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The impact of the energy performance improvement of historic buildings on the environmental sustainability

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Abstract

The historic buildings represent an important part of the built environment. The possibility to reuse spaces that represent the local cultural heritage plays an important role in maintaining the identity of a population and its traditions. The steps to be faced for smart renovation of historic buildings and recent constructions are not the same, as in the first case artistic and architectural constraints have to be respected. The most classic intervention technologies are not always applicable and different solutions must be taken into consideration, to be less invasive and not to disturb the constructive materials, the shapes and lines harmony of the existing structures. In this context, the sustainability of the energy renovation solutions is analysed, verifying if they lead jointly to good rating both in the energy performance and in the environmental sustainability certification.

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Keywords: energy audit, monumental historical architecture, energy performance, energy management process, environmental sustainability, energy sustainability

1. Introduction

Changes in contemporary age force the scientific community to face the challenges of sustainable growth, even within the historical Cultural Heritage, tangible or intangible, a crucial issue for human activity and behavior, strictly linked to the three main pillars of future development [1]. Heritage often becomes the driving force for commerce, business, leisure and tourism: numerous economic processes are based on the re-development or re-significance of the term «territoriality», starting from the consciousness of its cultural values (economic pillar). The global Cultural Heritage, moreover, strengthens identities, well-being, and respect for culture and societies and an appreciation of diverse inheritance and its

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continuity for future generations promote mutual understanding between people, communities and nations (social and cultural pillar). Traditionally, historical architecture is the complex and stratified product of a building culture, necessarily careful to environmental conditions and characters, to natural materials, to building morphologies that dialogue and safeguard with the territory (water regulation and storage, oversight of the slopes, soil erosion protection, governance of forest resources and agricultural etc..) (environmental pillar).

Nevertheless, the relation between Sustainability and Heritage is often reduced to the mere Energy Efficiency of the buildings, simplifying a complex problem into the exclusive item of energy saving. Consequently, technical innovation remains still largely a process of the application of products and technologies. This often leads to a greater emphasis on the technical components that do not correspond to effective cultural advancement. Neither do they improve the capacity to assimilate and modify the technology to achieve higher long-term objectives [2]. A new and different approach can then be investigated and practiced in the relationship between Heritage and Sustainability, to help overturning objectives and cultural references almost exclusively of technical nature, returning to consider the technique a mean and not the end of our actions.

Within this framework, the assessment of environmental sustainability of historical buildings, in an early stage of the energy improvement design, may help to recognize potential ways of enhancement, and this is specifically the aim of the work presented in this paper.

To make an appropriate choice, firstly, the available international and national tools have been analyzed, and the most suitable among them applied on a case study (a large complex built between the XVII and the XIX Century, not currently used in a significant part, almost 70%). Actions to reduce energy needs are considered and are evaluated in terms of sustainability, jointly with constraints and possibilities of intervention. Finally, the levels of sustainability are compared before and after the considered actions, to analyse how to enhance them more, and up to which point.

As in the sustainability protocols, in general, the energy aspects weights account for about 30%, the score improvement of the energy sustainability may not be particularly relevant. However, since the energy improvement interventions can also affect issues related to other sections of the assessment method, there can be positive impacts on a larger part of the criteria, according to the indications and constraints of the Cultural Heritage official body that guarantee the protection of the historical features.

Moreover, the growing interest given to the energy efficiency could increase also the attention to renewable energy adoption in historical contexts and valuable landscape. The support of renewable energy sources is often difficult to be considered, as their impact on the ancient structures may be not allowed, even if, in some cases, also photovoltaic systems have been incorporated in old structures [3], effectively supporting the energy-efficiency improvement [4]. Although the contribution of renewable energy sources can be, in the case study, very small, it could be nevertheless useful to a demonstration level, such as to show a greater sensitivity to energy conservation and renewable energy exploitation.

2. Methodology

The Environmental Sustainability protocols are promoted by some international organizations such as USGBC, iiSBE, BREEAM, etc.

The USGreen Building Council (USGBC) has, as its purpose, the promotion and the development of a comprehensive approach to sustainability, giving recognition to virtuous performances in key areas of human and environmental health. Its methodology, LEED - Leadership in Energy and Environmental Design, is a system of certification of buildings, born on a voluntary basis and applied in more than 140 countries worldwide [5]. Five rating systems that address multiple project types are considered: Building

Design and Construction, Interior Design and Construction, Building Operations and Maintenance, Neighborhood Development and Homes. The Green Building Council promotes the LEED methods in Italy through GBC-Italia: it has recently realized the GBC Historic Buildings procedure for the environmental sustainability assessment of historic buildings. Comparing the various project types, two new criteria are considered for this kind of assessment: the Historical Value and the Design innovation.

