This article was published in Journal of Toxicology and Environmental Health - Part A: Current Issues, 78(13), 886-896, 2015
http://dx.doi.org/10.1080/15287394.2015.1051203

Children indoor exposures to (ultra)fine particles in an urban area: comparison between school and home environments

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Abstract

Due to their detrimental effects on human health, the scientific interest in ultrafine particles (UFP) has been increasing but available information is far from comprehensive. Children, who represent one of the most vulnerable groups of society, spend the majority of their time in schools and homes. Thus, the aim of this work is to assess indoor levels of particle number concentrations (PNC) in ultrafine and fine range at school and home environments and to compare the indoor respective dose rates for 3–5 years old children. Indoor particle number concentrations in range of 20–1000 nm were consecutively measured during 56 days at two preschools (S1 and S2) and three homes (H1–H3) situated in Porto, Portugal; at both preschools different indoor microenvironments (classrooms, canteens) were evaluated. The results showed that the total mean indoor PNC (determined for all indoor microenvironments) were significantly higher ($p < 0.05$) at S1 than at S2. At homes the indoor levels of PNC (with means ranging between 1.09×10^4 and 1.24×10^4 particles cm^{-3}) were 10–70% lower than total indoor means of preschools (1.32×10^4 to 1.84×10^4 particles cm^{-3}). Nevertheless, estimated dose rates of particles were at homes 1.3–2.1 times higher than those of preschools, mainly due to longer period spent at home. Furthermore, daily activity patterns of 3–5 years old children significantly influenced overall dose rates of particles.

Keywords: (Ultra)fine particles, children, indoor air, schools, residential environment, exposure.

INTRODUCTION

During the last two decades, there has been considerable interest in the health effects of exposure to airborne particulate matter (Brunekreef et al., 2009; Krewski et al., 2003; Krewski & Rainham 2007; Samet & Krewski 2007). As the knowledge about the size dependency of particle toxicity has grown (Kelly & Fussel, 2012), the ongoing research has focused its attention on ultrafine particles (UFP) (Morawska et al., 2013).

UFP represent a fraction of particulate matter (PM) with particles of aerodynamic diameter smaller than 0.1 μm (Morawska et al., 2013). Unlike coarse particles, UFP contribute little to PM mass but they dominate number concentrations. Due to their small size, high number concentrations, high surface area, and ability to penetrate into the interstitial spaces of the lungs (Bakand et al., 2012; Pereira Gomes et al., 2012), UFP can cause various adverse health effects. Clinical and epidemiological studies have linked exposure to ambient UFP with adverse respiratory outcomes (impaired lung function and pulmonary defense mechanisms, inflammatory responses and worsening of respiratory diseases), and possibly with cardiovascular health effects (Bakand et al., 2012; Heal et al., 2012; Ibald-Mulli et al., 2002) though the evidence is not consistent (Rückerl, et al., 2011). While more epidemiological studies on UFP fraction are needed, exposure assessment issues for UFP (such as spatial variability, indoor sources, infiltration of UPF from various outdoor emission sources, seasonal variability in concentrations and composition) are being further addressed (Azarmi et al., 2014; Bekö et al., 2013; Rivas et al., 2015; Viana et al., 2014, 2015; Wang et al., 2013).

In view of the evidences of negative health impacts of UFP, research has focused on investigation of main sources and processes affecting the levels and size distributions of these particles in ambient air of urban areas (Kumar et al., 2010; Morawska et al., 2008; Solomon, 2012). UFP can be formed by condensation of semi-volatile organic aerosols, photochemically induced nucleation, and/or nucleation through gas-to particle conversion (Morawska et al., 2008, 2013). Concerning the indoor air, UFP originate from combustion processes which includes cooking (namely boiling, stewing, frying, baking, grilling), smoking and use of candles (Bekö et al., 2013; Morawska et al., 2013), and as result from occupant–related activities such as use of consumer products, use of painting and cleaning products (Bhangar et al., 2011; Long et al., 2000).

Young children represent one of the most vulnerable group with regard to potentially harmful effects induced by airborne particulate exposure (Schüepp & Sly, 2012). As their physiological and immunological systems are still developing, young children receive a higher dose of airborne particles relative to lung size compared to adults (Burtscher & Schüepp, 2012; Laiman et al., 2014; Mazaheri et al., 2014; Morawska et al., 2013). Children spend a significant percentage of their time at schools and at homes. Specifically in Portugal, young children spend at school approximately 30% of their time (8-9 h/day). Therefore, the knowledge and understanding of indoor air pollution in these specific environments is important in order to child health. As a pollutant of both indoors and ambient air, UFP have the potential to harm children's health (Burtscher & Schüepp, 2012; Moreno et al. 2014; Reche et al., 2014; Rivas et al. 2014; Schüepp & Sly, 2012; Viana et al. 2014), yet the information concerning the children exposure to UFP is limited.

The aim of this work is to assess the indoor exposure to particles in (ultra)fine range (20-1000 nm) of 3–5 years old children, living in urban areas. The specific objectives of this work are: (i) to measure the levels of indoor particle number concentrations (PNC) in two preschools and three homes situated in urban low-moderately trafficked zones of Oporto Metropolitan Area (Portugal); and (ii) to compare the dose rates of the indoor (ultra)fine particles at schools and home environments.

