A new price list for retrofit intervention evaluation on some archetypical buildings

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key words: buildings energy efficiency, price list, Reference Buildings, investment costs, running costs

Abstract

The latest Directive 2018/844/EU represents the guideline for the preparation of the Italian long-term strategy for the renovation of the building stock. The Directive proposes to the Member States the realization of a complete review of the buildings on the national territory, both public and private. This study wants to contribute to the reduction of lack of quality data in terms of structured price lists for energy investments on buildings, being a reference and support for professionals and researchers in the feasibility evaluations.

In particular, the aim of this research is defining a parametric price list for retrofit intervention on multi-family buildings. Beside the costs, energy consumptions and greenhouse gas emissions for different retrofit scenarios are also provided. The methodology adopted to reach this aim is organized into two subsequent processes: the energetic assessment and the financial evaluation. After the description of the methodology, an application on 8 archetypical buildings selected from the TABULA database is proposed. The methodological approach is potentially replicable to enlarge the knowledge on reference prices, consumptions and emissions values for buildings energy retrofit.

1. INTRODUCTION

In accordance with the Kyoto Protocol, the Member States of the European Union have committed themselves to a process aimed at fighting climate change through the adoption of community and national decarbonization policies. For the first time, an integrated approach between energy policies and the match against climate change was foreseen with the 2020 Climate-Energy Package at EU level. Starting in 2009, a series of Directives, and furthermore recast, have followed one another with the main objective of reducing greenhouse gas emissions, increasing the share of energy produced from renewable sources and increasing energy savings (European Commission, 2002; 2010). In 2015, during the XXI Conference of the Parties to the Framework Convention for the fight against climate change held in Paris (COP 21), the Paris Agreement was adopted as confirmation of the commitment. The latest Directive 2018/844/EU (European Commission, 2018), amending Directive 2010/31/EU on the energy performance of buildings, is the guideline for the preparation of the Italian long-term strategy for the renovation of the building stock. The Directive proposes to the Member States the realization of a complete review of the buildings on the national territory, both public and private, and an indicator-based roadmap, for the achievement of the decarbonization objective to 2050, with intermediate stages to 2030 and 2040.

In this context, Italy has adopted an Integrated National Plan for Energy and Climate (PNIEC – Piano Nazionale

Integrato per l'Energia e il Clima, 2018) for the achievement of detailed objectives in the energy field. The first objective aims to accelerate the process of cutting emissions based on the electrification of energy consumption, considering 2030 as an intermediate step towards a deep decarbonization of the energy sector by 2050. Sustainable actions should value the different forms of self-consumption in a distributed system favoring citizens and businesses. The PNIEC defines preliminary estimates that will be the basis for the preparation of the aforementioned strategy.

According to a statistical study based on ISTAT data (2011), the Italian building sector is mainly composed of residential buildings (84.3%). 51.8% of residential buildings are made up of single houses, but around 70% of the Italian population lives in multi-family buildings. The residential sector is followed by buildings for productive use, for commercial use and for services. The buildings for tourist/hospitality and management/ tertiary use cover only about 4% in both cases (Buso *et al.*, 2017). Most of the residential buildings are located in the average climate zone E (47.4%) including 4250 Italian municipalities out of a total of 8100. The achievement of the energy objectives is strategically linked to the use of a mix of fiscal and economic regulatory, and planning instruments (Bottero *et al.*, 2019a; D'Alpaos and Bragolusi, 2018). In this context, an elaboration of reference buildings (RBs) can be an useful tool for public administrations and individuals in order to estimate the potential energy savings coming from building sectors.

This study starts from the TABULA database (Typology Approach for Building Stock Energy Assessment, 2009-2012) aimed at creating a European building typology structure to make known the energy performance and potential energy savings achievable through energy efficiency measures (EMMs) (Ballarini *et al.*, 2014). Our study assesses the potential of residential buildings that fall into the most common building typologies in urban contexts update according the last European and National regulations. Indeed, the environmental quality of cities is lower than in suburban and rural context, and buildings play a fundamental role in this sense. Several energy efficiency measures (EEMs) were applied to the scale of the individual building and the connection to a district heating system has been evaluated. The different EMMs have been assessed from an energy point of view, in terms of kWh saved, but also by evaluating the reductions in greenhouse gas emissions of equivalent CO_2 (CO_{2eq}). Financial information has been coupled in terms of investment and running costs. The study aims to reduce the lack of quality data in terms of structured price lists building a reference and support for professionals and researchers in the feasibility phase of the energy investments (Becchio *et al.*, 2018; Bottero *et al.*, 2019b). The research stems from collaboration between the Department of Regional and Urban Studies and Planning (DIST) and the Energy Department (DENERG) of the Politecnico di Torino, which in recent years have collaborated for the development of integrated studies in the energy and economic fields.

The paper is structured in 5 sections; after the Introduction, Section 2 describes the applied methodology in the research. The application of the methodology on 8 archetypical buildings is foreseen in Section 3. The results are discussed in Section 4. The main conclusions are summarized in Section 5.

2. METHODOLOGY

The aim of this study is to define a parametric price list for retrofit intervention on 8 archetypical buildings. Beside the costs, energy consumptions and greenhouse gas (GHG) emissions for different retrofit scenarios are also provided. The methodology adopted to reach this aim is organized into two subsequent processes: the energy assessment and the financial evaluation. While the latter is fundamental to define running expenses and (if any) investments costs for each archetypical building in its current performance condition and under different retrofit scenarios, the former evaluation process is functional to the calculation of the energy consumptions and the subsequent GHG emissions of the buildings under the same assumptions. The two processes are described in the following sub-sections.

2.1 Energy assessment

The aim of the energy assessment phase is to define the energy consumptions and the subsequent GHG emissions for the analyzed buildings in their current performance condition and under different retrofit scenarios in order to provide reference values for them. To reach this aim, it is required to develop building energy models of the selected buildings and to run them under current and retrofitted conditions.

In detail, the energy assessment phase requires to: i) choose the sample of buildings on which perform the analysis; ii) collect data; iii) build the energy models, prior to the choice of the proper modelling approach; iv) choose the retrofit scenarios the analyst wants to assess; v) run the models under current conditions and different retrofit scenarios.

As mentioned in the introduction, being the aim of the study the definition of parametric values of costs and of reference estimations for energy consumptions and GHG emissions under different retrofit scenarios, the buildings selected for the analysis are Reference Buildings from the TABULA database. Reference Buildings (RBs) are real or statistically defined buildings that can be considered representative of a broader sample of buildings, identified by key variables like the typology (single family house, terrace house, multi-family house, apartment block) and the period of construction ("<1900", "1901-1920", "1921-1945", "1946-1960", "1961-1975", "1976-1990", "1991-2005", ">2006") (Corgnati *et al.*, 2013). Among the 32 RBs defined in TABULA (8 period of constructions times 4 typological classes), 8 RBs were selected in this application, as will be express later (Section 3). As a consequence, the data collection process was conducted referring to the TABULA database as well. Data typically required for this kind of application are geometrical data, envelope and systems information and, finally, operation schedules. To build the energy models needed for the assessment of current and post-retrofit energy consumptions, a semi steady-state simulation approach can be chosen, which, in the Italian context, is regulated by the package of Technical Specification UNI/TS 11300 (CTI, 2019). The calculation process can be performed through specifically developed computation tools or using professional software. Among this, MasterClima (MasterClima, 2017) represents a flexible and reliable solution. Thanks to the models thus developed, current energy consumptions for the RBs can be calculated and compared with the one provided by TABULA for calibration. The models can be used to assess the potential energy and emissions savings under different energy efficiency measures (EEMs) and/or a series of their combinations (scenarios). EEMs can be related to both envelope (e.g. insulation, windows replacement, etc.) and systems. Changing envelope and systems features into the energy models and running them, energy consumptions and related emissions are computed.

