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Indoor air quality in urban nurseries at Porto city: Particulate matter assessment

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HIGHLIGHTS

- PM concentrations were often found high in the studied classrooms.
- Indoor sources were clearly the main contributors to indoor PM.
- Poor ventilation to outdoors affected IAQ by increasing the PM accumulation.

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ABSTRACT

Indoor air quality in nurseries is an interesting case of study mainly due to children's high vulnerability to exposure to air pollution (with special attention to younger ones), and because nursery is the public environment where young children spend most of their time. Particulate matter (PM) constitutes one of the air pollutants with greater interest. In fact, it can cause acute effects on children's health, as well as may contribute to the prevalence of chronic respiratory diseases like asthma. Thus, the main objectives of this study were: i) to evaluate indoor concentrations of particulate matter (PM_1, $PM_{2.5}$, PM_{10} and PM_{Total}) on different indoor microenvironments in urban nurseries of Porto city; and ii) to analyse those concentrations according to guidelines and references for indoor air quality and children's health. Indoor PM measurements were performed in several class and lunch rooms in three nurseries on weekdays and weekends. Outdoor PM_{10} concentrations were also obtained to determine I/O ratios. PM concentrations were often found high in the studied classrooms, especially for the finer fractions, reaching maxima hourly mean concentrations of 145 μg m^{-3} for PM_1 and 158 μg m^{-3} $PM_{2.5}$, being often above the limits recommended by WHO, reaching 80% of exceedances for $PM_{2.5}$, which is concerning in terms of exposure effects on children's health. Mean I/O ratios were always above 1 and most times above 2 showing that indoor sources (re-suspension phenomena due to children's activities, cleaning and cooking) were clearly the main contributors to indoor PM concentrations when compared with the outdoor influence. Though, poor ventilation to outdoors in classrooms affected indoor air quality by increasing the PM accumulation. So, enhancing air renovation rate and performing cleaning activities after the occupancy period could be good practices to reduce PM indoor air concentrations in nurseries and, consequently, to improve children's health and welfare.

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1. Introduction

Public health awareness on indoor air pollution has lagged behind that on outdoor air pollution. However, air quality inside public and private buildings where people spend a large part of their life is an essential determinant of healthy life and people's welfare. Evidence has been made that people, especially children, spend most of their time in indoor environments and therefore are more exposed to indoor air pollution (Almeida et al., 2011). Whilst this does not per se mean that indoor exposures will produce more harmful effects, the evidence is that indoor concentrations of many air pollutants are often higher than those typically encountered outside (Jones, 1999).

In this particular field, nurseries could be a very interesting case study (Sousa et al., 2012a) for two main reasons. Firstly, because of children's not fully developed immune system and lungs, their relative higher amount of air inhalation (the air intake per weight unit of a resting infant is twice that of an adult) and their growing

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tissue and organs (Mendell and Heath, 2005), which together raise the possibility of higher exposures than seen in adults (Schwartz, 2004). Secondly, because children spend more time in schools (or preschools and nurseries in the case of younger children) than in any other indoor environments besides home, and there is a correlation between pollutant concentrations and the onset of health problems in schoolchildren (Cartieaux et al., 2011). Indoor air quality in nurseries and preschools is different from primary or higher schools (Yoon et al., 2011), although this has been largely ignored (Ashmore and Dimitroulopoulou, 2009).

Several pollutants are present in nurseries' indoor air, but particulate matter (PM) is of great interest mainly because of its public health significance (Harrison et al., 2002). PM comprises material in solid or liquid phase suspended in the air and may have very diverse chemical compositions that are highly dependent on their source. On the other hand, it has been demonstrated that the finer PM fractions are the ones with the most acute effects on human health (Schwartz and Neas, 2000). This is why recently measurements of total suspended PM (PM_{Total}) have been replaced by total thoracic particles (particles with an aerodynamic diameter smaller than 10 μm, PM_{10}) and also, more recently, by finer particles (particles with an aerodynamic diameter smaller than 2.5 μm, $PM_{2.5}$, and smaller than 1 μm, PM_1) (Monn, 2001).

PM concentrations on nurseries can be influenced by several factors and can arise from both indoor and outdoor sources. Physical activities of the pupils lead to the re-suspension of mainly indoor coarse particles and greatly contribute for increasing PM_{10} in classrooms (Fromme et al., 2008). Furthermore, Lim et al. (2012) suggested that the impact of the activity pattern on personal exposure of PM is significant. Cleaning activities and ventilation are also major factors that determine indoor air PM concentrations in classrooms (Heudorf et al., 2009). Cooking is also an important source of indoor PM (Monn et al., 1997). Dust coming from outside of the buildings can be a major source of PM concentration and it can be responsible for the existence of very adverse compounds in particles, as the example of heavy metals mainly due to automobile emissions (Darus et al., 2012). Sousa et al. (2012b) recently reviewed the available studies that have been done concerning PM_{10} and $PM_{2.5}$ concentrations in nurseries and primary schools from 2008 to 2012, and found that: i) PM concentrations observed worldwide exceeded several times national legislations and WHO guidelines; ii) indoor/outdoor ratios were several times higher than 1; and iii) PM concentrations were reported as mainly due to constant re-suspension of particles. Added to it, there is spatial and temporal heterogeneity in the distribution of air quality within school environments, which is affected by the penetration of outdoor pollutants, wall absorption, emissions from furniture and other materials, level and length of occupancy, and quality of ventilation (Mejía et al., 2011).

