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Particulate matter in rural and urban nursery schools in Portugal

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ABSTRACT

Studies have been showing strong associations between exposures to indoor particulate matter (PM) and health effects on children. Urban and rural nursery schools have different known environmental and social differences which make their study relevant. Thus, this study aimed to evaluate indoor PM concentrations on different microenvironments of three rural nursery schools and one urban nursery school, being the only study comparing urban and rural nursery schools considering the PM_1, $PM_{2.5}$ and PM_{10} fractions (measured continuously and in terms of mass). Outdoor $PM_{2.5}$ and PM_{10} were also obtained and I/O ratios have been determined. Indoor PM mean concentrations were higher in the urban nursery than in rural ones, which might have been related to traffic emissions. However, I/O ratios allowed concluding that the recorded concentrations depended more significantly of indoor sources. WHO guidelines and Portuguese legislation exceedances for $PM_{2.5}$ and PM_{10} were observed mainly in the urban nursery school.

1. Introduction

PM have been recognized by various organizations such as USEPA and WHO as a priority pollutant, having high potential to induce various adverse effects to human health such as pulmonary diseases, asthma and other respiratory problems (Stanek et al., 2011; Sousa et al., 2012a). There is also evidence that particles can cause skin, eyes, nose, throat and upper airways irritations, shortness of breath, dizziness, and allergic reactions (Sousa et al., 2012a; USEPA, 2012).

Nursery schools could be a very interesting case study because children are vulnerable to compromised Indoor Air Quality (IAQ) due to their not fully developed immune system and lungs, greater inhaled breath per unit mass, and rapid growth of their tissues and organs, which raises the possibility of higher exposure than occurs in adults (Branco et al., 2014a; Yoon et al., 2011; Pegas et al., 2012). Beyond that, children spend more time in schools (or preschools and nursery schools) than in any other indoor microenvironment besides home (Branco et al., 2014b). Although no definitive proof exists, it can be assumed that preschool students, because of their activities, are more susceptible to the adverse effects of a poor IAQ than elementary or middle school students (Hagerhed-Engman et al., 2006). Many pollutants are present in nursery schools' indoor air, but PM is the one that has attracted more interest from researchers. Particles arise in indoor air from both indoor and outdoor sources and can be affected by many factors such as particle re-suspension from activities of building occupants, cooking, heating, consumer products, building materials (carpeting, flexible flooring, paint, and plastics), furnishings and equipment (Sousa et al., 2012b). Cleaning activities, ventilation rates and dust coming from outside of the buildings (responsible for the existence of very adverse compounds in particles such as heavy metals mainly due to traffic emissions) are also important factors that determine indoor PM concentrations (Lu et al., 2014; Sousa et al., 2012b; Darus et al., 2012).

In the last five years several studies on indoor air PM pollution have been conducted focussing on $PM_{2.5}$ and PM_{10} in primary schools (Sousa et al., 2012b; Almeida et al., 2011). Nevertheless, studies in nursery schools are still few. As far as it is known there are only eleven studies focussing on PM in nursery schools' indoor air. Tong and Lam (1998), Darus et al. (2012) and Lu et al. (2014) investigated the concentrations and contamination of metals in PM from nursery schools in Hong Kong, Malaysia and China, respectively. The results of Tong and Lam (1998) and Darus et al. (2012) studies demonstrated that some nursery schools have high levels of heavy metals and suggested that traffic was one of their major sources. Lu et al. (2014) concluded that most samples were moderately polluted by metals and their concentrations in dust

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samples from nursery schools located in the old downtown were lower than in the samples from schools situated outside the town. Fromme et al. (2005), that studied elemental carbon and respirable PM in the indoor air of apartments and nursery schools as well as ambient air in Berlin, also reported a strong relationship between motorway traffic and indoor air PM concentrations. Despite the determination of metal concentrations in dust samples and evaluation of their pollution levels and health risks to children, measurements were performed only in urban context and $PM_{2.5}$ and PM_{10} concentrations were not determined. Zuraimi and Tham (2008) conducted a cross-sectional study in nurseries in Singapore by evaluating comfort parameters, some gaseous compounds and $PM_{2.5}$, having concluded that for $PM_{2.5}$ concentrations, despite outdoor infiltrations, indoor sources were the main sources of PM indoor levels. Wichmann et al. (2010), that measured $PM_{2.5}$, soot, NO_2 and the air exchange rate in nursery schools in Sweden, Yang et al. (2009), that characterized the concentrations of different indoor air pollutants (PM_{10} fraction) in Korean nursery schools, and Cano et al. (2012), that performed a similar study in Portugal (Lisboa and Porto), also concluded the same. However, in these four studies only $PM_{2.5}$ or PM_{10} fraction were evaluated. Most recent research studies have been focussing in $PM_{2.5}$ (most harmful to human health) and PM_{10} simultaneous, both usually used in international guidelines. Cano et al. (2012) also referred to this in their study. Furthermore, results showed that cleaning activities increased PM concentrations in indoor air and suggested that cooking activities could increase PM concentrations in lunch rooms. Fonseca et al. (2014) studied ultrafine particle levels in urban and rural preschools in the north of Portugal. The results demonstrated that the levels of ultrafine particles in various microenvironments of preschools were significantly different, with the lowest levels found in the classrooms and the highest ones found in lunch rooms. These results also suggested that children attending urban preschools are potentially exposed to higher levels, mainly due to the contribution of outdoor traffic-related sources and cooking activities. However, in that study, measurements were performed only during occupation periods and particle mass concentrations were not measured (only particle number was considered). Yoon et al. (2011) is the only study besides Fonseca et al. (2014) that studied both urban and rural nursery schools. They studied 71 classrooms in 17 nursery schools and searched for indoor air quality differences (several pollutants including TSP and respirable particles) between urban and rural ones, and confirmed that the PM concentrations indoors were higher than those outdoors, and also that those in urban areas were higher than in rural areas. Lack of comparative analysis between different classrooms and other environments inside the same nursery and a limited analysis to the coarser PM fractions as well as gravimetric sampling for 6–8 h were the major limitations of this study.

