Energy and Buildings 99 (2015) 162–176

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

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

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ARTICLE INFO

Article history:
Received 28 January 2015
Received in revised form 21 March 2015
Accepted 18 April 2015
Available online 25 April 2015

Keywords:
Historic building
Reference building
Energy saving
Energy refurbishment
Cost-optimal methodology

ABSTRACT

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 of 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.

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 CO_2 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 CO_2 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,

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http://dx.doi.org/10.1016/j.enbuild.2015.04.027
0378-7788/

Nomenclature

Symbols

ACH	air changes per hours ($V\,h^{-1}$)
BHE	installation of high efficiency boiler
C_a	annual costs (€ or € m^{-2})
C_c	annual cost of greenhouse gas emissions, € or € m^{-2}
C_g	global cost referred to starting year (€ or € m^{-2})
C_I	investment cost, € or € m^{-2}
CDB	installation of condensing boiler
CHE	installation of high efficiency electric chiller
COP	coefficient of performance at design conditions (W_{TH}/W_{EL})
$CO_{2,eq}$	carbon dioxide equivalent emissions (kg)
CS	installation of solar control glazing
DHW	domestic hot water
EEMs	energy efficiency measures
EER	energy efficiency ratio at design conditions (W_{TH}/W_{EL})
EP	primary energy demand (kW h or kW h m^{-2})
EVM	envelope refurbishment measures
f_{pv}	present value factor (%)
HP	installation of high efficiency heat pump for radiant system
HPLE	installation of low efficiency heat pump for radiant system
HVAC	heating, ventilating and air conditioning
IR	insulation of roof slab
LE	installation of low-emissive glazing
M_c	annual maintenance operation and repair and service factor (%)
n	number of years considered for the cost
p	lifespan of building elements and systems
PV	photovoltaic system
R_d	discount factor (or rate) (%)
R_i	inflation rate (%)
R_r	real interest rate (%)
RB	reference building
RB_P	reference building of Palazzo Penne
S	installation of selective glazing
S/V	dispersing surface to conditioned volume ratio (m^{-1})
TE	thermal plaster application on outer face
TI	thermal plaster application on inner face
U	thermal unitary transmittance ($W\,m^{-2}\,K^{-1}$)
U_w	window unitary transmittance ($W\,m^{-2}\,K^{-1}$)
U_{wl}	external wall unitary thermal transmittance ($W\,m^{-2}\,K^{-1}$)
U_r	roof unitary thermal transmittance ($W\,m^{-2}\,K^{-1}$)
V	volume (m^3)
V_f	residual value at the end of the calculation period (€ or € m^{-2})
VD	installation of differentiated glazing for exposure
WM	window energy efficiency measures

Greek symbols

Δ	difference, dimensionless
h	nominal efficiency (%)
τ	calculation period, number of years

the energy refurbishment can be associated to structural consolidation or functional reorganization works. These buildings, indeed, are often used as educational and recreational facilities, museums, 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 Ascione et al. [12] has 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 allowed 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