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The cost optimal methodology for evaluating the energy retrofit of an ex-industrial building in Turin.

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Abstract

The recast of the Directive on the Energy Performance of Buildings (EPBD) requires Member States to set minimum energy performance requirements, for buildings, on the cost-optimal level. In Italy, the EPBD recast was transposed in a document (published in GU 2012/C 115) orienting the delegated regulation 244/2012 EU. Following cost-optimal methodology different energy efficiency measures were applied to an abandoned industrial building in Turin, Northern Italy, in order to identify the best retrofit configuration in terms of energy and cost effectiveness.

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Keywords: methodology; retrofit measures; environmental sustainability; economic sustainability; ex-industrial building; dynamic simulation

1. Introduction

Nowadays, the refurbishment offers many challenges and opportunities in a sector where most energy is consumed by existing buildings. The replacement rate of existing buildings by new ones is around 1–3% per annum. Retrofit actions on a large scale can determine significant energy savings. The definition of minimum energy performance requirements represents a key element in the European building codes. For this reason, EPBD recast [1] has set out Member States must ensure that minimum energy performance requirements are set with a view to achieve the cost optimal level. This is defined as the energy performance level which leads to the lowest cost during the estimated economic life cycle.

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The Italian context requires following the Guidelines accompanying the Commission Delegated Regulation No.244/2012 [2]. The paper applies the methodology described by Guidelines for identifying the cost-optimal levels of an abandoned industrial building in Turin, Northern Italy. Turin, just before the economic-financial crisis involving also the real estate market and the construction sector, has implemented urban transformations. This process has allowed the city of Turin to be one of the European cities which changed its structure and its urban landscape, marked by many ex-industrial areas, and starting its transformation from a post-industrial city to a "smart city".

For these reasons, the research aim is to test the cost-optimal methodology as a tool for supporting the evaluation of current and future energy retrofit projects related to Turin's transformation areas.

Specifically, the purpose of the work is to simulate a real situation, in which a potential real estate developer considers the opportunity to invest into an ex-industrial building retrofit project; implicitly, the focus is posed on the decision among alternative investment options, each related to an alternative energy scenario, in order to select the most energy and cost effective one/s. Furthermore, this work for the first time attempts to connect the concept of optimal cost to the concept of energy efficiency classes.

Through the application of the methodology to this specific case-study, the work aims to lay the foundation for extending the cost-optimal method to other ex-industrial buildings submitted to energy retrofit interventions.

2. Methodological framework

In 2012, the Commission Delegated Regulation (EU) No. 244/2012 and the Guidelines [2] that accompany the Regulation, supplementing the Directive 2010/31/EU were published. These documents represent a valid tool to apply the methodology framework for calculating cost-optimal levels.

The methodology applied in this research involves to:

- define a reference building (RB) representative of the examined building stock;
- define the energy efficiency measures (EEMs) involving the improvement of the building envelope thermal performances and the systems efficiency;
- combine EEMs into packages in order to create different scenarios;
- evaluate the final and primary energy consumptions for the different scenario;
- calculate the costs of each scenario related to proper economic life cycle.

Energy and economic input data (e.g. weather condition, energy costs, initial investment cost etc.) used in this study derive from existing databases or from specific research done in both energy and economic field, specifically the real estate market of the city of Turin. The energy assessment of different scenarios was conducted by means of dynamic simulation through the EnergyPlus program (version 8.0) [3], developed by the research laboratories of the U.S. Department of Energy since 2001. Given the use of dynamic simulation and the inherent calculation times, a study based on a limited amount of technically feasible scenarios constituted by different energy efficiency measures, rather than a parametric study, was conducted. The costs of the different scenarios were evaluated using the European Standard EN 15459:2007 methodology [4], in order to establish which scenario has the lowest global cost, and hence, the one which represents the cost optimal level.

3. The case-study

As shown in Figure 1, the RB consists of a two-storey building with a tower of three floors at an end and is located in the North area of Turin (Northern Italy). This town portion is characterized by an industrial urban setting with many empty spaces. Currently, many of these spaces are object of significant enhancement operations. The analyzed building was an electric cables factory, manufactured in 1888. Currently, the building is abandoned. The Turin Municipality reclaimed the surrounding area. Moreover, some neighboring buildings have already been under renovation. The building refurbishment includes also the transformation from an industrial use to a residential and commercial one.