Indoor air quality problems often cause non-specific symptoms rather than clearly defined illness, especially regarding the respiratory system (Jones, 1999). However, there are evidences that pollutants such as PM may cause acute effects as irritation in the skin, eyes, nose and throat and upper airways, as well as may contribute to the prevalence of chronic respiratory diseases, like asthma (Sousa et al., 2012a).

In addition to higher health concerns, classroom air quality also affects the performance of school activities by children, so it is important to understand cost-effective good practices and measures to improve indoor air quality in nurseries (Wargocki and Wyon, 2013). In order to protect human health from PM indoor air pollution exposure, national and international authorities set up standards and guidelines. Some of these are for industrial or occupational purposes, like the example of the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) that sets the limits of 5000 and 15 000 μg m^{-3} (8-h time weighted average) for $PM_{2.5}$ fraction and PM_{Total}, respectively. Other example is set by the Institute of Environmental Epidemiology, Ministry of the Environment of Singapore (Singapore, 1996), which recommended the maximum concentration of 150 μg m^{-3} for PM_{10} as the limit for acceptable indoor air quality. On the other hand, the Indoor Air Quality Management Group from the Government of the Hong Kong Special Administrative Region (Hong Kong, 2003) established, for 8-h average in offices and public spaces, the PM_{10} limits of 180 and 20 μg m^{-3} for good (represents the IAQ that provides protection to the public at large including the young and the aged) and excellent (represents an excellent IAQ that a high-class and comfortable building should have) classes respectively, the latter accordingly to the Finnish Society of Indoor Air Quality and Climate. The World Health Organization (WHO, 2010) recommended to apply to indoor spaces the same PM guidelines as for ambient air, presented on the 2005 global update, which are 25 and 50 μg m^{-3} for $PM_{2.5}$ and PM_{10}, respectively (over 24 h). These WHO guidelines are adopted by other authorities, like ANSES – French Agency for Food, Environmental and Occupational Health & Safety. The Federal Department of Health Canada recommended that $PM_{2.5}$ indoor concentrations should be kept as low as possible in all indoor environments (Health Canada, 2012). The Portuguese national legislation (*Decreto-Lei n° 79/2006*) established a maximum limit of 150 μg m^{-3} for PM_{10}, specifically in school indoor environments.

In the recent decades many studies have been carried out in children's dwellings to study indoor air quality, but children's dwelling is not, however, their only microenvironment; the most important indoor environment for children and their primary place of social activity is the nursery, and up till now indoor environment quality in this place has been poorly documented (Roda et al., 2011). In fact, and as far as known, there are only a few studies published concerning the indoor air quality in nurseries, particularly regarding PM measurements. Fromme et al. (2005) analysed respirable PM and elemental carbon levels in the indoor air of apartments and nursery schools in the urban area of Berlin (Germany), and found that the outdoor motorway traffic was correlated with the indoor air in the studied nurseries. However, only 1-day measurements were performed (sampling time from 7 to 8 h) and the samples occurred merely in one place per nursery. Yang et al. (2009) characterized the concentrations of different indoor air pollutants, including PM_{10}, within Korean schools and nurseries and concluded that, in average, children were more exposed to PM inside nurseries than outdoors and suggested that increasing ventilation rate could play a key role to improve indoor air quality in nurseries. Although measurement campaigns were performed during summer, autumn and winter, and it has had into account the building age, this study did not performed measurements in the lunch rooms neither in different floors inside each studied building, and only considered the PM_{10} fraction. Wichmann et al. (2010) studied the extent of infiltration of $PM_{2.5}$ (as well as soot and NO_2) from outdoor to indoor in the major indoor environments occupied by children (10 preschools, 6 schools and 18 homes) in different locations (city centre, suburban area and background), and found that, despite outdoor infiltrations, $PM_{2.5}$ concentrations in these indoor environments were mainly due to indoor sources. However, this study was limited to places occupied by children over 6 years old and measurements were only made for $PM_{2.5}$ fraction and in one classroom per preschool. More recently, Yoon et al. (2011) studied 71 classrooms in 17 nurseries (preschools) and searched for indoor air quality differences (several pollutants including PM_{Total} and respirable particulates) between urban and rural ones, and confirmed that the PM concentrations indoors were higher than those in outdoor, and also that those in urban areas were higher than in rural areas. Lack of comparative analysis

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