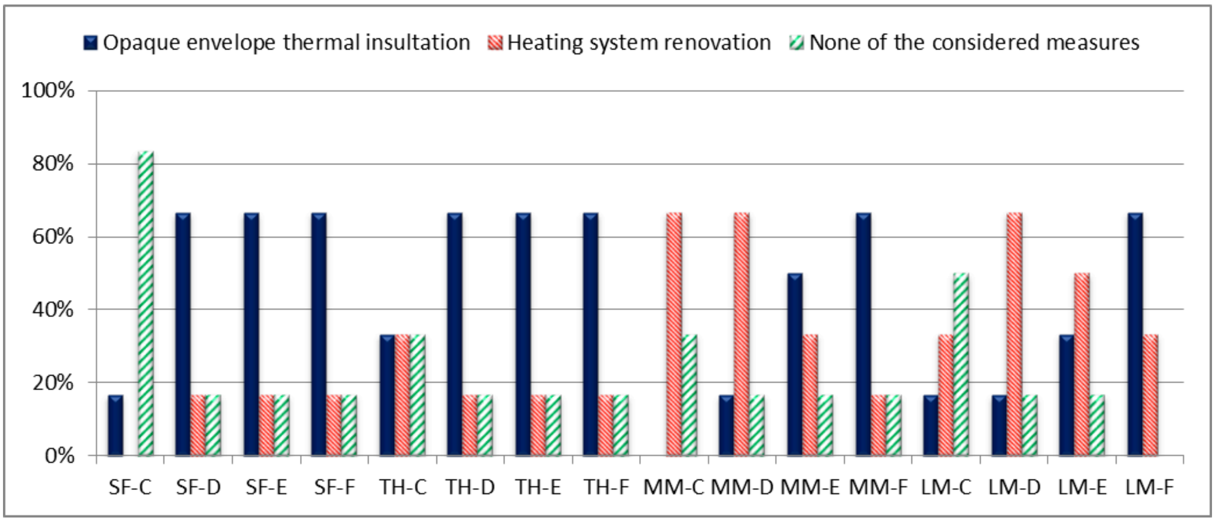

Figure 4. Cost-optimal renovations in archetype buildings considering tax credit (the first two letter identify building typology and the last identifies climate zone).

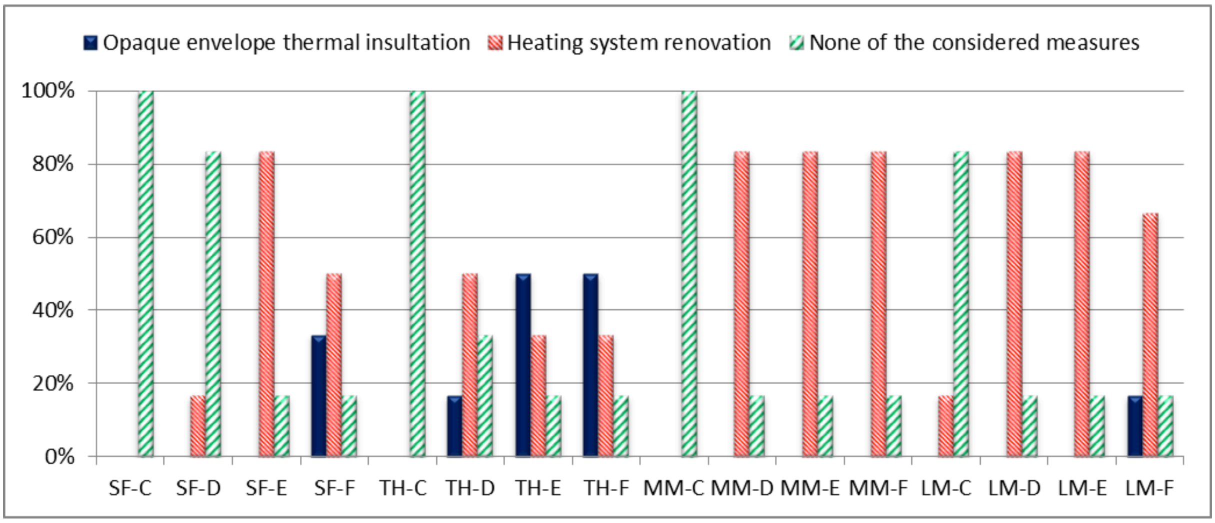

Figure 5. Cost-optimal renovations in archetype buildings without incentives (the first two letter identify building typology and the last identifies climate zone).

