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Indoor air quality in urban nurseries at Porto City: particulate matter assessment

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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 $\mu g\ m^{-3}$ for PM_1 and 158 $\mu g\ m^{-3}$ $PM_{2.5}$, 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.

Keywords

Indoor air, nursery, particulate matter, children, exposure

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 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 pre-schools 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 5 000 and 15 000 µg m^{-3} (8-hour 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-hour 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 hours). 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 nº 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 hours) 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 pre-schools, 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 pre-school. 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 between different classrooms and other environments inside the same nursery and a limited analysis to the coarser PM fractions were the major limitations of this study.

In Portugal, as far as it is known there are no studies focusing on PM in nurseries' indoor air; there are only few studies focusing on the indoor air of primary schools (Almeida et al., 2011; Pegas et al., 2012).

To reduce the above referred lacks, 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 in Porto city; and ii) to analyse those concentrations according to guidelines and references for indoor air quality and children's health.

2. Methods

In Portugal, there are a considerable number of children attending nurseries. In fact, there are 276,125 children (2.26% of the Portuguese population) attending a total of 6,812 nurseries, 64.3% of which are public. In the urban area of Porto city there are 161 nurseries of which 32.3% are public (PORDATA, 2013). This study was carried out on three different nurseries (N_URB1, N_URB2 and N_URB3), all located at urban sites influenced by traffic emissions in Porto city, Portugal (Figure 1). N_URB1 and N_URB2 buildings were located in the same traffic busy street and their front facades were directly facing this street. N_URB3 building was located in the same area, although its front facade was not facing directly the street. These three nurseries had different management models: i) N_URB1 was a full private for-profit nursery; ii) N_URB2 was managed by a private institution of social solidarity, non-profit and with a mix of public and private funds; and iii) N_URB3 was a public nursery, entirely managed with public funds by the municipality authorities and the Ministry of Education.

N_URB1 nursery had children until 5 years old, separated by age into 6 different classrooms, divided into 3 floors. During the period of measurements, the use of oil and/or electric heaters or air conditioners was common to heat the rooms in this nursery. To prevent heat loss to the outside, windows were usually closed, and the only natural ventilation in the rooms was done with the doors opened to the inside corridors. Very young children, infants (< 1 year old) and toddlers (1-3 years old) spent all the period in this nursery inside the same classroom, including sleeping and eating. On the opposite, older children (3-5 years old) used to have different daily patterns in this nursery, especially because they went to the lunch room to eat. There was a small outdoor playground, although rarely used during the measurements campaign.

N_URB2 nursery also had children until 5 years old, divided by age into 7 different classrooms. Although the building had 2 floors, all the nursery rooms were located in the ground floor. All the classrooms had direct access to small outdoor playgrounds and the access doors were usually opened. N_URB2 building had no air conditioning system and the electric heaters were rarely used during the periods of measurements.

N_URB3 nursery had children from 3 to 5 years old (pre-school children), mixed in 4 different classrooms, all located in the ground floor, although it was a building with 2 floors. There were also classrooms in the first floor, but they were occasionally used.

All the nurseries had a lunch room in the ground floor with a kitchen using gas stoves, except for N_URB3 where there were no cooking activities, as the food were brought to the nursery already cooked.

Cleaning activities' patterns were also different in all the three studied nurseries. In N_URB1 younger children classrooms (< 3 years old), daily cleaning activities were made during the sleeping time (after lunch), with children sleeping in the classroom; in the other classrooms, cleaning used to be made during lunch time (when children are not in the classroom) or at the end of the afternoon, after classes. On the opposite, daily cleaning activities in N_URB2 in all the building were made after the occupancy period, and the deep cleaning was made on weekends. In N_URB3 almost the same happened, except that some daily cleaning in corridors and common spaces were made during occupancy and the deep cleaning was made on weekdays after the occupancy period.

Measurements were performed in 4 classrooms in nursery N_URB1, 3 classrooms in nursery N_URB2, and 2 classrooms in nursery N_URB3, as well as in the lunch rooms of all nurseries. Table 1 summarizes some of the main important characteristics for indoor air quality in each studied room.

Indoor concentrations of the different fractions of PM (PM_1, $PM_{2.5}$, PM_{10} and PM_{Total}) were continuously measured using a TSI DustTrak DRX 8534 particle monitor using light-scattering laser method. The minimum and maximum limit detections for this equipment are, respectively, 0.001 mg m^{-3} and 150 mg m^{-3}. The equipment was submitted to a standard zero calibration (available in the equipment) and data were validated prior to each new measurement (in each new room). Indoor measurements were performed from 2 to 9 days in each considered room, and, in some cases, both in weekdays and weekends, between February and June 2013. Hourly averages were calculated from a set of four measurements per hour (each 15 minutes) per day of measurement.

Simultaneously, hourly PM_{10} concentrations were obtained from the nearest air quality station classified as urban traffic. These measurements were conducted by the Air Quality Monitoring Network of Porto Metropolitan Area, managed by the Regional Commission of Coordination and Development of Northern Portugal (*Comissão de Coordenação e Desenvolvimento Regional do Norte*) under the responsibility of the Ministry of Environment.

3. Results

3.1 PM concentrations

As previously stated and according to Table 1, samplings were performed for more than one day in each studied room of the three nurseries and hourly averages were calculated. Figure 2 shows as an example (a) PM_{total} measured during five days on weekdays at N_URB1 and (b) $PM_{2.5}$ measured on weekend at N_URB2. Assuming that there are no significant differences on indoor air pollution between different weekdays, and as the daily patterns during the different sampling weekdays in each room were very similar, average daily weekdays profiles were performed to represent an average indoor air quality scenario. The same was performed for the weekends.

Figures 3 to 7 show the average daily profiles of PM_1, $PM_{2.5}$, PM_{10} and PM_{Total}, respectively (a) to (d), for N_URB1 and N_URB2 during weekdays and weekends (respectively Figures 3 to 6) and N_URB3 during weekdays and weekends (Figure 7). Table 2 summarizes the statistical parameters (minimum, maximum, mean and median) of the hourly means for each room studied in the three nurseries.

Figures 3, 5 and 7 showed that PM concentrations in the classrooms started to rise up at the beginning of the occupancy period and started decreasing after the end of the occupancy period (time variable, depending on the room). Figures 4, 6 and 7 showed that the concentrations during weekends and non-occupancy periods did not seem to have high fluctuations neither peaks, thus being considered background concentrations for each respective room. The highest PM_1 and $PM_{2.5}$ concentrations were registered in N_URB2 (classroom C), while the highest PM_{10} and PM_{Total} concentrations were found in N_URB1 (classroom C). The minimum concentrations of all PM fractions were observed in the LR of N_URB1. Likewise, the minima concentrations in N_URB3 were observed in the LR; nevertheless, in N_URB2, the LR had higher concentrations than the other measured rooms. Minima concentrations were always found during weekends or periods of non-occupancy and maxima concentrations were always registered during occupancy periods, as can be observed on Figures 3 to 7. Table 2 showed that median values were very close to mean values, so there was not great scattering in the measurements in each room. The only exception was registered in PM_{Total}, in which mean concentrations were in general higher than median values.

3.2 PM size distribution

PM size ratios allowed to understand the size distribution on the PM measured concentrations. Three different ratios were used here: i) $PM_1/PM_{2.5}$; ii) $PM_{2.5}/PM_{10}$; and iii) PM_{10}/PM_{Total}. These ratios were calculated per microenvironment (room) and per nursery, with the calculated hourly mean concentrations, in three different conditions: (i) occupancy; (ii) non-occupancy (according to data on Table 1); and (iii) weekends (when applicable). These ratio results are represented in Table 3.