Branco et al. (2014a) studied PM concentrations (PM_1, $PM_{2.5}$, PM_{10} and TSP) in classrooms and lunch rooms in three urban nursery schools in the city of Porto. The results confirmed that indoor sources were clearly the main contributors to indoor PM concentrations when compared with outdoor influence and the classrooms occupied by older children were found to be those with the highest concentrations, due to the PM re-suspension phenomenon. Although various fractions of PM were analysed in continuous measurements over several days and in different microenvironments, measurements were performed only in urban nursery schools. Following Branco et al. (2014a) study (nevertheless considering different nurseries to reinforce conclusions) and in the scope of INAIRCHILD project (Sousa et al., 2012a), this study aimed to reduce the above referred gaps, through the evaluation of indoor concentrations of particulate matter (PM_1, $PM_{2.5}$, PM_{10} and TSP) on different indoor microenvironments (classrooms and lunch rooms) of rural nursery schools and in an urban nursery school. For that, PM concentrations were compared between rural and urban nursery schools and with Portuguese legislation and WHO guidelines for IAQ and children's health. Thus, this is the only study comparing urban and rural nurseries considering the PM_1, $PM_{2.5}$, PM_{10} and TSP fractions (measured continuously and in terms of mass).

2. Materials and methods

2.1. Sites description

A pre-inspection to the studied nursery schools and rooms (through observations and interviews with the staff) was developed to capture relevant information on activities, building characteristics and potential sources of pollution.

This study was carried out in three rural nursery schools (RUR1, RUR2 and RUR3) located in Bragança district without significant influence of traffic emissions, and in an urban nursery school (URB1) located in Porto city (influenced by traffic emissions).

These four nursery schools have different management models: i) RUR1 is a public preschool managed with public funds by the municipal authorities and the Ministry of Education; ii) RUR2 and RUR3 are managed by non-profit social solidarity institution, and with a mix of public and private funds; and iii) URB1 is a full private for-profit nursery school.

The front of URB1 building is surrounded by a street with a high volume of traffic while RUR2 and RUR3 schools are surrounded by low volume traffic streets in residential areas. RUR1 is located near a forested area.

In RUR1 there were children aged from 3 to 6 years separated in three classrooms located on the ground floor. Although the building has an HVAC system and electric heaters, these were not used during the sampling period, thus dominated natural ventilation (DNV) was considered for all classrooms.

RUR2 nursery school cares for 3–6 year old children and has only one classroom with air conditioning, but this unit was not in use during the sampling period, thus DNV was also considered.

In RUR3 children were aged up to 3 years old divided in 2 classrooms. The centennial building where it is located was in the past a primary school, but after 2011 it was remodelled to become a nursery school preserving the basic structural characteristics while providing the necessary comfort and functionality. Like RUR2, RUR3 had an HVAC system and electric heaters that were also turned off during the sampling period and DNV was considered.

URB1 nursery school had children from 3 months to 6 years of age divided in 6 different classrooms located on three floors. During the sampling periods, air conditioning and dehumidifier were frequently used in classrooms A and B, thus dominated forced ventilation (DFV) was considered in these cases. During the study period the younger children (3 months–1 year) spent the entire school period inside the classroom including sleeping time and meals.

All the studied nursery schools had a lunch room on the ground floor with a kitchen using gas stoves with exception of RUR3 where the meals were previously prepared in RUR2. It was also observed that in RUR1 preschool children had lunch together with the primary school students.

The general clean-up on the rural nursery schools was done by the school staff, while in the urban school was carried out by an external company. All schools' clean-up was done before the sleeping periods and at the end of the lunch time in the classrooms where children did not eat in the lunch room.

Measurements were performed in 2 classrooms in RUR1 and RUR3, 1 classroom in RUR2 and 3 classrooms in URB1, as well as in