thermal collectors or combinations of these measures) result cost-effective in 39 % of archetype buildings (particularly, in all buildings located in climate zone B, some located in climate zone C and in almost all those built after 1990). To be noted that deep renovations (75 % savings) never result cost-optimal. An outline is shown in Figure 4 (results for buildings located in climate zone B are not shown since none of the proposed measures are cost-effective in such buildings)

Without incentives the picture is completely different: none of the proposed measure are cost-effective in the majority of archetype buildings (53 %). We also note an increase of cases where heating system renovation is cost-optimal (38 %). On the contrary, opaque envelope thermal insulation results cost-optimal in very few cases (8 %).

Table 9. Range of payback period per climate zone (only building built before 1980) [years].

Climate zone	Heating system renovation				Opaque envelope thermal insulation			
	Without incentives		With tax credit		Without incentives		With tax credit	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
B	> lifespan	> lifespan	> lifespan	> lifespan	> lifespan	> lifespan	> lifespan	> lifespan
C	> lifespan	> lifespan	10	> lifespan	> lifespan	> lifespan	18	> lifespan
D	11	> lifespan	7	> lifespan	21	> lifespan	10	30
E	8	> lifespan	6	10	15	> lifespan	8	24
F	7	> lifespan	5	9	12	> lifespan	7	20

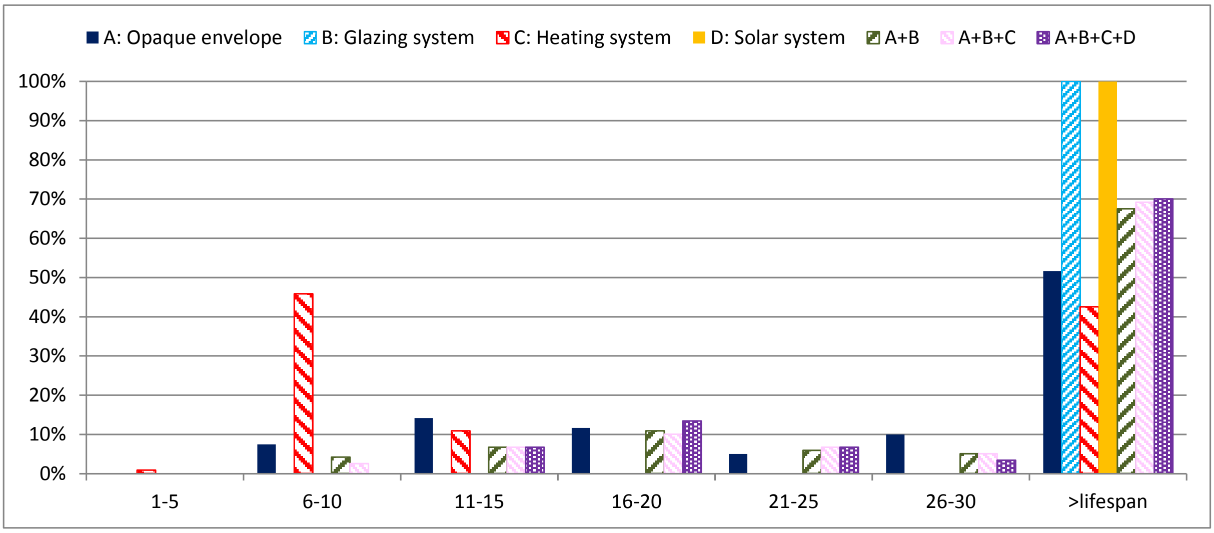

Figure 6. Payback periods in archetype buildings considering tax credit [years].

PAYBACK PERIODS

In Table 9 we show the range of payback period for heating system renovation and opaque envelope thermal insulation, highlighting the influence of climate zone. Actually, in colder climate zone payback period are shorter since energy saving are higher. We note that heating system renovation generally has shorter payback period, although this solution is not always the cost-optimal one. Without incentives payback periods are much longer, especially for opaque envelope thermal insulation: as a rule of thumb they double. In Figure 6 we also show payback periods of other measures and combination of measures. Particularly, payback periods for glazing system renovation and solar thermal system installation are longer than measure lifespans in all archetype buildings, even considering tax credit.