MATERIALS AND METHODS

Characterization of sampling sites

Particle number concentrations in ultrafine (20-100 nm) and fine (> 100-1000 nm) ranges were consecutively measured at two preschools and three homes, all of them situated in urban low-moderately trafficked zones of Oporto Metropolitan Area in Paranhos district (north of Portugal). The sample collection was conducted for 56 days. Both preschools (S1 and S2) and homes (H1–H3) were situated in an urban zone; previously studies that evaluated ambient air pollution demonstrated that emissions from vehicular traffic are the main pollution source in these areas (Slezakova et al., 2011, 2013).

In each preschools, PNC were simultaneously measured at different indoor microenvironments (classrooms, canteens, and, if existent, gymnasium or playroom); all microenvironments were assessed using the identical sampling methodology and during the same amount of time. At homes sampling of (ultra)fine particles was conducted in living rooms that were used also as dining rooms; all meals/snacks were served there.

All indoor places were naturally ventilated through open windows. The characteristic of the studied preschools and homes, the traffic density data, as well as the duration of the sampling at each place are summarized in Table 1.

Sample collection

Particle number concentrations in size range 0.02–1 μm were measured by condensation particle counters – TSI P-Trak™ (UPC 8525; TSI Inc., MN, USA). The instrument operates on the principle of condensing 100% grade isopropyl alcohol (Sigma-Aldrich, Steinheim, Germany) onto ultrafine particles in order to increase their dimensions to a detectable size. At preschools, PNC were measured daily between 8:30 a.m. to 5:30 p.m. which corresponded to the period that children were at preschools, whereas at homes PNC of (ultrafine) particles were measured continuously during 24 h. Intake flow of 0.7 $L.min^{-1}$ was used and logging interval was 60 s accordingly to previous studies (Diapouli et al., 2007; Norbäck et al., 2011; Zhang & Zhu, 2012). Instruments were mounted onto supports so that air was sampled from a height of 0.8 to 1.1 m (in order to simulate children breathing zone). In each indoor environment, particles counters were placed as far as possible from windows or doors, and from other probable sources of particles (heating equipment, blackboards, printers, etc.) in order to minimize direct influence of any source. All requirements to maintain child safety were fulfilled.

At both preschools a researcher was present during sample collection in order to keep a record of room occupancy, ventilation systems (door and window positions), and potential source activities; information concerning child activities and schedules at preschools were also registered by a researcher. At homes all information including child activities were recorded by the parents/child responsible. In addition, teachers, staff and parents were daily inquired regarding the occurrence of additional sources and activities. Furthermore, detailed questionnaires were used daily for better description of the studied indoor environments (both preschools, homes). The first questionnaire was dedicated to registering potential sources of particles where the occupants marked time when these sources/activities were used / conducted in order to cross-reference them with concentration levels. The second questionnaire focused to the occupancy/activities of room where sampling equipment was placed. The last questionnaire focused on schedule of children's activities and their physical activity during the sampling. All necessary permissions were obtained from administrative boarders of each preschool and directly from parents.

Dose rate analysis

Particle dose rates for children were calculated using Equation 1 (Castro et al., 2011; Slezakova et al., 2014):

$$\text{Dose rate (D)} = (BR_{WA}/BW) \times C_{WA} \times OF \times N \quad (1)$$

where D is the age-specific dose rate (particle number kg^{-1} day^{-1}); BR_{Wa} is the age-specific weighted average breathing rate (L min^{-1}); BW is age-specific body weight (kg); C_{WA} is the age-specific weighted average concentration of particles (number of particles L^{-1}); OF is the occupancy factor (i.e. percentage of residents likely to be in the microenvironment at a given interval; it was considered 1, as children kept their schedules and associated locations tightly); and N is the total time per day spent by age-specific children in the respective indoor environment (min day^{-1}). Particle dose rates were estimated for 3–4 and 5 years old children. The daily activity patterns of children were analyzed throughout each day. Locations in which the different activities happened during the day were identified. Total daily residence time of children spent in each micro-environment (home, preschool) and the types of performed activities were registered. Each activity was characterized in terms of intensity level in order to assess the corresponding BR. An example of children timetable and activity patterns is shown in Table 2. As the information concerning the Portuguese population is not available, the age–specific factors (BW, BR) were retrieved from USEPA data (USEPA, 2011) considering the mixed population (both male and females). BW of 18.6 kg for 3–5 years old children was used. The values of BR were selected as the followings: 4.3 L min^{-1} for rest or sleep; 4.5 L min^{-1} for sedentary or passive activities; 11.0 L min^{-1} for light intense activity, and 37.0 L min^{-1} for highly intense activities (running, etc.). BR_{WA} was estimated then as weighted average, i.e. considering the intensity of each performed activities and the amount of time. The dose rates were then estimated using the average indoor concentrations of each microenvironment (and considering the real amount of time that children spent in each place).

Statistical analysis

For the data treatment, the Student's t-test was applied to determine the statistical significance ($p<0.05$, two tailed) of the differences between the determined means. All statistical analyses were performed using IBM® SPSS® Statistics software.

RESULTS

Particle number concentrations

Total means of particle number concentrations and the statistical parameters (minimum and maximum values, 25th, and 75th percentile) at the two preschools and three homes are shown in Figure 1. These parameters of (ultra)fine particles were determined using all measured data of all existent indoor environments. Concerning two preschools, mean of indoor PNC was significantly (1.4 times) higher ($p < 0.05$) at S1 (1.84×10^4 particles cm^{-3}) than at S2 (mean of 1.32×10^4 particles cm^{-3}).