The energy consumptions assessed thanks to this methodological process represents the starting point for the calculation of running expenses (in terms of energy costs) under the different retrofit assumptions, composing the core of the financial valuation phase beside to the estimation of the maintenance costs and the investments required to achieve the different performance conditions.

2.2 Financial valuation

The European Directive 2010/31/EU (EPBD recast) has introduced the concept of cost-optimal for the evaluation both of energy retrofit projects and the construction of new buildings. The aim of the approach is to identify the optimal level of energy performance guaranteed by low investment and operating costs. If the energy performance level is measured as the amount of energy required to meet the building's energy needs, the cost is calculated using the Global Cost formula. The Global Cost is calculated according to the EN 15459-2017 (CEN, 2017) standard, which considers a series of costs that must be faced during the whole life cycle of building; initial investment costs, running costs, replacement costs and final value (Barthelmes *et al.*, 2016).

In the structured price list proposed in this paper, reference was mainly made to initial investment costs and running costs. The initial investment costs are all the initial costs to be faced for the realization of the energy efficiency of the building and plant system. Running costs include the main costs to be met for the energy consumption of the various plant systems and maintenance costs.

To obtain the total investment cost of each proposed measure, the initial costs for the redevelopment of the building envelope and generation system have been calculated analytically. Indeed, for each element the investment cost is determined by a reference price or by the direct search on the market.

Concerning the maintenance items, the preservation of buildings' technical components is considered. For this reason, we consulted the UNI EN 15459:2018 (CTI, 2018), in which are enumerated the lifespan and the maintenance costs for the different energy systems and building components. The costs, expressed as a percentage on the initial investment cost, are represented as annual expenditure including the maintenance, repair and servicing costs. In addition, operating costs were also considered for the different scenarios proposed for the RBs. Operating costs mainly refer to the costs to be incurred for space heating and domestic hot water (DHW) production, and auxiliaries of the distribution and generation systems.

3. APPLICATION

The application of the methodology described in Section 2 is proposed in this section of the paper. In particular, prior to the choice of the sample of buildings to study, this section aims to describe the process thanks to which reference values of energy consumptions, GHG emissions and running and investments costs were defined for 8 archetypical buildings were defined. The structure of this section reflects the methodological steps of energy assessment (3.1) and financial valuation (3.2).

3.1 Buildings energy performance assessment

In accordance to the aim of delivering reference values of consumptions, emissions and costs as a support for professionals and researchers in the feasibility phase of the energy investments, the building sample to analyze was selected among the database of RBs defined within TABULA project to be representative of the Italian building stock. In particular, 8 RBs were selected. They are Apartment Block (AB) and Multi-Family House (MFH) for 4 period of construction ("1946-1960", "1961-1975", "1976-1990" and "1991-2005"), representing the most numerous typologies, especially in urban context. As mentioned above, RBs can be real or statistically defined buildings. The ones selected for this study are all real buildings that TABULA project identified as representative. The data collection required to build their energy models was conducted using TABULA database as the main reference for geometrical data and for envelope and systems characteristics and performances. The latter are defined in terms of transmittances U (measured in W/m^2K) and efficiencies, respectively. Performances of the different sub-systems (emission, regulation, distribution, storage and generation) are defined as efficiencies or as mean thermal losses, parametrized on heated net floor area of the RB, like for consumptions of electric auxiliaries. The main information on RB are reported in Section 4 of this paper, while further information can be found in TABULA brochure (Corrado *et al.*, 2014). Thanks to this database, 8 energy models were built, allowing the computation of current energy-environmental performance of RB, and as the basis for EEMs simulations. The quasi steady-state simulation was performed through MasterClima software and in accordance with the national Technical Specification UNI/TS 11300-1 as an energy balance to determine space heating energy needs (considering also thermal capacities of the building components and including internal gains, as well as solar gains through windows, assuming to have no obstructions and shading effects), to which thermal losses due to all the different sub-systems of the plants (emission, regulation, distribution, storage and generation) are added to compute the final energy consumption for space heating (UNI/TS 11300-2). The same approach is used for domestic hot water production, whose needs at final users' level are estimated basing on medium square meters (UNI/TS 11300-2). Before running the simulations for the different energy efficiency scenarios, the models were calibrated against TABULA results, with an error below the 3% in 5 cases out of 8 and between 4% and 8% (only in one case) in the remaining 3. Then, three energy efficiency scenarios were selected, derived by the combination of different EEMs, as described in Table 1.

In particular, 3 energy efficiency (EE) scenarios were defined: Gas, Electric and District Heating one, suggesting through their names the choice of the thermal generator technology. All the scenarios include a deep renovation of the envelope, accomplishing the minimum transmittances defined in national standard (Ministry of Economic Development, 2015), in order to reduce thermal needs. Where a condensing gas boiler is installed, traditional radiators are replaced with low-temperature ones, while heat pumps introduction comes with the installation of a radiant floor system. In all the RBs in which the space heating final use is autonomous (namely, at apartment level) it is combined with DHW production, unless there are electric boilers for DHW. In all these cases, both space heating and DHW final uses become centralized when the retrofit occurs. When only DHW is autonomous, the condensing gas boiler introduction does not imply the centralization of this service, that conversely occurs when heat pumps of district heating are chosen. A thermal storage introduction and/or replacement is always included for both final uses (Figure 1)

The simulations of each scenario were run starting from the RBs MasterClima models, then, adopting the same computational approach discussed above and permitting to assess energy needs and final consumptions for the two analyzed final uses (space heating and domestic hot water production). None results in terms of comfort level has been evaluated. Moreover, it is important to say that, to run the simulation of the retrofit scenarios on the 8 models of RBs, assumptions similar to the ones defined in TABULA are fixed. For example, parametric values for storage thermal losses (expressed as kWh/m^2) are inputted into the model in order to simulate their installation. Similarly, mean seasonal coefficient of performance was fixed for heat pumps.

Running the models before the retrofit and under the different retrofit conditions bring to the results of consumptions and GHG emissions reported in Table 6. In particular, the final consumptions for each energy carrier (gas, electricity and district heating) were computed and, starting from them, GHG emissions and primary energy consumptions were derived according to the following coefficients (Table 2).

