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Particulate matter in urban nursery schools: A case study of Seoul, Korea during winter months

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ABSTRACT

Airborne particulate matter (PM) is closely linked to a range of adverse health outcomes such as oxidative stress-induced DNA damage and respiratory symptoms. A number of young children aged under 5 years spend a significant amount of time in nurseries worldwide. However, few studies examine children's exposure to PM in nursery environments. The objective of this study is to characterize five important metrics of particulate matter pollutants in urban nurseries in a mega-city, Seoul, Korea during winter days. 48 h field measurements were performed at four urban nurseries to monitor size-resolved particle number (PN) concentration (10–700 nm), lung-deposited surface area (LDSA, 10–1000 nm), and mass concentrations of $PM_{2.5}$, PM_{10}, and black carbon (BC). Other environmental parameters such as CO_2 concentration, temperature, and relative humidity (RH) were measured. Results show that indoor PN concentrations and LDSA are notably elevated during occupancy, mainly due to window opening. During window-open periods, the geometric mean of indoor particle size distribution is in the range of 30–40 nm, similar to the geometric mean of the outdoor particle size distribution. For all nurseries, the daily-integrated exposure to PN had an overall mean of $170 \times 10^3/cm^3$ h/day and a relative standard deviation of 32%. The indoor mean concentrations of BC and LDSA during occupancy is comparable to those of busy roads in populated cities such as Zurich, Lisbon and Barcelona, suggesting high potential for lung deposition of UFP in nursery classrooms.

1. Introduction

Human exposure to airborne particulate matter (PM) is closely linked to adverse health impacts such as prevalence of asthma symptoms, oxidative stress-induced DNA damage, and disorders of the central nervous system [1–5]. Studies performed in Asia and Europe have reported that $PM_{2.5}$ (particulate matter (PM) with aerodynamic diameter ≤ 2.5 μm) and PM_{10} (PM with aerodynamic diameter ≤ 10 μm) mass concentrations in classrooms often exceed several times World Health Organization (WHO) guidelines [6–8]. Ultrafine particles (UFP, ≤ 100 nm) also have detrimental health effects as their small size facilitates uptake into cells, the circulatory system, and the respiratory system [9–12]. Infants and toddlers are especially sensitive to PM pollution because of their immature immune system and relatively large dose per unit body weight compared to adults [13–15]. Considering that young children aged under 5 years may spend 6–10 h in nursery schools daily, PM pollution in nurseries can contribute to a substantial portion of PM exposure in young children.

Several studies have documented the contribution of outdoor and indoor sources to in-classroom PM exposure [9,16–18]. Amato et al. [16] reported that on average, outdoor PM contributes to 53% of $PM_{2.5}$ in classrooms based on measurements of 39 primary schools in Barcelona. Outdoor traffic-related PM can penetrate into buildings and elevate indoor concentrations of black carbon (BC) and UFP [19,20]. BC is primarily emitted by incomplete combustion of carbonaceous fuels [21]; outdoor road traffic can be an important source of BC indoors [22–24]. Vehicular traffic is also an important source of UFP. Studies report that UFP number concentration are pronounced near major freeways and that UFP levels decrease exponentially with distance, becoming indistinguishable from background at distances several hundred meters downwind of the freeway [25,26]. Previous studies have also identified indoor PM sources such as gas combustion, high surface temperature process,

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cleaning, painting, and consumer products [27–30]. However, few studies have characterized size-resolved UFP number and lung-deposited surface area (LDSA) in urban nursery environments.

The objective of the present study is to examine size-resolved UFP, LDSA, PM mass concentrations and daily integrated exposure to UFP in urban nurseries during several days in winter in a mega-city, Seoul, Korea. Seoul is the capital of South Korea and is the country's most populated city. The city has a population of over 10 million and often experiences severe outdoor air pollution due to heavy traffic and frequent air pollution events such as Asian dust storms originating from China. Many nurseries in Seoul are located within close proximity (<100 m) to major roadways. This study focuses on indoor PM pollution for urban nursery schools considering three main factors: 1) outdoor traffic-related sources, 2) indoor occupancy, and 3) ventilation condition.