At all three homes, obtained means of indoor (ultra)fine particles (Table 1) were rather similar; the results showed that the total indoor means of PNC at three homes were not statistically different ($p < 0.05$). Overall, the highest mean and the ranges of PNC were observed at H1 with mean concentration 1.1 times higher than at H2 and H3.

Dose rates

The activities that children conducted during their school time were alike at both preschools. However, the dose rates of indoor particles were estimated for 2 age categories, namely 3–4 years old and 5 years old children because their daily schedules slightly differed. Children spent the majority of their preschool time in classrooms (approximately 70–75% for 3–4 years old, and 57%–70% for 5 years old). The younger children rested (i.e. slept which was an activity associated with the lowest breathing rates) after lunch for 2–2.5 hours whereas older children performed indoors more frequently physical activities (such as running, playing, exercising, use of climbers, swings and slides). In addition, the 5 years old children spent less time (0.75–1.75 h) indoors. Overall, the daily activity patterns of children at three homes were remarkably similar. On average, children spent 13 h at home, out of which 3 h took place in a living room (sedentary or light activities; studying, games playing, drawing, or eating). Morning and evening routines (breakfast, bath, and etc.) took approximately for 1 h whereas child sleep accounted for about 9 h.

Dose rates associated with inhalation exposure to (ultra)fine particles (20–1000 nm) number concentrations at two preschools and three homes were estimated for two different age categories of children. The results are shown in Table 3. Concerning preschools, the results clearly show that: (i) for both age categories the highest dose rates of PNC were found at S1; and ii) for both schools the highest values of PNC total dose rates were observed for 5 years old children. Furthermore, the results in Table 3 clearly show that for 3–4 years and 5 years old children dose rates at homes were 1.3–2.1 times higher than at schools.

DISCUSSION

As children represent one of the most vulnerable groups in society, more information concerning the air pollutants to which they are adversely exposed in schools and home environments is needed. Overall, levels of (ultra)fine particles at the two Portuguese preschools were in similar ranges to those reported for indoor air of schools in Greece (2.4×10^4 particles cm^{-3}; Diapouli et al., 2008), Italy ($1.95–2.04\times10^4$ particles cm^{-3}; Buonanno et al., 2012, 2013a), Spain (1.56×10^4 particles cm^{-3}; Reche et al.. 2014; Rivas et al.; 2014), South Korea (1.82×10^4 particles cm^{-3}; Kim et al., 2011;) or Australia ($1.21–1.69\times10^4$ particles cm^{-3}; Rumchev et al., 2007). In addition, large ongoing epidemiological study of UFP in schools has been conducted in Melbourne (Australia). The authors reported emission rates of UFP as well as deposition of UFP in lungs so direct comparison with levels in air was not possible. Other studies from Europe, namely from Denmark, Germany, and Sweden, (Clausen et al., 2012; Fromme et al., 2007; Norbäck et al., 2011) reported much lower levels of ultrafine particles (0.7×10^3–6.5×10^3 particles cm^{-3}) than in present work. Different levels of urbanization and development of area surrounding schools, meteorological conditions or seasonal influences could account for some of these differences (Morawska et al., 2009). It is also necessary to point that the majority of the existent studies on UFP in educational settings focused on assessments in classrooms (Clausen et al., 2012; Fromme et al., 2007; Guo et al., 2010; Mullen et al., 2011; Norbäck et al., 2011; Weichenthal et al., 2008). Only one study (Zhang & Zhu, 2012) reported the information on ultrafine particles also in other school microenvironments (gymnasium, canteen, libraries), being otherwise inexistent. In this work, classrooms were the microenvironment associated with lower particle number concentrations at both preschools (mean of 9.31×10^3 and 1.13×10^4 particle cm^{-3} at S1 and S2, respectively), which is reassuring, considering that they are the places where children spend the majority of their school time. The major identified sources of (ultra)fine particles, based on the daily registered information, were: classroom cleaning, children activities during classes (such as sculpturing, and etc.) and combustion sources; levels of (ultra)fine particles in ambient air ranged from 2.4×10^3 to 4.3×10^4 (Slezakova et al., 2014). On the contrary, at both preschools PNC in canteens (mean of 5.17×10^4 and 3.28×10^4 particle cm^{-3} at S1 and S2, respectively) were the highest ones. Although, children spend in canteens rather short periods of time (18 and 19% of their school time at S1 and S2, respectively) the exposures in this type of indoor microenvironment might be relevant for overall child school exposure. Furthermore, exposure to high levels of ultrafine particles numbers, even if during a limited period of time, may pose some risks to child health (Burtscher & Schüepp, 2012). In agreement with these findings, Mullen et al. (2011) previously reported that cooking events were the most significant indoor sources (during normal occupancy) at six schools in California (USA). The importance of cooking and eating activities have been also demonstrated in more recent studies evaluating particle deposition in the alveolar and tracheobronchial region (Buonanno et al., 2011, 2012; 2013b; Mazaheri et al., 2013).