Final energy consumptions for the different energy carriers represents the starting point for the estimation of

Table 1 - *Energy Efficiency (EE) scenarios coupling envelope and systems interventions*

EE scenarios	SYSTEMS Substitution of traditional gas boilers with condensing ones (radiators replacement).	Substitution of traditional gas boilers Heat Pumps (radiators replacement) + Photovoltaic panels Installation.	Connection of the buildings to the district heating network (for both space heating and DHW production)
ENVELOPE Opaque envelope (walls and floors) insulation and windows replacement.	**Scenario Gas**	**Scenario Electric**	**Scenario DH**

the energy costs, that represents the core part of the running costs estimated in the followings (Section 3.2).

3.2 Life cycle costs estimation

As regards the succession of renovation works, reference is made to the work phases proposed in the DEI price lists (DEI, 2018); scaffolding assembly; retrofit of the opaque envelope with remaking of the external plasters, insufflation or external insulation, and replacement of windows according to the Italian regulations in force; installation of new insulated distribution pipes for heating and DHW; upgrading of systems for the production of DHW and supplying of heating; installation of photovoltaic

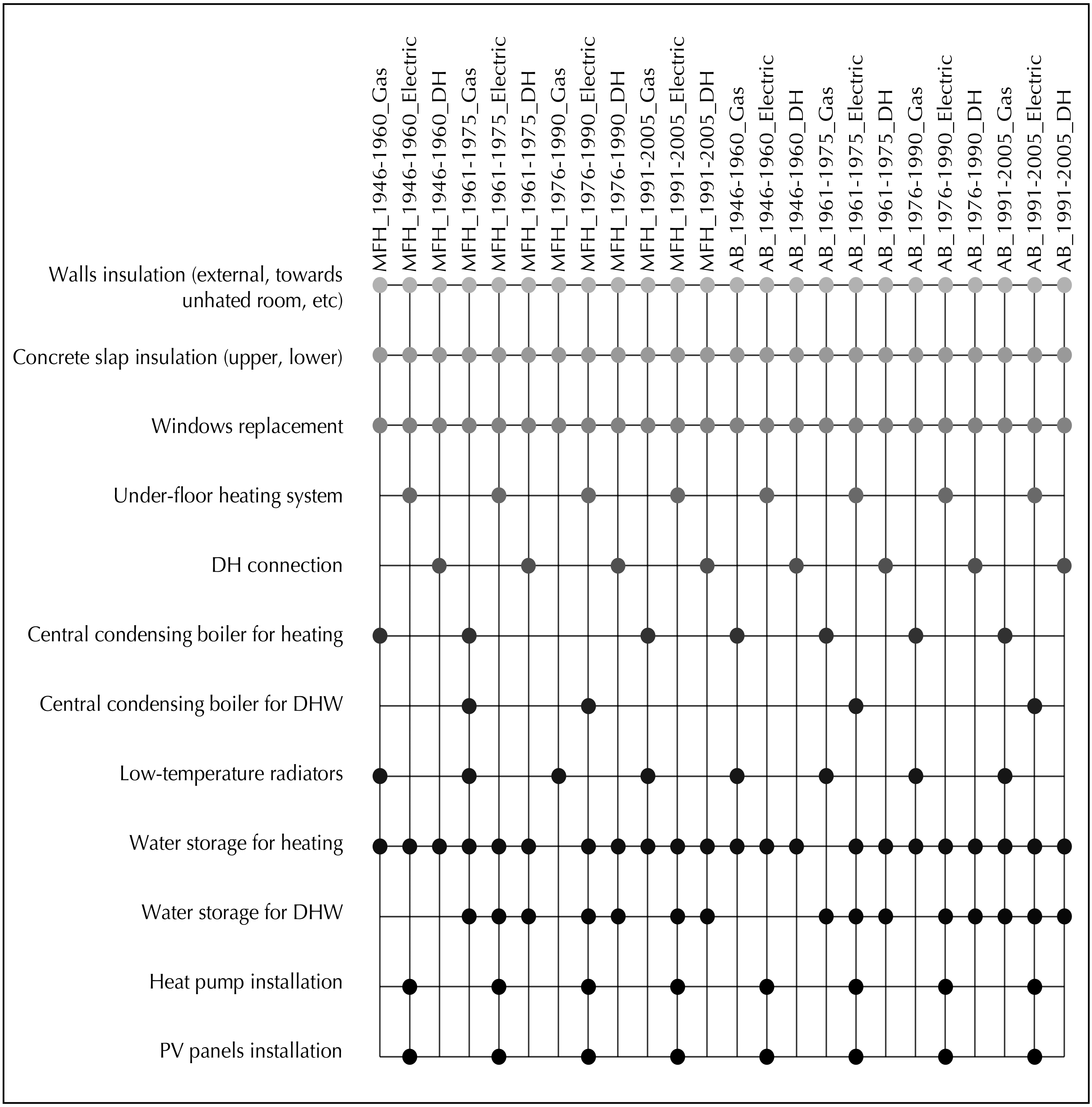

Figure 1 - *Retrofit scenarios configuration*

Table 2 - *Primary energy conversion factors and CO2$_{eq}$ emissions factors*

	Primary energy conversion factor	CO_{2eq} emissions factors
Natural gas	1.05 [-]	0.1969 [$kgCO_{2eq}$/kWh]
Electricity from the grid	2.42 [-]	0.4332 [$kgCO_{2eq}$/kWh]
Electricity from PV	1 [-]	0 [$kgCO_{2eq}$/kWh]
District heating	1.5 [-]	0.3088 [$kgCO_{2eq}$/kWh]

Source: DM 26/06/2015 (primary energy conversion factors) UNI/TS 11300-4 (emission factors).

(PV) panels where required. For each single measure implemented, the cost was analytically calculated using a bill of quantities. Indeed, for each element its cost is determined by a reference price list (unit price, €/m^2 or €/unit) or by direct market research.

The main reference price list used in this research comes from Piedmont Region (2018), in order to identify the prices of the area in which the RBs studied in this research are located. In case of absent elements, reference was made to the price list of the Autonomous Province of Bolzano (2018) and price list of Municipality of Milan (Municipality of Milan, 2018). We included all the prices connected to materials, work hours and technical installations retrofit. To do this, for each typology of building retrofitted, we estimated the cost per square meter of retrofitted envelope and the cost of substitution of the technical systems.

The first step was to create a unit price list, in which all the cost items are specified for each building element. The cost of labor was also considered if it was not already included in the cost of the element. Subsequently, an analytic calculation was drawn up which allows to determine all the surfaces to be calculated for each construction element (external wall, doors and windows, HVAC systems, etc.). Table 3 shows an excerpt of the analytic calculation as regards the transparent and opaque envelope of a RB. To obtain the initial investment cost for each of the RBs the costs of the individual items have been combined. The retrofit scenarios that include the connection to district heating, in addition to the plant costs, must support a connection cost to the network. For the calculation of the connection contribution, reference was made to the values provided by IREN (2019a), considering that the building is located near the existing network. In this case, the contribution amount is set at a flat rate depending on the volume of the building to be heated.

