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RESEARCH ARTICLE

Indoor air quality differences between urban and rural preschools in Korea

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Abstract
Background, aims, and scope Preschool indoor air quality (IAQ) is believed to be different from elementary school or higher school IAQ and preschool is the first place for social activity. Younger children are more susceptible than higher-grade children and spend more time indoors. The purpose of this study was to compare the indoor air quality by investigating the concentrations of airborne particulates and gaseous materials at preschools in urban and rural locations in Korea.
Methods We investigated the concentrations of airborne particulates and gaseous materials in 71 classrooms at 17 Korean preschools. For comparison, outdoor air was sampled simultaneously with indoor air samples. Airborne concentrations of total suspended particulates, respirable particulates, lead, asbestos, total volatile organic compounds and components, formaldehyde, and CO_2 were measured with National Institute for Occupational Safety and Health and/or Environmental Protection Agency analytical methods.
Results The concentration profiles of the investigated pollutants in indoor and urban settings were higher than those in outdoor and rural areas, respectively. The ratios of indoor/outdoor concentrations (I/O) of particulates and gaseous pollutants were characterized in urban and rural preschools. Total dust concentration was highest in urban indoor settings followed by urban outdoor, rural indoor, and rural outdoor locations with an I/O ratio of 1.37 in urban and 1.35 in rural areas. Although I/O ratios of lead were close to 1, lead concentrations were much higher in urban than in rural areas. The I/O ratio of total VOCs was 2.29 in urban and 2.52 in rural areas, with the highest level in urban indoor settings. The I/O ratio of formaldehyde concentrations was higher in rural than in urban areas because the outdoor rural level was much lower than the urban concentration. Since an I/O ratio higher than 1 implies the presence of indoor sources, we concluded that there are many indoor sources in preschools.
Conclusions We confirmed that pollutants in indoor and urban settings were higher than those in outdoor and rural areas, respectively. Preschool children are expected to spend more time inside preschool facilities and therefore to be more exposed to pollutants. As far as we know, preschool IAQ is different from elementary school or higher school IAQ. Also, they are more vulnerable than higher-grade children. We found that the indoor and urban concentration profiles of the studied pollutants in preschools were higher than those in outdoor and rural areas. We believe that our findings may be useful for understanding the potential health effects of exposure and intervention studies in preschools.

Keywords Children · IAQ · I/O ratio · Pollutants · Preschools

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1 Introduction

Children are exposed to a complex mixture of air pollutants that includes particulates, gaseous materials, and microorganisms generated in different microenvironments. Compared to adults, children are more vulnerable to compromised indoor air quality (IAQ) because of their immature immune systems, greater food intake and inhaled breath per unit mass, and rapid growth (United States Environmental Protection Agency (US EPA) 1995). Although no definitive proof exists, it can be assumed that preschool students are more vulnerable to reduced IAQ than elementary or middle school students because their activities in preschool are more diverse, and their immune systems and bodies are less mature. Children attending preschools may be exposed to many pollutants that might increase the risk of allergies and asthma (Hagerhed-Engman et al. 2006; Kim et al. 2007) and may be more susceptible to infectious disease than those cared for at home (Hernandez et al. 1999). Younger children are also less likely than adults to understand and clearly communicate their symptoms (Dulmen 1998; Ruland et al. 2008).

Hazardous indoor agents include respiratory particulates, bioaerosols, and toxic chemicals such as lead, asbestos, aldehydes, and total volatile organic compounds (TVOCs). Indoor exposure can be affected by many factors that influence indoor air pollution levels: activities of building occupants, building materials, furnishings and equipment, outdoor contamination levels, season, temperature, humidity, and ventilation rates (US EPA 1991). Other risk factors include poor ventilation, various indoor materials, or finishings such as carpeting, flexible flooring, paint, plastics, and indoor activities related to these materials (Mendell 2007). All these IAQ issues could be applied to the preschool classroom. Poor IAQ in schools has been linked to reduced school attendance, respiratory infections, asthma, allergies, and compromised performance (Kim et al. 2007; Rosén and Richardson 1999; Daisey et al. 2003; Mendell and Heath 2005; Putus et al. 2004; Meklin et al. 2005; Fanger 2006; Mendell 2007).

