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# An integrated evaluation study of the ventilation rate, the exposure and the indoor air quality in naturally ventilated classrooms in the Mediterranean region during spring

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## HIGHLIGHTS

- Ventilation rates were adequate for certain cases for the majority of the schools.
- Increased $PM_{10}$ due to the students' presence, inadequate ACH and chalk use.
- The excessive exceedence of 1 of the PM I/O ratio shows strong indoor sources.
- Schools using chalk had higher $PM_{10}$ levels compared to schools using marker.
- Schools using marker had greater CO and VOCs levels compared to schools using chalk.

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## ABSTRACT

Ventilation rates and indoor air pollutants have been extensively monitored in nine naturally ventilated primary schools of Athens, Greece during spring. The ventilation rates and pollutant levels were studied during the teaching and non-teaching periods and ventilation profiles were created for each of the schools. The median ventilation rates per school ranged between 0.7 and 8 ACH while the average ventilation rate in all schools (11.7 l/s/p) was greater than the minimum recommended rates by ASHRAE for school classrooms. The average carbon dioxide ($CO_2$) concentrations per school varied between 893 and 2082 ppm, while the majority of the cases were slightly above the recommended limit values. $CO_2$ concentrations were also positively correlated to the number of students and negatively correlated to the ventilation rates. Particles of several size ranges ($PM_{10}$, $PM_5$, $PM_{2.5}$, $PM_1$, $PM_{0.5}$ and UFP) were also measured and analyzed. $PM_{10}$ concentrations exceeded the recommended limit values by more than 10 times for the majority of the cases. There were also many cases that the $PM_{2.5}$ concentrations exceeded their limit values. PM concentrations were significantly affected by the ventilation rates and the presence of students. All of the measured particle sizes were greater during teaching than the non-teaching hours. For most of the cases the indoor to outdoor (I/O) concentrations ratios of $PM_{10}$ and $PM_{2.5}$ were much greater than one, indicating that the indoor environment was being mostly affected by indoor sources instead of the outdoor air. Furthermore it was found that chalk and marker boards' usage significantly affect indoor pollutant concentrations. Overall, the measured levels of exposure were for most of the cases greater than the recommended guideline values due to the intense presence of indoor pollution sources, even though the ventilation rates were in general satisfactory.



## 1. Introduction

There is epidemiological evidence that the exposure of human to air pollutants such as particulate matter (PM) can lead to hazardous health effects such as asthma (Pope and Dockery, 2006; Bakke et al., 2012). Atmospheric PM is mainly responsible for adverse health effects in urban areas (Sarigiannis et al., 2004). Studies conducted in indoor environments and human exposure, have related poor air quality with asthma, rhinitis, allergic diseases and eczema increases (Annesi-Maesano et al., 2003; Sarigiannis et al., 2009; Kim et al., 2010; Jantunen et al., 2011; Bakke et al., 2012). As the indoor air quality (IAQ) can influence by far human health, numerous studies have been carried on in several indoor environments such as dentistry clinics, underground trains, residences and even air traffic control towers (Helmis et al., 2007; Chau et al., 2008; Helmis et al., 2009; Assimakopoulos et al., 2013).

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Infants and young children are highly vulnerable to the health effects compared to adults, to the exposure to indoor air pollution, due to their higher resting metabolic rate in proportion to their body weight. In particular, the air intake of an infant is proportionally about double that of an adult meaning that children have significantly greater exposures to any kind of toxicants in the air compared to adults (WHO, 2005a; Annesi-Maesano et al., 2003).

In developing countries and urban areas children spent a substantial amount of their day indoors and mainly in schools (Silvers et al., 1994; Bai et al., 2007; Hussein et al., 2012). Several studies conducted in school environments have concluded that the indoor air quality of classrooms is significantly unhealthy (Dorizas et al., 2013a; Fromme et al., 2007; Fromme et al., 2005; Goyal and Khare, 2009; Siskos et al., 2001; Synnefa et al., 2003; Tippayawong et al., 2009). It has also been found that mean cancer risk for urban school children is higher than the corresponding sub-urban school children (Demirel et al., 2014). Poor indoor environment in classrooms may be linked to many factors such as inadequate levels of ventilation as well as to the lack of necessary resources for the adequate operation and maintenance of facilities. Recent studies made by Myhrvold et al. (1996), Mendell and Heath (2005), Wargocki et al. (2005), and Wargocki and Wyon (2007) have found that poor IAQ and inadequate ventilation rate can also be linked to reduced academic achievements and general performance of schoolwork.

Furthermore, studies related with the indoor and outdoor air quality of schools have found that the outdoor environment plays a decisive role on the indoor pollutant levels (Chaloulakou et al., 2003; Diapouli et al., 2007; Goyal and Khare, 2009; Guo et al., 2010; Tippayawong et al., 2009; Yoon et al., 2011). Further relationships between the indoor and outdoor levels of particulate matter have been examined by Jamriska et al., 1999; Jones et al., 2000 and Morawksa et al., 2001.