A further aspect to be taken into consideration during the life cycle is the maintenance of the building elements and the plant systems. These costs cover the expenses necessary to maintain the correct functioning of the system over the years. UNI EN 15459/2018 (CTI, 2018) defines maintenance costs during the useful life of the elements; in particular, these costs are calculated as a percentage of the initial investment cost. Following the European standard, annual maintenance costs mainly concern the plant system (Table 4). Where maintenance costs were not available, reference was made to real case studies (SUPSI, 2010).

The running costs also include the costs generated during the operation phase of the building. In this case, these are costs mainly due to the energy need of the building-plant system, which can be covered by different energy carrier. In particular, natural gas from national network, electric energy from the grid, district heating from a local supplier and electric energy from on-site PV panels are included in the selected scenarios. It was therefore necessary to calculate the operating costs based the energy consumptions per carrier estimated thanks to the energy models (Section 3.1). The ARERA (Italian Regulatory Authority for Energy, Networks and Environment - Autorità di Regolazione per Energia Reti e Ambiente) was consulted for the definition of gas and electricity prices (ARERA, 2018), while the operating cost in the case of the TLR scenarios was extrapolated from the actual district heating rates updated to the first quarter of 2019 for the Turin area (IREN, 2019b). All the energy carriers include a fixed and a variable quota. In particular, the variable one is expressed in €/kWh, to be multiplied for consumptions, while the fixed one is expressed in €/year, €kW and €/heated m^3 for gas, electricity and district heating respectively, and it is independent by the actual consumption.

The variable quota for gas varies according to the administrative region. Reference was made to domestic customers resident in North-West of Italy. Taxes, management and transport charges, VAT and excise duties were included. The fixed quota was translated into a parametric value express in €/m^2 for each RB, knowing the number of families occupying the building.

The variable quota for electricity varies according to the consumption band. Dividing the total consumptions for

Table 3 - *Investment cost for a RB*

1946-1960 AB	Description	Reference Price List Id.	Unit price	Total price
Measure: Windows replacement				
Windows area: 217 m^2	Removal of windows, removal of debris, their transport to an authorized disposal plant.	01.A02.C00.005	12.58 €/m^2	2’729.86
	Window with two doors; surface up to 3.5 m^2	03.P08.G01.045	235.91 €/m^2	51’192.47
	Installation of windows and doors, for any thickness, of any shape, size and number of doors in any timber.	01.A17.B30.005	39.90 €/m^2	8’658.30
	Double glazing with low emission.	01.P20.B04.025	44.67 €/m^2	9’636.39
Measure: Envelope insulation				
External walls area: 1’050 m^2	Stripping of plaster, removal of debris, including the transport of the debris to an authorized disposal plant.	01.A02.B60.005	6.53 €/m^2	6’856.50
	Plaster made with cement mortar, on rough coat, flat or curved.	01.A10.B20.065	15.91 €/m^2	16’705.50
	Multidirectional external tubular scaffolding hoist. Transport, assembly and disassembly are included (first 30 days)	01.P25.A98.005	11.65 €/m^2	12’232.50
	Multidirectional external tubular scaffolding hoist. Transport, assembly and disassembly are included (for five months beyond the first)	01.P25.A98.010	1.75 €/m^2	5’127.50
	Loose thermo-acoustic insulator in flakes for dry blowing.	03.P09.G08.005	2.64 €/kg	16’428.30
	Insufflation of thermo-acoustic insulating materials in flakes in wall cavities by dry blowing at low pressure.	03.A07.B02.005	67.80 €/m^2	71’190.00
	Water-based paint based on synthetic resins, washable, on external plaster.	01.A20.E30.010	9.36 €/m^2	5’484.96

Table 4 - *Annual maintenance cost according to UNI EN 15459/2018*

Component	% on investment costs
Plaster sheet	0
Insulation	0
Windows (wood)	0.5
Condensing boiler	2
Water floor heating	2
Heat pump (HP)	2-4
Pumps - circulation	2
Photovoltaic panel (PV)	1
Tank storage for DHW	1

the number of families it was defined that it was possible to assume to make reference to the lowest band for all cases apart for the “MFH 1946-1969” and “AB1946-1969”. Taxes, VAT and excise duties were also included. The fixed quota was translated into a parametric value express in €/m^2 for each RB, knowing the number of households and fixing a medium counter power per family (equal to 3 kW or to 4.5 kW, when a heat pump is installed). As defined at national level, for the consumed self-generated electricity, only excise duties were computed.

Finally, the variable quota for district heating was assumed by a local supplier, and the related fixed quota was translated into a parametric value expressed in €/m^2 for each RB, knowing the heated volume. All the costs items are resumed into the following table (Table 5).

Table 5 - *Variable and fixed quota of energy costs for each RB derived from ARERA (2018)*

		Apartment Block (AB)			
		'46 -'60	'61 -'75	'76 -'90	'91 -'05
Gas	[€/kWh]	0.0618	0.0618	0.0618	0.0618
DH	[€/kWh]	0.0749	0.0749	0.0749	0.0749
Electricity	[€/kWh]	0.1907	0.1414	0.1414	0.1414
PV electricity	[€/kWh]	0.0227	0.0227	0.0227	0.0227
Gas	[€/m^2]	1.3498	1.3824	1.1538	1.0913
DH (space heating)	[€/m^2]	2.9392	–	–	–
DH (space and water heating)	[€/m^2]	–	3.6072	3.6072	3.6072
Electricity	[€/m^2]	1.0004	1.0053	0.8350	0.7961
Electricity (with HP)	[€/m^2]	1.0238	1.0197	0.8451	0.8087
		Multi-family House (MFH)			
		'46 -'60	'61 -'75	'76 -'90	'91 -'05
Gas	[€/kWh]	0.0618	0.0618	0.0618	0,0618
DH	[€/kWh]	0.0749	0.0749	0.0749	0.0749
Electricity	[€/kWh]	0.1907	0.1414	0.1414	0.1414
PV electricity	[€/kWh]	0.0227	0.0227	0.0227	0.0227
Gas	[€/m^2]	1.2377	1.0615	0.9838	1.3279
DH (space heating)	[€/m^2]	2.9392	–	–	–
DH (space and water heating)	[€/m^2]	–	3.6072	3.6072	3.6072
Electricity	[€/m^2]	0.9603	0.8383	0.7633	1.0118
Electricity (with HP)	[€/m^2]	1.0033	0.8825	0.7975	1.0487

4. RESULTS

The application reported in Section 3 resulted in a set of sheets presented in the followings (Table 6). For each RB, the main geometric characteristics, the structure of the envelope and the installed technologies both for the state of the art and for future scenarios have been described. In the current state, energy performance, annual energy costs and CO_{2eq} emissions were indicated. For the 3 retrofit scenarios, maintenance costs are also implemented. The energy performance of the 8 selected RBs are expressed as primary energy consumptions per net heated floor area for space heating and DHW production, including auxiliaries. The CO_{2eq} emissions due to energy consumptions for space heating and DHW, normalised by the heated floor area, represent the environmental performance of RBs in current and retrofitted conditions. This graphic representation allows a better understanding of the relationships between the measures implemented for each archetype and a critical view of the energy, environmental and economic impact. Parameterized data on consumption and emissions make it possible to verify the economic and environmental convenience of certain interventions. This price list helps set up feasibility plans for energy redevelopment projects for multi-family buildings.