In previous evaluations, energy renovations have been compared with "doing nothing". However, periodically, it is necessary to replace obsolete elements and refurbish deteriorated building parts. Assuming the actual necessity of elements replacement or repair, investments for a "basic" refurbishment would be supported anyhow, even if smaller than those required by energy renovations. To be noted that a basic refurbishment could bring a certain amount of energy savings as well. So we calculate energy renovation payback periods assuming to implement it when a refurbishment is necessary. Particularly, we compare opaque envelope thermal insulation with façade repair, glazing systems described in Table 5 with double glazing system (no gas filling nor coating), heating system renovation (condensing boiler and thermostatic valves) with a simple boiler replacement. Results are shown in Table 10 and Figure 7. As expected, payback periods are significantly shorter, particularly for opaque envelope thermal insulation.

Please note that in the following sections, if not otherwise stated, we assume payback period calculation comparing energy renovation with "doing nothing". Particularly, we use payback period calculated comparing energy renovations with basic refurbishment only in "Yearly potential (renovation opportunities)" section.

Cost-effective energy savings potential

In this section we combine cost-benefit analyses developed on archetype buildings and census data on Italian building stock in order to derive conclusion on national basis. The aim is to calculate the amount of energy savings exploitable in a cost-effective way with current technologies and conditions. So, en-

Table 10. Range of payback period per climate zone (only building built before 1980) [years].

Climate zone	Heating system renovation				Opaque envelope thermal insulation			
	Without incentives		With tax credit		Without incentives		With tax credit	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
B	> lifespan	> lifespan	8	> lifespan	> lifespan	> lifespan	10	> lifespan
C	10	> lifespan	6	> lifespan	16	> lifespan	7	23
D	7	> lifespan	5	13	11	> lifespan	6	12
E	6	> lifespan	4	9	8	27	5	10
F	5	17	4	8	7	23	5	9

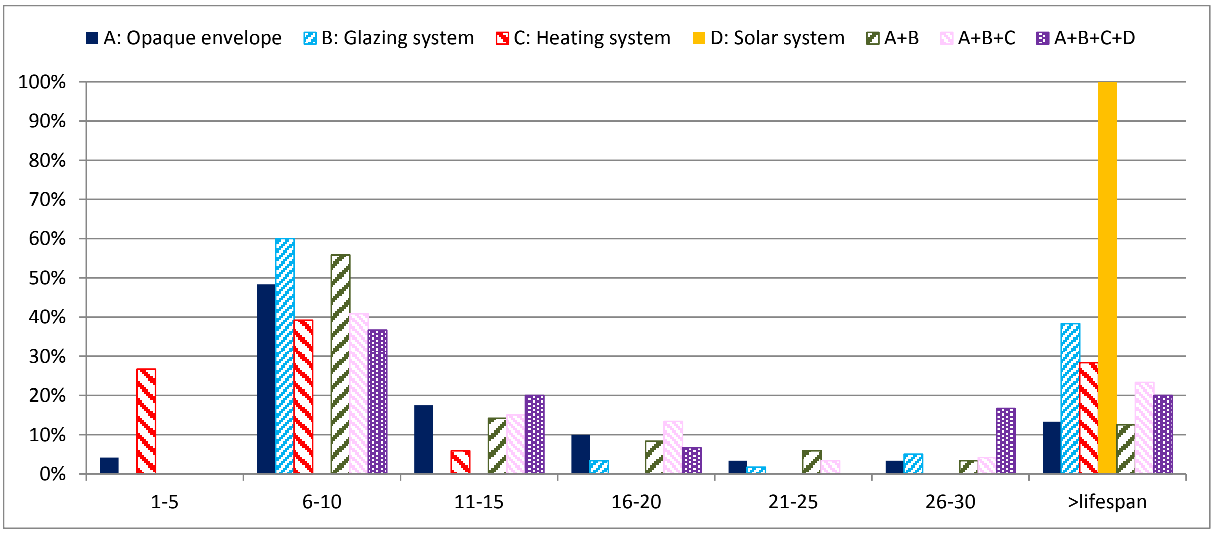

Figure 7. Payback periods in archetype buildings considering tax credit [years]. Calculation performed comparing energy renovations with "basic" refurbishments.