Despite the fact that a great number of studies have been carried out in school environments, the ventilation requirements in naturally ventilated buildings in conjunction to the indoor air pollutant levels are still not well understood. Therefore, additional information concerning ventilation rate and indoor air pollutants are necessary. The main objectives of this study are: 1. to extensively analyze the airflow rates of naturally ventilated classrooms in warm (Mediterranean) climates, 2. to examine the concentration levels of the main indoor air pollutant concentrations such as $CO_2$, CO, VOCs, and PM of several size ranges within classrooms, 3. to investigate the level at which the outdoor air affects the indoor air pollutant levels, and 4. to identify to which extend factors such as human presence, ventilation rate and the use of chalk or marker boards can influence indoor air pollutants concentrations.

## 2. Methodology

### 2.1. Sampling site description & measurement period

The measurements were carried out during spring 2013 in nine naturally ventilated primary schools of Attika basin in Greece (Dorizas et al., 2013b). Eight of them are located in the north-western part of Attika (Thrakomakedones, Acharrnae) and one school was located in the eastern regional area of Attika (Pallini) (Fig. 1). According to CORINE 2000 land cover database (Geodata, 2010), the majority (6 out of 9) of the schools (code names: 1, 14, 4, 18, 2, 8, see Table 1) are in areas characterized as 'discontinuous urban fabric' in which a great percentage of the land is covered by structures (EEA, ETC./TE, 2004) (Fig. 2, left). One of the schools (code 12) is at an area of 'continuous urban fabric' where buildings and roads cover more than 80% of the total surface (Fig. 2, right), and two other schools (codes: 3 & 11) are in areas having 'complex cultivation patterns 'where small areas of annual crops are present (Fig. 3).

It is worth mentioning that our aim was to conduct measurements at an adequate number of schools for a period of the order of one week at each location. On the other hand according to our preliminary measurements, the values of concentration of pollutants and ventilation rates in the schools were within the same range, under the same activity pattern and meteorological conditions. Also there were limitations in time given by the school directors. Thus, all conducted measurements, even with different measuring periods, were included in the data base, in order to use measurements from an adequate number of schools.

The monitoring was carried out in one classroom per school, the 6th grade where students are of 11–12 years old. Table 1 summarizes some of the main characteristics of the schools, buildings and classrooms. The occupancy density ranged from 1.84 to 3.67 $m^2$/student, while the average floor area of the monitored classrooms is 51.78 $m^2$ which is similar for the majority of the schools. Six out of the nine schools used chalk whiteboards (codes: 1, 14, 4, 3, 18, 11) while the remaining three used marker white boards (codes: 12, 2, 8). The age of the school buildings varied from 10 to 35 years. The experimental campaign was performed during mid-season (spring), from the beginning of April until the ending of May 2013. The reason that the monitoring took place outside the heating season was in order to assess the ventilation conditions and pollutant levels into a free-running mode of the school buildings, as the variations in temperature and relative humidity from a mechanically operated heating system would influence by far their diurnal distribution and fluctuations (Teli et al., 2013). In this case the

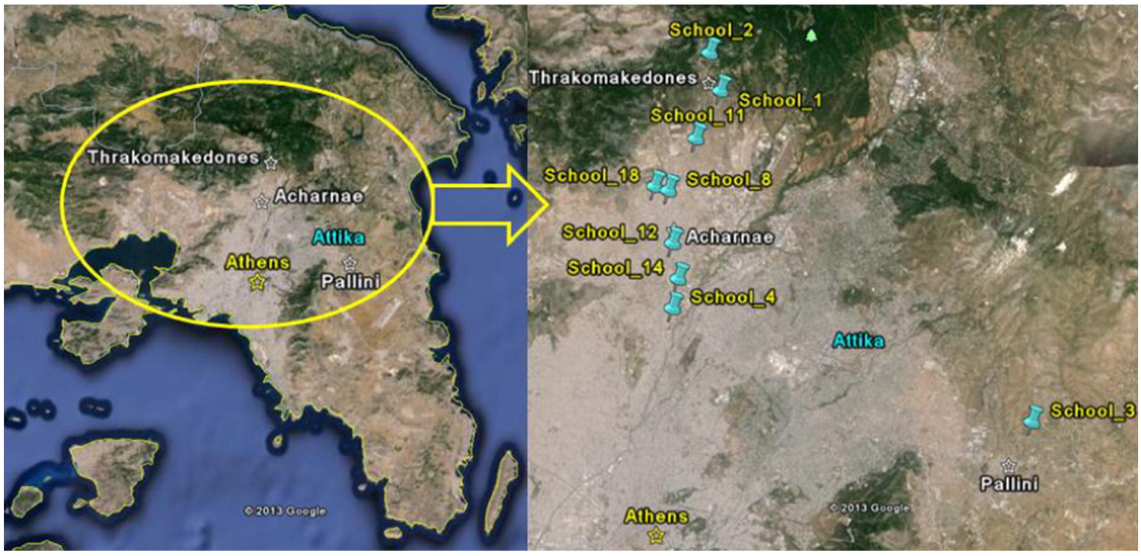


**Fig. 1.** Map of Attika, Greece (left), and location of the 9 schools (right).