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Original research article

An integrated approach on energy consumption and indoor environmental quality performance in six Portuguese secondary schools

Luísa Dias Pereira[a,*], Luis Neto[a,b], Hermano Bernardo[c], Manuel Gameiro da Silva[a]

[a] ADAI, LAETA – Department of Mechanical Engineering, University of Coimbra, Rua Luis Reis Santos, 3030-789 Coimbra, Portugal
[b] Instituto Politécnico de Castelo Branco, Portugal
[c] INESC Coimbra – Institute for Systems Engineering and Computers at Coimbra, Portugal

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ABSTRACT

A major rehabilitation programme of secondary school buildings has been carried out in the last few years in Portugal. With the introduction of HVAC systems in buildings that were previously naturally ventilated, an increase on energy consumption has been verified. During the first occupancy periods of new and refurbished buildings, energy and indoor climate quality audits are important strategies to improve the buildings' energy use. In this context, this paper aims at showing the relations between the energy consumption and indoor environment quality (IEQ) parameters, obtained from the energy and IEQ audit in six representative modernised secondary schools – part of a larger R&D project untitled 3Es – geographically and climatically distributed in Portugal mainland.

The monitoring period during the mid-season 2013 varied between schools, between two and three weeks. Air exchange rates, more specifically infiltration rates, were quantified aiming at determining the current airtightness condition of the refurbished schools. A subjective IEQ assessment was also performed, focusing on occupants' feedback, providing insight on the potential linkages between energy use and occupants' comfort.

A reflection on the energy consumption indicators and the indoor conditions obtained in the classrooms was proposed, and some suggestions were anticipated.

1. Introduction

1.1. Background

The physical and non-physical boundaries of school buildings environments have a critical effect on students' health and sense of well-being. School buildings are therefore a fundamental element of society [1]. The indoor environmental quality (IEQ) is a very important topic – not only children are particularly sensitive to low quality indoor environments because they are still under development [2] but also, classrooms have a high occupancy rate that may degrade users' health, comfort and performance conditions [3,4]. Among the consequences of poor indoor air quality (IAQ) conditions in schools, recent studies have focused on students and teachers performance [3,4] and verified a notably increased student absenteeism.

To achieve and maintain satisfying IAQ levels, large buildings use mechanical ventilation systems. The "EE-TC-IAQ" dilemma (energy efficiency – thermal comfort – indoor air quality), as presented by Becker et al. [5], is still a challenge within the building sector. Other than external factors, such as climate, energy demand in buildings is determined by three main types of factors and the linkages between those – building services, building envelope and human factors [6].

Since the Kyoto Protocol and European Union's first commitment period, large efforts towards GHG mitigation have been undertaken globally [7], and specially within the European energetic context. Many European policies towards energy conservation and rational use of energy have focused on the building sector. The Energy Performance Buildings Directive (EPBD) 2002/91/EC [8] and its 2010 recast [9], assumed special relevance in this context. In the Portuguese legislation, the EPBD was ensured in the form of three decree-laws, in 2006 [10–12].

* Corresponding author at: ADAI, LAETA – Department of Mechanical Engineering, Rua Luis Reis Santos, University of Coimbra – Pólo II, 3030-789 Coimbra, Portugal.
E-mail address: luisa.pereira@uc.pt (L. Dias Pereira).

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Nomenclature

AER	Air exchange rates
BJA	Secondary school in Beja
BGC	Secondary school in Bragança
CCD	Census County Division
EE	Energy efficiency
EPBD	Energy performance of buildings directive
GFA	Gross floor area
GRD	Secondary school in Guarda
HDD	Heating Degree Days
HVAC	Heating ventilation and air conditioning
IAQ	Indoor air quality
IEQ	Indoor environmental quality
MMV	Secondary school in Montemor-o-Velho
PBL	Secondary school in Pombal
PD	Percentage of dissatisfied
PE	Parque Escolar E.P.E.
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
PTG	Secondary school in Portalegre
RH	Relative humidity
SBI	School building indicator
Ta	Indoor air temperature
TA	Thermal acceptability
TC	Thermal comfort
TUFA	Total useful floor area

By the end of 2009, a large building modernisation programme of the secondary schools was taking place in Portugal, led by the state-owned company *Parque Escolar E.P.E.* (PE) [13]. Most existing school buildings, which were naturally ventilated at their origin, were refurbished in accordance to the new legislation [10–12], integrating both insulation elements on walls and/or ceilings and 'heating ventilation and air conditioning' (HVAC) systems to comply with the new requirements of thermal comfort (TC) and indoor air quality (IAQ).

1.2. Problem statement

Research on IEQ related specifically to new or refurbished school construction was relatively scarce until the end of last century. Today worldwide studies are being performed on this field. In [14], the authors presented a literature survey on the influence of different factors on human comfort in indoor environments, presenting various case studies, data analysis strategies, different building types – including secondary schools, and results. They also mention studies that related outdoor climate and season with IEQ satisfaction. Wargocki and Wyon's extensive work on students' schoolwork performance has been continuously published [3,15,16], and the study of Shendell et al. [17] relating CO_2 concentrations to student attendance also included a relevant literature review on the topic.

CO_2 control in classrooms and different ventilation strategies [18–20] – as the one suggested by the most recent UK legislation (BB101) [21] – have been well thought-out, and the most recent studies on its consequences are being closely followed [22–24]. It is noteworthy that changes to the legislation in the UK were preceded by the intensive studies on adaptive comfort by Humphreys and Nicol [25–27]. Currently this legislation is again under public consultation [28].

