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Energy performance and indoor environmental quality in Hellenic schools

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ABSTRACT

School buildings constitute a major part of the non-residential building stock, though due to their operational characteristics, they represent a low percentage of the overall energy balance of the building sector. Although health and productivity of pupils and teachers is strongly affected by the indoor environmental quality of their school, poor indoor air quality has been reported in published literature, even so for recently constructed school buildings. The same applies for the energy consumption, with large amounts of energy being wasted because no energy saving measures are applied for the operation of schools. This paper presents the outcome of a study on the energy performance of Hellenic school buildings. The general features of the contemporary building stock are presented along with the results from an energy survey in 135 Hellenic schools. The derived energy consumption benchmarks are compared with published literature. Finally, the energy performance and indoor environmental quality of a representative sample of schools in metropolitan Athens are assessed in a holistic approach to the "energy efficiency – thermal comfort – indoor air quality" dilemma. The IEQ assessment was based on an objective evaluation by monitoring crucial indoor conditions and a subjective occupant evaluation using standardized questionnaires. The potential of several energy conservation measures is evaluated in terms of energy savings and reduction of greenhouse gas emissions along with the related payback periods.

1. Introduction

The main legislative instrument in the European Union (EU) for improving the energy performance of buildings is the European Directive 2002/91/EC (EPBD). The EPBD recast (Directive 2010/31/EU) strengthens the energy performance requirements, clarifies and streamlines some of its provisions to reduce the large differences between Member States' practices. It prescribes a very ambitious target that all new buildings must be nearly zero energy buildings by 31 December 2020, while Member States should set intermediate targets for 2015. New buildings occupied and owned by public authorities have to be nearly zero energy buildings after 31 December 2018. The nearly zero or very low amount of energy required should to a very significant level be covered by renewable energy sources (RES), including on-site energy production using combined heat and power generation or district heating and cooling, to satisfy most of their demand. EU Members States should also take measures and set targets, to stimulate building refurbishments into nearly zero energy buildings.

Over the past decades numerous international studies have been carried out addressing the topic of energy consumption and indoor environmental quality (IEQ) in school buildings. Inadequate IEQ has been reported in investigated schools in UK [1] and Canada [2]. Very high levels of CO_2 were measured in 66 schools in Germany [3,4], while in Belgium the concentrations of gaseous pollutants recorded in 27 schools were found to exceed the acceptable limits by 50% [5]. The energy efficiency and gas emission performance of 15 schools in Argentina is reported in [6]. The average energy consumption was found to be 123 kWh/m^2 while 87% of the primary and secondary schools were characterized as "low emission buildings". The life cycle energy consumption of 20 public secondary school projects in New South Wales, Australia is reported in [7]. The energy consumption in 29 investigated school buildings in Slovenia was found to exceed the acceptable limits of the Slovenian codes [8]. In the same study the IEQ is reported as rather poor, with CO_2 concentrations exceeding 4,000 ppm. The thermal and electrical energy consumption is reported in [9] for a total of 42 schools in Perugia, Italy. Energy indices are derived for three different types of schools classified according to their construction period. Finally, a total of 117 schools were investigated in the Province of Torino [10], in order to derive energy consumption indices. The obtained average consumption for space heating was 100 kWh/m^2.

According to the Natural Resources Canada, the average annual energy consumption of schools in Canada is 472 kWh/m^2, while the reference building according to the Model National Energy Code for Buildings (MNECB) of Canada averages 357 kWh/m^2 [11]. How-

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ever, even under the adverse winter Canadian conditions there are shining examples of energy efficient buildings. For example, a 2300 m^2 school with actual energy consumption of 72 kWh/m^2 as a result of well insulated thermal envelope (0.27 W/(m^2 K) for walls, 0.25 W/(m^2 K) for roof), double-pane, low-e glazing filled with argon, low lighting power density (8.7 W/m^2) optimizing the use of daylight and high efficient lamps, geothermal heat pumps, two solar walls for preheating the outdoor fresh air entering the building, heat recovery, occupancy and CO_2 sensors connected on an intelligent control system [12].

A better IEQ can help the learning process of students and in many cases improving its attributes can also reduce energy use [13]. There is also evidence that high performance schools help teacher and student performance with improved indicators on standardized test scores, absenteeism, college acceptance rates, and teacher retention [14].

In Greece, during the early 1990s, a measurement and short-term monitoring campaign in four types of schools was carried in order to identify the problems and the actual conditions under which they operated [15]. In a more elaborate campaign over the same period, 238 school buildings were audited for construction, heating, cooling, lighting and electromechanical systems [16]. The total energy consumption and its breakdown for heating and cooling were reported and comparisons of energy performance indicators were made between insulated and non-insulated school buildings.