In N_URB1 during occupancy on weekdays, $PM_1/PM_{2.5}$ ratio varied from 0.91 to 0.95, $PM_{2.5}/PM_{10}$ ratio from 0.50 to 0.75, and PM_{10}/PM_{Total} ratio from 0.42 to 0.59. During non-occupancy periods on weekdays, $PM_1/PM_{2.5}$ ratio varied from 0.94 to 0.98, $PM_{2.5}/PM_{10}$ ratio from 0.95 to 0.97, and PM_{10}/PM_{Total} ratio from 0.97 to 0.99. On weekends, $PM_1/PM_{2.5}$ ratio varied from 0.87 to 0.98, $PM_{2.5}/PM_{10}$ ratio from 0.88 to 0.98, and PM_{10}/PM_{Total} ratio from 0.95 to 1.

On weekdays during occupancy in N_URB2, $PM_1/PM_{2.5}$ ratio varied from 0.94 to 0.97, $PM_{2.5}/PM_{10}$ ratio varied from 0.60 to 0.76, and PM_{10}/PM_{Total} ratio varied from 0.41 to 0.61. During non-occupancy periods on weekdays, $PM_1/PM_{2.5}$ ratio varied from 0.96 to 0.98, $PM_{2.5}/PM_{10}$ ratio from 0.93 to 0.95, and PM_{10}/PM_{Total} ratio from 0.97 to 0.98. On weekends, ratios were very close to 1 ($PM_1/PM_{2.5}$ and $PM_{2.5}/PM_{10}$ ratios were 0.97, and PM_{10}/PM_{Total} ratio was 0.99).

In N_URB3 on weekdays during occupancy, $PM_1/PM_{2.5}$ ratio varied from 0.95 to 0.98, $PM_{2.5}/PM_{10}$ ratio from 0.64 to 0.89, and PM_{10}/PM_{Total} ratio from 0.50 to 0.89. During non-occupancy periods on weekdays, $PM_1/PM_{2.5}$ ratio varied from 0.95 to 0.99, $PM_{2.5}/PM_{10}$ ratio from 0.93 to 0.98, and PM_{10}/PM_{Total} ratio from 0.97 to 0.99. On weekends, ratios were also very close to 1 ($PM_1/PM_{2.5}$ and PM_{10}/PM_{Total} ratios were 0.99, and $PM_{2.5}/PM_{10}$ ratio was 0.97).

3.3 Comparison with standards and guidelines

PM concentrations were compared with WHO guidelines and with the Portuguese legislation (*Decreto-Lei nº 79/2006*). Table 4 summarizes the exceedances per room and per nursery to the WHO guidelines, as no exceedances were observed to the Portuguese standards.

In nursery N_URB1, the worst scenario was found in classroom C, where the WHO guidelines were exceeded 80% and 40% of times, for $PM_{2.5}$ and PM_{10} respectively. On the opposite, in classroom A the WHO guidelines were not exceeded. In N_URB2, it was possible to found the worst scenario in LR, where the WHO guideline for $PM_{2.5}$ was always exceeded and for PM_{10} was exceeded half of the times. It is also important to point out that in classroom C the WHO guidelines were exceeded 40% and 20% of times for $PM_{2.5}$ and PM_{10}, respectively. Lastly, in the case of N_URB3, WHO guideline for $PM_{2.5}$ was mostly exceeded (60%, 50% and 100% of times respectively in rooms A, B and LR). On the other hand, the WHO guideline for PM_{10} was never exceeded in this nursery.

3.4 Indoor/Outdoor ratios

Collected outdoor PM_{10} concentrations allowed obtaining an average daily profile of PM_{10}, represented in Figure 8. It was possible to observe an increase throughout the morning, a decrease in the early afternoon (12h-14h), and an increase throughout the rest of afternoon and evening, decreasing along the dawn. According to the obtained results, PM_{10} concentration profiles were found similar on weekdays and weekends.

Indoor measured concentrations were compared with outdoors using the indoor/outdoor ratio (I/O ratio). Mean I/O ratios were obtained for each studied room in the three nurseries (Table 5). Generically, I/O mean ratios were always higher than 1. On a closer look, in N_URB1, the highest I/O mean ratio was found in LR and the lowest was found in classroom A, both for weekdays and weekends. Unfortunately, there was not enough outdoor data available to determine I/O ratio for classroom C (considering the period of measurement in this classroom). In N_URB2, it was possible to find the highest I/O ratio of all the studied nurseries on weekdays (in classroom C). It is also important to point out the high I/O ratio observed in classroom A. In N_URB3, the worst scenario was found in LR. On weekends, I/O mean ratios were never higher 2.65 (N_URB3, classroom A).

4. Discussion

In nursery N_URB1, classroom C had the highest PM concentrations which could have been the result of the cumulative effect of three major conditions: i) poor ventilation (there were no open direct access to the outdoor and the door to the inner corridor was almost always closed); ii) high occupancy, with a total of 25 persons, despites being the room with the higher volume; and iii) intense activity, characteristic of 5 years old children. Additionally, it was possible to notice three peaks in the PM profiles for all the studied classrooms, which represented the three main occupancy periods (morning and afternoon before and after the break). In nursery N_URB1, classroom B revealed the lower PM concentrations during occupancy, most probably due to the lower occupancy on this classroom (only 7 people) when comparing to the others. The lower concentrations observed in the LR on this nursery were possibly due to its size and the existence of a small hall that creates a discontinuity between the kitchen and the lunch room, which possibly diminishes kitchen PM penetration into the lunch room. On weekends the concentrations were lower than on weekdays, and the behaviour for the different rooms was similar, with the exception of classroom C where they were higher on the first hours of the day. As this was clearly the room with the highest concentrations during weekdays, this was the result of the decrease of PM concentrations in the beginning of the weekend (Saturday dawn) – settlement phenomenon.

In nursery N_URB2, LR showed the highest PM concentrations for the finer fractions (PM_1 and $PM_{2.5}$) during the occupancy period and during the dawn and morning. Cooking activities are also one of the major indoor sources of PM (Monn, 2001) and might explain the higher concentrations observed as these activities started very early in the morning (8h) and ended late at the afternoon (19h). In this nursery it was also possible to observe that classroom C had the maximum PM concentrations (peaks) in all fractions, but especially higher for PM_{Total}, which can be attributed to three major synergetic factors: i) a higher occupancy in this classroom when compared with others in this nursery with similar areas (Table 1); ii) poor ventilation (doors to outdoor were always closed and to the inner corridor were almost always closed); and iii) normal activities characteristic of 4 years old children (occupants of this classroom). Also in classrooms C and B in this nursery, it was possible to observe the three peaks in the concentrations on weekdays, also in the three main occupancy periods (morning and afternoon before and after the break), and for the same reasons than in N_URB1. On the other hand, classroom A (baby nursery) showed a different pattern, with the highest concentrations being registered between 13-15h. This was the period of sleeping for the babies in the cribs room (next to and opened to classroom A) and teachers took the chance to do some tidying. On weekends, PM concentrations were lower and the profiles were similar and almost constant for the two measured classrooms (A and C).

In nursery N_URB3, PM concentrations in classroom A had a typical behaviour throughout the weekdays, with clear peaks matching the occupancy periods. On the opposite, classroom B had a peculiar PM profile, due to its occupancy (a wide space that was only used late at the afternoon, from 16 to 19h). In the lunch room of this nursery, the PM concentrations profile was slightly different from the other two lunch rooms (in N_URB1 and N_URB2). As there were no cooking activities in the kitchen attached to the lunch room and the cleaning activities were made immediately after lunch time, PM concentrations were lower and the maximum was observed after the lunch time (early afternoon). On weekends, concentrations were found much lower, and there was an expected almost constant PM behaviour during this period.

