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Potential and limits to improve energy efficiency in space heating in existing school buildings in northern Italy

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A B S T R A C T

Improving the energy performance of public buildings is important for the promotion of a culture of energy efficiency among the local population. Indeed the European Union has developed strategies particularly for this sector using specific legislation and has targeted projects for economic support.

In this paper we present a energy audit campaign conducted on 49 school building complexes located in the Lombardy region of Italy to collect data concerning their actual energy consumption for space heating, occupant behaviour and the technical characteristics of the buildings. On the basis of these data, different energy retrofit scenarios were studied with different performance and cost-effectiveness targets. The results show that it is not always convenient to improve excessively energy performance for heating.

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1. Introduction

The energy performance of existing school buildings in Italy is very poor when compared with the current minimum energy standards introduced by the Italian national laws [1,2] which have assimilated Directive 2002/91/EC [3]. In a study promoted by ENEA (Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile), Citterio and Fasano [4] show that 67% of the 43,000 school buildings were built before 1974, prior to the introduction of the first Italian law concerning energy efficiency (national law no. 373/76), and about 8% were built in the last 20 years. The estimated primary energy consumption for heating is approximately 1 million PET (Petroleum Equivalent Ton).

Desideri and Provetti [5] estimate that this energy consumption can be significantly reduced through appropriate energy measures (i.e. increasing the energy efficiency of the building envelope and plants, using renewables, and improving energy management). Evaluating possible remedial action on the school buildings in a province (county) in central Italy they calculate that potential thermal energy savings could be as high as 38% and electrical energy savings 46%.

Energy retrofitting the school buildings definitely helps to reduce the management costs of local public authorities (municipalities, provinces/counties and regions) and reduces greenhouse gas emissions. Additionally, improving the energy efficiency of public buildings is important since it promotes a culture of energy efficiency in the local population, and public buildings are considered an excellent example of how things should be done. For these very reasons, the European Union has given careful consideration to this sector by using specific legislation and has targeted projects for economic support.

Article 7 of the Directive 2002/91/EC [3] invites Member States to take measures in order to improve the energy performance of existing buildings, especially those of public services or used by the general public.

The more recent Directive 31/2010 [6], named "EPBD (Energy Performance Building Directive) recast", increases efforts to promote the energy efficiency of buildings, further raising energy standards for new buildings (see Article 9) but also for existing buildings when undergoing major renovation (see Article 7).

The EPBD recast Directive is being transposed into their national legislation by Member States, although in Italy, the rules have not yet been fully defined: however, it is clear that the objective of the Directive is to reduce the gap between the energy performance of existing buildings and that of new buildings.

The EU's interest in the energy upgrade of public buildings is confirmed by the Directive 2012/27/UE [7]: Article 5 states that Member States shall ensure that, as from 1 January 2014, 3% of the total floor area of existing public buildings is renovated each year to meet at least the minimum energy performance requirements.

In order to facilitate the mobilisation of funds for investments in sustainable energy at the local level, the European Commission and the European Investment Bank have established the ELENA (European Local Energy Assistance) technical assistance facility, financed through the Intelligent Energy-Europe programme. ELENA support covers a share of the cost for the technical support that is necessary

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to prepare, implement and finance the investment programme. ELENA assistance could well facilitate access to EIB (European Bank of investments) financing or financing from another bank (ELENA is managed by the EIB).

The financial support, targeted for buildings owned by public authorities, is a loan that must be repaid to the EIB within a reasonable period (approximately 12–14 years); therefore, it is essential that the pay-back period for the energy retrofit measures be shorter than 14 years.

The issue of energy performance and energy management in public buildings has been the subject of several significant publications.

Butala and Novak [8] find that in Slovenian school buildings, the nominal heating capacity is 57% oversized, and the heat losses are 89% higher than the recommended values. Santamouris et al. [9] carried out energy audits on 238 schools buildings in Greece for construction, heating, cooling, lighting, and mechanical and electrical systems, in order to verify the energy-consumption indicators and the energy-saving opportunities. This study discerned that the annual average total energy consumption is 93 kWh/m^2, of which approximately 72% is consumed for space heating. The assessment of various energy-conservation techniques shows a potential for 20% overall energy conservation. Dimoudi and Kostarela [10] assessed the energy performance, based on monitored data, of school buildings in the C′ climatic zone of Greece, a region with the lowest air temperature during the winter period, and evaluated the potential of energy conservation measures. The mean annual energy consumption was estimated to be of 123.31 kWh/m^2 for all school buildings, with non-insulated buildings having a mean energy consumption of 139.16 kWh/m^2 and insulated buildings 115.38 kWh/m^2. The benefit resulting by improving the thermal insulation was a reduction of up to 13.34% in the energy consumption.