Looking at the results in terms of energy costs, it is possible to observe that fixed costs represents a percentage between 10% and 25% of the total energy costs in current conditions. The incidence of fixed costs increases in the retrofitted buildings, because the consumptions decrease, and are generally higher in newer buildings, since they have better energy performances than older ones. The district heating solution is not so convenient as expected, especially in buildings built in recent years. Indeed, although the energy performances of the newer buildings are greater, the fixed costs of DH are not affordable, compromising in some cases a positive result in its competition against gas-fuelled technologies. Even the environmental impacts of district heating are not the best solution compared to new centralized solutions at the block level. However, it is important to keep in mind that primary energy and emissions for DH have been computed considering standard values of conversion and emission factors respectively. Different results might be obtained accounting for local suppliers' specificities instead of standard ones. On the other hand, electric scenarios allow an energy costs reduction in most of the cases. Indeed, the energy efficiency of heat pumps guarantees a reduction in consumptions that counterbalanced the high cost of electricity with respect to natural gas one. However, since the retrofit scenarios have a limited impact on DHW energy needs, positive energy costs variation are related to space heating and not always the shifting to new energy carrier is convenient for DHW production. Besides higher investment costs, technologies based on the electrification of the generation system (heat pumps and PV panels) also require more maintenance operations and specialized technicians, determining the increase of the overall running cost. To have a picture about the investment costs composing the parametric values reported in Table 6, make reference to Figure 1 of this paper, while more specificities related to energy costs and maintenance ones have been reported in Table 4 and Table 5.

5. CONCLUSIONS AND FUTURE PERSPECTIVE

Thanks to this study the potential of energy saving and CO_{2eq} emission reductions from the current state to a retrofitted state of a set of RBs can be investigated. This study starts from the results of the TABULA project, which aimed to demonstrate how the RBs can be useful to define strategies at national level for the reduction of energy consumption. In this study reference was made to the Italian building stock, in particular to multi-family buildings located in climate zone E. In fact, the 8 RBs selected in this application are all real buildings located in the Piedmont Region (Italy) that, within TABULA project, were selected as Reference Buildings, namely as representative of the Italian building stock. Using TABULA database, energy models have been developed and costs have been associated with energy and environmental parameters. Referring to the Global Cost formula provided by the EU Directive, in this study the realization costs of the different retrofit scenarios analyzed and the running costs were calculated, in terms of operating and maintenance costs. This allowed the construction of a reference price list for certain building types, and the determination of parameterized values in terms of energy, environmental and economic impacts. The price list proposed in this work allows to have a detailed view of various energy efficiency packages that involve the building envelope.

The values reported in this work must be considered as indicative and used keeping in mind that the basic data refer to a specific Italian regional area. Construction costs, operating costs, and maintenance costs vary over time, and may change. Moreover, it is important to consider that, to run the energy simulation of the energy retrofit scenarios on the 8 models of RBs, assumptions similar to the ones defined in TABULA are fixed for sub-systems and generators features in order to keep the results generalizable.

The results obtained from this study are the basis of further investigations aimed at evaluating further building types, so as to cover the entire building stock. Further work may concern the evaluation of the potential of the energy retrofit of buildings starting from parameterized data by RBs price lists. Very important issues are coming up regarding the evaluation of the externalities produced by energy efficiency operations, the so-called co-benefits (IPCC, 2014). Generally, the extra-impacts involve different actors, first the property owners (Becchio *et al.*, 2017). In the future, it is possible to propose price lists that include other parameters to be taken into consideration in the preliminary assessment phases. The choice of the decision maker between different solutions can be influenced not only by financial and energy parameters, but also qualitative and perceptive aspects. In the private sector, the hours of thermal comfort guaranteed by a certain combination of efficiency measures compared to others can provide useful indications. The parameter of energy security

Table 6 - *Reference Buildings descriptions and results*

	BUILDING	Envelope	System	*Results*
MFH 1946-1960	 *Heated volume* 3076 m^3 *Total net floor area* 961.3 m^2 *N. of apartments* 12	***Walls*** Brick-masonry (25-38 cm) U_m = 1.53 W/m^2°C ***Roof*** Wooden pitch roof U_m = 1.8 W/m^2°C ***Floor*** Latero-cement slab U_m = 1.3 W/m^2°C ***Windows*** Wood frame, single glass U_m = 4.9 W/m^2°C	***Space heating*** Centralized system, Gas boiler (efficiency 0.85) ***Domestic hot water*** Autonomous systems, electric boilers (efficiency 0.75) ***Renewable energy sources*** None	*Consumptions (primary energy)* 335.86 kWh/m^2y *Emissions* 62.38 kgCO_{2eq}/m^2y *Energy costs* 23.39 €/m^2y (of which fixed: 9%)
MFH 1961-1975	 *Heated volume* 3074 m^3 *Total net floor area* 934 m^2 *N. of apartments* 10	***Walls*** Brick-masonry (25-30 cm) U_m = 1.23 W/m^2°C ***Roof*** Latero-cement pitch roof U_m = 2.2 W/m^2°C ***Floor*** Latero-cement slab U_m = 1.3 W/m^2°C *Windows* Wood frame, single glass U_m = 4.9 W/m^2°C	***Space heating*** Autonomous systems, Gas boilers (efficiency 0.88) ***Domestic hot water*** Autonomous systems, gas boilers (efficiency 0.84), combined with Space heating ***Renewable energy sources*** None	*Consumptions (primary energy)* 238.15 kWh/m^2y *Emissions* 44.63 kgCO_{2eq}/m^2y *Energy costs* 15.92 €/m^2y (of which fixed: 12%)
MFH 1976-1990	 *Heated volume* 4136 m^3 *Total net floor area* 1209 m^2 *N. of apartments* 12	***Walls*** Low insulated brick-masonry (25 cm) U_m = 0.79 W/m^2°C ***Roof*** Latero-cement pitch roof U_m = 2.2 W/m^2°C *Floor* Low insulated latero-cement slab U_m = 1.12 W/m^2°C ***Windows*** Steel frame, double glazed U_m = 3.7 W/m^2°C	***Space heating*** Autonomous systems, Gas boilers (efficiency 0.88) ***Domestic hot water*** Autonomous systems, gas boilers (efficiency 0.84), combined with Space heating ***Renewable energy sources*** None	*Consumptions (primary energy)* 156.58 kWh/m^2y *Emissions* 29.33 kgCO_{2eq}/m^2y *Energy costs* 10.97 €/m^2y (of which fixed: 16%)
MFH 1991-2005	 *Heated volume* 3526 m^3 *Total net floor area* 1120.5 m^2 *N. of apartments* 15	***Walls*** Brick-masonry and concrete walls (30 cm) with medium insulation U_m = 0.59 W/m^2°C ***Roof*** Latero-cement pitch roof U_m = 2.2 W/m^2°C ***Floor*** Medium insulated latero-cement slab U_m = 0.81 W/m^2°C ***Windows*** Wood frame, treated double glazed U_m = 2.2 W/m^2°C	***Space heating*** Centralized system, Gas boiler (efficiency 0.77) ***Domestic hot water*** Autonomous systems, gas boilers (efficiency 0.8) ***Renewable energy sources*** None	*Consumptions (primary energy)* 131.11 kWh/m^2y *Emissions* 24.55 kgCO_{2eq}/m^2y *Energy costs* 10.06 €/m^2y (of which fixed: 23%)

