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Building energy retrofitting in urban areas

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Abstract

The analysis of existing built environment shows that the critical values of the peripheral areas, together with the very poor energy performance of existing buildings and the levels of possible transformations they imply, may contribute, collectively, to formulate from light to radical proposals for urban and building retrofitting.

In such urban contexts, the reading of urban spaces and the environmental evaluation of their use, both in relation to the intrinsic features of the buildings and with the outdoor spaces, take on a renewed importance. In terms of architectural structure, this importance is focused on the building shell, which can be properly re-thought by proposing new energy efficient technological solutions aimed at re-shaping the technical and formal aspect of the building. These solutions, although developed and conducted on a single building and at the building-level technology, thus contributing to re-function the spatial units, may also been conceived in order to positively affect the urban places and the surrounding environment, fostering a mending relation between the built space and the environmental boundary conditions.

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1. Introduction

Every hypothesis of adaptation/transformation of existing buildings is inextricably linked to the careful reading of their typological and constructive systems as well as to the search of a sustainable integration between the buildings' features and their surrounding boundary conditions. In particular, the reading of the existing values of the peculiar building types and their urban surroundings as well as the consequent

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possible transformation aimed at the building energy retrofitting may result in a critical framework able to drive and address, at the operational level, the process of re-design the built urban environment.

Over the last decades, energy oriented innovations in building technology have emerged in many areas of the building construction sector. The strong interest in energy saving measures is also evident when considering the increasing number of green Zero Energy Buildings (ZEB) and the subsequent media attention they attract [1].

In addition to the growing investments in renewable energy technology from private companies [2] feed-in tariffs and to the policy incentives contributing to the city government of climate change [3], huge additional investments are needed to reduce carbon emissions and fossil fuel consumption. The treaty issued by several NGOs calls for a doubling of market investments by 2012 and quadrupling by 2020 to attain the proposed carbon emission reduction targets. “Needless to say, this is particularly challenging in a context of global economic slowdown such as the one the world is currently experiencing” [4]. In fact, in a period of economic crisis, rather than thinking of large incremental development plans, it is wiser to suggest urban retrofitting operations conceived as the punctual nodes of a longer term re-planning, as they have the potential to generate new identity processes at the urban scale.

As also reported in [5], there is a strong need for feasible solutions where energy saving can be reached by the search of an integrated design combining constructive passive tools with existing renewable energy systems, such as solar and wind energy micro-generation, without recurring to more sophisticated high-tech or innovative components. It’s therefore necessary to exploit the potential of available technologies in current energy efficient and low energy buildings by exploring their integration into demonstrative residential projects at urban scale. On the other side, measures to improve the energy efficiency of heating existing buildings offer a significant opportunity to reduce primary energy use and CO_2 emissions [6]. Therefore, instead of focusing on new developments and newly conceived buildings we need to shift our energy-efficient technical knowledge to existing buildings within the urban areas of active cities, since they represent the biggest challenge both in carbon terms –because of the large amount of existing stock- and for its potential impact on re-activating existing urban sites towards low carbon transitional processes. In this framework Bologna seems to have an enclosed potential represented by those buildings of the first and second fringe areas that are often pictured as denigrating the historical beauty of the city.

2. Retrofitting existing buildings in urban areas: a case study in Bologna

In the formation of the historical quarters of the “Bolognina”, the north sector peripheral area of Bologna, the court dwellings designed an inclusive sociability in well-defined urban forms, very different from the subsequent urban residential areas, which are characterized by the "fragmentation" of the morphological types and by the loss of urban identity. From 1932 on, in fact, by reducing the continuity of the façade construction along the streets, the social Houses “Popolari” and “Popolarissime”, introduced a dwelling/urban type, which definitely altered the profile of the urban islands. These building types, in fact, marked a clear break in the physical perception of the urban environment, especially in the relationship between the built spaces and the urban community places: since then, the perception by the public space (the street) will change radically, as it hosts, in fact, the blind slat heads of the long buildings. However these buildings, built from 1934 to 1937 and for the first time constructed with a reinforced concrete structure, set an example so far unique in the panorama of the construction and building type of the city. Compared with the limited possibilities of energy adaptation in historic buildings, on the contrary, the energy and environmental adaptation of these more recent dwellings shows higher levels of appropriate transformability: the technological and constructive characteristics of the buildings, along with the critical issues and the potential values of the urban spaces they are located in, concur to the formulation of proposals for energy retrofitting not necessarily limited to the scale of the single building, but more extensively intertwined with the urban scale's rehabilitation.

