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A new procedure of energy audit and cost analysis for the transformation of a school into a nearly zero-energy building

Vincenzo Corrado[a,]*, Ilaria Ballarini[a], Simona Paduos[a], Lidia Tulipano[a]

[a]*Department of Energy, Politecnico di Torino, corso Duca degli Abruzzi 24, Torino 10129, Italy*

Abstract

The article presents the fundamental steps of building refurbishment toward the nZEB target; it is based on a detailed energy audit and on a financial analysis. The methodology starts from the set-up of a numerical model of the building, calibrated through actual data on operation, climate and energy consumption. Then, a cost-optimisation procedure is applied to identify the energy efficiency measures that determine the minimum global cost in 30 years lifetime. Finally, the measures are improved as to comply with the nZEB requirements and to be cost-effective as well. The methodology was applied to a high school in Torino.

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Keywords: building refurbishment; public building; school; nZEB; energy audit; cost-optimisation; building energy performance; model calibration; energy signature; energy efficiency measures.

1. Introduction

1.1. Energy audits of educational buildings

The Directive 2010/31/EU specifies that the public sector should lead the way in the field of energy performance of buildings and the national plans should set more ambitious targets for the buildings occupied by public authorities [1]. Among the public buildings, the educational buildings account 17% of the built area and 12% of the final energy use of the non-residential sector in Europe [2].

* Corresponding author. Tel.: +39-011-090-4456; fax: +39-011-090-4499.
E-mail address: vincenzo.corrado@polito.it

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Energy consumption benchmarks of existing schools are provided by several studies in the EU countries and high potentials for energy savings are generally revealed. The highest values of energy consumption occur in the schools of southern Finland; according to Sekki et al. [3], the yearly mean final energy consumption is 214 kWh·m^{-2} and 229 kWh·m^{-2} for primary schools and universities, respectively. In Slovenia, Butala and Novak [4] analysed a sample of 24 school buildings and found out an average total final energy consumption of 192 kWh·m^{-2} per year. Similar results, but considering space heating only, were got by Bull et al. [5], which simulated school building archetypes in United Kingdom. In Luxemburg, a sample of 68 schools showed thermal and electricity yearly consumptions of 93 and 32 kWh·m^{-2}, respectively [6]. The energy consumption data of schools in southern Europe are comparatively lower. For example, studies conducted in Cyprus show average yearly energy consumption of 63 kWh·m^{-2} including electricity and fuel [7].

The educational buildings in Italy are 51 000 units, with a built surface of 73.2 million m^2 and a volume of 256 million m^3. According to reports from CRESME [8] and ENEA [9], most of the schools were built in the period 1960-80, and 48% of the schools are located in the climatic zones E and F ($HDD > 2100$). The average yearly energy consumption amounts to 130 kWh·m^{-2} (thermal energy) and 20 kWh·m^{-2} (electricity) [10].

The knowledge of the building energy performance through effective energy assessment methodologies is necessary to set-up suitable retrofit measures able to increase the building energy efficiency. Energy and environmental audits allow to identify the building weaknesses and to provide potential improvements. Thus, the implementation of effective energy audits on educational buildings is crucial to identify suitable solutions aimed at reducing their high energy consumption.

Studies on the development of energy audits for educational buildings were conducted throughout Italy. In the north of Italy, a field survey was carried out to collect and process data on the actual energy consumption of 120 high schools in the district of Torino. The average yearly energy consumption for space heating of the sample revealed to be about 115 kWh·m^{-2} [11]. Other studies were conducted in the centre of Italy; Desideri and Proietti [12] presented two applications of energy audit for schools of the province of Perugia, and determined potential thermal and electrical energy savings. Studies in the south of Italy were carried out by Rospi et al. [13] for different typologies of schools in Matera. They carried out measurements and monitoring activities for energy audit and assessed the energy performance before and after the application of retrofit measures to the building envelope and to the technical building systems.

Several methodologies for the energy audit of educational buildings have been developed and applied. For instance, following the procedure of the EN 16247-2 Standard, Magrini et al. [14] applied the quasi-steady-state calculation method of the EN ISO 13790 Standard to carry out the energy audit of the University of Pavia. A simplified approach to the energy diagnosis has been followed for the School of Engineering and Architecture of Bologna; the standardized method of the energy signature reported in EN 15603 was applied by Marinosci et al. [15]. Other studies compared the actual energy consumption of school buildings with the energy performance estimated through dynamic and quasi-steady-state calculation methods [13]. Finally, some researchers developed tools that support local administrators to assess the energy performance of educational buildings through simple data input and to identify the most convenient energy efficiency measures easily [16].

Nomenclature

A	area	[m^2]
$b_{tr,U}$	adjustment factor for heat transfer through unheated spaces	[-]
C	cost	[€]
COP	coefficient of performance	[-]
E	energy	[Wh]
EP	energy performance indicator	[kWh·m^{-2}]
F_O	occupancy dependency factor	[-]
GC	global cost	[€·m^{-2}]