The building, characterized by a total floor area of about 2500 square meters, has a rectangular plan and its main axis is North-South oriented. Nowadays, it comprises external opaque façades distinguished for historic value, roof and intermediate slabs without any interior partitions. Due to the fact that the ground floor is characterized by about 8.7 meter height, building refurbishment includes the addiction of an intermediate slab. Consequently new total floor area amounts to 3600 square meters.

a b

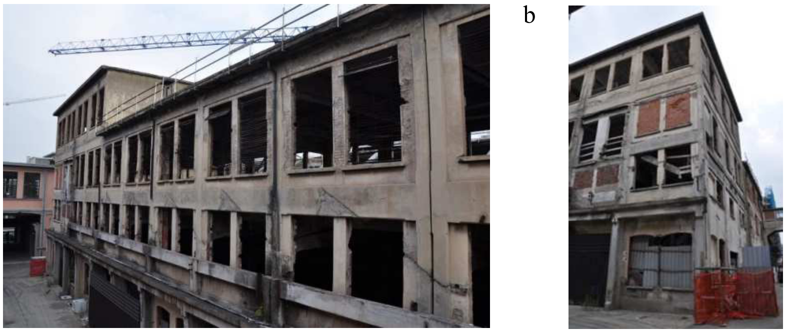

Fig. 1. The ex-industrial building.

4. Energy evaluation

1. 4.1. Energy Efficiency Measures and scenarios

In accordance with the EPBD Guidelines [2], different energy efficiency measures (EEMs) were defined and applied to RB. EEMs regard the improvement of the building envelope thermal insulation coupled with different HVAC systems configurations together with the exploitation of renewable energy sources.

The identified measures were combined in order to create twenty-four scenarios characterized by different performances in terms of both energy consumptions and costs.

Since the RB is located in Turin, thermal transmittance U-values for EEM 1, EEM 2 and EEM 3 were set respectively in compliance with the minimum and the optional values required by regional regulation [5], and the optional values required by the Turin city regulation [6]. For the purpose of not altering the external façades of the building characterized by historic value, the insulation layer was applied on the inside surface of the external walls.

Regarding to residential spaces, the primary system is constituted by a water-to-water heat pump or a condensing boiler coupled with a chiller with cooling tower with (CMV) or without controlled mechanical ventilation (NV) depending for different scenarios; for all scenarios the terminal devices of heating and cooling system are radiant floors. Regarding to commercial spaces, the hypotheses for the primary system are the same of those of residential ones; the terminals of heating and cooling system are four-pipe fan coil units. Moreover, in order to comply with national regulations on the minimum total power output for photovoltaic systems [7], for all scenarios forty PV panels were installed on the roof together with twelve flat plate solar collectors, designed to cover 60% of the DHW net energy need.

In Table 1 the features of the different energy scenarios are summarized.

2. 4.2. Dynamic simulation assumptions

The objective of the dynamic energy evaluation was to determine the annual overall energy use (including space heating and cooling, ventilation, lighting, equipment) of the hypothesized scenarios in terms of delivered energy (divided by sources) and of primary energy (primary conversion factor for electricity is equal to 2.18, for natural gas is 1[8]).

The energy simulation was conducted with reference to the current use of the building. The building was divided into 8 thermal zones; one of them was unconditioned. A detailed sub-hourly simulation was conducted for each scenario, using the reference IWEC (International Weather for Energy Calculations) weather file for Turin retrieved from the EnergyPlus weather data files database. Operational parameters were set to be consistent with the building typology. In accordance with EN 13790:2008 [9] lighting and appliances power densities were respectively defined to 3.88 W/m² and 2.9 W/m² for residential use and 15.06 W/m² and 4.8 W/m² for commercial one. These densities were connected to activities schedules carried out in the building during the weekdays and the weekends. The heating system has been assumed to be active from the 15th of October to the 15th of April in compliance to the Italian regulations for the climatic zone E (Turin). The cooling system has been set to operate from the 1th of May to the 30th of September. All days, the heating and cooling setpoints were set respectively to 21 °C and 26 °C from 7 a.m. to 8 p.m. in both residential and commercial spaces. During weekdays, the outdoor air flow rate is set at 11 l/s per person operating from 7 a.m. to 8 p.m.

5. Economic evaluation

3. 5.1. Calculation assumptions

After the energy evaluation, the calculation of the global cost was performed for each scenario in order to select the lowest global cost scenario, representing the cost-optimal level.

The global cost was valuated applying the EN 15459 methodology [4]. In accordance with the Guidelines [2] the calculation results in a net present value of costs incurred during a defined calculation period, set to 30 years. The time period used for the calculation was specifically defined for buildings with residential use. In the analysis residual values of components with longer lifetimes were also considered. The data on the duration of the system components cost were defined referring to Appendix A of EN 15459:2007. In this Appendix are also available annual maintenance costs of systems components as percentage of the components costs.

EEMs investment costs refer to the price list of the Piedmont Region of 2012 [10]. For each scenario the costs related to energy consumption for space heating (natural gas), for space cooling, lighting and equipment (electricity) were considered [8]. In detail, the cost of natural gas cost was assumed equal to 0.49 €/m³, while that of electricity equal to 0.30 €/ kWh. Concerning gas and electricity prices an annual increase amounting to 2.3% was taken into account according to the European trends until 2030 [11].