There was occasionally an increase of PM concentrations at the end of the afternoon, which was kept even after the end of classroom occupancy, mainly due to cleaning activities. Fromme et al. (2005) also reported that cleaning activities could contribute to the increase of PM in the indoor air. To minimize this contribution, cleaning activities in nurseries should be performed when children go home and with high ventilation rates to outdoor.

$PM_1/PM_{2.5}$ ratios were, in all situations, equal or higher than 0.90, i.e., very close to 1, meaning that the majority of the $PM_{2.5}$ was less than 1 µm. On weekends and non-occupancy periods, PM concentrations were mainly due to the finer fraction, with $PM_{2.5}/PM_{10}$ ratios close to 1, on the opposite to the periods of occupancy when $PM_{2.5}/PM_{10}$ (as well as PM_{10}/PM_{Total}) ratios were in average half of those in weekends and non-occupancy periods.

Overall, PM concentrations on nurseries were found to be much higher during occupancy periods than during non-occupancy periods and weekends and almost constant on the latter ones, which was consistent with the presence of children and their activities, even in lunch rooms. However, PM_{10} mean levels in all studied rooms were below mean level obtained by Yang et al. (2009) in Korean nurseries (94.94 µg m^{-3}). This means that the presence of children and their activities in nurseries' microenvironments potentiated, in general, the suspension and/or re-suspension phenomena of PM indoors, mainly coarser fractions, which was also found by Parker et al. (2008) for school buildings. In general, occupancy increases PM concentrations indoors (Sousa et al., 2012b).

The PM concentrations found in all the studied nurseries were high, often above WHO guidelines, which is concerning, especially for the finer fractions. Those were often found in the classrooms of older children (4-5 years old). These have greater freedom and ability to move when compared with younger ones, which is reflected in their usual daily activities on nurseries increasing PM concentrations in indoor air, as reported by Fromme et al. (2005). Lunch rooms also exceeded WHO guidelines, especially in N_URB2 and N_URB3, mainly due to cooking activities and children movements. Of concern were also the exceedances in 50% of the measurement days to WHO $PM_{2.5}$ guideline in N_URB2 classroom 1, which is a baby nursery, and these younger children are most vulnerable to adverse health effects of PM suspended in the air.

I/O ratios were always higher than 1, meaning that PM_{10} indoor concentrations were, in average, higher than ambient levels, which is consistent with the findings from Yoon et al. (2011) in urban preschools in Korea and from Almeida et al. (2011) in Portuguese primary schools. On weekdays, indoor concentrations were always at least 2 times higher than those found outdoors. Even on weekends indoor concentrations were found to be until 2.65 times (in average) higher than those found outdoors. This suggested that outdoor influence on PM indoor concentrations was not significant when compared with indoor sources and re-suspension phenomena. In fact, the highest I/O ratios in N_URB1 and N_URB3 were found in lunch rooms, which is consistent with indoor sources already stated (cooking activities and children drives). The higher I/O ratio found in classroom C in N_URB2, as well as the high ratio found in classroom A in the same nursery, were also due to indoor sources and poor ventilation to outdoors. In fact, poor ventilation to the outdoor turned indoor sources as the major increasing factor of indoor PM concentrations, which was also stated by Yang et al. (2009).

5. Conclusions

PM concentrations were often found high in the studied classrooms, mainly in the finer fractions (PM_1 and $PM_{2.5}$), and often above the limits recommended by WHO, which is concerning in terms of exposure effects on children's health. The classrooms occupied by older children were found to be those with the highest PM concentrations, due to their higher mobility when compared with younger ones, thus increasing PM re-suspension. Results allowed concluding that indoor sources were clearly the main contributors to indoor PM concentrations when compared with outdoor influence. Due to that, the poor ventilation to outdoors in classrooms affected indoor air quality by increasing the PM accumulation. Results also confirmed that cleaning activities increased PM concentrations in indoor air and suggested that cooking activities could increase PM concentrations in lunch rooms. To improve the air renovation rate (higher and better ventilation), as well as to do the cleaning activities after the occupancy period could be good practices to reduce PM indoor air concentrations in nurseries and, consequently, improve children's health and welfare.

For the future, it could be important to study other nurseries to help supporting these findings, not only in urban traffic influence context, but also in other contexts, like urban background and rural. In next studies it could be important to determine the particulate matter composition (heavy metals, PAH's). Measurements of the air flow rates could also be important to refine the analysis on the occupancy and air renovation rates. It could also be important to study the association of PM air pollution in these nurseries with children's daily exposure. Further investigations at home and in other microenvironments occupied by children are needed to understand if there is, or not, an increased risk of adverse health effects on children attending nurseries when compared with those cared at home.

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Figure captions

Figure 1. Location of the three studied urban nurseries in Porto city: a) N_URB1, b) N_URB3 and c) N_URB2.

Figure 2. Distribution of PM hourly average concentrations of a) N_URB1 Room A weekdays, and b) N_URB2 Room A weekend.

Figure 3 – PM average concentrations on weekdays in N_URB1: a) PM_1, b) $PM_{2.5}$, c) PM_{10} and d) PM_{Total}.

Figure 4 – PM average concentrations on weekends in N_URB1: a) PM_1, b) $PM_{2.5}$, c) PM_{10} and d) PM_{Total}.

Figure 5 – PM average concentrations on weekdays in N_URB2: a) PM_1, b) $PM_{2.5}$, c) PM_{10} and d) PM_{Total}.

Figure 6 – PM average concentrations on weekends in N_URB2: a) PM_1, b) $PM_{2.5}$, c) PM_{10} and d) PM_{Total}.

Figure 7 – PM average concentrations in N_URB3: a) PM_1, b) $PM_{2.5}$, c) PM_{10} and d) PM_{Total}.

Figure 8 – Distribution of PM_{10} outdoor hourly average concentrations in weekdays and weekend.

Table 1 – Summary of the main characteristics for indoor air quality analysis in each studied microenvironment.

Nursery	Room	Type of use	Children's age (years)	Floor	Volume (m^3)	Occupancy	Period of occupation	Ventilation	Sampling time (weekdays + weekend days)
N_URB1	A	Classroom	1	Ground floor (back)	115	19	07h30 – 19h30	Windows to outdoor closed. Door to inner corridor almost always closed. A/C on.	5 + 2
	B	Classroom	3	1st floor (front)	63	7	09h – 11h30 15h – 15h30	Windows to outdoor closed. Door to inner corridor almost always closed. No A/C. Electric/oil heater on.	3 + 2
	C	Classroom	5	2nd floor (front)	176	25	08h – 11h30 15h30 – 17h30	Windows to outdoor closed. Door to inner corridor almost always closed. No A/C. Electric/oil heater on.	3 + 2
	LR	Lunch room	3-5	Ground floor (back)	115	21-74	11h30 – 13h30	Open to kitchen and to inner corridor. No direct connection to outdoor.	7 + 2
N_URB2	A	Classroom	<1	Ground floor (front)	51	12	09h – 12h00 15h30 – 18h	Windows directly to outdoor (traffic street) closed – opened only after occupancy. Door to inner corridor always open. Open passage to cribs room and a small lunch room.	2 + 2
	B	Classroom	2	Ground floor	120	20	09h30-12h 14h-16h30	Door to inner corridor almost always closed. Direct access to outdoor playground often opened. No A/C and heating off.	3 + 0
	C	Classroom	4	Ground floor (back)	151	27	09h30-12h 14h-16h30	Door to inner corridor almost always opened. Direct access to outdoor playground often closed. No A/C and heating off.	3 + 2
	LR	Lunch room	1-5	Ground floor (back)		17-68	11h – 12h30	Open to kitchen, to inner corridor, and to outdoor (during occupancy).	2 + 0
N_URB3	A	Classroom	3-5	Ground floor	133,5	23	09h – 11h30 13h30 – 16h	Door to inner corridor often closed. Passage to outdoor playground usually opened. No A/C and heater.	3 + 2
	B	Classroom	3-5	1st floor	108	35	16h – 19h	Door to inner corridor often opened. Window to outdoor open during occupancy. No A/C and heater.	2 + 0
	LR	Lunch room	3-5	Ground floor	168	17-45	11h30 – 13h30	Open to inner corridor and kitchen. Windows to outdoor closed.	2 + 0

Table 2 – Statistical parameters of the hourly mean data for each room studied in all the three nurseries (values in µg m^{-3}).

