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The effect of natural ventilation strategy on indoor air quality in schools

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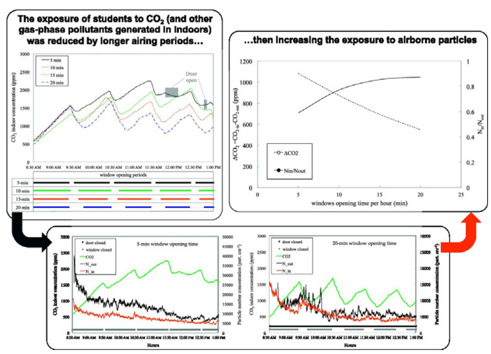
HIGHLIGHTS

- Indoor air quality in naturally ventilated Italian classrooms
- Comparison between heating and non heating season in different schools
- Evaluation of the effect of different airing procedure on classroom air quality
- Longer airing periods reduced gaseous indoor-generated pollutants concentrations.
- Higher ultrafine particle levels in classrooms due to infiltration from outdoors.

GRAPHICAL ABSTRACT



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ABSTRACT

In order to reduce children's exposure to pollutants in classrooms a proper ventilation strategy need to be adopted. Such strategy is even more important in naturally ventilated schools where the air exchange rate is only based on the manual airing of classrooms. The present work aimed to evaluate the effect of the manual airing strategy on indoor air quality in Italian classrooms. For this aim, schools located in the Central Italy were investigated. Indoor air quality was studied in terms of CO_2, particle number and PM concentrations and compared to corresponding outdoor levels. In particular two experimental analyses were performed: i) a comparison between heating and non heating season in different schools; ii) an evaluation of the effect of scheduled airing periods on the dilution of indoor-generated pollutants and the penetration of outdoor-generated ones. In particular, different airing procedures, i.e. different window opening periods (5 to 20 min per hour) were imposed and controlled through contacts installed on classroom windows and doors. Results revealed that the airing strategy differently affect the several pollutants detected in indoors depending on their size, origin and dynamics. Longer airing periods may result in reduced indoor CO_2 concentrations and, similarly, other gaseous indoor-generated pollutants. Simultaneously, higher ultrafine particle (and other vehicular-related pollutants) levels in indoors were measured due to infiltration from outdoors. Finally, a negligible effect of the manual airing on PM levels in classroom was detected. Therefore, a simultaneous reduction in concentration levels for all the pollutant metrics in classrooms cannot be obtained just relying upon air permeability of the building envelope and manual airing of the classrooms.

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1. Introduction

The indoor air quality was recognized as a one of the most influencing concerns in terms of health effect. Indeed, people are typically exposed to high concentrations of pollutants in indoors, resulting in large doses received with significant related health effects (Buonanno et al., 2011b; Buonanno et al., 2015; Buonanno et al., 2013b; Burtscher and Schüepp, 2012; Cesaroni et al., 2013; Fuoco et al., 2013; Morawska et al., 2013; Schwartz et al., 2008; Trassierra et al., 2016). Great attention was paid by the scientific literature to microenvironments where high pollutant emitters are typically located, such as homes (e.g. cooking activity (See and Balasubramanian, 2006a; See and Balasubramanian, 2006b), incense and candle burning activity (Stabile et al., 2012), cigarette smoking (Fuoco et al., 2017; Stabile et al., 2017)), offices (e.g. printers, copiers (Destaillats et al., 2008; Scungio et al., 2017; Stabile et al., 2016b)) and other workplace environments (e.g. industrial activity (Buonanno et al., 2011c), schools (Stabile et al., 2016a)). Nonetheless, a significant dose (and then a significant health risk) can be also received during long lasting exposures in non-occupational indoor microenvironments such as schools.

1.1. Indoor air quality in schools

Schools represent an interesting micro-environment since the population residing therein, i.e. students, can be considered a susceptible population due to their age: in fact, the possible effects of a long-lasting exposure of pupils to pollutants could be more severe than those affecting adults (Buonanno et al., 2012b; Peled, 2011; Selgrade et al., 2008). For this purpose the scientific community performed a number of researches in order to evaluate the concentration levels of different pollutants in classrooms (Krawczyk et al., 2016; Madureira et al., 2016a; Rosbach et al., 2016; Salthammer et al., 2016). Most of these researches are focused on the measurement of CO_2 concentrations. Even if high concentration of CO_2 itself may cause negative effects on the students' vigilance and attention (Mendell and Heath, 2005), CO_2 is not classified as a pollutant by the World Health Organization. Nonetheless, it can be considered a good proxy of the indoor air quality (Apte, 2000; Chatzidiakou et al., 2015): indeed, CO_2 is the parameter typically used (i) to alert teachers to open windows due to the poor air quality and classroom overheating (manual airing) or (ii) to adjust the amount of outdoor ventilation in Heating, Ventilating and Air Conditioning (HVAC) systems. Moreover, European standards aiming to provide guidelines on indoor comfort, air quality and ventilation system design still adopt the CO_2 concentration solely as a marker of indoor air quality (European Committee for Standardisation, 2007; European Committee for Standardisation, 2008).

