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Air Quality Inside a School Building : Air Exchange Monitoring, Evolution of Carbon Dioxide and Assessment of Ventilation Strategies

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Abstract

This paper presents an assessment of indoor air quality and various ventilation strategies inside a school building located in the south of Portugal . In the first phase, ventilation rate was experimentally evaluated using the tracer gas method. In the second part, different airflow typologies were investigated and, after calculating the air exchange and flow rates for each of them, the evolution of metabolic carbon dioxide inside the spaces was numerically estimated.

Ventilation measurements were made in classrooms, auditorium, offices, staff and computer rooms. The assessment of ventilation was based on evaluating the carbon dioxide produced by the occupants for three ventilation approaches; these were: one based on cross-flow natural ventilation (in current use) and two based on forced ventilation systems. In the case of the forced systems, one was based on providing a constant flow to meet the required Portuguese ventilation standard in the main occupied rooms while the other was an adjusted constant rate based on a simple calculation procedure that took into consideration the air quality needs of all the spaces including corridors and atria. This approach was developed to produce an efficient yet inexpensive ventilation approach that did not incorporate expensive sensors and control systems.

Carbon dioxide evolution predictions were made using software that evaluated the thermal response and the air quality of a building with complex topology. The numerical model used to evaluate air quality, was based on mass conservation integral equations in which the final equations system was solved through the Runge-Kutta-Fehlberg method with error control. A statistical study of the occupation cycle in the school building during the day was developed.

Key words: indoor air quality, schools, tracer gas measurements, carbon dioxide evolution, air exchange rate, airflow rate, ventilation systems, age of air, ventilation efficiency, occupancy schedule.

1. Introduction

The ability of students to learn is dependent on several issues such as developmental, sociological, psychological and pedagogical factors, as well as physical parameters including thermal quality, air quality, visual quality and ergonomics, among other parameters of lower importance. In this work the air quality, namely the air exchange rate, airflow rate and the evolution of metabolic carbon dioxide concentration released by the occupants, for different ventilation systems, has been analysed.

Several school buildings studies have been made over the last years (see, for example, Lazzerini, *et al.,* 1991a; Lazzerini, *et al.*, 1991b; Lee and Chang, 2000; Scheff *et al.,* 2000; Bayer *et al.,* 2000; WHO/ROE, 2000; Chaloulakou and Mavroidis, 2002; Kolokotroni and Katsoulas, 2002; Warden, 2004; and Howell and Land, 2004). Due to the importance of good ventilation in schools which controls air quality and influences the well-being of occupants these and similar studies have been made throughout the world.

In order to evaluate indoor air quality, micro-models and macro-models can be used (see, for example, Heinsohn, 1989). In the former, space discretizing grids are used and environmental variables are calculated at all the grid nodes, while in macro-models these variables are calculated inside all spaces.

The airflow rate inside an occupied space can be calculated using different recommendations and methodologies presented in national and international standards (see also Olesen, 1997). ANSI/ASHRAE Standard 62.1 (2004) defines a limit for carbon dioxide concentration inside a space of around 1800 mg/m^3 and an airflow rate per occupant and type of space. This Standard recommends minimum ventilation rates from between 3.8 L/s and 5 L/s per person with additional needs to allow for pollution emission from materials. The Portuguese Standard presented in D.-L. nº 79/2006 of April 4th, defines airflow rates for occupants according to the type of space. These recommended values are 30 m^3/h per occupant (8.3 L/s) for classrooms, auditoriums and libraries, and 35 m^3/h per occupant (9.7 L/s) for science laboratories. This Standard recommends a maximum indoor carbon dioxide concentration of 1800 mg/m^3.

CR 1752 (1998) considers airflow rate based on occupants' comfort level. In this methodology, three quality levels are applied (category A, with 10 % of dissatisfied persons; category B, with 20 % of dissatisfied persons and category C, with 30 % of dissatisfied persons). Occupants and materials existing inside the room are considered as pollution sources. This perspective, based on the *Olf* and *Decipol* units, is presented in detail by Fanger (1988). For the categories A, B and C the recommended, ventilation rates are respectively, 16, 7 and 4 L/s per Olf. For all categories it is also necessary to consider the pollution load caused by the building itself (including furnishings, carpets and ventilation systems). For school classrooms, the value 0.3 Olf per m^2 of floor area is recommended. Applying these various Standards to school buildings showed that CR 1752 category A required the highest ventilation rate while D.-L. nº 79/2006 gave the lowest rate.

Air quality may be assessed directly from the metabolic carbon dioxide concentration i.e. CO_2 generated by the occupants themselves. EUR 14449 EN (1992) and CR 1752 (1998) use a PPD index (percentage of persons dissatisfied) to express the degree of discomfort in relation to carbon dioxide concentration. Using this approach a concentration of approximately 1100 mg/m^3 of CO_2 translates to 10% of dissatisfied persons (category A), an approximate concentration of 1700 mg/m^3 to 20% of dissatisfied persons (category B) and an approximate concentration of 2700 mg/m^3 to 30% of dissatisfied persons (category C).

The tracer gas method can be used to determine the air exchange rate and the airflow rate, as well as the air age and ventilation system efficiency, among other values. Several methods are available to calculate these values including: monitoring metabolic carbon dioxide concentration (see Levine et al, 1993), concentration decay, constant emission, constant concentration, and pulsed injection (see as examples Sandberg, 1981; Sandberg and Sjöberg, 1983; Breum, 1988; Niemelä *et al.*, 1989; Roulet, 1991; Grieve, 1991; and Roulet and Cretton, 1992). The option for each method is associated with the particular need and building configuration.

In this work it is intended to develop a ventilation system to be implemented in Portuguese school buildings (located in the South - Algarve). This kind of system, which could be used in all schools in this region in the future, is intended to be efficient and to have a low cost. Being so, a system that includes fans running continuously instead of fans running intermittently will be developed due to the high cost of sensors to this kind of running.

The philosophy of the ventilation system being considered was to increase the air quality in classrooms and other predominantly occupied spaces at low cost. To achieve this, a fresh airflow path, passing through corridors and atria was considered from which each classroom intakes the fresh air via a door vent or grid. Continuously running window extract fans are then used to exhaust air from the classrooms.

In order to obtain good air quality in relation to the proposed airflow philosophy it was necessary to calculate the required average airflow rate through the fans. This calculation was based on occupancy schedules which allowed for short periods during the day in which rooms are unoccupied. By continuously running fans, good air quality could be secured at all times in these rooms as well as in the corridors and atria.

The work described in this paper included measuring ventilation rates and numerically calculating metabolic carbon dioxide concentrations for the selected ventilation strategies. These calculations were used to optimise the continuous fan extract rates.