PM	Nursery	N_URB1				N_URB2				N_URB3		
	Room	A	B	C	LR	A	B	C	LR	A	B	LR
PM_1	Min	8.60	7.25	6.67	2.75	13.75	4.00	7.00	16.25	13.00	11.75	7.00
	Max	46.29	45.25	120.25	70.25	74.25	54.75	145.00	125.25	71.25	62.00	82.00
	Mean	18.38	21.97	33.08	16.79	27.84	19.95	25.42	47.85	27.84	32.29	26.74
	Median	15.42	19.38	29.25	14.00	23.13	21.00	16.63	42.50	24.75	33.25	19.25
$PM_{2.5}$	Min	8.95	8.00	8.00	3.25	14.00	4.25	7.00	17.00	13.25	12.00	7.25
	Max	47.77	46.00	135.75	74.25	77.75	58.75	158.00	126.75	74.75	62.75	86.50
	Mean	19.70	22.75	34.69	18.17	28.69	21.09	26.65	48.94	28.50	32.63	28.01
	Median	17.04	20.00	30.00	15.25	23.75	21.50	17.38	43.25	25.00	33.25	20.75
PM_{10}	Min	9.42	8.00	10.00	3.25	14.75	5.00	7.00	19.25	14.00	13.25	7.75
	Max	71.72	71.00	318.00	84.00	129.50	104.50	197.25	139.00	134.50	73.50	166.00
	Mean	26.11	25.56	50.94	22.31	34.82	31.62	28.88	56.77	34.15	34.86	40.15
	Median	19.53	21.75	32.00	17.29	24.25	23.63	18.13	46.75	26.00	35.00	23.00
PM_{Total}	Min	9.42	8.00	10.33	3.25	15.00	5.00	7.25	19.75	14.00	14.25	8.00
	Max	208.34	190.50	605.00	202.00	368.75	248.25	427.25	224.75	336.00	86.00	401.25
	Mean	48.89	32.61	85.81	32.97	63.74	66.09	40.18	77.69	50.55	37.04	70.55
	Median	20.23	23.00	32.50	18.88	25.38	23.63	19.50	55.50	26.25	36.25	23.25

Table 3 - PM size ratios in each studied microenvironment: average values according to the occupancy patterns.

Nursery	Room	Week						Weekend		
		During occupancy			During non-occupancy					
		$PM_1/PM_{2.5}$	$PM_{2.5}/PM_{10}$	PM_{10}/PM_{Total}	$PM_1/PM_{2.5}$	$PM_{2.5}/PM_{10}$	PM_{10}/PM_{Total}	$PM_1/PM_{2.5}$	$PM_{2.5}/PM_{10}$	PM_{10}/PM_{Total}
N_URB1	A	0.93	0.63	0.42	0.96	0.95	0.97	0.90	0.94	0.99
	B	0.95	0.70	0.50	0.98	0.97	0.99	0.98	0.98	1.00
	C	0.91	0.50	0.51	0.98	0.95	0.98	0.98	0.96	0.98
	LR	0.92	0.75	0.59	0.94	0.95	0.98	0.87	0.88	0.95
N_URB2	A	0.96	0.69	0.41	0.97	0.95	0.98	0.97	0.97	0.99
	B	0.94	0.61	0.45	0.96	0.93	0.97	-	-	-
	C	0.94	0.60	0.49	0.97	0.94	0.98	0.97	0.97	0.99
	LR	0.97	0.76	0.61	0.98	0.95	0.97	-	-	-
N_URB3	A	0.95	0.64	0.50	0.97	0.97	0.97	0.99	0.97	0.99
	B	0.98	0.89	0.89	0.99	0.98	0.99	-	-	-
	LR	0.96	0.64	0.54	0.95	0.93	0.98	-	-	-

Table 4 – Exceedances of 24-hour mean PM concentrations to the WHO guidelines ($PM_{2.5}$ - 25 µg m^{-3} and PM_{10} - 25 µg m^{-3}).

Nursery	Room	24h exceedances (%)	
		WHO ($PM_{2.5}$)	WHO (PM_{10})
N_URB1	A	0	0
	B	40	0
	C	80	40
	LR	11	0
N_URB2	A	50	0
	B	33	0
	C	40	20
	LR	100	50
N_URB3	A	60	0
	B	50	0
	LR	100	0

Table 5 – PM_{10} I/O ratios: mean values observed in each studied site for weekdays and weekends, and respective minima (min) and maxima (max) values.

Nursery	Room	Weekday	Weekend
N_URB1	A	2.17 (min-max: 0.46-18.32)	1.06 (min-max: 0.34-9.42)
	B	2.23 (min-max: 0.42-12.75)	1.35 (min-max: 0.55-3.80)
	C	*	*
	LR	3.05 (min-max: 0.41-37.50)	1.54 (min-max: 0.35-11.50)
N_URB2	A	5.31 (min-max: 0.56-129.50)	2.02 (min-max: 0.40-20.00)
	B	1.96 (min-max:0.23-11.00)	-
	C	13.96 (min-max: 0.57-213.63)	2.02 (min-max: 0.39-7.00)
	LR	2.41 (min-max: 0.60-9.35)	-
N_URB3	A	2.67 (min-max: 0.48-10.44)	2.65 (min-max: 0.83-15.00)
	B	2.12 (min-max: 0.42-21.00)	-
	LR	4.57 (min-max:0.43-25.44)	-

* For room C in N_URB1 nursery, outdoor PM_{10} concentrations data available were only for less than 50% of the study period, which was not statistically relevant.