In Great Britain, BREEAM [6] is used as an environmental assessment method and rating system for buildings. It sets criteria for best practice in sustainable building design, considering elements such as energy, pollution, internal environment, materials, waste, transport, etc. The Energy section is based on national assessment methodologies.

iiSBE is another international organization whose overall aim is to facilitate and promote the adoption of policies, methods and tools to accelerate the process towards a global sustainable built environment [7]. Its building performance assessment system, known at first as GBTool and now called SBTool, can be configured to suit almost any local condition or building type. It is based on the SB Method for rating the sustainable performance of buildings and projects. National chapters of the organization contribute to customize SBTool methodology, to take into account local dispositions. The Italian rating system developed by iiSBE-Italia is identified as ITACA tool, customized for the Italian national application, and adopted by some regional laws [8]. As it will be the rating system chosen for the present analysis, some notes are added on its use. For this rating system, the National Standardization Authority (UNI) has recently developed a Reference Practice concerning the "Evaluation of environmental sustainability of buildings: reference practice", which is based on the sharing of ITACA experiences (Institute for Innovation and Transparency of Contracts and Environmental Compatibility) [9].

These guidelines represent a useful reference for the general framework and the methodological procedural principles that underlie the multi-criteria analysis system for the evaluation of environmental sustainability of buildings, for their classification by assigning a score of performance, applicable to both new buildings and renovations. They are devoted to residential buildings; additional sections relating to other uses are under development. The Reference Practice, two years after its publication (estimated time necessary to enable the dissemination and application on the market) will be reviewed to assess the interest "to evolve" in a regulatory document on the same subject. In fact, the Practices have a useful life of not more than five years, the maximum period within which they can be transformed into National Standard, or Technical Standard or Technical Report or withdrawn.

While the Reference Practice has not yet been realized for different uses, the ITACA rating system is already used for residential, offices, businesses, industries, schools, even if a tool corresponding to GBC Historic Buildings is not already available. Anyway, considering that this last one can be applied mainly at the end of the design process, since it requires a series of detailed information on the implementation of the whole restoration, the ITACA methodology appears to be more suitable in this analysis, even if the case study is represented by a historic building.

3. Application of the procedure to a case study

The case study is a monumental complex, named "Albergo dei Poveri", which occupies a total surface of about 60,000 m^2, with a square plant divided symmetrically into four quadrants, centered on the Greek cross, located at the intersection of two axes of the square base (Fig.1). It was mainly built, for charitable purpose (giving a home to the poor and disadvantage people of the city of Genoa), between 1656 and 1696, during which the east and north wings were completed. The building was ended in 1832 with the construction of the west wing.

The complex, almost completely abandoned at the beginning of 2000, is actually under the management of the University of Genoa, which plans to complete its reuse and restoration, installing the humanistic didactic and research pole (Foreign Languages, Political Sciences, and Law). Nowadays only 30% of the available space has been recovered. In the meantime, most of its parts are still abandoned and subject to the natural deterioration and decay.

Fig. 1 – Map of the urban context and 3D representation

3.1. Calculation results: energy performance improvement calculations used for the sustainability assessment

The complex is now object of a feasibility study, finalized to its complete reuse; within this work, its thermal behavior has been investigated, to study the most useful measures to increase the energy performance of the less efficient building structures.

As some energy saving efficient solutions can be considered and reasonably applied in the future, some different scenarios were considered to reduce the energy consumption of the whole complex. They take into account the improvement by the adoption of different building interventions: the insulation of the roof and the floors (ground floors and the ceiling under the roof structure, up to a mean U-value 16% of the present one) and of the wall under the windows, and the superposition of a certificated frame windows to the existing ones (this intervention specifically responds to the need on conservation and safeguard of historical values).

3.2. Comparison of the results

Generally, two aspects are considered in the ITACA rating system: Site (10%) and Building (90%). Five evaluation building areas count for different weights:

A – Site quality (5%),
B – Resources consumption (45%),
C – Environmental loads (20%),
D – Indoor environmental quality, IEQ, (20%),
E – Services quality (10%).

The ITACA rating system considers various building destinations, Residential (R), Office (O), School (S) refurbishment. It can be observed that the elements that differentiate the three applications are mainly concentrated in the following fields: drinking water (R,S: +1% Difference compared to Office Score - DOS), walls thermal inertia and indoor temperatures (R:-1% DOS), magnetic field (R:+1% DOS), site design (S:+1% DOS), service quality (S:-2% DOS), social aspects (only S:+2% DOS).

The case study collects a lot of different activities (that will be even more with its reuse), therefore a mean value was considered in the calculations, weighted on the surface occupied by three main different destinations, supposed distributed in all the building even if in the present configuration only 30% of the areas are in use.