The issue of IAQ in preschool is of great importance for younger children. Along with potentially high exposure in preschool, preschool exposure is a major part of total personal exposure among young age groups. Preschool is the first place for social activity and the most important indoor environment for children besides the home. Children aged 3–5 can attend preschool in Korea and this age range will be expanded to 0–5 years in 2008 because of the increasing number of two-income families. Children regularly spend 5–7 h a day in preschool, while some spend an additional 3–4 h. Thus, preschool children spend 5–11 h (21–46%) of their day in preschool. Korea had 37,527 preschools and 1,581,911 preschool students (2.7% of the population) in 2007 (Ministry of Education and Human Resources Development (MEHRD) 2008; Ministry of Gender Equality and Family (MGEF) 2007). The purpose of this study was to compare the indoor and outdoor concentrations of airborne particulates and gaseous materials at preschools in urban and rural locations in Korea. Particulate matter included total suspended dust, respirable dust, lead, and asbestos. Gaseous pollutants included TVOCs, several VOC components, formaldehyde, and carbon dioxide (CO_2).

2 Methods

We measured the indoor air quality of 17 preschools in Korea. One hundred preschools were randomly selected. A letter was sent to the principals of these schools and consent to participate was received from 17 schools. Of these, 13 preschools were located in urban areas and four were in rural areas. On average, four classrooms, representing 80% of the total number of classrooms per school, were randomly selected in each preschool. Out of a total of 91 classrooms in the 17 preschools, 71 were measured. The mean building age was 12.6 (range, 3~50) years. The mean numbers of children, teachers, and classrooms per facility were 115, 5.3, and 5.4, respectively. Children stayed an average of 7.1 h per day, 5 days per week in preschool. However, some children, if both parents worked, spent over 10 h per day and 6 days per week in preschool. Children usually spent most of their time on the chair or floor during class. Physical activity including playing was done about 1 h every day inside of classroom because of no playground. All preschool have a policy that children under five have a nap time in preschool.

Ninety-four percent of classrooms were cleaned daily; 60% were first broom-swept with wet cleaning applied afterward, and 34% were vacuumed. Sixty-five percent of trash cans were emptied daily and 18% were emptied every other day. All facilities were constructed before year 2000. Four preschool facilities in rural area were separate buildings while halves of urban preschool facilities were a part of commercial building. Main construction materials were concrete. Floor was covered with linoleum (82%) or wood (28%). There was no carpet in the classroom. Food for lunch was cooked at the separate kitchen but served in the classroom.

Airborne concentrations of total suspended particulates (TSPs), respirable particulates (RSPs), lead, asbestos, TVOCs and components, formaldehyde, and CO_2 were measured. The samplers for TSPs, RSPs, TVOCs, and formaldehyde were placed in a rack at the center of each classroom. Each rack was about 1 m above the floor and at least 1 m from a wall. For comparison, outdoor air was

sampled at the same time that indoor air was monitored. The outdoor samplers were placed in a secure location sheltered from rain and direct sunlight approximately 1 m above the ground and at least 1 m away from an outside wall. Wipe samples for lead and bulk samples for asbestos were also collected. All the samples were analyzed blind. The sampling period was approximately 6~8 h except for TVOCs, which were sampled for approximately 60–100 min, beginning about 10:00 AM which is 1 h later of morning rush hour; CO_2 and CO were checked every 2 h using a direct-reading instrument (IAQ Calc 8762 meter, TSI, USA). Sampling duration was designed to include cleaning period.

TSPs and RSPs were sampled on PVC filters (pore size 0.45 μm, diameter 37 mm, SKC, USA) at 2.5 L/min based on National Institute for Occupational Safety and Health (NIOSH) methods 0500 and 0600, respectively (NIOSH 1994; 1998). Aluminum cyclones (SKC, USA) were used for preselection of RSPs. Sampling pumps (HFS, Gillian, USA) were calibrated before and after sampling. Filters were equilibrated before and after sampling for at least 24 h at 40~45% relative humidity and 21~23°C, and weighed by a microbalance (ME5-F, Sartorius, USA) with accuracy of 0.001 mg.