ergy savings potential is evaluated selecting the cost-optimal measure or package for each building. In buildings where none of the proposed renovations result cost-effective, we assume to do nothing. Furthermore, considering that in historical building and, generally, in old town there are obligations that deeply affect both renovation costs and energy savings (e.g. constraints that prevent façade thermal improvement) we decide not to implement energy renovations in houses built before 1918. Assuming these hypotheses, energy renovation are cost-effective in 62 % of the building stock (about 1,500 million of m^2 in term of useful floor area) and the potential energy savings are 9.2 Mtoe.

Furthermore, we add a constraint in our evaluation in order to consider only renovations with a payback period less than or equal to 15 years. In fact, it is a common experience that energy renovations are unlikely if payback periods are too long, also considering that the usual duration of a loan period is significantly shorter. This constraint doesn't really affect the fraction of the building stock involved (-3 %), but mostly the kind of measures selected. Particularly, there is a relative lesser extent of opaque envelope thermal insulation. Energy savings potential amounts to 8.0 Mtoe (Table 11). This value corresponds to 34 % of space heating and domestic hot water final energy use in residential buildings (26 % of all residential sector final energy use). According to 2014 Energy Efficiency Action Plan (ENEA 2014) residential sector expected final energy savings by 2020 are set to 3,67 Mtoe, also considering savings in new buildings (as a consequence of new regulations) and electrical uses (lighting and appliances). It means that it could be possible to more than triple the 2020 target set for renovations in a cost-effective way. However, there are many barriers preventing it, especially project founding. In fact, potential investments are very high and attain €137 G. This huge number has to be compared to €50 G of current annual expenditure in residential building refurbishment (ANCE 2014), €4 G of which refers to energy renovations.

We also perform a sensitivity analysis on the percentage of the investment covered by tax credit as shown in Figure 8. To be noted that energy savings potential reduces down to 3.3 Mtoe without incentives. In such a case almost all renovation (89 %) involves the heating system. So, it is important to stress that tax credit promotes especially renovations that have high investment and high energy savings as opaque envelope thermal insulation.

From a governmental point of view, it is not easy to evaluate the effectiveness of this incentive mechanism since tax credit is related to investment costs and not to energy savings. In Table 12 we show the ratio between lost tax revenues and energy savings calculated over measure lifespan. These values have to be compared with a white certificate value, that currently is about €100/toe. As expected, tax credit is a more generous mechanism than white certificates.

YEARLY POTENTIAL (RENOVATION OPPORTUNITIES)

As we previously said, we evaluate payback period in two circumstances: comparing energy renovation with doing nothing and with a "basic" refurbishment. We motivate this choice considering that energy renovations are more cost-effective if a building already need a refurbishment. However this "opportunity" occurs only periodically: it means that in a given year only a fraction of the building stock has this opportunity. Consequently, since in this paper we evaluate energy savings potential exploitable with current technologies and conditions, it is interesting to evaluate just yearly potential (if such opportunity materializes in ten or twenty years, conditions and technologies will not be the same). In order to perform such evaluation we assume that a boiler replacement occurs every 20 years, glazing system replacement every 30 and façade repair every 40 years.

Results are shown in Table 13. We note that considering tax credit and a maximum payback period of 15 years, energy savings potential attains 427 ktoe/year, i.e. more than the double of energy savings expected from tax credit incentive mechanism in Energy Efficiency Action Plan. These energy renovations involve 72 % of buildings that every year need a refurbishment anyhow, i.e. a useful floor area of 50 million of m^2 (3.61 of the whole building stock). The percentage is still high (67 %) if we only consider the most energy effective renovations (opaque envelope thermal insulation or combination of more than a measure). Investments (€12 G/year) are three times the current ones. So we observe that currently this potential is mainly unexploited. To be noted that loosing such opportunities means to lock-in energy savings for a long period.

Assuming a maximum payback period of 10 years, energy savings reduce by 8 % involving 3,4 % of building stock. Ignoring incentives has a stronger effect: energy savings reduce by 40 % involving 2,5 % of building stock.