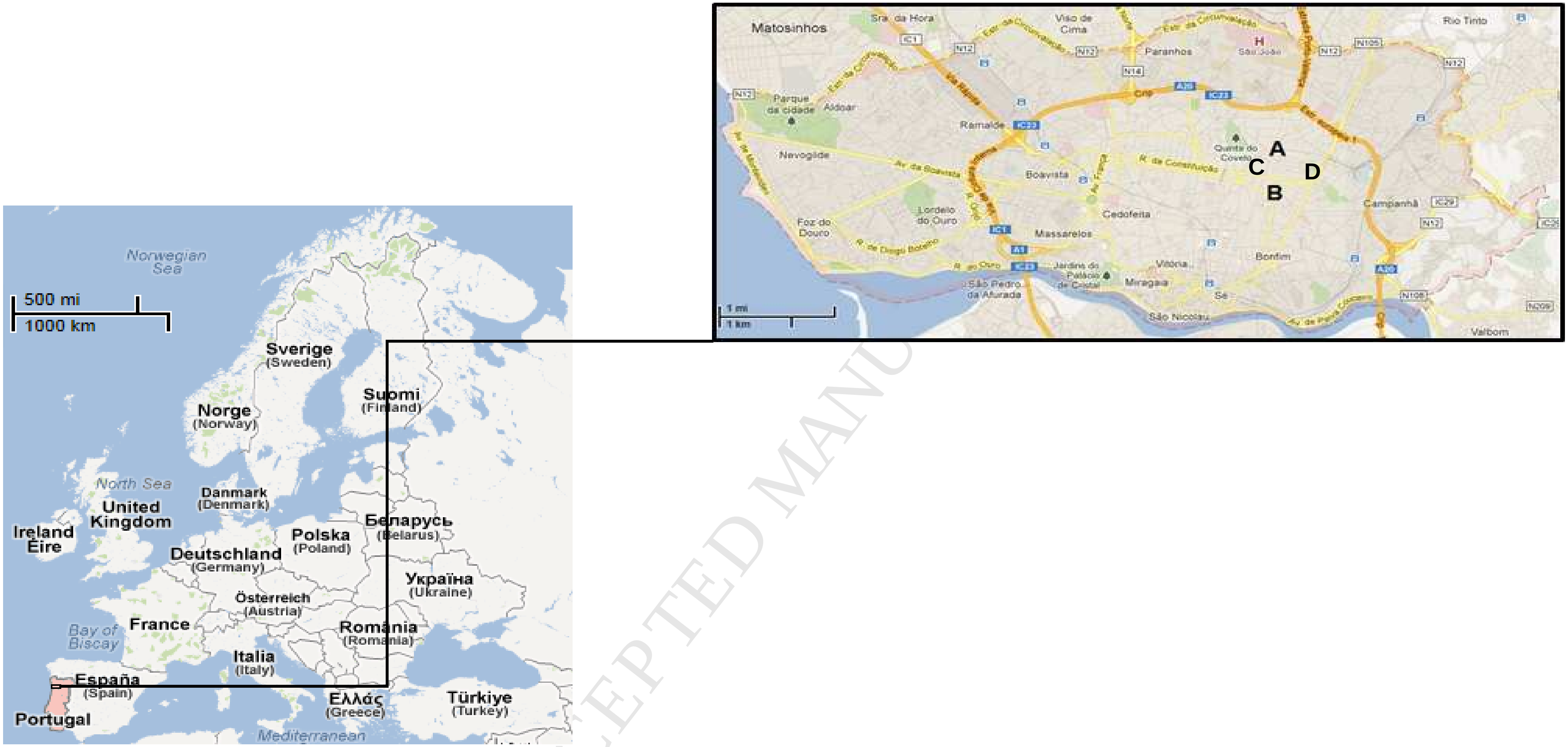
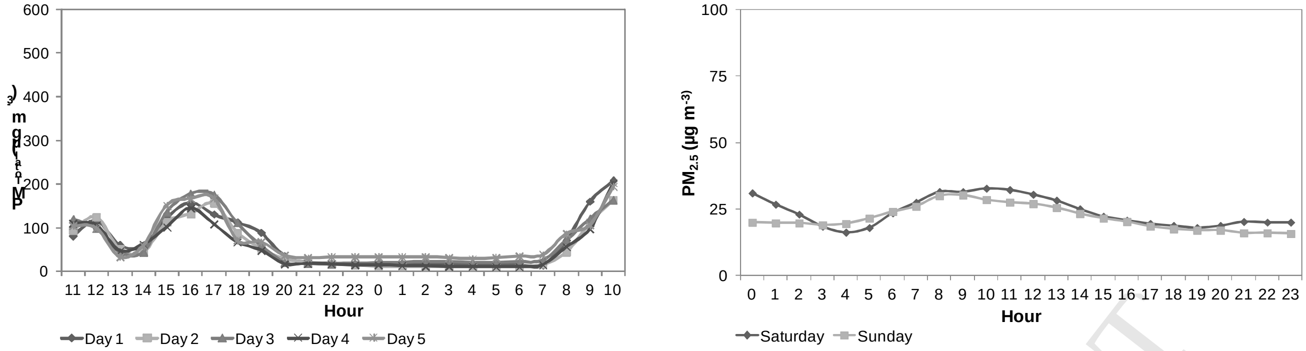

Norwegian Sea
500 mi
1000 km
Sverige (Sweden)
Suomi (Finland)
Norge (Norway)
North Sea
Danmark (Denmark)
United Kingdom
Ireland Éire
Беларусь (Belarus)
Polska (Poland)
Deutschland (Germany)
Україна (Ukraine)
Österreich (Austria)
Bay of Biscay
France
România (Romania)
Italia (Italy)
España (Spain)
Ελλάς (Greece)
Türkiye (Turkey)
Portugal
Mediterranean
Matosinhos
Parque da cidade
Aldoar
Ramalde
Nevogilde
Boavista
Foz do Douro
Lordelo do Ouro
Massarelos
Cedofeita
Paranhos
Rio Tinto
Campanhã
Bonfim
Miragaia
São Nicolau
Valbom
A
B
C
D
1 mi
1 km

Figure 1.


600
500
400
300
200
100
0
11 12 13 14 15 16 17 18 19 20 21 22 23 0 1 2 3 4 5 6 7 8 9 10
Hour
Day 1
Day 2
Day 3
Day 4
Day 5
100
75
50
25
0
PM2.5 (µg m-3)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour
Saturday
Sunday

(a) (b)

Figure 2.