At three homes the mean concentrations of particles number ranged between 1.09×10^{4} and 1.24×10^{4} particles cm^{-3}. These levels of PNC were similar to mean concentrations reported in literature for homes in Germany (0.9×10^{4} particles cm^{-3}; Fittschen et al., 2013), Greece ($1.3–1.4\times10^{4}$ particles cm^{-3}; Diapouli et al., 2011), Canada ($0.8–1.03\times10^{4}$ particles cm^{-3}; Kearney et al., 2011; Wheeler et al., 2011), and Australia (1.24×10^{4} particles cm^{-3}; Morawska et al., 2003). However, recently Bekö et al. (2013) conducted a large study that assessed UFP in 56 residences in Denmark. These authors reported UFP approximately three times higher than in Portuguese homes (mean of 2.91×10^{4} particle cm^{-3}; Bekö et al., 2013). Different study design (sampling period, duration, number of homes) and/or different particle size ranges of measured ultrafine fraction could also contribute to these differences (Morawska et al., 2013).

Overall, the highest mean of PNC as well maximal levels (i.e. 2.1×10^{5} particle cm^{-3}) were observed at H1. Based on the analysis of information available from the questionnaires, the indoor sources of UFP at H1 included: cooking (boiling and frying), use of toaster and oven, use of cleaning products, vacuuming and ironing. Certainly the frequency and durations of these indoor activities might have influenced the respective levels. However, it is also necessary to remark that contrary to the other two homes, at H1 the room where the sampling was conducted was directly connected with a kitchen. In addition, occupants of this home maintained doors between kitchen and living room almost constantly opened. Thus, PNC from cooking emissions easily penetrated to the sampling area (Bordado et al., 2012; Buonanno et al., 2013b), and accounted for the high concentrations at this home. The variation of time and location (room type) can account for the obtained differences of (ultra)fine particles (Bekö, et al., 2013).

Overall, the levels of PNC at three homes were 10–70% lower than at preschools. However, activities (and the levels of their physical intensity) that are typically performed in an educational institution vary greatly from those of home. Therefore, the dose rates resulting from a stay in these two environments might differ considerably.

The highest doses of PNC at preschools were found for children of S1 (Table 3). Although levels of PNC in classrooms were the highest at S2, doses of UFP resulting from school exposure were higher (up to 50%) for children at S1, probably due to the higher levels of PNC in the canteen of the respective preschool. These findings thus demonstrate that all potential microenvironments should be considered when assessing children exposure to PNC in preschools and schools.

The estimated dose rates of indoor PNC at both schools were compared between both age groups of children. The results in Table 3 show that at S2 the dose rates were higher for 5 years old children. As mentioned previously, older children performed more frequently physical activities which were associated with the highest breathing rates and consequently led to higher inhalation doses of particles. On the contrary 3–4 years old children spent more time in classrooms where levels of PNC were the lowest. Furthermore, after the lunch 3–4 years old children slept in the classrooms which was an activity associated with the lowest breathing rates. At S1, the estimated dose rates were not statistically different ($p < 0.05$) between 3–4 years old and 5 years old children, which was probably due to the different activity patterns; older children spent indoors less 1.75 h and contributions resulting from the outdoor exposure was not considered in this work. Therefore, in future work when assessing children a period spent during school daytime outdoors should be considered as it might be relevant to child overall school exposure.

When evaluating the three homes (Table 3), the highest dose rates of particles were observed for children at H1 due to the highest levels of UFP at this home. When in use, particles samplers make minor noise. Therefore, in order to maintain soundless rest of children it was not possible to conduct measurements directly in children bedrooms. The obtained dose rates of PNC at H1–H3 thus represent an approximation of child home exposure and need to be interpreted carefully.

Finally, dose rates of particles in (ultra)fine range at homes were higher than those of preschools. Although number concentrations (ultra)fine particles at the three homes were lower than total levels at both preschools (Figure 1), children spent at homes approximately 13 h (opposed to 9 h at preschools). The longer exposure time could account for the obtained values. These results thus show that daily activity patterns significantly influenced overall doses to PNC in 3–5 years old children.

The dose rates of in (ultra)fine particles estimated in this work were due to indoor exposure at preschools and homes only. However, children spend on a daily basis some of their time in other microenvironments (transportation modes, extracurricular activities, and etc.) where they are exposed to UFP from additional sources. Therefore, characterization of the respective exposures to UFP for children in these microenvironments is of upmost importance. Furthermore, future studies focusing on the health effects of airborne pollutants should always account for children exposures in different microenvironments (homes, schools, transportation modes, and etc.) in order to obtain a correct representation of child's overall exposure.

Acknowledgments

This work was supported by Fundação para Ciência e Tecnologia with grant number SFRH/BPD/65722/2009. It also received financial support from the European Union (FEDER funds through COMPETE) and National Funds (Fundação para a Ciência e Tecnologia) through project Pest-C/EQB/LA0006/2013.

References

Azarmi, F., Kumar, P., and Mulheron, M. 2014. The exposure to coarse, fine and ultrafine particle emissions from concrete mixing, drilling and cutting activities. *J. Hazard. Mater*. 279:268–279.

Bakand, S., Hayes, A., and Dechsakulthorn, F. 2012. Nanoparticles: A review of particle toxicology following inhalation exposure. *Inhal. Toxicol.* 24(2): 125–135.

Bhangar, S., Mullen, N. A., Hering, S. V., Kreisberg, N. M., and Nazaroff, W. W. 2011. Ultrafine particle concentrations and exposures in seven residences in northern California. *Indoor Air* 21(2): 132–144.

Bekö, G., Weschler, C. J., Wierzbicka, A., Karottki, D. G., Toftum, J., Loft, S., and Clausen, G. 2013. Ultrafine particles: Exposure and source apportionment in 56 Danish homes. *Environ. Sci. Technol* .47(18): 10240–10248.

