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Particulate matter analysis in indoor environments of urban and rural primary schools using passive sampling methodology

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HIGHLIGHTS

- Passive sampling methodology for particulate matter in indoors is proposed.
- Autumn was the season that presented higher particle masses concentrations.
- Calcium is the major indoor PM component in rural and urban classrooms.
- Soil re-suspension, traffic and chalk are the main sources of indoor PM.
- Natural ventilation is a major contributor to the variability of indoor PM.

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ABSTRACT

Passive sampling methodology was applied to collect particulate matter (PM) in classrooms of urban and rural primary schools. The samples were taken during a year by passive deposition allowing the study of seasonal variability of the particles masses and chemical content. Chemical characterization of the collected particles was performed in order to measure its soluble ions content and elemental composition. To identify the main polluting sources, correlations between parameters and enrichment factors were studied. Higher particle masses concentrations were registered in autumn, with a mean of 1.54 ± 0.74 μg day^{-1} cm^{-2}. The major element in the collected particles was calcium, representing 63–73% of the analyzed mass of the particles inside the urban classrooms. In the rural cluster, calcium remained the major component but with a slight lower contribution to the overall particles composition (42–46%). The calcium source was hypothesized to be the chalk used in the blackboards of the classrooms due to a strong correlation found between Ca^{2+} and SO_4^{2-}. Soil re-suspension, traffic and other anthropogenic emission sources were also identified. Analysis showed enrichment of the particles with Br, Ca, Zn and Sb in the urban cluster and enrichment of the same elements, except for Ca, in the rural cluster. The comparison between the results from both clusters allowed the identification of classrooms with higher particles concentrations that can indicate potential indoor air quality problems (reflected by an indoor accumulation of pollutants).

1. Introduction

Over the last decade, several studies have been conducted to assess the indoor air quality in schools since the importance of the indoor air quality concerning health, performance and students attendance have been demonstrated (Mendell and Health, 2005). In fact, children spend most of their time in indoor environments leading them to a higher exposure to indoor pollutants than outdoor ones. Additionally, children breathe higher air volumes when compared to their body weight and have a lower capacity to deal with toxic chemicals, which consequently enhances their susceptibility to potential health consequences due to indoor air contaminants (Stranger et al., 2008; Selgrade et al., 2007; Canha et al., 2012a).

Health implications due to atmospheric particles pollution have been shown by epidemiological studies where correlations were

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found between particles concentration and number of deaths from cancer, cardiovascular and respiratory diseases (Pope et al., 2002). Evidence on the increase of hospital admissions due to respiratory and cardiovascular diseases caused by particulate air pollution has also been shown (Middleton et al., 2008). Associations between air pollutants and illness-related absences in school children (Park et al., 2002), suggest that air pollution is closely linked to daily activities, particularly of school-aged children. Higher numbers of children suffering from bronchial hyperresponsiveness, positive allergic sensitization to common allergens or both were identified in schools close to motorways with heavy traffic than in schools near motorways with low traffic (Janssen et al., 2003).

The indoor environmental quality at schools can be characterized by: 1) insufficient ventilation, especially in winter; 2) infrequent and inadequate cleaning of indoor surfaces and 3) a large number of students per classroom area and volume, with constant re-suspension of particles from room surfaces along with suspension of soil material due to the activity of the children (Janssen et al., 1999). As a result, particulate matter (PM) concentrations in classrooms are about six times higher than outdoor air (Oeder et al., 2012). On an equal weight base, indoor air PM_{10} has been shown to be toxicologically more active than outdoor PM_{10}, with the main difference being the higher concentration of organic and silicate particles in indoor air (Oeder et al., 2012).

The indoor guideline values for particulate matter vary a lot within the few countries that have already defined such regulation (Stranger et al., 2007). For $PM_{2.5}$, Norway established the limit value of 20 $\mu g\ m^{-3}$ (averaged over a 24 h sampling period), while Belgium established the limit value of 15 $\mu g\ m^{-3}$ (averaged over one year) and Canada introduced acceptance values below 40 $mg\ m^{-3}$ (averaged over one hour). Concerning indoor PM_{10}, Belgium established a limit value of 40 $\mu g\ m^{-3}$ (averaged over one year) while China and Portugal (Decreto Lei no. 79, 2006) introduced the limit value of 150 $\mu g\ m^{-3}$.