2.1. Environmental adaptation and energy retrofitting of "popolarissime" in Via Vezza.

The re-adaptation design procedure at the urban scale aims to enhance the relations between the spatial and fruition network and the surrounding relevant areas, with particular reference to the public parks and green areas. For this purpose, it is assumed the close Via Vezza to traffic and to build an underground car park. The dashed red line in Figure 1 represents the portion of the street closed to traffic.

Fig. 1. (a) The urban boundary conditions retrofitting actions around the reference buildings; (b) a view of the buildings from Via Vezza (top) and Via del Lavoro (below).

Even though the paper does not assess the positive effects of open green spaces on the improvement of microclimate and outdoor temperatures [7], [8], [9] green and "sustainable" paths linking the open spaces within the area have been regarded as key elements to drive the building retrofitting while considering the surrounding areas and the local urban conditions. This urban scenario at the urban scale has been assumed as the boundary conditions' frame of the single buildings' rehabilitation process. The thermal analysis of the building demonstrates a really poor energy performance: Ep index is equal to 206.39 kWh/m^2y, against a limit value for the entire building Ep_{lim} of 64.69 kWh/m^2y; thus it is a very energy-intensive consuming building (Class F according to the regional energy laws -Class F: $170 < EP_{tot} < 210$-). The rehabilitation procedure has set the reference building against a dual scenario, with subsequent different and alternative design scenarios: on the one hand the provision of thermal insulation and a complete replacement of the components window, on the other hand, the introduction of a buffer zone between the inside and the outside of the building, designed to reduce the energy losses through the building envelope and improve overall energy performance. This buffer zone, a "greenhouse", made up by the installation of a steel structure, can be considered as a direct intervention on the building envelope. The first retrofitting scenario (thermal insulation of opaque walls), results in a class C (Ep = 82.31), while with the sole replacement of window components, the building is in Class E (Ep = 169.26).

Higher transformation of the building shell have been furthermore hypothesized and a buffer zone consisting of a sunspace between the building and the outdoor environment has been designed; in particular, a secondary structure has been designed as an opportunity to improve the building performance. The energy potential and overheating problems of sunspace structures connected to the building has been investigated in [10]; in this specific context these added space is considered open during the hot summer season (thus providing balconies and shading on the building envelope) and closed in winter period, when the spaces interposed between the filter and the outside may greatly reduce the transmission losses through the building envelope. The proposed solution also provides a level far superior in terms of maintainability of the façade; if this solution is furthermore combined to an external thermal insulation, the building envelope can satisfy the values of transmittance and, simultaneously, the building as a whole may achieve the minimum limit required for the building energy performance index; in this case the building performance results in the increase of the energy class to the B, which corresponds, in winter conditions, to energy savings of 80% compared to the current situation. Because of the favorable solar orientation of the reference building, the integration with the energy generation technologies from renewable sources have been further explored, thus extending the possibility of transformation to the re-plant systems. Colored photovoltaic panels in red and gray, made up by mono-crystalline silicon, are used in the south façade; as a partial replacement of glass components, semi-transparent panels, always in single-crystal silicon (with level transparency 10-15%) are supposed to be used. A significant improvement in the energy performance of the building can be achieved through the replacement of gas boilers with a geothermal heat pump and probe powered by the photovoltaic plant. Table 1 highlights (in green) the solutions that allow to bring the building energy requirements within regulatory limits (Ep lower than Eplim kWh/m2y- -64.69).

Table 1. A comparison among the different energy retrofitting actions in the reference building and the corresponding energy saving

Different scenarios	Q_{ht}	Q_H	Q_P	EP_i	EP_{acs}	EP_{tot}	EP_{lim}	classe	€/kWh	€	Saving €/year	%
0 - Original	234.062,19	208.237,19	260.296,49	188,39	18,00	206,39	64,69	F	0,086	22.385,50	\	\
1 – External	110.579,12	72.297,20	90.371,50	64,31	18,00	82,31	64,69	C	0,086	7.771,95	14.613,55	- 65,3
2 – Insulated	196.265,34	166.637,64	208.297,05	151,26	18,00	169,26	64,69	E	0,086	17.913,55	4.471,95	- 20,0
3 – 1+2 Sunspaces	74.970,01	36.270,68	45.338,34	32,47	18,00	50,47	64,69	B	0,086	3.899,10	18.486,40	- 82,6
4 – (4-12-	87.256,40	49.256,83	61.571,04	48,65	18,00	66,65	65,35	C	0,086	5.295,11	17.090,39	- 76,3
5 – Sunspaces	81.574,70	40.452,64	50.565,80	39,98	18,00	57,98	65,35	B	0,086	4.348,66	18.036,84	- 80,6
6 – 1+4	64.800,50	33.110,17	41.387,72	32,75	18,00	50,75	65,35	B	0,086	3.559,34	18.826,15	- 84,1
7 – 3 + PV Plant	74.970,01	36.270,68	45.338,34	32,47	18,00	50,47	64,69	B	0,086	3.899,10	18.486,40	- 82,6
8 – 6+PV Plant	64.800,50	33.110,17	41.387,72	32,75	18,00	50,75	65,35	B	0,086	3.559,34	18.826,15	- 84,1
9 – 7 + Plant	74.970,01	36.270,68	15.633,94	5,67	5,18	10,70	64,69	A+	0,086	1.344,52	21.040,98	- 94,0
10 – 8+Plant	64.800,50	33.110,17	13.866,86	4,67	5,72	10,39	65,35	A+	0,086	1.192,55	21.192,95	- 94,7