Bordado, J. C., Gomes J. F., and Albuquerque P. C. 2012. Exposure to airborne ultrafine particles from cooking in Portuguese homes. *J. Air Waste Manag. Assoc.* 62(10): 1116–126.

Brunekreef, B., Beelen, R., Hoek, G., Schouten, L., Bausch-Goldbohm, S., Fischer, P., Armstrong, B., Hughes, E., Jerrett, M., and van den Brandt, P. 2009. Effects of long-term exposure to traffic-related air pollution on respiratory and cardiovascular mortality in the Netherlands: the NLCS-AIR study. *Res. Rep. Health Eff. Inst*. 139: 5–71.

Buonanno, G., Fuoco, F. C., Morawska, L., and Stabile, L. 2013a. Airborne particle concentrations at schools measured at different spatial scales. *Atmos. Environ*. 67: 38–45.

Buonanno, G. Giovinco, G., Morawska, L., and Stabile, L. 2011. Tracheobronchial and alveolar dose of submicrometer particles for different population age groups in Italy. *Atmos. Environ*. 45:6216–6224.

Buonanno, G., Marini, S., Morawska, L., and Fuoco, F. C. 2012. Individual dose and exposure of Italian children to ultrafine particles. *Sci. Total Environ*. 438: 271–277.

Buonanno, G., Morawska, L, Stabile, L., Wang, L., and Giovinco, G. 2012. A comparison of submicrometer particle dose between Australian and Italian people. *Environ. Pollut*. 169:183–189.

Buonanno, G., Stabile, L., Morawska, L., and Russi, A. 2013b. Children exposure assessment to ultrafine particles and black carbon: The role of transport and cooking activities. *Atmos. Environ*. 79: 53–58.

Burtscher, H., and Schüepp, K. 2012. The occurrence of ultrafine particles in the specific environment of children. *Paediatr. Respir. Rev*. 13(2): 89–94.

Castro, D., Slezakova, K., Delerue-Matos, C., Alvim-Ferraz, M. C., Morais, S., and Pereira, M. C. 2011. Polycyclic aromatic hydrocarbons in gas and particulate phases of indoor environments influenced by tobacco smoke: Levels, phase distributions, and health risks. *Atmos. Environ*. 45(10): 1799–1808.

Clausen, G., Høst, A., Toftum, J., Bekö, G., Weschler, C., Callesen, M., Buhl, S., Ladegaard, M. B., Langer, S., Andersen, B., Sundell, J., Bornehag, C. G., and Sigsgaard, T. 2012. Children's health and its association with indoor environments in Danish homes and daycare centres – methods. *Indoor Air* 22(6): 467–475.

Diapouli, E., Chaloulakou, A., and Spyrellis, N. 2007. Levels of ultrafine particles in different microenvironment—implications to children exposure. *Sci. Total Environ.* 388: 128–136.

Diapouli, E., Eleftheriadis, K., Karanasiou, A. A., Vratolis, S., Hermansen, O., Colbeck, I., and Lazaridis, M. 2011. Indoor and outdoor particle number and mass concentrations in Athens. Sources, sinks and variability of aerosol parameters. *Aerosol Air Qual. Res*. 11(6): 632–642.

Diapouli, E., Chaloulakou, A., Mihalopoulos, N., and Spyrellis, N. 2008. Indoor and outdoor PM mass and number concentrations at schools in the Athens area. *Environ. Monit. Assess.* 136(1–3): 13–20.

Fittschen, U. E. A., Santen, M., Rehmers, A., Durukan, I., and Wesselmann, M. 2013. Indoor aerosol determination with respect to a soiling phenomenon in private residences. *Environ. Sci. Technol.* 47(1), 608–615.

Fromme, H., Twardella, D., Dietrich, S., Heitmann, D., Schierl, R., Liebl, B., and Rüden, H. 2007. Particulate matter in the indoor air of classrooms-exploratory results from Munich and surrounding area. *Atmos. Environ*. 41(4): 854–866.

Guo, H., Morawska, L., He, C., Zhang, Y. L., Ayoko, G., and Cao, M. 2010. Characterization of particle number concentrations and PM2.5 in a school: Influence of outdoor air pollution on indoor air. *Environ. Sci. Pollut. Res*. 17: 1268–1278.

Heal, M. R., Kumar, P., and Harrison, R. M. 2012. Particles, air quality, policy and health. *Chem. Soc. Rev*. 41(19): 6606–6630.

Ibald-Mulli, A., Wichmann, H. E., Kreyling, W., Peters, A. 2002. Epidemiological evidence on health effects of ultrafine particles. *J. Aerosol. Med*. 15(2): 189–201.

Kearney, J., Wallace, L., MacNeill, M., Xu, X., Vanryswyk, K., You, H., Kulka, R., and Wheeler, A. 2011. Residential indoor and outdoor ultrafine particles in Windsor, Ontario. *Atmos. Environ*. 45(40): 7583–7593.

Kelly, F. J., and Fussell, J. C. 2012. Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter. *Atmos. Environ*. 60: 504–526.

Kim, J.-L., Elfman, L., Wieslander, G., Ferm, M., Torén, K., and Norbäck, D. 2011. Respiratory health among Korean pupils in relation to home, school and outdoor environment. *J. Korean Med. Sci.* 26(2): 166–173.