Indoor air quality in schools is worsened by several pollutants: as an example, high concentrations of indoor-generated gaseous pollutants as radon and Volatile Organic Compounds (VOCs) have been measured in classrooms worldwide (de Gennaro et al., 2013; Foster et al., 2015; Istrate et al., 2016; Madureira et al., 2016b; Stabile et al., 2016a), in particular in naturally ventilated buildings during colder months, i.e. when the reduced classroom air change rates are not able to properly ex-filtrate indoor-generated pollutants. Therefore, measurements of CO_2 trends in schools may be useful to predict trends of other indoor-generated gaseous pollutants (when their emission rates are known), but they cannot be useful to predict traffic-related pollutants in indoors (Chatzidiakou et al., 2015). Therefore, ventilation/airing methods based on CO_2 trends may result in not expectedly high concentrations of outdoor-generated pollutants (and then in related worse health effects (Gao et al., 2014)), in particular for naturally ventilated buildings where no filtration of fresh outdoor air entering the building is applied.

As an example, sub-micron and ultrafine particles (particles smaller than 100 nm in diameter), which represents the aerosol metrics characteristics of tailpipe traffic emission (i.e. due to the combustion phenomena (Buonanno et al., 2011a; Buonanno et al., 2009b)), may result in high concentrations in school microenvironments, in particular when schools are located close to main urban roads (Buonanno et al., 2013a; Stabile et al., 2013a). Nonetheless, few studies were carried out by the scientific community to determine sub-micron and ultrafine particle concentration levels in classrooms (Mazaheri et al., 2016; Salthammer et al., 2016). Indeed, in terms of particle concentrations, studies were mainly focused on the PM_{10} and $PM_{2.5}$ levels (i.e. mass concentrations of particles sized smaller than 10 and 2.5 μm, respectively). In particular, PM_{10} and $PM_{2.5}$ concentrations in classrooms were found larger than outdoor ones mainly due to resuspension phenomena and to the usage of chalk sticks for writing (Braniš and Šafránek, 2011; Braniš et al., 2009; Braniš et al., 2011; Buonanno et al., 2012a; Lin et al., 2015; Salma et al., 2013).

Despite the enhanced outdoor-to-indoor pollutant infiltration, a further negative aspect of ventilation/airing methods is represented by the energy losses (Ficco et al., 2015; Massimo et al., 2014) related to the air leakages and air exchange rates. A possible approach to control simultaneously the indoor air quality and the energy losses in classrooms is the use of properly designed Heating, Ventilating and Air Conditioning (HVAC) systems which are able to reduce both the indoor-generated gas-phase pollutant concentrations, due to the increased air change rates, and the outdoor-generated pollutants, thanks to high-efficiency filters (Rosbach et al., 2016; Toftum et al., 2015; van der Zee et al., 2016). However, most of the schools worldwide are not provided with mechanical ventilation systems, thus the air exchange just relies upon the natural ventilation via infiltration through leakages of the building and the possible manual airing (i.e. manual window/door opening) (d'Ambrosio Alfano et al., 2016b; d'Ambrosio Alfano et al., 2012; d'Ambrosio Alfano et al., 2015). Anyway, the effect of such ventilation approach on indoor concentrations is not easily predictable since the micro-climatic conditions and the individual thermal comfort can randomly affect the airing strategy and, consequently, the indoor air quality. Therefore, the effect of the natural airing strategy on indoor air quality in naturally ventilated classrooms needs to be investigated.

1.2. Aims of the work

In order to evaluate the effect of the ventilation strategy on indoor air quality, an experimental analysis was performed in Italian schools considering different pollutants characterized by diverse origin, size and dynamics: CO_2 and airborne particles (both in terms of number and mass concentrations). Two different experimental analyses were carried out:

a) a comparison between the pollutant concentration levels measured during “heating season” and “non heating season” in all the investigated classrooms to highlight the effect of typical airing strategy usually applied in the schools;
b) a detailed analysis of pollutant concentration levels as a function of prescribed airing procedures (in terms of window opening time) aimed to highlight penetration and ex-filtration of outdoor- and indoor-generated pollutants, respectively.

2. Experiments

2.1. The sampling sites: school description

Three public primary schools (named A, B and C) located in the urban area of Cassino (Central Italy) were considered in the experimental campaign. The school buildings were built between the 60's and 80's. Indeed, they were not provided by cutting-edge Central Heating Ventilation and Air-Conditioning systems: a simple heating system made up of hot-water radiators (in operation during the cold season or “heating season” ranging from November to March) was present in the schools, whereas the ventilation was performed by naturally ventilating the classrooms (by opening windows/doors, i.e. “airing” method).