Another study, again in Greece, was carried out by Theodosiou and Ordoumpozanis [11] with the purpose of investigating the energy efficiency, thermal environment and indoor air quality in public nursery and elementary school buildings in the city of Kozani, located in the cold climatic zone of Greece. The survey, conducted both by means of measurements in the field and through questionnaires, reveals the main parameters affecting the overall performance of the buildings investigated. The improper control of heating and lighting systems, the absence of proper legislative measures and, above all, the lack of interest concerning the efficiency of such buildings are the main factors in the efficiencies reported.

Another piece of research, aimed at improving energy performance in school buildings whilst ensuring indoor air ventilation, was proposed by Becker et al. [12]. In this study, a step by step process was used for the development of deemed-to-satisfy design solutions, which cope with the EE-TC-IAQ (energy efficiency—thermal comfort—indoor air quality) Dilemma. Results indicate that implementation of improved ventilation schemes in an otherwise well-designed energy-conscious building result in savings of 28–30% and 17–18% respectively for northern and southern classroom orientations. On the same issue is the work of Butala et al. [13] which analysed 24 school buildings in both towns and the countryside of Slovenia, considering and comparing both real energy consumption and indoor air quality data.

Other research studies focus on classifying and rating the energy performance of school buildings. Santamouris et al. [14] propose a new energy classification technique based on intelligent clustering tailored for school buildings, using energy consumption data that were collected through energy surveys performed in 320 schools in Greece. A simpler method is proposed by Patxi et al. [15] which outlines techniques to develop energy benchmarks and rating systems starting from the very first step of data collection from the building stock of Irish primary schools. Erhorn et al. [16] propose the "Energy Concept Adviser", a tool that assists educational building decision-makers in identifying and calculating the potential energy savings of new and existing buildings. Moreover, it provides a database of case studies from 10 European countries.

Hernandez et al. [17] outline a methodology for the development of energy benchmarks and rating systems starting from the very first step of data collection from the building stock. Methods for rating a sample Irish school according to both calculated and measured ratings are applied, and finally the paper discusses the advantages and disadvantages of the two approaches.

Lastly a probabilistic energy model for non-domestic building sectors applied to analysis of schools buildings in greater London is proposed by Tian and Choudhary [18].

In Italy the work of Corgnati et al. [19] proposes a method for the heating consumption assessment of a sample of approximately 140 buildings (120 high schools) in the Province of Turin.

Another two studies were interesting in support this work. The first concerns the issue of the methodologies for energy retrofits on existing buildings. Ma et al. [20] provide a systematic approach to proper selection and identification of the best retrofit options for existing buildings.

The theme of high energy-performance school buildings is covered by Zeiler and Boxem [21]. The Authors analysed the first NZEB (Net Zero Energy Building) designed school in the Netherlands comparing the results with other more traditional schools. The article gives a list of advantages and disadvantages taking account of the technologies actually available.

From the above considerations it is clear that the issue of improving the energy performance of public buildings, and specifically school buildings, is a topic of current interest. The matter is even more relevant today since Member States, in implementing the Directive 2012/27/EU, must define strategies for, and decide the energy retrofit actions to undertake on their existing public building stock.

The studies discussed above have explored many important aspects of the subject. However, the European legislative framework has evolved significantly in recent years and a more comprehensive approach, enabling the assessment of the economic effects of the choices related to energy performance retrofit, is now required.

The study presented here fits into this context: through the application of a method that combines the need to analyse a great building patrimony whilst maintaining a high level of quality, it provides a tool that will assist the public administrators dealing with the problem in making the most appropriate decisions. In essence the study aims to provide the answer to the question: what should be done, considering the existing and unavoidable trade-off between efficiency and cost?

Initially data was collected concerning the actual energy consumption due to space heating, occupant behaviour and the technical characteristics of 49 school building complexes (77 buildings) in the Lombardy region of Italy. In the first phase, the actual energy consumption is compared with the calculated energy consumption using a tailored simplified model based on audits. In the second phase, a variety of energy retrofit scenarios were developed with different performance and cost-effectiveness targets calculated with the model.

Going beyond the existing knowledge on the subject, the study presented provides new elements that can help to promote the state of the art.

Although the number of buildings considered is consistent, the surveys were conducted by analysing in detail each single building, obtaining accurate evaluations, both with respect to the data collected (validated by comparing theoretical calculation with actual consumption) and of the energy retrofits proposed in different scenarios. The building stock examined is particularly interesting in

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