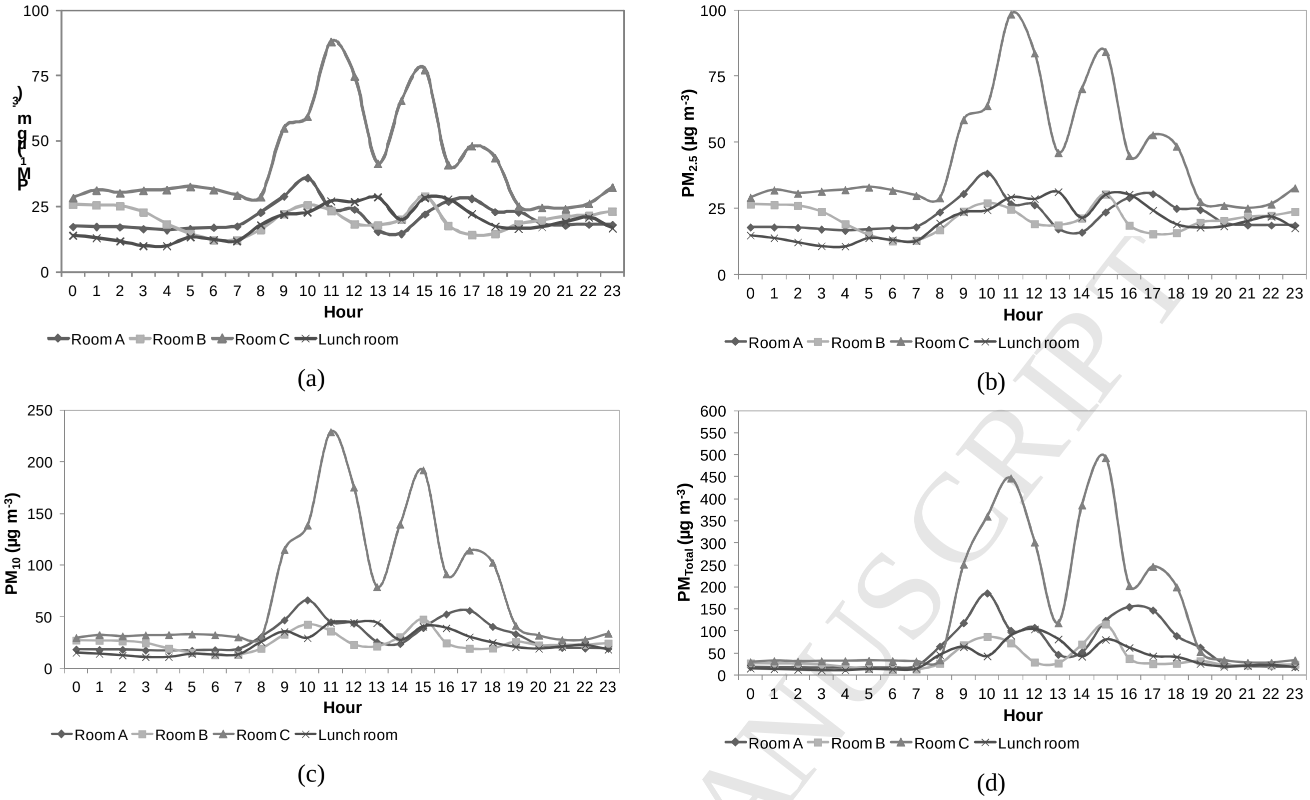

PM$_{2.5}$ (µg m^{-3})
PM$_{10}$ (µg m^{-3})
PM$_{Total}$ (µg m^{-3})
Hour
Room A
Room B
Room C
Lunch room
(a)
(b)
(c)
(d)

Figure 3.

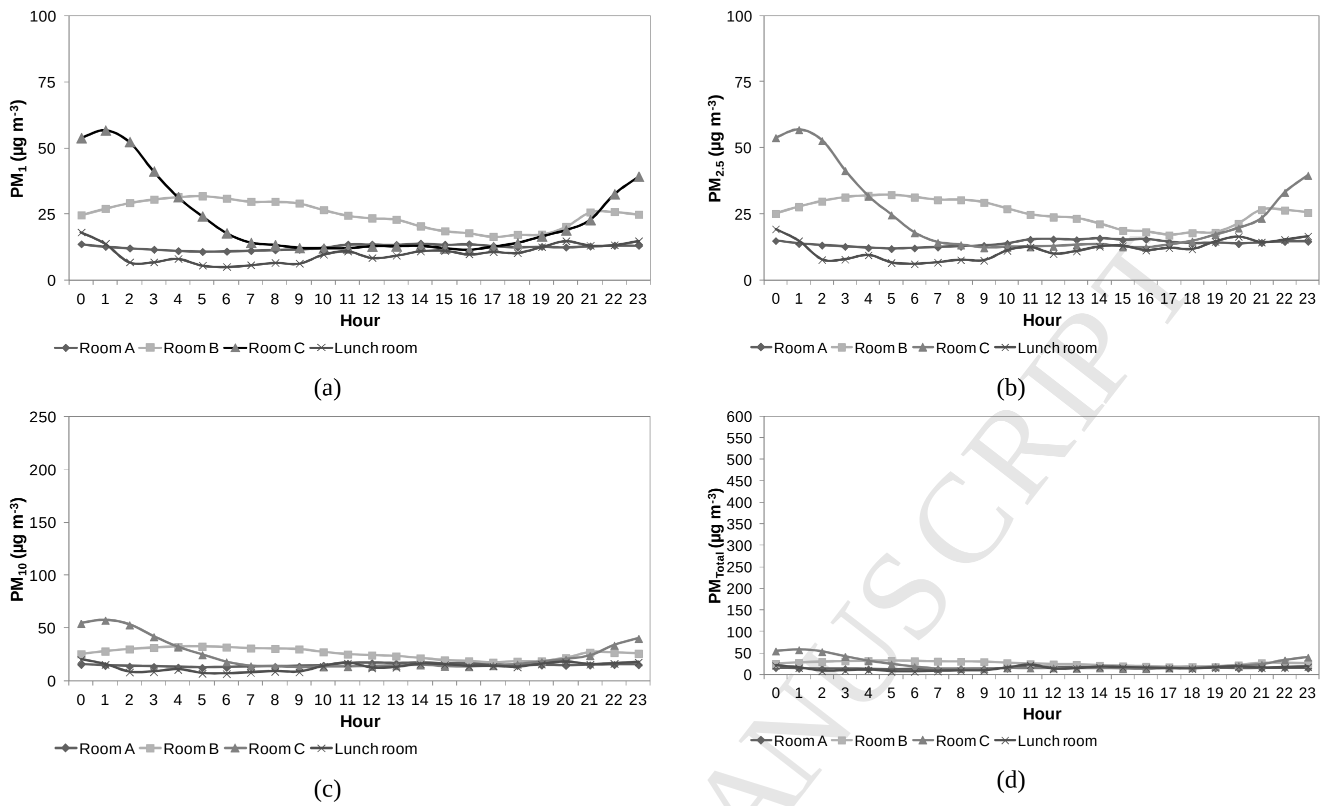
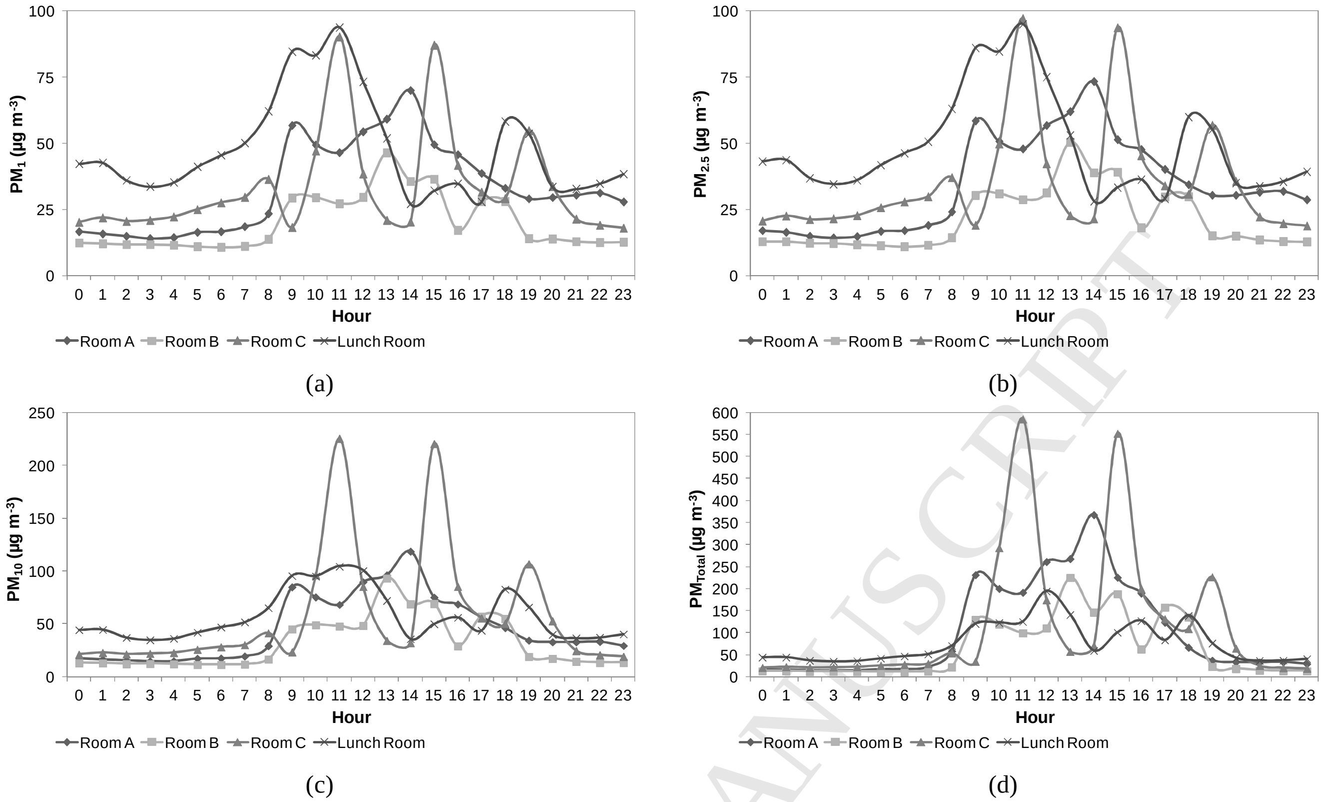
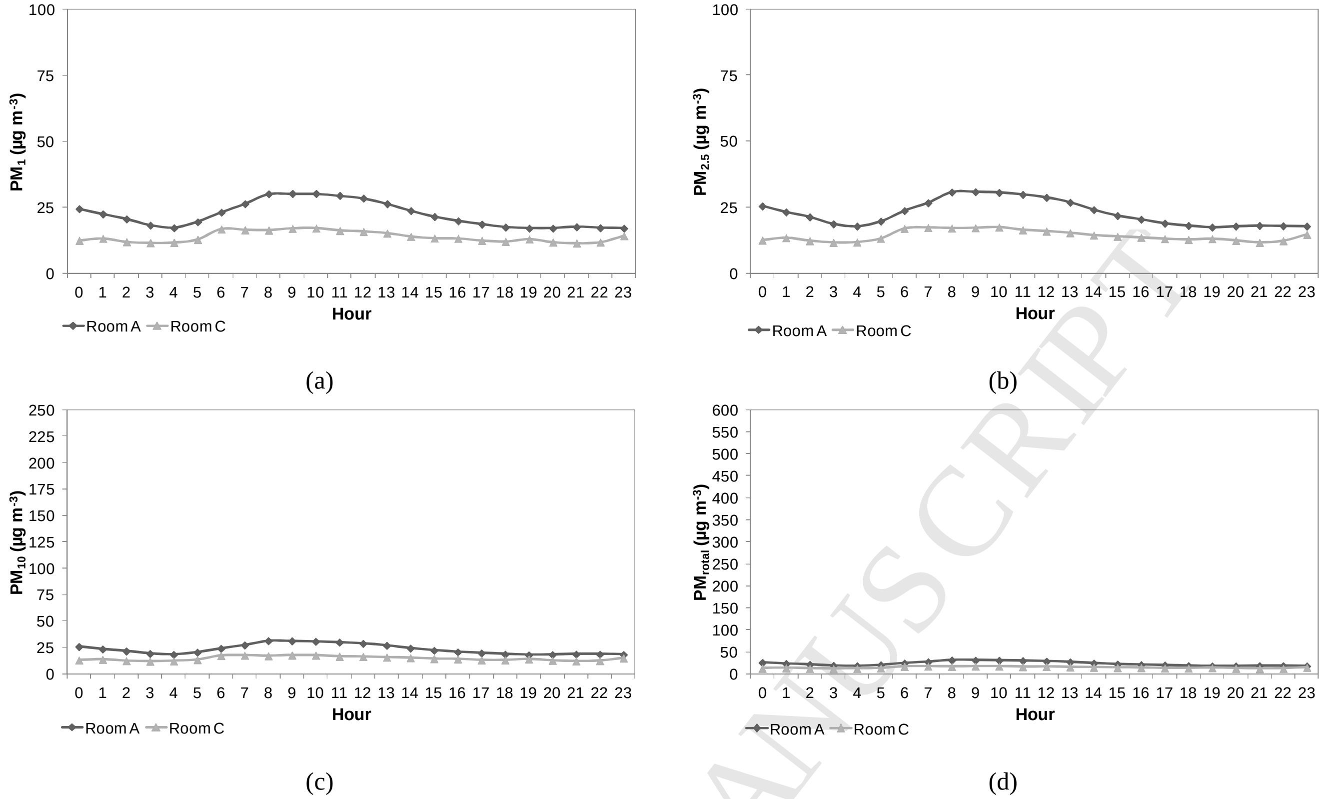