Krewski, D., Burnett, R. T., Goldberg, M. S., Hoover, B. K., Siemiatycki, J., Jerrett, M., Abrahamowicz, M., and White, W. H. 2003. Overview of the Reanalysis of the

Harvard Six Cities Study and American Cancer Society study of particulate air pollution and mortality. *J. Toxicol. Env. Health A* 66(16–19): 1507–1551.

Krewski, D., and Rainham, D. 2007. Ambient air pollution and population health: Overview. *J. Toxicol. Env. Health A* 70 (3–4): 275–283.

Kumar, P., Robins, A., Vardoulakis, S., and Britter, R. 2010. A review of the characteristics of nanoparticles in the urban atmosphere and the prospects for developing regulatory controls. *Atmos. Environ*. 44(39): 5035–5052.

Laiman, R., He, C., Mazaheri, M., Clifford, S., Salimi, F., Crilley, L. R., Megat Mokhtar, M. A., and Morawska, L. 2014. Characteristics of ultrafine particle sources and deposition rates in primary school classrooms. *Atmos. Environ*. 94:28–35.

Long, C. M., Suh, H. H., and Koutrakis, P. 2000. Characterization of indoor particle sources using continuous mass and size monitors. *J. Air Waste Manag. Assoc.* 50: 1236–1250.

Mazaheri, M., Clifford, S., Jayaratne, R., Megat Mokhtar, M. A., Fuoco, F., Buonanno, G., and Morawska, L. 2014. School children's personal exposure to ultrafine particles in the urban environment. *Environ. Sci. Technol*. 48(1):113–120.

Morawska, L., Afshari, A., Bae, G. N., Buonanno, G., Chao, C. Y. H., Hänninen, O., Hofmann, W., Isaxon, C., Jayaratne, E. R., Pasanen, P., Salthammer, T., Waring M., and Wierzbicka A. 2013. Indoor aerosols: from personal exposure to risk assessment. *Indoor Air* 23(6): 462–487.

Morawska, L., He, C., Hitchins, J., Mengersen, K., and Gilbert, D. 2003. Characteristics of particle number and mass concentrations in residential houses in Brisbane, Australia. *Atmos. Environ*. 37: 4195–4203.

Morawska, L., He, C., Johnson, G., Guo, H., Uhde, E., and Ayoko, G. 2009. Ultrafine particles in indoor air of a school: possible role of secondary organic aerosols. *Environ. Sci. Technol.* 43(24): 9103–9109.

Morawska, L., Ristovski, Z., Jayaratne, E. R., Keogh, D. U., and Ling, X. 2008. Ambient nano and ultrafine particles from motor vehicle emissions: characteristics, ambient processing and implications on human exposure. *Atmos. Environ*. 42(35): 8113–8138.

Moreno, T., Rivas, I., Bouso, L., Viana, M., Jones, T., Àlvarez-Pedrerol, M., Alastuey, A., Sunyer, J., and Querol, X. 2014. Variations in school playground and classroom atmospheric particulate chemistry. *Atmos. Environ*. 91:162–171.

Mullen, N. A., Bhangar, S., Hering, S. V., Kreisberg, N. M., and Nazaroff, W. W. 2011. Ultrafine particle concentrations and exposures in six elementary school classrooms in northern California. *Indoor Air* 21(1): 77–87.

Norbäck, D., Wieslander, G., Zhang, X., and Zhao, Z. 2011 Respiratory symptoms, perceived air quality and physiological signs in elementary school pupils in relation to displacement and mixing ventilation system: an intervention study. *Indoor Air* 21(5): 427–437.

Pereira Gomes, J. F., Moura Bordado, J. C., and Silva Albuquerque, P. C. 2012. On the assessment of exposure to airborne ultrafine particles in urban environments. *J. Toxicol. Env. Health A* 75(22–23): 1316–1329.

Reche, C., Viana, M., Rivas, I., Bouso, L., Àlvarez-Pedrerol, M., Alastuey, A., Sunyer, J., and Querol, X. 2014. Outdoor and indoor UFP in primary schools across Barcelona. *Sci. Total Environ*. 493:943–953.

Rivas, I., Viana, M., Moreno, T., Bouso, L., Pandolfi, M., Alvarez-Pedrerol, M., Forns, J., Alastuey, A., Sunyer, J., and Querol, X. 2015. Outdoor infiltration and indoor contribution of UFP and BC, OC, secondary inorganic ions and metals in PM2.5 in schools. *Atmos. Environ*. 106:129–138.

Rivas, I., Viana, M., Moreno, T., Pandolfi, M., Amato, F., Reche, C., Bouso, L., Àlvarez-Pedrerol, M., Alastuey, A., Sunyer, J., and Querol, X. 2014. Child exposure to indoor and outdoor air pollutants in schools in Barcelona, Spain. *Environ. Int.* 69:200–212.

Rückerl, R., Schneider, A., Breitner, S., Cyrys, J., and Peters, A. 2011. Health effects of particulate air pollution: A review of epidemiological evidence. *Inhalation. Toxicol.* 23(10): 555–592.

Rumchev, K., Ourangui, R., Bertolatti, D., and Spickett, J. 2007. Indoor air quality in old and new schools. *WIT Trans. Biomed. Health* 11: 25–32.

Samet, J., and Krewski, D. 2007. Health effects associated with exposure to ambient air pollution. *J. Toxicol. Env. Health A* 70 (3–4): 227–242.