Airborne lead was sampled on a mixed cellulose ester filter (pore size 0.8 μm, diameter 37 mm, Millipore, USA) at a flow rate of 4 L/min and analyzed with a Varian GTA-100 model graphite furnace mounted on a Varian SpectrAA-880 model atomic absorption spectrophotometer (Varian, Australia) based on NIOSH method 7105 (NIOSH 1994a). After sampling, the filters were placed in a Teflon vessel and treated with 2 mL of nitric acid (redistilled to 99.999%, Aldrich, USA) and 1 mL of hydrogen peroxide (Aldrich, USA) in a microwave digestion system (MARS, CEM corp., USA) and finally massed up to 10 mL.

To determine surface lead levels on floors, desks, walls, and window sills, wipe samples were collected with wet tissues (SKC 225-2401, SKC, USA) in 31 classrooms of 12 preschools based on NIOSH method 9100 (NIOSH 1994b). We carefully wiped, both vertically and horizontally, the area inside a 15×15 cm plastic template using a wet tissue and three S-strokes per wipe. Pretreatment and analysis was the same as described above for airborne lead. Dust from the air conditioner filter was collected in 12 schools to analyze lead concentrations in filter dust.

Airborne asbestos was sampled on an open-faced mixed cellulose ester filter (37 mm diameter and 0.8 μm pore size, Millipore, USA) at a flowrate of 2.5 L/min based on NIOSH method 7400 (NIOSH 1994c). After sampling, the filters were cleared with acetone vapor, mounted on a glass slide, and fixed with triacetin (Aldrich, USA). Fiber was counted under phase contrast microscopy (BH2, Olympus, USA) with ×400 magnification. Suspected asbestos-containing materials like ceiling boards, tiles, and floor mats were examined with a polarized light microscope (BX51, Olympus, USA) based on NIOSH method 9002 (NIOSH 1994d).

TVOCs were sampled in the morning using a thermal desorption tube (Tenax® TA SS, Supelco, USA) with a flow rate of 0.07~0.1 L/min, and analyzed by gas chromatograph/mass selective detector (GC/MSD) according to US EPA method TO-01 (United States Environmental Protection Agency USEPA 1984). For analysis, a sorbent tube was inserted into a thermal desorption/cryofocusing system (Aerotrap, Tekmar 6000, USA) that is directly connected to the injector part of the GC/MSD (HP 6890 plus/HP 5973, Hewlett-Packard, USA) with a capillary column (HP-5MS, 30 m×0.25 mm, Hewlett Packard). VOCs Mix 2 (Supelco, 4-8167, Bellefonte, PA, USA) which includes 13 aromatic compounds was used to prepare the stock solution. The eight most frequently found aromatic hydrocarbons, i.e., benzene, toluene, ethyl benzene, xylene, styrene, 1,3,5-trimethylbenzene, 1,2,4-trimethylbenzene, and naphthalene, were quantified individually. Toluene was used as a surrogate to calculate the concentration of TVOCs. For xylene, meta-xylene was used as the standard for three isomers (ortho-, meta-, para-).

Formaldehyde, a suspected human carcinogen, was sampled in a 2,4-dinitrophenylhydrazine-coated silica (300/150 mg, 226-119, SKC, USA) tube at 0.1 L/min and analyzed using a gas chromatography-nitrogen phosphorus detector (Agilent Technologies, USA) based on a newly developed method (Jeong and Paik 2005). The limit of detection was 0.06 μg per sample, which corresponded to 1.3 ppb in air, assuming 6 h of sampling at a flow rate of 0.1 L/min.