100
75
50
25
0
PM1 (µg m-3)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour
Room A
Room B
Room C
Lunch room
(a)
PM2.5 (µg m-3)
(b)
250
200
150
100
PM10 (µg m-3)
(c)
600
550
500
450
400
350
300
250
200
150
PMTotal (µg m-3)
(d)

Figure 4.



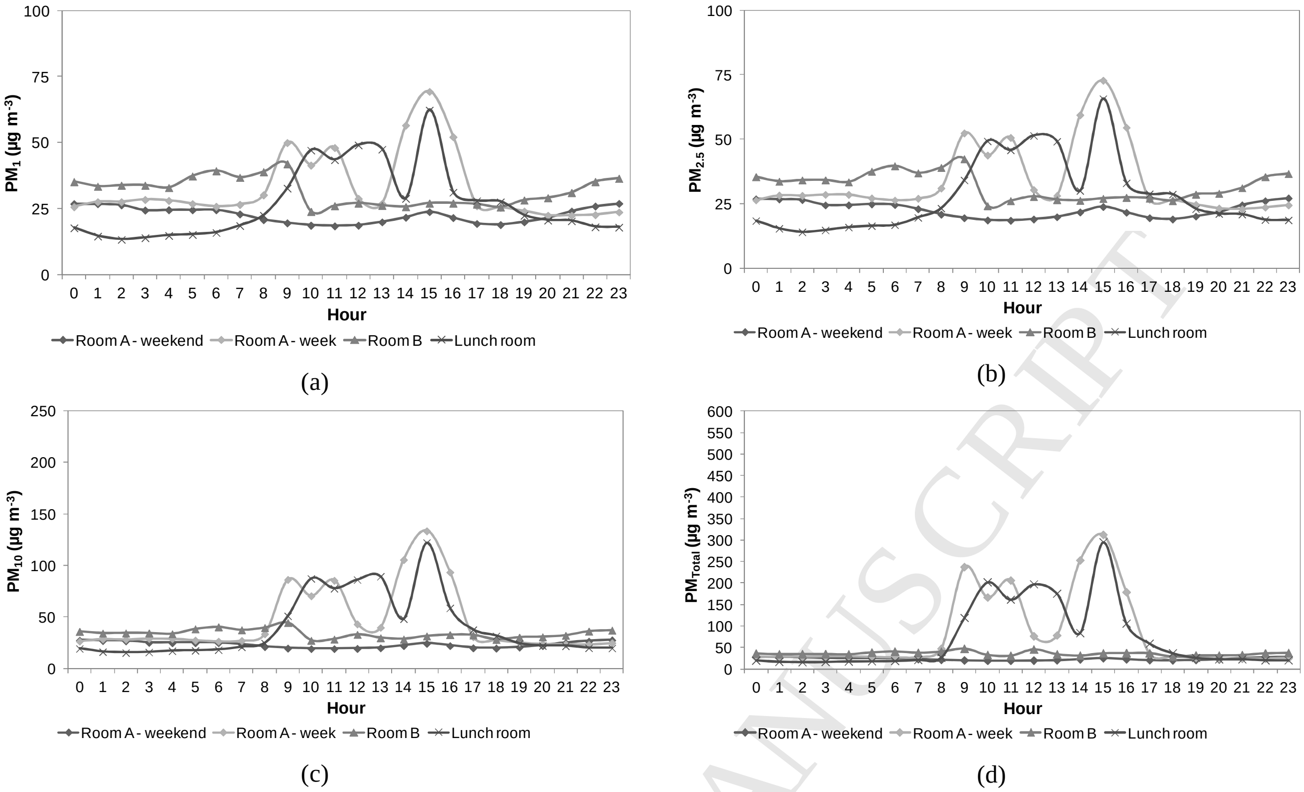
PM1 (µg m-3)
Hour
Room A
Room B
Room C
Lunch Room
(a)
PM2.5 (µg m-3)
Hour
Room A
Room B
Room C
Lunch Room
(b)
PM10 (µg m-3)
Hour
Room A
Room B
Room C
Lunch Room
(c)
PMTotal (µg m-3)
Hour
Room A
Room B
Room C
Lunch Room
(d)

Figure 5.