2. Methods

2.1. Study site description and test conditions

We selected four nurseries in inner-city neighborhoods of Seoul as case study sites (See Fig. S1). The nurseries were inhabited by between eight and fifteen children under five years of age during weekdays. Table 1 summarizes characteristics of the four nursery rooms studied at four nurseries (labeled N1, N2, N3, and N4) and indoor/outdoor climatic conditions. Each nursey was monitored for continuous 48-h periods; monitoring periods for each nursery are given in Table 1. During site visits, the only noted indoor or outdoor air pollution sources were those associated with indoor classroom human activities (e.g., resuspension processes) and outdoor vehicular traffic combustion. Three of the nurseries (N1, N2, and N3) were located within 70 m from major (6- to 10-lane) roadways, and the fourth nursery (N4) was located about 285 m from a 10-lane freeway. Detailed area maps and description of the field measurement campaign are provided in the Supporting Information (see Figs. S2 and S3).

At each nursery, time-varying concentrations of five metrics of particulate pollution (UFP, LDSA, BC, $PM_{2.5}$, and PM_{10}) were measured in a main classroom where at least eight children were present during the day. Simultaneous particle sampling was conducted outdoors within 10 m of the classroom. During measurements, the classroom was occupied by 8–15 children from 07:30 to 17:30 each day. The indoor instruments were placed in a data acquisition rack with a height ranging from 0.6 to 1.1 m in order to monitor PM concentrations at breathing levels of the children. The data acquisition rack was placed as far as possible from entrance doors and corridors. Besides indoor monitoring, researchers recorded information of occupancy, and ventilation conditions (e.g., window opening). Detailed activity logs were not kept to minimize disruption of normal activities by the researcher. All nurseries did not have mechanical outdoor air ventilation systems. Instead, doors and windows were routinely opened at least 4 times a day (30–60 min) based on a strict protocol performed by the teachers, to facilitate indoor-outdoor air exchange.

2.2. Instrumentation and quality assurance

Table 2 summarizes the instruments used for indoor and outdoor air monitoring with a 1-min time interval. Sampling at each nursery involved a 48-h monitoring of indoor and outdoor

Table 1
Summary of the building characteristics and test conditions.

Test ID	Location District (distance to the major road)	Test room description (# of children, age range & room volume)	Measurement periods	Indoor temperature/relative humidity during occupancy[a]
N1	Yeongdeungpo (65 m from a 10-lane roadway)	1st floor of a 17 story building (8, 1–2 yr old, volume: 133 m^3)	Feb. 11, 17:40–Feb. 13, 17:40, 2014	11.8–27.0 °C 8.6–26.8%
N2	Gangnam (55 m from a 6-lane roadway)	3rd floor 5-story building (15, 3–4 yr old, volume: 103 m^3)	Nov. 12,, 17:30–Nov. 14, 17:30, 2013	16.3–26.2 °C 12.0–28.6%
N3	Songpa (38 m from a 8-lane roadway)	1st floor of a 4 story building (13, 2–3 yr old, volume: 60.8 m^3)	Dec. 16, 17:30–Dec. 18, 17:30, 2013	13.9–25.2 °C 18.3–41.9%
N4	Seocho (285 m from 10-lane freeway)	2nd floor of a 5-story building (13, 3–4 yr old, volume: 122 m^3)	Nov. 26, 18:00–Nov. 28, 18:00, 2013	13.4–25.4 °C 14.5–55.5%

[a] The nurseries were occupied by children between 07:30 and 17:30.

Table 2
Instrumentation used in this study and their characteristics.

Measurement	Location	Instrument & model[a]	Principle	Detection range/limit
$PM_{2.5}$/PM_{10} mass	Indoor, outdoor (2 units)	Portable Aerosol Spectrometer (Grimm, 1.109)	Light scattering	0.25–32 μm
BC-TSP	Indoor, outdoor (2 units)	Aethalometer (Magee Scientific, AE51)	Optical absorption	Total suspended particulate mass
Particle number (PN)	Indoor	Nanoscan SMPS (TSI, 3910)	Diffusion charger + electrometer	10-420 nm
	Outdoor	DiSCmini (Matter Aerosol, 101336)	Diffusion charger + electrometer	20-700 nm
Lung deposited surface area (LDSA)	Indoor, outdoor (2 units)	NAM (TSI, AeroTrak 9000)	Diffusion charger + electrometer	10-1000 nm
Temperature, relative humidity (RH), CO_2	Indoor, outdoor (2 units)	TES model 1370	CO_2: Nondispersive infrared (NDIR) Temp: Thermistor RH%: Resistance	0-6000 ppm −20-60 °C 10-95%

[a] Detailed side-by-side comparison results of indoor and outdoor monitors provided in Supporting Information (Fig. S4).