Table 11. Cost-effective energy and carbon savings, investments and building stock involved.

	Without incentives	*With tax credit (65 %)*
Energy savings [Mtoe]	3,3	8,0
Carbon savings [Mt]	8	19
Investiments [G€]	30	137
Building stock involved	36 %	59 %

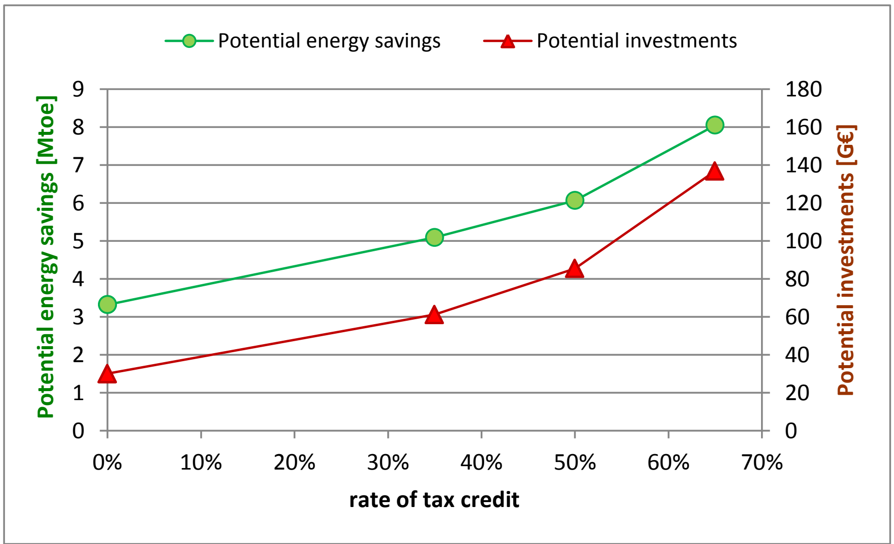

Figure 8. Potential energy savings and investment as a function of the percentage of investment covered by tax credit.

Table 12. Ratio between lost tax revenue and energy savings calculated over measure lifespan.

Rate of tax credit		
35 %	50 %	65 %
€134/toe	€214/toe	€320/toe

Table 13. Energy renovation potential depending on payback period and incentives.

	Without incentives		*With tax crediti (65 %)*	
	PBP ≤ 10	*PBP ≤ 15*	*PBP ≤ 10*	*PBP ≤ 15*
Energy savings [ktoe/year]	144	257	393	427
Carbon savings [kt/year]	345	615	941	1023
Investiments [€G/year]	1,3	3,7	9,8	11,9
Building stock involved per year	1,69 %	2,47 %	3,39 %	3,61 %

Conclusions

This paper shows that renovations with payback periods less than or equal to 15 years could be implemented in 59 % of Italian residential building stock. Depending on building typology, age and location, opaque envelope thermal insulation or heating system renovation are the cost-optimal solutions. However, heating system renovation generally has a shorter payback period.

Potential energy savings reach 8 Mtoe, i.e. 26 % of household actual consumption and 34 % of space heating and domestic hot water energy consumption. The overall investments would be €137 G. To reach the target set for residential sector by Italian Energy Efficiency Action Plan, it would be sufficient to achieve about a third of these potential savings by 2020.

This study points out that incentives (tax credit) are fundamental to promote building renovation, especially such renovations that require high investments and give more energy savings. In fact, decreasing the percentage of investment covered by tax credit, many energy efficiency measures become no more cost-effective and payback periods significantly increase. Without any incentives, potential energy savings would be reduced down to 3.3 Mtoe (-59 %), involving the 36 % of building stock and generating investments for only €30 G (-78 %). To be noted that white certificate scheme, that is an alternative to tax credit, is about three times less favourable.

Finally, if a building already needs a refurbishment (because of obsolete elements or deteriorated parts) it is important to exploit this opportunity to implement an energy renovation. Exploiting these opportunities generates potential savings for 427 ktoe/year and corresponding investments of about €12 G, i.e. three times current yearly investment in energy renovations. Avoiding these opportunities means to lock-in these energy savings for a long period.

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