Schüepp, K., and Sly, P. D. 2012. The developing respiratory tract and its specific needs in regard to ultrafine particulate matter exposure. *Paediatr. Respir. Rev*. 13(2): 95–99.

Schwab, M., McDermott, A., and Spengler, J. D. 1992. Using longitudinal data to understand children's activity patterns in an exposure context: Data from the Kanawha County Health Study. *Environ. Int*. 18(2): 173–189.

Slezakova, K., Castro, D., Begonha, A., Delerue-Matos, C., Alvim-Ferraz, M. C., Morais, S., and Pereira, M. C. 2011. Air pollution from traffic emissions in Oporto, Portugal: Health and environmental implications. *Microchem. J.* 99 (1): 51–59.

Slezakova, K., Fonseca, J., Morais, S., and Pereira, M. C. 2014. Ultrafine particles in ambient air of an urban area: Dose implications for elderly. *J. Toxicol. Env. Health A* 77 (14–16): 827–836.

Slezakova, K., Pires, J. C. M., Castro, D., Alvim-Ferraz, M. C. M., Delerue-Matos, C., Morais, S., and Pereira, M. C. 2013. PAH air pollution at a Portuguese urban area: Carcinogenic risks and sources identification. *Environ. Sci. Pollut. Res. Int*. 20 (6): 3932–3945.

Solomon, P. A. 2012. An overview of ultrafine particles in ambient air. *EM* issue May: 18–23.

United States Environmental Protection Agency (USEPA) 2011. *Exposure Factors Handbook: 2011 edition*. EPA/600/R–09/052F, Washington, DC: USEPA Office for Research and Development.

Viana, M., Rivas, I., Querol, X., Alastuey, A., Álvarez-Pedrerol, M., Bouso, L., Sioutas, C., and Sunyer, J. 2015. Partitioning of trace elements and metals between quasi-ultrafine, accumulation and coarse aerosols in indoor and outdoor air in schools. *Atmos. Environ.* in presss, doi: 10.1021/es403721w.

Viana, M., Rivas, I., Querol, X., Alastuey, A., Sunyer, J., Álvarez-Pedrerol, M., Bouso, L., and Sioutas, C. 2014. Indoor/outdoor relationships and mass closure of quasi-ultrafine, accumulation and coarse mode particles in Barcelona schools. *Atmos. Chem. Phys*.14:4459–4472.

Wang, Y., Hopke, P. K., Chalupa, D. C., and Utell, M. J. 2011. Long-term study of urban ultrafine particles and other pollutants. *Atmos. Environ*. 45(40):7672–7680.

Weichenthal, S., Dufresne, A., Infante-Rivard, C., and Joseph, L. 2008. Characterizing and predicting ultrafine particle counts in Canadian classrooms during the winter months: model development and evaluation. *Environ. Res*. 106(3): 349–360.

Wheeler, A. J., Wallace, L. A., Kearney, J., Van Ryswyk, K., You, H., Kulka, R., Brook, J. R., and Xu, X. 2011. Personal, indoor, and outdoor concentrations of fine and ultrafine particles using continuous monitors in multiple residences. *Aerosol Sci. Technol.* 45(9): 1078–1089.

Zhang, Q., and Zhu, Y. 2012. Characterizing ultrafine particles and other air pollutants at five schools in South Texas. *Indoor Air* 22(1): 33–42.

Figure Captions

FIGURE 1. Levels of (ultra)fine particles at two schools (S1, S2) and three homes (H1–H3): minimum and maximum values, average, 25^{th}, and 75^{th} percentile. Particle number concentrations were determined considering the measured levels in all indoor microenvironments existent in each school and home.

TABLE 1. Characterization of the studied environments (preschools and homes) and obtained concentrations of (ultra)fine particles.

Site	Description	Location	Traffic density data[a]	Studied indoor microenvironments	Sampled period	Particle number concentration (particles cm^{-3})		
							Mean	Standard deviation
S1	Two–floors building 173 students 3–5 years old	Situated on moderately trafficked street	Mean: 16 vehicles/min	Classrooms (3) Canteen (1) Playroom (1)	13 days	Classrooms	9.31×10^{3}	8.23×10^{3}
						Canteen	5.17×10^{4}	3.41×10^{4}
						Playroom	1.70×10^{4}	1.25×10^{4}
						Total	1.82×10^{4}	2.16×10^{4}
S2	Three–floors building 30 student 3–5 years old	Situated on intersection of moderate and low trafficked street	Mean: 13 vehicles/min	Classrooms (3) Canteen (1) Gymnasium (1)	13 days	Classrooms	1.13×10^{4}	5.24×10^{4}
						Canteen	3.28×10^{4}	3.21×10^{4}
						Gymnasium	9.72×10^{3}	2.36×10^{3}
						Total	1.32×10^{4}	1.25×10^{4}

H1	Multi–unit apartment building Situated on 4th floor 4 occupants (2 children of 3 and 5 years old)	Situated on intersection of two low trafficked street	Mean: 3 vehicles/min	Living room	10 days	1.24×10^4	1.28×10^4
H2	Multi–unit apartment building Situated on 4th floor 4 occupants (1 child of 5 years old)	Situated nearby highly trafficked road	Not available	Living room	9 days	1.11×10^4	1.15×10^4
H3	Two–floors house	Situated in suburban zone with moderate traffic	Mean: 4 vehicles/min	Living room	11 days	1.09×10^4	1.11×10^4

4 occupants (1 child of 5 years old)

[a] Data was obtained by manual counts during 10 min of each hour (between 5 a.m. to 12p.m.) on two consecutive days (avoiding Mondays and Fridays). The location distance between the counting point and main entrance/building outside wall was 5 and 8 m at S1 and S2, respectively and 3–4 m at H1 and H3.