Table 1. Summary table of primary energy consumptions, global costs and energy efficiency classes subdivided for commercial and residential uses.

	Envelope EEM	System EEM of commercial spaces	System EEM of residential spaces	Primary energy consumption (*kWh/m²year*)	Cost (*€/m²*)	Energy class of Residential spaces	Energy class of Commercial spaces
Scenario_1	EEM1	fancoil; boiler+chiller; CMV	radiant floor; bolier+chiller; NV	149	989	B	A
Scenario_2	EEM1	fancoil; boiler+chiller; CMV	radiant floor; boiler+chiller; CMV	151	1030	B	A
Scenario_3	EEM1	fancoil; boiler+chiller; CMV	radiant floor; heat pump; NV	164	1151	C	A
Scenario_4	EEM1	fancoil; boiler+chiller; CMV	radiant floor; heat pump; CMV	166	1115	C	A
Scenario_5	EEM1	fancoil; heat pump; CMV	radiant floor; boiler+chiller; NV	155	1032	B	B
Scenario_6	EEM1	fancoil; heat pump; CMV	radiant floor; boiler+chiller; CMV	156	1070	B	B
Scenario_7	EEM1	fancoil; heat pump; CMV	radiant floor; heat pump; NV	168	1197	C	B
Scenario_8	EEM1	fancoil; heat pump; CMV	radiant floor; heat pump; CMV	168	1148	C	B
Scenario_9	EEM2	fancoil; boiler+chiller; CMV	radiant floor; boiler+chiller; NV	134	995	A	A+
Scenario_10	EEM2	fancoil; boiler+chiller; CMV	radiant floor; boiler+chiller; CMV	136	1019	A	A+
Scenario_11	EEM2	fancoil; boiler+chiller; CMV	radiant floor; heat pump; NV	144	1111	B	A+
Scenario_12	EEM2	fancoil; boiler+chiller; CMV	radiant floor; heat pump; CMV	148	1059	B	A
Scenario_13	EEM2	fancoil; heat pump; CMV	radiant floor; boiler+chiller; NV	136	1011	A	A
Scenario_14	EEM2	fancoil; heat pump; CMV	radiant floor; boiler+chiller; CMV	137	1036	A	A
Scenario_15	EEM2	fancoil; heat pump; CMV	radiant floor; heat pump; NV	146	1125	B	A
Scenario_16	EEM2	fancoil; heat pump; CMV	radiant floor; heat pump; CMV	146	1072	B	A
Scenario_17	EEM3	fancoil; boiler+chiller; CMV	radiant floor; boiler+chiller; NV	132	1024	A	A+
Scenario_18	EEM3	fancoil; boiler+chiller; CMV	radiant floor; boiler+chiller; CMV	134	1045	A	A+
Scenario_19	EEM3	fancoil; boiler+chiller; CMV	radiant floor; heat pump; NV	146	1127	B	A+
Scenario_20	EEM3	fancoil; boiler+chiller; CMV	radiant floor; heat pump; CMV	143	1070	B	A
Scenario_21	EEM3	fancoil; heat pump; CMV	radiant floor; boiler+chiller; NV	142	1041	A	A
Scenario_22	EEM3	fancoil; heat pump; CMV	radiant floor; boiler+chiller; CMV	136	1065	A	A
Scenario_23	EEM3	fancoil; heat pump; CMV	radiant floor; heat pump; NV	148	1144	B	A
Scenario_24	EEM3	fancoil; heat pump; CMV	radiant floor; heat pump; CMV	141	1083	B	A

4. 5.2. Cost Optimal Level

For each scenario the global cost was calculated. It was expressed as a function of the conditioned floor area of the entire RB. This cost is fundamental in order to identify the scenario which can be defined the cost-optimal level of energy performance. In this way it's possible to analyze the different scenarios not only in terms of energy consumptions, but also in the economic ones, which greatly influence the investor/user intervention choices.

Finally, according with regional regulation [12], estimated primary energy consumptions were used to assess the energy efficiency classes for each scenario. In this case, only primary consumptions for space heating and domestic hot water production were considered. The Table 1 sums up the primary energy consumptions, the global-cost and the energy efficiency class for the twenty-four scenarios.

6. Results

The cost-optimal graph, in the Figure 2, shows the global costs values of the different scenarios expressed in €/m^2 (y-axis), in function of the primary energy consumptions expressed in kWh/(m^2·year) (x-axis). The data were divided into the three categories of intervention and have different graphic forms.

The cost-optimal graph was modified in order to apply the methodology correctly. In detail, in addiction the energy efficiency class, with the aim to implement the research, was inserted.

