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Improving energy performance of school buildings while ensuring indoor air quality ventilation

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Abstract

Energy conscious design of school buildings, as well as deemed-to-satisfy provisions in a Performance Based Energy Code, should address the problem known as the energy efficiency—thermal comfort—indoor air quality dilemma (EE-TC-IAQ Dilemma). In warm and moderate climates, the large internal heat sources usually found in school buildings prevent achieving thermal comfort without active cooling in summer, but are not sufficient to eliminate the need for heating in winter. Commonly used air-conditioners do not improve air quality, while natural ventilation induces uncontrolled energy losses. 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 Dilemma, for a performance based code. A distinction is made between improving building design variables and improving ventilation schemes. 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% for northern and southern classroom orientations, respectively.

Keywords: School buildings; Indoor air quality; Energy performance; Thermal comfort; Ventilation; Thermal insulation; Shading

1. Introduction

The methodology and results presented in this paper were developed within the framework of an extended Israeli research program, which aims at the establishment of a modern Building Energy Code that addresses all building occupancies.

The Code will enable two design options: a performance-based option that requires a comparative assessment of computationally-estimated energy expenditure against a calculated energy budget, and a prescriptive option. For the latter the Code will provide a set of solutions that are considered deemed-to-satisfy, and are based on a systematic investigation and identification of preferred sets of solutions. The reference energy budget will be based on such a preferred solution set.

The identification of preferred solutions for school buildings must address the inherent conflict that stems from the wish to save energy while having to provide adequate indoor air quality in addition to thermal comfort.

School buildings include nowadays various functional spaces. However, classrooms are still the most common functional space. They occupy the largest area of every school building, and host the largest part of daily activities and occupants. One of the most dominant features of a classroom is its high occupancy density, which results in very large values of the internal heat sources (approximately 5 kW), as well as of the internal emissions of body odors, water vapor and CO_2, causing an increasing concern with regard to the indoor air quality youngsters are exposed to along the major period of their growing up years [1,2].

Extensive natural or controlled ventilation, intended to remove internally generated contaminants, without active heating or cooling, is only seldom sufficient for the provision of required thermal comfort conditions.

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In summer, whenever external temperatures are lower than the required indoor temperature, ventilation can remove the excessive heat load produced by both incident solar radiation and internal sources, thus allowing the achievement of comfortable indoor temperatures. However, whenever external temperatures exceed the required comfort level temperature, active mechanical cooling must be provided.

Heating classrooms in winter is significantly assisted by the large internal heat sources, which can replace a large part of the heating energy demand. However, when external temperatures are smaller than the required indoor temperature, ventilation removes most of the internal heat load as well as the heat gains from solar radiation. Natural non-controlled ventilation leads then to excessive energy losses, as well as to chilling draughts and loss of thermal comfort. Controlled ventilation in winter is thus essential.

Consequently, simultaneous catering for thermal comfort, indoor air quality and energy conservation in schools is a design dilemma with apparently no obvious solution.

In the sequel, we denote this dilemma by: the EE-TC-IAQ Dilemma (energy efficiency—thermal comfort—indoor air quality dilemma). Efficient energy design of the classroom wing of school buildings should thus be primarily concerned with providing optimal solutions able to cope with the above dilemma.

Within the framework of a performance-based building code, the aim is to propose a range of engineering valid ''preferred'' solutions that establish a basis for creative and routine design, but not to prescribe an optimal unique solution, which may be too restrictive and become an unreasonable barrier to creative design.

This paper presents the methodology adopted for deriving such ''preferred'' solutions that cope with the EE-TC-IAQ Dilemma in school buildings, as well as some results that may be of general interest though they were derived for a typical local Mediterranean climate (see Appendix for some typical data). Locally significant observations or conclusions that are not relevant elsewhere have been intentionally omitted.

2. Energy performance, thermal comfort and IAQ in schools

Most of the literature concerned with energy performance of school buildings is devoted to savings via specific features such as utilization of solar energy [3–6], construction features, such as thermal insulation, thermal mass, and shading [5,7–9], HVAC performance [10–13], and geothermal pumps [14–17]. However, basic assumptions regarding thermal comfort, indoor air quality, occupancy and acclimatization schedules, internal loads, and architectural features of the school building are not identical in the various publications, and are usually based on local preferences. Consequently, even when similar climatic conditions prevail, conclusions cannot be regarded as sufficiently general. Moreover, the topic of energy performance of schools located in the Mediterranean region's climatic conditions and culture has not been explored at all.

The basic assumptions relevant to this paper's methodology, analysis and results are presented in Sections 2.2–2.4 below, while Section 2.1 briefly summarizes the literature concerned with the EE-TC-IAQ Dilemma.

2.1. Coping with the EE-TC-IAQ Dilemma in schools—literature overview

Despite the obvious need to cope with the EE-TC-IAQ Dilemma in school buildings, and the wealth of literature emphasizing the need to improve IAQ on one hand [1,2,18,19], and on the other one addressing the impact on acclimatization energy imposed by direct IAQ ventilation [4,18,20,21], only a few publications were found that present integrated solutions accompanied by thermal and energy analysis. Of these, only a few were concerned with the main classroom wings, addressing the inherent large internal loads as well as the more stringent IAQ requirements that exist there.

Studies since 1997 include Davanagere and colleagues [22], who studied the effect of the new ASHRAE-62 IAQ requirements for school buildings on life cycle costs when using different HVAC systems, but did not address the architectural or construction features of the building; Dorer and Weber [23], who pointed to the significance of an integrated evaluation of the energy and IAQ response of a multi-story school building, but addressed only two specific features: natural night ventilation enabled by two modes of window opening, and shaft ventilation via a double glazed façade; Kavanaugh and Xie [16], who demonstrated the significance of addressing the fan energy required for ventilation, either IAQ ventilation or heat recovery ventilation, in the total energy analysis; Eriksson and Whalstrom [24], who analyzed the performance of a hybrid ventilation system based on a solar chimney implemented in a Swedish school, utilizing multi-zone air transfer to model effects of wind conditions as well as door opening strategies; Becker and Paciuk [25], who showed the improved effect on total energy loads of various IAQ ventilation and night ventilation schemes, enabled by utilizing the buffering effect of an existing central atrium, but did not address their impact on total electricity consumption.

Additional articles are devoted to some specific solutions or features of the EE-TC-IAQ Dilemma in other functional spaces of school buildings. Recent publications address atria [26], staff rooms and auditoria [19], and sport halls [27].

The literature survey revealed that research in the area has been mostly concerned with improving the implementation and control of natural ventilation, or replacing some specific features of the HVAC system. No publications were found that address enhanced energy conservation by utilizing some of the regular, though specific, architectural features of classroom wings (such as the