The calculated energy performance index, the different scores and the global sustainability rating are summarised in Table I. Two different reference ratings are calculated:

- the **a**-scores that correspond to the Maximum Energy related Ratings. They take into account of the energy performance index E_{pi}, U and Y heat transmittances, equal to the limiting values, the CO_2 emissions corresponding to the E_{pi} limiting value, and optimized indoor comfort. They are compared with the present situation (**0**-scores) and with the planned energy-performance improvement actions (**b**-scores).
- the **c**-scores that take into account the **a**-scores, and consider the maximum use of renewable energy, a significant improvement of the sustainable materials use, a limited use of drinking water, an optimal waste management, and ventilation, services, controls and social aspects improvement. They are compared with a realistic application of the available technologies, significantly limited by the historic preservation constraints (**d**-scores).

Table I - Energy performance and Sustainability classification

		Epi [kWh/(m^{2}y)]	Resources consumption	Environmental loads	IEQ	Service quality	Weighted global score
0	Existing building	79.77	0.51	0.79	0.61	1.20	0.95
a	Reference values Energy performance improvements	Ep_{iLim} =23.26 (residential)	0.66	1.38	2.36	1.87	1.51
b	Energy performance improvements	33.7 (-42%)	1.18	1.58	0.61	1.87	1.44
c	Ref. **a** + sustainable materials & Renewable Energy	Ep_{iLim} =23.26 (residential)	1.99	3.06	2.55	5.00	2.72
d	**b** + realistic (limited) sustainable materials & Renewable Energy	33.7 (-42%)	2.13	3.21	1.79	5.00	2.69

Note: The scale varies from the maximum score +5, and the minimum value -1.

The existing building energy consumption (**0-**case) results not too high for the local climatic conditions, due to the wall thickness (1.5 – 2 m) and the window surface that is only 6% of the external envelope.

The **a-**case represents the best energy performance that could be obtained with the maximum effort: the results show that anyway the global score remains quite low, even if they highlight that good results can be reached mainly in the IEQ field (ventilation, thermal comfort, natural lighting, and acoustic quality).

The **c-**case represents the same **a**-case but with the resources consumption score improved by other elements like renewable energy use, sustainable materials, reduced water consumption etc. The environmental loads score increases a lot, and also the IEQ one; service quality score reaches the maximum value of 5 (building automation). The **c**-score can be considered the maximum level of sustainability that can be reached with a smart refurbishment of the examined historic building.

The **b** and **d** cases seem good in comparison to the corresponding references. The planned energy performance improvements (**b**-case) reduce significantly the energy consumption of the **0-**case (-58%) even if the energy performance index doesn't reach the limit for new and restored buildings imposed by law in the Italian territory (valid only for residential use and anyway not mandatory for the historic buildings). The corresponding resource consumption score increases significantly (2.8 times the **0**-score).

The **d**-case considers also a higher attention on the sustainable materials for the restoration and a limited use of renewable solutions by the way of energy co-generation, or also tri-generation. This solution could be considered to reach the highest realistic sustainability rating score, to give a more significant global value to the restoration of an ancient building. The single scores reach better levels: the resource consumption and the environmental loads scores (CO_2 emissions, waste management) can be even higher than the planned ones, the IEQ struggles to achieve a good score, while service quality can obtain the maximum value, as the reference **c**-case.

The global weighted score increases up to 2.69 that represents the maximum effort to improve environmental sustainability of this historic building, very close to the target of 2.72, calculated in the **c**-case.

4. Conclusions

The study has considered the possibility to increase energy performance of historic buildings through actions compatible with the preservation constraints to which they are subdued. The reduction of energy consumption allows an easier management of large monumental complexes, which have to be maintained in use for their historic value. The sustainability of the restoration actions can be considered as a benefit, and it can be increased with some attentions to materials and resources management.

The results show that even if the scores of the sustainability rating system do not reach high values, they can be maximized if the attention is focused not only to the energy consumption reduction, but also to other elements that can give an added value to the building restoration.

The analysis highlights also that the rating system should make available a special issue for historic buildings, to consider also some other elements, like as preservation, historic value, or presence of paintings that limit some refurbishment actions, and to adjust the maximum scores with these elements.

A special issue should take into account that the environmental sustainability of the restoration process of a large historical complex, as the case study, requests a continuous and dynamic management. Beyond technical design and more than individual actions, there is the need for strong and clear policies as well for some adequate administrative, technical, and cultural decisions through the whole process (i.e. the preparation of the contracting procedures, the management of the construction site).

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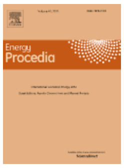

Biography

Anna Magrini – PHD, Professor of Applied and Building Physics, member of working group of ISO/TC163 Thermal performance of buildings and components (CEN, European Committee for Standardisation). Expert member of Italian Standardisation Technical Committee 102/SC01 “Insulating materials – calculation and measurement methods. Researches: energy performance, moisture problems and environmental sustainability of buildings