The curve connecting the outer points closest to the abscissa axis and the ordinate axis is the specific cost curve, called "cost-curve". The minimum value lying on the curve represents the cost optimal level. The scenario with the lowest global cost specified in the graph also shows the optimal level of energy performance in relation to the costs, which is the cost-optimal level of energy performance.

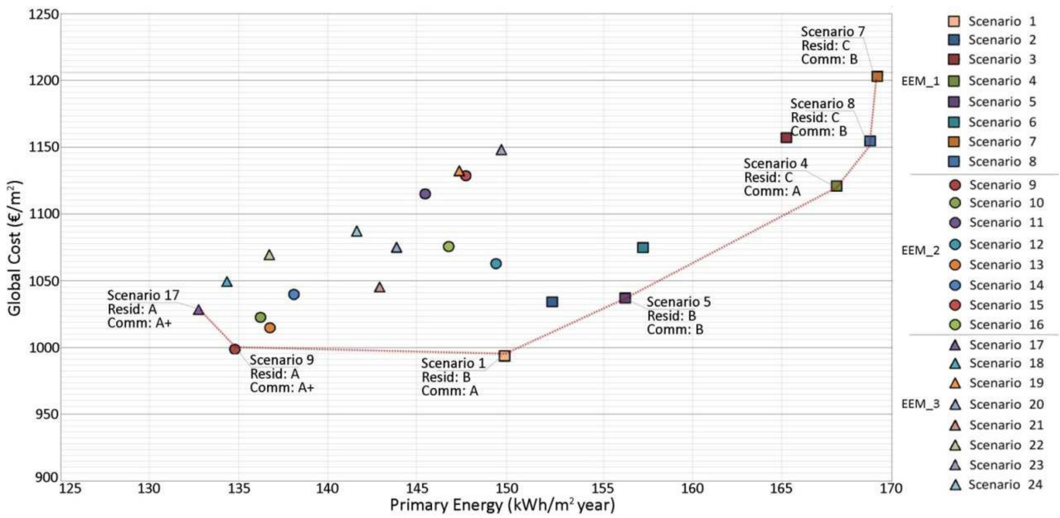

Fig. 2.Cost-optimal graph.

Scenario 1 has the lowest global cost, indeed it lies at the lowest point of the curve. According to the methodology, this one may be considered as the best retrofit scenario, and it can be defined cost-optimal level. Also the scenario 9 can be taken into account, although it presents a slightly higher specific global cost. However, it provides lower primary energy consumption, reduced by about 15 kWh/m^2 year. The reduced need for energy demand in scenario 9 determines a better evaluation of the energy class. The residential building switches from a class B to a class A, while for commercial building rises from class A to an A +. Both scenarios present the same primary energy system; radiant floor, condensing boiler and chiller with natural ventilation for residential use; fan-coil units, condensing boiler and chiller with controlled mechanical ventilation for commercial spaces; the thermal solar and photovoltaic system consist of the same number of panels. The only difference between the two scenarios, which determines the increasing cost and the decreasing consumptions, is constituted by the thermal insulation level of building envelope. Building envelope of scenario 1is less performing than that of scenario 9.

Therefore, the final choice between the two scenarios depends on the user's propensity to invest resources to get the best energy performance and, consequently, lower running costs.

7. Conclusions

Throughout the research some issues correlating physical data to estimative ones were detected. With the aim to apply the cost-optimal methodology on a concrete local context, it is necessary a preliminary reasoning about the criticalities listed below:

- the lifespan of building elements used for the redevelopment and for upgrading the energy efficiency. Lifespans proposed by the guidelines of EN 15459 [4], or by other Italian rules are reflected in the UNI 11156/2006 [13], are reliable, but must be adapted to each specific case. Also in the mentioned above documents, all types of systems are not considered;
- the estimate of the evolution of energy prices. The information, that the guidance accompanying the Delegated Regulation (EU) No. 244/2012 provides, are taken from energy trend scenarios, elaborated with the Prime model [14]. However, if the predictions differ much from reality, the results, and therefore the scenarios, would be greatly affected;
- the methodology is designed to hypothetical private subject, for example a developer that will manage the property for all the calculation period. The utility of the methodology can be adapted to other kind of subjects, but in this case, it must be carefully designed according to the different goals and roles of the subjects themselves;

The expectation is that this work could be the starting point for other researches, which could further deepen the aspects here studied. Furthermore, the expectation is that the relationships between the Real Estate Appraisal and Project Evaluation discipline and the Building Physics discipline would be increasingly studied in order to strengthen their synergy.

An interesting direction toward address the research could be the use of the proposed methodology as a tool to direct policy interventions on building heritage, also at urban scale.

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