Design the refurbishment of historic buildings with the cost-optimal methodology: The case study of a XV century Italian building

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A B S T R A C T
In order to deliver the European energy and climate objectives to 2050, significant changes are essential in the building sector, especially regarding the existing stock. Indeed, there is a huge potential for action, also regarding historic buildings. In this regard, today the question is: how to combine the building protection requirements and the application of energy efficiency measures?

This paper tries to answer, evaluating if the refurbishment of historic architectures, in order to achieve very low energy need, is possible and economically feasible. More in detail, the applicability of the cost-optimal methodology (EPBD Recast 2010/31/EU) for historic buildings is discussed, by adopting the macroeconomic perspective, in order to take into account the energy, environmental and economic impacts of about 60 packages of energy efficiency measures. The study is aimed to introduce a methodological approach to define reference buildings for historic architectures, through in-situ investigation of structural and energy peculiarities and, as real case study, the refurbishment of an Italian building of the XV century is presented. Moreover, guidelines are proposed to properly select energy efficiency measures, according to a point of view of cost-optimality. Conservation, aesthetical requirements, structural and energy issues are considered, as well as the incidence of all economic factors.

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1. Introduction: Energy efficiency and historic buildings

The Roadmap to a Resource-Efficient Europe [1] identifies buildings and constructions among the three key-sectors responsible of about 70—80% of the overall environmental impact. A better construction activity and use of buildings in the EU would influence the 42% of the final energy consumption, about 35% of the CO₂ emissions, more than 50% of all extracted materials and could reduce water consumption of about 30%. Recent statistics reveal that 14% of EU-27 building stock dates before 1919, about 12% between 1919 and 1945, even if considerable national differences occur. Due to significant opportunities for reducing primary energy consumptions, the energy retrofit of historic buildings is considered the “new challenge” of research [2]. Indeed, the historic listed buildings and buildings with unique outlook in Europe account for almost the 18% of the total energy demand of their sector [3,4].

At present time, the European legislation does not provide prescriptive limits about the energy performance of historic buildings. The only regulation, dealing with Architectural Heritage, is the “Convention for the Protection of the Architectural Heritage of Europe” [5], signed in Granada in 1985, and ratified by 41 European countries. Recently, the Building Performance Institute of Europe [6] has specified that “minor and moderate interventions might be performed also in case of heritage buildings” in order to achieve energy and CO₂ reduction, according to the European objectives, “because there will always be some energy efficiency measures that can be applied, even if it is not a total renovation”. However, it should be remarked that energy efficiency objectives are more complicated to achieve when the refurbishment concerns historic buildings. As underlined by Mazzarella [7], in the current state of art of standards and codes, it is possible to highlight the lack of a specific protocol aimed at providing well-balanced solutions for the energy efficiency improvement and conservation requirements of cultural heritage. These aspects must be always combined, and often it is difficult find a proper compromise. Really,
libraries or dwellings, and thus are frequently interested by interventions for static security. Therefore, as underlined by de Santoli [8], the energy efficiency measures should be considered as a tool for protecting the building historical value rather than a process of upgrading which could conflict with the conservation requirements.

A wide literature concerns the refurbishment of historical buildings. Zagorskas et al. [9] have discussed the problems of moisture in brick wall construction and a method for selecting the best insulating alternative is shown. Ben and Steemers [10] have underlined that, for protected housing in London, a mere behavioural change has the potential for allowing significant energy saving, higher than those derived from a physical improvements. Moreover, several studies show that energy efficiency can also be greatly improved through the optimization of building envelope (replacement of windows, doors) and by means of a rational management of HVAC systems. For instance, Bellia et al. [11] have illustrated the energy improvement proposal of Palazzo Fuga, a very important historical building in Naples (Italy). For this building, an opaque PV roof has been evaluated more convenient than a semi-transparent PV roof, in terms of aesthetic, energy conversion and thermal comfort goals. Moreover, the feasibility study proposed by Astone et al. [12] demonstrated that, for an ancient educational building of the University of Sannio, in the historic center of Benevento (Campania, Italy), the more suitable package of energy efficiency measures is the replacement of existing windows with low-emissive ones, application of thermal plaster and thermal insulation of the roof. Recently, Milone et al. [13] have demonstrated, with a case study of a building in Ragusa (Sicily, Italy), that technologies allowing for improving this kind of buildings might provide a less effective energy performance and a higher investment cost compared to the Best Available Technologies, with reference to both the opaque and glazed envelopes. About the adoption of renewable resources also for historical buildings, until now, these have had a minor diffusion, because of psychosocial barriers [14]. However, there are worthy examples that demonstrate the potential of integration of solar technology into historical buildings [15].

Regarding the methodology of investigation, Ascione et al. [16] have proposed a multi-criteria approach for the energy refurbishment of historical buildings, aimed to predict suitable retrofit actions. Similarly, Franco et al. [17] showed a preliminary approach and general criteria for refurbishment, in relation to the architectural and historical constraints. Of course, in the retrofit or restoration of a historic building, the target cannot be a mere prescriptive limit value concerning one or more energy performance indicators. The additional value of improved energy efficiency (e.g., improved indoor climate, lower energy demands and operational costs) must be recognized and the lifetime costs of buildings have to be considered rather than a simple focus on the mere investment costs [18]. According to this point, the recast of Energy Performance of Building Directive (EPBD) [19] has introduced the cost-optimal methodology. This approach allows the evaluation of buildings’ requirements not anymore according to the sole investment costs, but taking into account operational, maintenance, disposal and energy costs of buildings along their entire lifespan. Presently, the literature has a lack of studies concerning the application of the cost-optimal methodology for the design of the energy retrofit of historical buildings. Indeed, only few aspects about the identification of the optimality range have been already investigated. Kurnitski et al. [20] studied the correlation between cost-optimal levels and nearly Zero Energy Building (nZEB), for Estonian detached houses. Similarly, Hamdy et al. [21] applied the methodology to find the cost-optimal and the energy performance levels of nZEB for a single-family house in Finland. Various options of thermo-physics of the building envelope, heat-recovery units, heating/cooling systems as well as various sizes of thermal and photovoltaic solar systems have
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