Table 1 shows that the combination of these two plant systems (photovoltaic generation and geothermal heat pump and probe powered by a photovoltaic system) would drastically reduce the energy performance index of the building (energy class A + in solutions 9 and 10).

The high-efficiency mono-crystalline photovoltaic panels would address both the energy required by the heat pump and the energy demand for residential users for domestic purposes, thus bringing the building to zero energy balance.

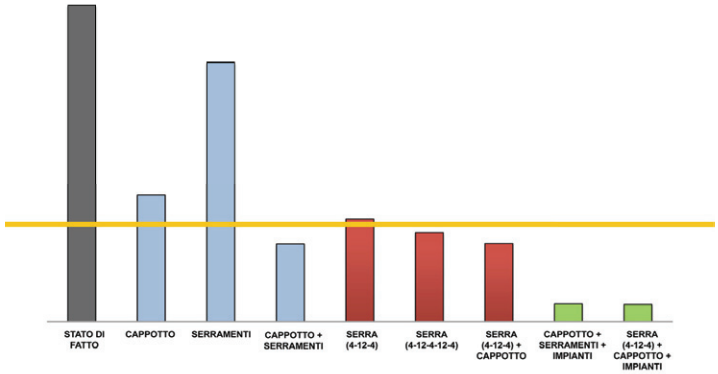

Fig. 2. Energy needs and performance assessment in the different intervention hypotheses for the reference building.

It can be deduced from Fig. 2 the potential reduction of the energy performance index produced by the combination of the photovoltaic generation system with the geothermal heat pump and probe powered by the same photovoltaic system.

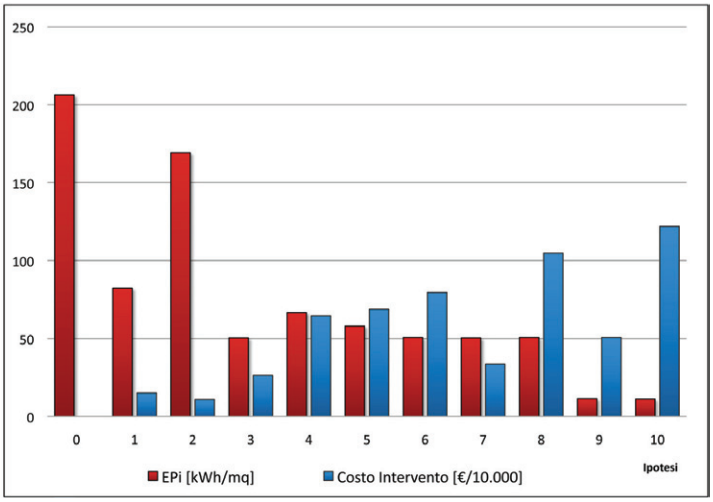

Fig 3. Investment costs for the different rehabilitation works on the reference building

An economic evaluation of the proposed solutions to improve the energy performance of the building has been conducted by means of a financial analysis calculating the costs of the single actions and the assessment of pay back time. In particular, the analysis of profitability the method of differential cash flows to calculate the net present value (NPV).

The graphs drawn in Fig. 4a and 4b show that for interventions not including the installation of photovoltaic systems, replacement of heating equipment and DHW production, there will be no return of investment (descending curve in the hypothesis 3 and 6).

The solutions providing plant retrofitting combined to the energy production require a higher initial investment; thus, even if they are economically unfavourable in the short term period, they will produce a capital return after some years of life, with a net income at end of the plant life (considered equal to 25-30 years). This financial performance also depends on the Italian national feed-in tariffs.