TABLE 2. Timetable and child activity patterns during a weekday: an example for 3–4years old children at school and a home.

Time		**Environment**	**Observed activities**	**Activity intensity**
School				
8:30–9:00	Arrival to school	Indoor	Playing (calm, seated, TV)	Sedentary
9:03–10:29	Classes/education	Indoor	Seated only (talking)	Sedentary
10:30–11:15	Recess	Playground	Running, jumping, swings	High intensity
11:17–11:40	Classes/education	Indoor	Sedentary and other (painting, walking)	Sedentary
11:45–13:00	Lunch	Indoor	Seated (eating, drinking, talking)	Light
13:05–15:00	Rest	Indoor	Sleeping	Sleep
15:04–16:00	Classes/education	Indoor	Seated, and other	Sedentary
16:00–17:30	Leaving school	Indoor	Organized activities (singing dancing), running	High intensity
Home				
18:00–19:20	Living room		Home works, school preparation, studying	Sedentary
19:25–20:00	Living room		Seated (eating, drinking, talking)	Sedentary

20:05–:22:00	Living room	Playing games, painting, walking	Light
22:00–6:50	Bedroom	Sleeping	Sleep
7:00–8:00	Various	Morning routine, breakfast	Light

TABLE 3. Age–specific dose rates (particles kg^{-1} day^{-1}) to UFP for 3–4 years and 5 years old children at two preschools (S1 and S2) and three homes (H1–H3).

	S1		**S2**		**H1**	**H2**	**H3**
	3–4 years	5 years old	3–4 years	5 years old	3–5 years	3–5 years	3–5 years
Dose rate (particles kg^{-1} day^{-1})	1.99×10^{9}	2.02×10^{9}	1.49×10^{9}	1.92×10^{9}	3.06×10^{9}	2.74×10^{9}	2.69×10^{9}

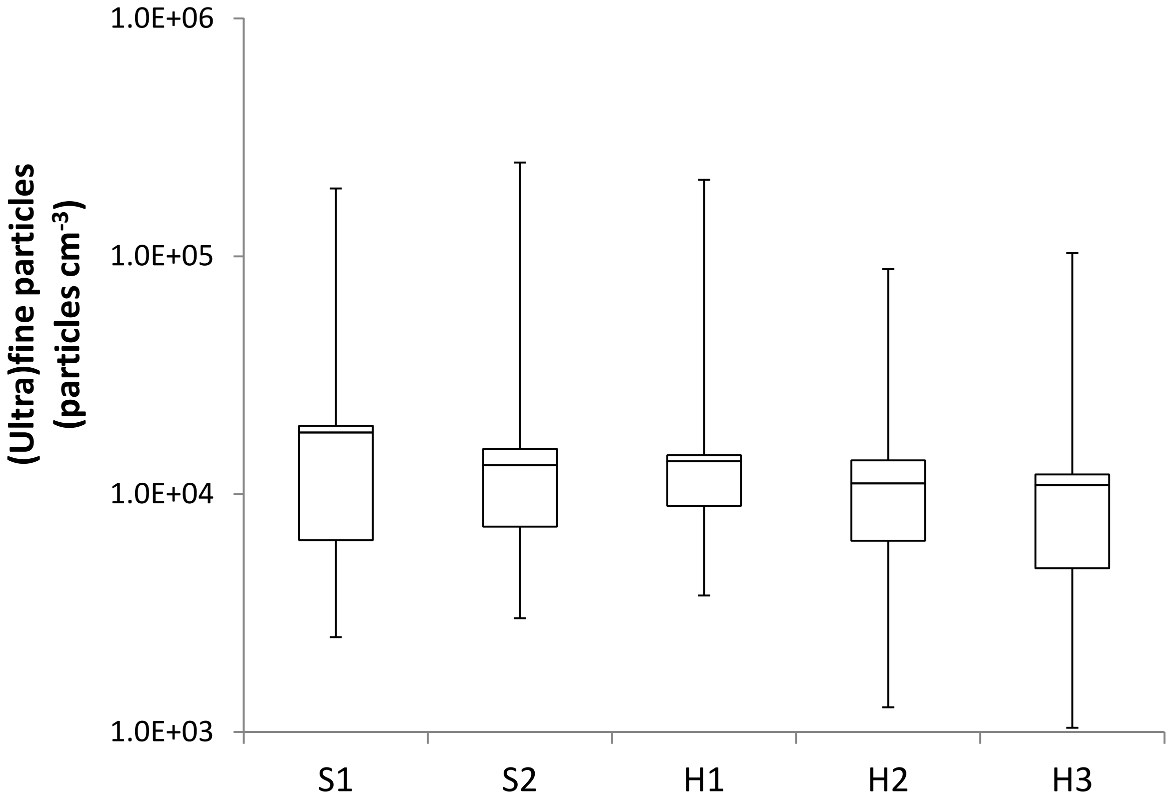
1.0E+06
1.0E+05
1.0E+04
1.0E+03
(Ultra)fine particles (particles cm-3)
S1
S2
H1
H2
H3

FIGURE 1