The study performed by [29], in a Mediterranean climate, demonstrated that considering outdoor conditions, clothing levels and indoor air temperatures in buildings is crucial to correctly analyse occupants behaviours and preferences. In fact, it showed that people who moved from HVAC equipped spaces to others, non-equipped, had their temperature range preference enlarged beyond those defined in ISO 7730 [30]. In winter, the verified acceptable indoor temperatures were slightly lower and during summer, for high outdoor temperatures, the indoor ones were higher than those suggested in the standards, resulting in operating range temperatures between 22–27 °C and 19°–25 °C, in summer and winter, respectively, for category C (representative of the *highest acceptable range around the optimum temperature – 15% dissatisfied people*).

As such, it became relevant to reflect on the IAQ parameters of the current Portuguese legislation (2013) that rules HVAC requirements for schools (as those expressed in SCE [31,32] facing the previous one, RSECE [11], 2006). Some studies, based on field measurements (e.g. Santamouris et al., 2008 [33]) or simulation (Gameiro da Silva, 2009 in [2]), suggested that the 2006 requirements of outdoor air flow (30 m^3/h) proposed by the Portuguese legislation, could be oversized (significantly higher than those from ASHRAE 62/1:2010 [34]), therefore over consuming and potentially over charging the contracted power (a lower fresh air flow rate means necessarily a lower energy consumption of the adopted mechanical system). The simulation tool developed by the author demonstrated that a relaxation of the "optimum" daily average concentration of CO_2 from 1,8 g/m^3 (1000 ppm) to 2,7 g/m^3 (1500 ppm) significantly minimizes fresh air flow rates – practically by half.

1.3. Aim and scope of the paper

For the reasons previously presented, it was questionable if the energy bill associated with ventilation on Portuguese schools modernised by PE was being overcharged, and if this corresponded to an effective satisfaction on occupants comfort.

This concern with energy expenses has been clearly stated by Santamouris et al. (2007) in [35]: the *"increased use of air conditioning creates a serious peak electricity load problem to utilities and increases the cost of electricity"*. This condition was familiar to the Portuguese educational sector. Previously to PE's intervention, most schools were naturally ventilated and therefore, had smaller energy bills. Due to the mechanization of the heating and ventilation system (cooling was not mandatory according to the 2006 legislation), monthly energy expenditures increased. Because some schools could have their HVAC systems turned off to reduce energy bills, an IEQ audit was mandatory to evaluate the indoor climate condition of the classrooms.

To sum up, this study aimed at assessing the energy and IEQ of recently refurbished classrooms. In parallel to the energy data collection (both from billed energy data and field monitoring campaign), an IEQ analysis of indoor environmental parameters (as air temperature, relative humidity, air velocity and CO_2 concentration values) was performed – measured every minute over a two-week period (on average), complemented with a subjective survey driven to the students occupying the monitored rooms.

The development of an inquiry/survey between school populations was a fundamental procedure to assess the school population sensitive response to the recently installed HVAC systems. This type of data collection allowed in 2013, Montazami and Nicol [23] revealing overheating problems in the UK schools – in their case studies, school teachers were asked to rate the level of thermal comfort (TC) and temperature inside classrooms.

Moreover, Fanger's thermal comfort indices (PPD and PMV) [36] were estimated based on data collection, from both monitored parameters and surveys – accounting for the metabolic rate and clothing insulation. These indices calculation allowed establishing a comparative evaluation between subjective results and those obtained from the measurements on the field, attending also the perception in terms of acceptability and preference. The TC and

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در اجرای درخواست شما مشکلی رخ داده است

با سلام متأسفانه مشکلی در فرایند اجرای درخواست شما رخ داده است

همکاران ما در حال تلاش برای رفع این مشکل هستند

لطفاً درخواست خود را در ساعات دیگری مجدداً تکرار فرمایید و اگر باز هم با این مشکل رو به رو شدید، از طریق فرم تماس با ما به واحد پشتیبانی اطلاع دهید

برای یافتن مطلب مورد نظر خود می توانید از روش های جستجوی زیر استفاده فرمایید :

جســـــتجو در میـــــان موضوعات

برای جستجو در میان موضوعات، به محض این که عبارت خود را در فیلـد زیر بنویسـید، موضوع های مرتبط در درخت سمت چپ با رنگ متمایزی مشخص می شوند.

جستجو ...

جســـــتجو در میـــــان مقالات

اگر موضــوع مــورد نظر شـــما در لیســت موضوعات اصلی وجود نداشت، با استفاده از فیلـــد زیر می توانیـــد آن را در بیـــن کل مقاله های سایت جستجو فرمایید.

جستجو ...

جستجو

لیست درختی موضوعات

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- مدیریت دولتی
- مدیریت رفتار سازمانی
- مدیریت مالی
- مدیریت منابع انسانی
- مطالعات اسلامی
- کارآفرینی و مدیریت کسب و کار

تماس با واحد پشتیبانی

همکاران ما در واحد پشتیبانی آمادگی دارند تمـامی درخـواست هـای شـما عزیزان را بررسـی نمـوده و در اسـرع وقـت رسـیدگی نمایند

پیگیری خرید مقاله

پس از خریـد هر مقـاله، یـک کـد رهگیری منحصر به فرد به شما تقدیم خواهد شد که با استفاده از آن می توانید وضعیت خرید خود را پیگیری فرمایید

کد رهگیری

ارسال

پیگیری سفارش ترجمه

با ثبت کد رهگیری پرداخت، می توانید سفارش خود را پیگیری نموده و به محض اتمام ترجمه، فایل ترجمه مقاله خود را دانلود نمایید

کد رهگیری

ارسال