The mutual comparison among data shows that the solution of standard thermal wall insulation and insulated glazed components windows is the one requiring low initial costs while providing high energy performance. If this solution is coupled with a photovoltaic system (Hypothesis 7), thanks to the feed-in tariff, a substantial gain is obtained in the long term. If we add to this last hypothesis also the plant replacement of the heating equipment and DHW (Hypothesis 9) the resulting incoming cash flows would not be able to match the initial cost of the plant; in this case the plant retrofitting would result in a non-competitive action.

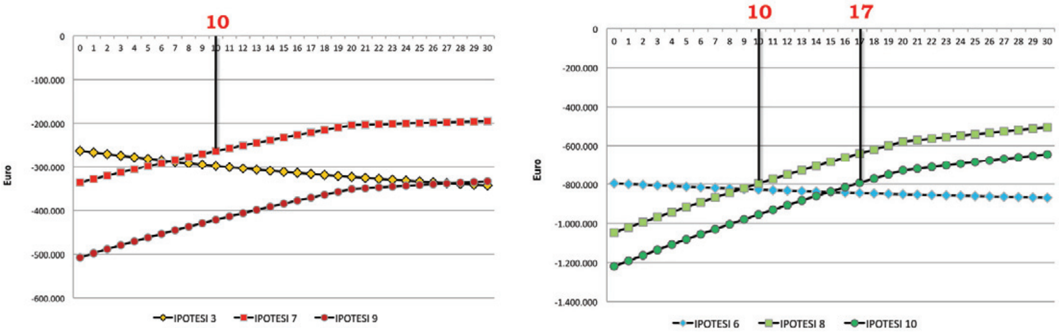

Fig 4. (a). Investment Profitability (NPV) and Pay Back Time (PBT) for the different scenarios (3, 7, 9); (b) NPV and PBT (6, 8, 9).

Finally, the further increase of building transformation's levels by the introduction of bioclimatic double skin integrated with photovoltaic panels (hypothesis 8), which involves also the formal and aesthetic building architecture, turns out to be economically advantageous from the tenth operational year; the addition of a plant retrofitting with a geothermal heat pump powered by photovoltaic panels and flanked by solar panels, when combined with the complete re-qualification of the building architecture (Hypothesis 8 + regeneration systems Hypothesis = 10) is able to match its costs in sixteen years; in this case the plant retrofit reaches its economic and financial viability.

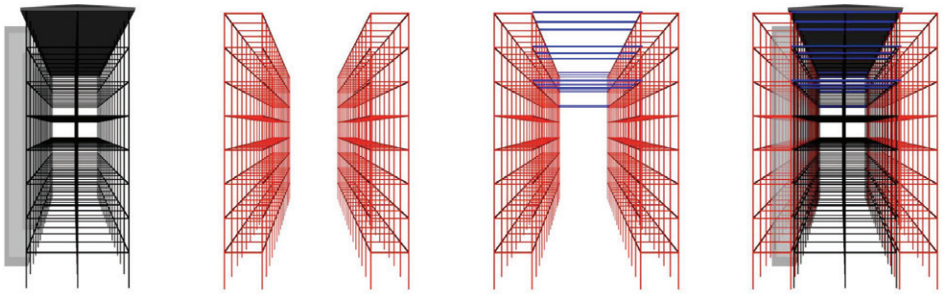

Fig 5. From left to right: the structural grid of the existing buildings; the addition of external grids; the top connection; finally the building-grid integration.

The most incisive solution is obviously the one covering all the design tools: the energy, architectural, engineering and economic (though long-term) rehabilitation by the "radical improvement" transformation - Scenario 10 – including the replacement of heating systems, photovoltaic system and solar thermal for DHW production in the formal resolution and characterization of new building envelope.

The incisiveness of this solution can be only partially quantified, since the new building configuration would result in additional energy benefits that are not taken into account in this paper: for example the use of land as a source of heat has the advantage of provide a significant contribution to solve the problem of overheating in the hot summer season, providing free cooling and thus lowering costs; this further advantage is not quantified in the present discussion. Furthermore, the use of plants that use renewable sources decreases the massive consumption of fossil fuels, reducing CO_2 emissions. This environmental outcome, together with the increased commercial value of the resulting new housing, is not easily quantifiable.

Fig 6. The final 3d vision of the retrofitted reference buildings.

3. Conclusions

While generic conclusions cannot be drawn from one single case study, we think that this specific design and research work may inspire and enable other researchers and designers to perform similar studies, thus helping to disseminate Zero Energy Balance (ZEB) into building retrofitting practices. The energy rehabilitation of existing building stock, especially if it is combined with the overall enhancement of the surrounding urban places and integrated with socio-environmental components and values of public spaces, is one of the major opportunities to decrease energy consumption while improving the quality of life in the urban contexts.

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