follows

Table 6 - *Reference Buildings descriptions and results (continue)*

	Envelope	System	*Results*
MFH 1946-1960	Insulation of the entire envelope and window substitution according to national standards (DM 26/06/2015)	Substitution of gas boilers with more performing ones (only for heating)	*Consumptions:* 90.92 kWh/m²y *Emissions:* 16.45 $kgCO_{2eq}/m^2y$ *Energy costs:* 8.95 €/m²y (of which fixed: 25%) *Maintenance costs:* 0.097 €/m²y *Investment costs:* 182.38 €/m²
		Substitution of gas boilers with electric heat pumps (only for heating) + PV panels	*Consumptions:* 58.98 kWh/m²y *Emissions:* 6.52 $kgCO_{2eq}/m^2y$ *Energy costs:* 4.39 €/m²y (of which fixed: 23%) *Maintenance costs:* 1.20 €/m²y *Investment costs:* 444.53 €/m²
		Connection to district heating system (only for heating)	*Consumptions:* 106.27 kWh/m²y *Emissions:* 19.95 $kgCO_{2eq}/m^2y$ *Energy costs:* 11.28 €/m²y (of which fixed: 35%) *Maintenance costs:* 0.029 €/m²y *Investment costs:* 206.91 €/m²
MFH 1961-1975	Insulation of the entire envelope and window substitution according to national standards (DM 26/06/2015)	Substitution of gas boilers with more performing ones	*Consumptions:* 55.82 kWh/m²y *Emissions:* 10.37 $kgCO_{2eq}/m^2y$ *Energy costs:* 5.18 €/m²y (of which fixed: 37%) *Maintenance costs:* 0.162 €/m²y *Investment costs:* 227.72 €/m²
		Substitution of gas boilers with electric heat pumps + PV panels	*Consumptions:* 27.26 kWh/m²y *Emissions:* 3.46 $kgCO_{2eq}/m^2y$ *Energy costs:* 2.19 €/m²y (of which fixed: 40%) *Maintenance costs:* 1.113 €/m²y *Investment costs:* 456.71 €/m²
		Connection to district heating system	*Consumptions:* 81.46 kWh/m²y *Emissions:* 4.58 $kgCO_{2eq}/m^2y$ *Energy costs:* 8.59 €/m²y (of which fixed: 52%) *Maintenance costs:* 0.473 €/m²y *Investment costs:* 250.96 €/m²
MFH 1976-1990	Insulation of the entire envelope and window substitution according to national standards (DM 26/06/2015)	Substitution of gas boilers with more performing ones	*Consumptions:* 49.97 kWh/m²y *Emissions:* 9.26 $kgCO_{2eq}/m^2y$ *Energy costs:* 4.68 €/m²y (of which fixed: 37%) *Maintenance costs:* 0.361 €/m²y *Investment costs:* 224.23 €/m²
		Substitution of gas boilers with electric heat pumps + PV panels	*Consumptions:* 29.46 kWh/m²y *Emissions:* 4.77 $kgCO_{2eq}/m^2y$ *Energy costs:* 2.42 €/m²y (of which fixed: 33%) *Maintenance costs:* 1.096 €/m²y *Investment costs:* 364.01 €/m²
		Connection to district heating system	*Consumptions:* 76.67 kWh/m²y *Emissions:* 15.55 $kgCO_{2eq}/m^2y$ *Energy costs:* 8.27 €/m²y (of which fixed: 53%) *Maintenance costs:* 0.543 €/m²y *Investment costs:* 211.02 €/m²
MFH 1991-2005	Insulation of the entire envelope and window substitution according to national standards (DM 26/06/2015)	Substitution of gas boilers with more performing ones	*Consumptions:* 45.21 kWh/m²y *Emissions:* 8.45 $kgCO_{2eq}/m^2y$ *Energy costs:* 5.00 €/m²y (of which fixed: 47%) *Maintenance costs:* 0.201 €/m²y *Investment costs:* 194.35 €/m²
		Substitution of gas boilers with electric heat pumps + PV panels	*Consumptions:* 25.92 kWh/m²y *Emissions:* 3.29 $kgCO_{2eq}/m^2y$ *Energy costs:* 2.68 €/m²y (of which fixed: 39%) *Maintenance costs:* 1.793 €/m²y *Investment costs:* 437.40 €/m²
		Connection to district heating system	*Consumptions:* 78.32 kWh/m²y *Emissions:* 15.89 $kgCO_{2eq}/m^2y$ *Energy costs:* 8.60 €/m²y (of which fixed: 54%) *Maintenance costs:* 0.554 €/m²y *Investment costs:* 212.53 €/m²