PM$_1$ (µg m^{-3})
PM$_{2.5}$ (µg m^{-3})
PM$_{10}$ (µg m^{-3})
PM$_{total}$ (µg m^{-3})
Hour
Room A
Room C
(a)
(b)
(c)
(d)

Figure 6.



PM1 (µg m-3)
Hour
Room A - weekend
Room A - week
Room B
Lunch room
(a)
PM2,5 (µg m-3)
Hour
Room A - weekend
Room A - week
Room B
Lunch room
(b)
PM10 (µg m-3)
Hour
Room A - weekend
Room A - week
Room B
Lunch room
(c)
PMTotal (µg m-3)
Hour
Room A - weekend
Room A - week
Room B
Lunch room
(d)

Figure 7.

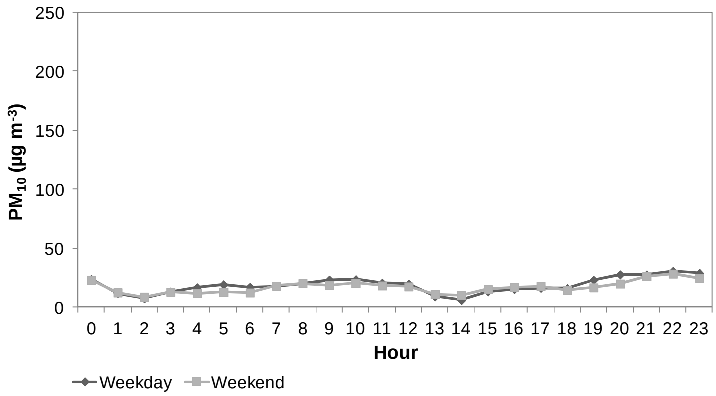

250
200
150
100
50
0
PM10 (µg m-3)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Hour
Weekday
Weekend

Figure 8.

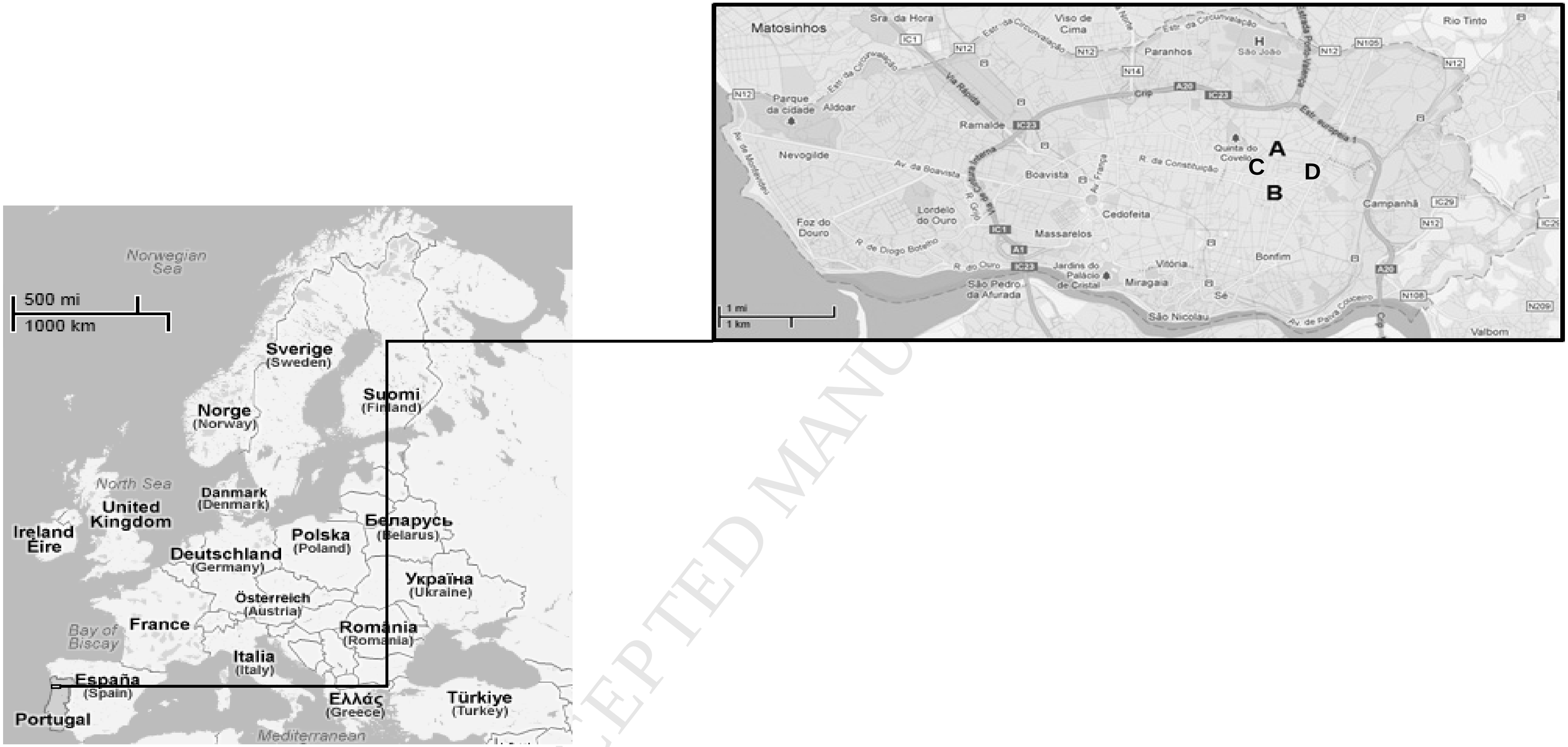

Matosinhos
Sra. da Hora
Viso de Cima
Paranhos
São João
Rio Tinto
Parque da cidade
Aldoar
Ramalde
Nevogilde
Av. da Boavista
Boavista
R. da Constituição
Quinta do Covelo
A
C
D
B
Campanhã
Foz do Douro
Lordelo do Ouro
Cedofeita
Massarelos
Bonfim
Vitória
Miragaia
Sé
São Pedro da Afurada
São Nicolau
Valbom
1 mi
1 km
Norwegian Sea
500 mi
1000 km
Sverige
(Sweden)
Norge
(Norway)
Suomi
(Finland)
North Sea
Danmark
(Denmark)
United Kingdom
Ireland
Éire
Polska
(Poland)
Беларусь
(Belarus)
Deutschland
(Germany)
Україна
(Ukraine)
Österreich
(Austria)
Bay of Biscay
France
România
(Romania)
Italia
(Italy)
España
(Spain)
Ελλάς
(Greece)
Türkiye
(Turkey)
Portugal
Mediterranean

Figure 1.

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