Quantification of the potential benefits and determination of priorities for energy conservation strategies in the school building sector is reported in [17]. This study is based on official data supplied by the Hellenic School Buildings Organization and relevant existing studies. The building stock is grouped in three temporal classes according to the year of construction namely pre-1980, 1980–2001 and 2002–2010 for the different national climatic zones. A technoeconomic analysis revealed the benefits from the implementation of 14 different energy conservation measures.

In a recent publication [18] data from a total of 320 schools are analyzed to derive energy benchmarks. The study also highlights the fact that school buildings suffer from important indoor air quality problems. The results of a study regarding the air flow rate and the corresponding CO_2 concentrations in 62 classrooms of 27 naturally ventilated schools in Athens are presented in [19] and compared with existing published data of naturally (NV) and mechanically ventilated (MV) schools. The measured mean and median flow rates expressed as liters per person per second were found to be significantly higher than those previously reported ones for NV schools (4.5 l/p/s compared to 3 l/p/s), but considerably lower than those concerning MV schools (8 l/p/s).

A number of studies have focused on the thermal behavior of school buildings in Northern Greece [20,21]. Poor IEQ was observed in the studied samples of schools mainly due to the absence of thermal insulation, lack of maintenance and insufficient thermal and lighting system control. The most efficient energy saving scenarios were thermal insulation for heating, night ventilation and ceiling fans for cooling.

Information on typical energy consumption of school buildings in Europe is rather limited and even more so regarding school energy performance and perceived thermal comfort in the Mediterranean region [22]. In Greece, few contemporary energy studies have been published so far concerning school buildings. The majority addresses the issue regionally and not enough information exists on a national level. Additionally, only a few publications exist proposing integrated solutions supported by thermal and energy analysis; the literature review illustrated that research in the area has mainly focused on the assessment of specific energy conservation measures and their contribution to the overall energy performance, without addressing the problem holistically.

This paper presents the results of a recent research aiming to complement existing published literature with up-to-date information on the energy consumption, IEQ, potential energy savings and reduction of greenhouse gas emissions in the Hellenic school building sector. An assessment of the entire school building stock based on official data is presented together with the results of an extensive energy survey on a national level in order to derive representative information on the energy behavior, construction characteristics and operating conditions of Hellenic schools. Finally, the results from a holistic approach involving energy auditing, performance assessment and subjective/objective IEQ evaluation applied in selected schools are presented and discussed.

2. The Hellenic school building stock

The tertiary sector (non-residential and agricultural buildings) is the fastest growing energy demand sector and is expected to increase by 1.2% per annum (pa) in 2000–2030 [23]. According to the National Hellenic Statistical Service, non-residential (NR) buildings represent about 25% of the Hellenic building stock and account for 7.3% of the total final consumption in the country. They are also responsible for 23.7% of the total electrical energy consumed by Hellenic building sector.

In order to derive reliable information on the contemporary Hellenic school building stock, official data were retrieved from the database of the Hellenic School Buildings Organization (SBO) and the archives of the Centre of Educational Research (CER) for the period 2007–2008 [24], as well as from the most recent published research work of 2005 [25].

According to official data from CER [25], the total number of Hellenic school buildings is 14,446 hosting the activities of five different educational grades, namely: nursery schools (38%), elementary schools (37%), gymnasiums (13%), lyceums (9%) and technical lyceums (3%). The total area occupied by the Hellenic school building stock is 10,772,913 m^2, 34% of which belong to classrooms whereas the total number of pupils enrolled is 1,357,480. Hence, it is concluded that an average area of 7.9 m^2 of school building and 2.7 m^2 of classroom are allocated to each student.

The majority of the school building stock, irrespective of the grade, is obsolete since it has been constructed before 1964. About 41% of the total number of school buildings is aged over 30 years, with 58.6% of the elementary schools constructed prior to 1975. Consequently, these buildings are not thermally insulated since the Hellenic Building Thermal Insulation Regulation was introduced in 1979. On the other hand, a significant percentage (about 42%) of school buildings is considered relatively new since they have been constructed after 1985. Specifically, the majority of nursery schools are less than 20 years old. This may be justified by the fact that this grade has recently become mandatory in the Hellenic educational system and hence there has been a necessity of constructing additional nursery schools. A general evaluation of the school buildings regarding the quality of construction and installed electromechanical (E/M) systems is presented in Fig. 1 based on data from CER [24]. The data reflects the extensive problems with the building envelope and aging E/M installations that would have an adverse impact the buildings' energy performance and IEQ.

The building envelope of the majority of the schools (54.1%) is in good condition whereas the corresponding percentage concerning the condition of the window frames is only 42.3%. An increased proportion of poorly insulated schools (about 25%) are observed in all grades with technical lyceums presenting the highest percentage (34.3%). The heating system operation is assessed as "satisfactory" for the majority of the stock (about 70%). The installed heating systems include central oil-fired boilers with radiators, local heat