Due to its importance, several studies have been conducted to assess the particulate matter (PM_{10}, $PM_{2.5}$ and ultrafine particles) in indoor environments of schools concerning their concentrations and chemical composition (Blondeau et al., 2005; Fromme et al., 2008; Zhang and Zhu, 2012). Despite the several studies performed in the last years, few aimed to study the particulate matter composition and its elemental and water soluble ions contents in order to understand their sources and trends (John et al., 2007; Pegas et al., 2012). Moreover, in these studies sampling was not usually performed simultaneously in the schools of interest and sampling was limited to a period of time (from days to a few weeks). Therefore, this sampling method has several limitations and do not constitute a full representative exposure assessment of the children attending the classrooms.

Particulate matter is usually collected with active samplers, a sampling methodology widely used. However, there are some disadvantages of active samplers such as the need of expensive equipment and additional accessories, like a power supply, air-flow meters and a pump, which are not very convenient or feasible for use in remote areas or to do simultaneous sampling on multiple sites (Guéguen et al., 2012). Additionally, optical methods do not control for humidity or density of the specific aerosol monitored (Fromme et al., 2007; Morawska and Salthamer, 2003). Moreover, indoor active sampling in classrooms is limited because it can interfere with the classrooms activities due to, for instance, the noise of the equipment.

In the last years, several studies have applied passive sampling methodologies to assess several environmental parameters, including particulate matter (Seethapathy et al., 2008). For example, Wagner and Leith (2001a, 2001b; Wagner and Macher, 2003) developed a passive sampler to collect $PM_{10-2.5}$ which was improved with protective shelters (Ott et al., 2008). A passive sampler, called Sigma-2 (VDI 2119, 2011), was also developed to collect the ambient-air particles with sizes in the range of 2.5–80 μm, which are mainly deposited via sedimentation into a small acceptor dish (~5.5 cm in diameter). Einstein et al. (2012) developed the Einstein–Lioy Deposition Sampler (ELDS) that uses 37 mm filters to collect surface deposition samples through passive deposition. Several configurations were optimized (with a protective hood or not; suspension with a specific support) to allow indoor and outdoor sampling.

This study focuses on the application of a new passive methodology to collect particulate matter in different classrooms of primary schools simultaneously. The experimental work was carried in urban and rural environments to understand the differences in different type of clusters. The seasonal variability was assessed by the sampling methodology since it covered 4 seasons over a 1 year period. The collected particulate matter was analyzed gravimetrically and the water soluble ions content and chemical composition were determined. The main components of the collected particles and their sources were assessed to understand the children exposure at classroom environments.

2. Materials and methods

2.1. Sampling site and schools description

This study was performed in primary schools of two distinct types of areas, urban and rural, of mainland Portugal. The chosen urban area was Lisbon, which is the largest city of Portugal and the westernmost capital in mainland Europe. Lisbon city has a population density of 6663 inhabitants km^{-2} while its metropolitan area has a population density of 976 inhabitants km^{-2}. The chosen rural area was the municipality of Ponte de Sor where primary schools of 3 villages were studied, namely Foros de Arrão, Longomel and Vale de Açor with a population density of 12.4, 32.3 and 13.2 inhabitants km^{-2}, respectively. The location of the primary schools for both clusters is shown in Fig. 1.

The schools had natural ventilation and no other ventilation or air conditioning system was used. Students' age attending the classrooms ranged from 6 to 12 years old.

2.2. Sampling

This study was conducted in 4 sampling campaigns, namely during the autumn, winter, spring and summer of 2009 and 2010. The summer campaign was done during the school holidays, therefore this campaign represents the absence of students in the classrooms during the sampling ("blank" sample). The sampling periods are shown in Table 1. The rural cluster has only information for 3 of the 4 sampling campaigns, namely, winter, spring and summer. For the urban primary schools, two classrooms were studied per school while in the rural primary schools only one classroom per school was studied.

The number of students attending the classrooms during the different sampling seasons remained constant. All the studied classrooms had a similar number of students, with a mean of 21.0 ± 1.5 students per classroom.

Filters were passively exposed, as shown in Fig. 2. A total of six 47-mm diameter Millipore (Isopore™) polycarbonate filters (with a pore size of 0.4 μm) and two 47-mm diameter quartz were exposed in each classroom, distributed over a tray with an area of 25 cm × 20 cm, at 120-cm high to approximate the breathing height of children inside the classrooms. Each filter was placed inside an uncovered plastic Petri dish. For each sampling campaign a set of 4 filters were used as blanks.