follows

Table 6 - *Reference Buildings descriptions and results (continue)*

	BUILDING	Envelope	System	*Results*
AB 1946-1960	 *Heated volume* 5949 m^3 *Total net floor area* 1763 m^2 *N. of apartments* 24	***Walls*** Brick-masonry (30 cm) and concrete walls (18 cm) U_m = 1.67 W/m^2°C ***Roof*** Wooden pitch roof U_m = 1.8 W/m^2°C ***Floor*** Latero-cement slab U_m = 1.3 W/m^2°C ***Windows*** Wood frame, single glass U_m = 4.9 W/m^2°C	***Space heating*** Centralized system, Gas boiler (efficiency 0.85) ***Domestic hot water*** Autonomous systems, electric boilers (efficiency 0.75) ***Renewable energy sources*** None	*Consumptions (primary energy)* 292.74 kWh/m^2y *Emissions* 54.28 $kgCO_{2eq}$/m^2y *Energy costs* 21.02 €/m^2y (of which fixed: 11%)
AB 1961-1975	 *Heated volume* 9438 m^3 *Total net floor area* 2869 m^2 *N. of apartments* 40	***Walls*** Brick-masonry (40 cm) U_m = 1.11 W/m^2°C ***Roof*** Latero-cement pitch roof U_m = 2.2 W/m^2°C ***Floor*** Latero-cement slab U_m = 1.52 W/m^2°C ***Windows*** Wood frame, single glass U_m = 4.9 W/m^2°C	***Space heating*** Centralized system, Gas boiler (efficiency 0.71) ***Domestic hot water*** Centralized system, Gas boiler (efficiency 0.73) ***Renewable energy sources*** None	*Consumptions (primary energy)* 281.25 kWh/m^2y *Emissions* 52.66 $kgCO_{2eq}$/m^2y *Energy costs* 18.95 €/m^2y (of which fixed: 13%)
AB 1976-1990	 *Heated volume* 12685 m^3 *Total net floor area* 4125 m^2 *N. of apartments* 48	***Walls*** Brick-masonry (40 cm) and concrete walls (18 cm) with low insulation U_m = 0.76 W/m^2°C ***Roof*** Latero-cement flat roof U_m = 1.85 W/m^2°C ***Floor*** Low insulated latero-cement slab U_m = 0.98 W/m^2°C ***Windows*** Steel frame, double glazed U_m = 3.7 W/m^2°C	***Space heating*** Centralized system, Gas boiler (efficiency 0.85) ***Domestic hot water*** Autonomous systems, gas boilers (efficiency 0.80) ***Renewable energy sources*** None	*Consumptions (primary energy)* 124 kWh/m^2y *Emissions* 23.20 $kgCO_{2eq}$/m^2y *Energy costs* 9.29 €/m^2y (of which fixed: 21%)
AB 1991-2005	 *Heated volume* 9912 m^3 *Total net floor area* 3271 m^2 *N. of apartments* 36	***Walls*** Brick-masonry (40 cm) and concrete walls (30 cm) with medium insulation U_m = 0.59 W/m^2°C ***Roof*** Medium insulated latero-cement flat roof U_m = 0.7 W/m^2°C ***Floor*** Medium insulated latero-cement slab U_m = 0.77 W/m^2°C ***Windows*** Wood frame, double glazed U_m = 3.4 W/m^2°C	***Space heating*** Autonomous systems, Gas boilers (efficiency 0.88) ***Domestic hot water*** Autonomous systems, gas boilers (efficiency 0.84), combined with Space heating ***Renewable energy sources*** None	*Consumptions (primary energy)* 97.36 kWh/m^2y *Emissions* 18.22 $kgCO_{2eq}$/m^2y *Energy costs* 7.62 €/m^2y (of which fixed: 25%)

follows

Table 6 - *Reference Buildings descriptions and results (continue)*

	Envelope	System	*Results*
AB 1946-1960	Insulation of the entire envelope and window substitution according to national standards (DM 26/06/2015)	Substitution of gas boilers with more performing ones (only for heating)	*Consumptions:* 88.13 kWh/m²y *Emissions:* 15.91 $kgCO_{2eq}/m^2y$ *Energy costs:* 8.97 €/m²y (of which fixed: 26%) *Maintenance costs:* 0.021 €/m²y *Investment costs:* 181.03 €/m²
		Substitution of gas boilers with electric heat pumps (only for heating) + PV panels	*Consumptions:* 61.04 kWh/m²y *Emissions:* 7.37 $kgCO_{2eq}/m^2y$ *Energy costs:* 4.72 €/m²y (of which fixed: 22%) *Maintenance costs:* 1.305 €/m²y *Investment costs:* 425.08 €/m²
		Connection to district heating system (only for heating)	*Consumptions:* 96.65 kWh/m²y *Emissions:* 18.03 $kgCO_{2eq}/m^2y$ *Energy costs:* 10.77 €/m²y (of which fixed: 37%) *Maintenance costs:* 0.016 €/m²y *Investment costs:* 180.50 €/m²
AB 1961-1975	Insulation of the entire envelope and window substitution according to national standards (DM 26/06/2015)	Substitution of gas boilers with more performing ones	*Consumptions:* 53.85 kWh/m²y *Emissions:* 10 $kgCO_{2eq}/m^2y$ *Energy costs:* 5.55 €/m²y (of which fixed: 43%) *Maintenance costs:* 0.181 €/m²y *Investment costs:* 184.02 €/m²
		Substitution of gas boilers with electric heat pumps + PV panels	*Consumptions:* 26.96 kWh/m²y *Emissions:* 3.37 $kgCO_{2eq}/m^2y$ *Energy costs:* 2.30 €/m²y (of which fixed: 44%) *Maintenance costs:* 1.893 €/m²y *Investment costs:* 430.16 €/m²
		Connection to district heating system	*Consumptions:* 78.64 kWh/m²y *Emissions:* 15.95 $kgCO_{2eq}/m^2y$ *Energy costs:* 8.61 €/m²y (of which fixed: 54%) *Maintenance costs:* 0.025 €/m²y *Investment costs:* 195.06 €/m²
AB 1976-1990	Insulation of the entire envelope and window substitution according to national standards (DM 26/06/2015)	Substitution of gas boilers with more performing ones	*Consumptions:* 39.79 kWh/m²y *Emissions:* 7.41 $kgCO_{2eq}/m^2y$ *Energy costs:* 4.33 €/m²y (of which fixed: 46%) *Maintenance costs:* 0.102 €/m²y *Investment costs:* 134.51 €/m²
		Substitution of gas boilers with electric heat pumps + PV panels	*Consumptions:* 23.59 kWh/m²y *Emissions:* 2.91 $kgCO_{2eq}/m^2y$ *Energy costs:* 1.96 €/m²y (of which fixed: 43%) *Maintenance costs:* 1.427 €/m²y *Investment costs:* 356.52 €/m²
		Connection to district heating system	*Consumptions:* 68.12 kWh/m²y *Emissions:* 13.79 $kgCO_{2eq}/m^2y$ *Energy costs:* 7.92 €/m²y (of which fixed: 56%) *Maintenance costs:* 0.029 €/m²y *Investment costs:* 137.39 €/m²
AB 1991-2005	Insulation of the entire envelope and window substitution according to national standards (DM 26/06/2015)	Substitution of gas boilers with more performing ones	*Consumptions:* 49.28 kWh/m²y *Emissions:* 9.13 $kgCO_{2eq}/m^2y$ *Energy costs:* 4.78 €/m²y (of which fixed: 39%) *Maintenance costs:* 0.159 €/m²y *Investment costs:* 160.67 €/m²
		Substitution of gas boilers with electric heat pumps + PV panels	*Consumptions:* 24.10 kWh/m²y *Emissions:* 3.04 $kgCO_{2eq}/m^2y$ *Energy costs:* 1.96 €/m²y (of which fixed: 41%) *Maintenance costs:* 1.656 €/m²y *Investment costs:* 387.75 €/m²
		Connection to district heating system	*Consumptions:* 67.86 kWh/m²y *Emissions:* 13.74 $kgCO_{2eq}/m^2y$ *Energy costs:* 7.86 €/m²y (of which fixed: 56%) *Maintenance costs:* 0.017 €/m²y *Investment costs:* 161.48 €/m²

guaranteed by a photovoltaic system in terms of reduction of energy blackouts can be implemented. The real estate value increase is one of the most studied and verified parameters in the scientific literature (Bottero *et al.*, 2018). In this context, qualitative information on the performance of buildings in terms of energy efficiency labeling is an indicator that reflects the advantages of retrofit directly.

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Bibliography

ARERA (2018), Italian Regulatory Authority for Energy, Networks and Environment. Available at: https://www.arera.it/it/inglese/index.htm. Accessed 12 May 2018.

AUTONOMOUS PROVINCE OF BOLZANO (2018), Provincial price list. Available at: http://www.provincia.bz.it/lavoro-economia/appalti/elenco-prezzi-provinciale-online.asp#accept-cookies. Accessed 12 May 2018.

Ballarini I., Corgnati S., Corrado V. (2014), *Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project*, Energy Policy, Vol. 68, 2014, pp. 273-284.

Barthelmes V., Becchio C., Bottero M., Corgnati S., *Cost-optimal analysis for the definition of energy design strategies: the case of a nearly-Zero Energy Building,* Valori e valutazioni, Vol. 16, 2016, pp. 61-76.

Becchio C., Bottero M., Corgnati S., Dell'Anna F., *A MCDA-based approach for evaluating alternative requalification strategies for a Net-Zero Energy District (NZED), Multiple Criteria Decision Making.* Springer, Cham, 2017, pp. 189-211.

Becchio C., Bottero M., Corgnati S., Dell'anna F., *Decision making for sustainable urban energy planning: an integrated evaluation framework of alternative solutions for a NZED (Net Zero-Energy District) in Turin*, Land Use Policy, Vol. 78, 2018, pp. 803-817.

Bottero M., Bravi M., Dell'anna F., Mondini G., *Valuing buildings energy efficiency through Hedonic Prices Method: are spatial effects relevant?*, Valori e valutazioni, Vol. 21, 2018, pp. 27-39.

Bottero M., Comino E., Dell'anna F., Dominici L., Rosso M., *Strategic Assessment and Economic Evaluation: The Case Study of Yanzhou Island (China)*, Sustainability, Vol. 11(4), 1076, 2019b.

Bottero M., D'alpaos C., Dell'anna F., *Boosting investments in buildings energy retrofit: The role of incentives,* Smart Innovation, Systems and Technologies, Vol. 101, 2019a, pp. 593-600.

Buso T., Dell'anna F., Becchio C., Bottero M., Corgnati S., *Of comfort and cost: Examining indoor comfort conditions and guests' valuations in Italian hotel rooms*, Energy Research & Social Science, Vol. 32, 2017, pp. 94-111.

CEN (2017), *Energy performance of buildings - Economic Evaluation Procedure for Energy Systems in Buildings*, EN 15459:2017. Comité Européen de Normalisation Standard.

Corgnati S. P., Fabrizio E., Filippi M., Monetti V., *Reference buildings for cost optimal analysis: Method of definition and application*, Applied Energy, Vol. 102, 2013, pp. 983-993.

Corrado V., Ballarini I., Corgnati S. P. (2014). *Building Typology Brochure – Italy. Fascicolo sulla Tipologia Edilizia Italiana.* ISBN: 987-88-8202-065-1. Available at: http://www.building-typology.eu/downloads/public/docs/brochure/IT_TABULA_TypologyBrochure_POLITO.pdf. Accessed 15 March 2019.

CTI (2018), Prestazione energetica degli edifici - Sistemi di riscaldamento e sistemi di raffrescamento idronici negli edifici - Parte 1: Procedura di valutazione economica per i sistemi energetici negli edifici, UNI EN 15459-1:2018. Comitato Termotecnico Italiano.

CTI (2019), Prestazioni energetiche degli edifici - 2: Determinazione del fabbisogno di energia primaria e dei rendimenti per la climatizzazione invernale, per la produzione di acqua calda sanitaria, per la ventilazione e per l'illuminazione in edifici non residenziali. UNI/TS 11300-2:2019. Comitato Termotecnico Italiano.

D'alpaos C., Bragolusi P., *Buildings energy retrofit valuation approaches: State of the art and future perspectives*, Valori e Valutazioni, Vol. 20, 2018, pp. 79-92.

DEI, Tipografia del Genio Civile (2018), Prezzi informativi dell'edilizia per Recupero, Ristrutturazione e Manutenzione; Rome.

EUROPEAN COMMISSION (2002), Directive 2002/91/CE, Energy Performance of Building Directive (EPBD), Bruxelles.

EUROPEAN COMMISSION (2010), Directive 2010/31/UE, Energy Performance of Building Directive Recast (EPBD recast), 2010, Bruxelles.

EUROPEAN COMMISSION (2018), Directive 2018/844/UE, Energy Performance of Building Directive 2nd Recast (new EPBD), Bruxelles.

IPCC, Intergovernmental Panel on Climate Change (2014), Climate Change 2014: Mitigation of Climate Change Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. University Press Cambridge, Cambridge. Available at: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf. Accessed 11 March 2019.

IREN (2019a), Connection fee and activities included. Available at: https://www.gruppoiren.it/modalita-di-allacciamento. Accessed 11 March 2019.

IREN (2019b), District heating rates for domestic use in Turin. Available at: https://www.irenlucegas.it/documents/66424/360788/TORINO+tariffe+tele+I%C2%B0+trim+2019.pdf/af2d6de4-69e7-4b90-b4b4-660f1418c30e. Accessed 11 March 2019.

ISTAT (2011), Population Housing Census 2011. Available at: http://dati-censimentopopolazione.istat.it/Index.aspx?DataSetCode=DICA_EDIFICIRES. Accessed 11 March 2019.

MASTERCLIMA SOFTWARE (2017). Available at: http://www.masterclima.info/page/Software.aspx. Accessed 15 March 2019.

MUNICIPALITY OF MILAN (2018), Listino prezzi per l'esecuzione di opere pubbliche e manutenzioni, Volume 1.2.

MINISTRY OF ECONOMIC DEVELOPMENT (2015). DM 26/06/2015 - *Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici*. Available at: https://www.mise.gov.it/index.php/it/normativa/decreti-interministeriali/2032966-decreto-interministeriale-26-giugno-2015-applicazione-delle-metodologie-di-calcolo-delle-prestazioni-energetiche-e-definizione-delle-prescrizioni-e-dei-requisiti-minimi-degli-edifici. Accessed 15 March 2019.

PIEDMONT REGION (2018), Piedmont Region price list. Prezzi di riferimento per opere e lavori pubblici nella regione Piemonte. Available at: http://www.sistemapiemonte.it/cms/privati/territorio/servizi/929-consultazione-prezzario-regionale-opere-pubbliche/3427-prezzario-2018. Accessed 11 May 2018.

PNIEC (2018), Piano Nazionale Integrato per l'Energia e il Clima Italiano. Available at: https://www.mise.gov.it/images/stories/documenti/Proposta_di_Piano_Nazionale_Integrato_per_Energia_e_il_Clima_Italiano.pdf. Accessed 11 March 2019.

SUPSI (2010), Preliminary analysis of district heating. Available at: http://www.supsi.ch/isaac/dms/isaac/docs/studi-ambientali/Rapporto-analisi-preliminare-teleriscaldamento--quartiere-Casarico-/Rapporto%20analisi%20preliminare%20teleriscaldamento%20%28quartiere%20Casarico%29.pdf. Accessed 11 March 2018.