A Shapiro–Wilk test (W-test) was performed to determine the data distribution at a significance level of 0.05 (Bullock and Ignacio 2006). Distributions were normal or log-normal if untransformed data or log-transformed data sets passed the normal distribution test. Both the arithmetic mean (AM) and geometric mean and their standard deviations were calculated because some data sets showed normal distributions while others were log-normal. For example, both urban indoor and outdoor TSPs showed a log-normal distribution while a normal distribution in rural indoor settings; rural outdoor TSPs exhibited both normal and log-normal distributions. An analysis of variance (ANOVA) or *t* test was performed to compare indoor/outdoor levels between urban and rural areas. For convenience, we assumed a normal distribution to run ANOVAs or *t* tests if some subdatasets were normal and others were log-normal. Wipe sample concentrations were represented as an arithmetic mean. Pearson's correlation coefficient was calculated to assess the relationship between measured compounds. Values below the limit of detection (LOD)

were substituted by the LOD/2 method to estimate means and standard deviations (Hornung and Reed 1990).

3 Results

1. Total suspended particulates and respirable dust

Table 1 summarizes the TSP and RSP concentrations. Indoor TSP concentrations were higher (66.5±35.1 μg/m^3) than outdoor TSP concentrations (48.8±25.0 μg/m^3; p=0.05). Indoor TSP concentrations were higher in urban (71.01±38.4 μg/m^3) than in rural areas (52.2±15.1 μg/m^3; p=0.05). Outdoor TSP concentrations were higher in urban (51.9±25.8 μg/m^3) than in rural areas (38.7±22. 5 μg/m^3), but not significantly (p=0.37). Levels were significantly different with sampling location (ANOVA, p<0.001); the highest concentrations were measured in urban indoor settings, followed in order by rural indoor, urban outdoor, and rural outdoor settings.

The mean concentrations of RSPs in classrooms and outdoors, 29.8±15.4 and 25.9±13.4 μg/m^3, respectively, were not significantly different (p=0.34). Indoor RSP concentrations were similar between urban (29.9±16.9 μg/m^3) and rural (29.5±10.1 μg/m^3) settings (p=0.93). Outdoor RSP concentrations were higher in urban (28.2±14.4 μg/m^3) than in rural (18.5±8.3 μg/m^3) areas, but not significantly (p=0.22). Levels were significantly different with sampling location (ANOVA, p<0.001); the highest concentrations were measured in urban indoor settings, followed in order by rural indoor, urban outdoor, and rural outdoor settings (Table 1).

2. Airborne lead and lead in wipe samples

Both indoor and outdoor airborne lead concentrations are shown in Fig. 1. Lead concentrations were higher in urban (42.8±28.4 ng/m^3 indoors, 39.4±23.9 ng/m^3 outdoors) than in rural areas (14.2±9.8 ng/m^3 indoors, 12.6±7.0 ng/m^3 outdoors). There are significant differences between urban indoor and rural indoor concentrations (p<0.001), between urban outdoor and rural outdoor concentrations (p=0.05). However, indoor levels did not differ from outdoor levels in urban (p=0.69) and rural settings (p=0.76; Fig. 1).

Lead concentrations in wipe samples are summarized in Table 2. Lead concentrations in urban wipe samples were higher (2.89±4.15 μg/100 cm^2) than those in rural wipe samples (1.62±3.00 μg/100 cm^2), but not significantly (p=0.18). Only floor lead concentrations were significantly higher in urban (1.13±0.79 μg/100 cm^2) than in rural classrooms (0.24±0.21 μg/100 cm^2; p=0.002); no significant differences between urban and rural areas were found in concentrations from walls, desks, or other samples (p=0.20, p=0.24, and p=0.37, respectively). None of the floor or window sill levels exceeded US EPA guidelines for floor (4.3 μg/100 cm^2) or window sill lead concentrations (26.9 μg/100 cm^2). We also measured lead concentrations in 12 bulk dust samples from the classroom air conditioner filters (data not shown); mean lead concentrations in filter dust from nine urban classrooms (170.63±66.77 μg/g) was higher than that in three rural classrooms (68.3±13.12 μg/g; p=0.03; Table 2).

3. Airborne fiber and asbestos-containing materials

Airborne fiber concentrations are shown in Fig. 2. Eleven out of 54 samples (20.4%) from urban classrooms and one out of 17 rural indoor samples (5.9%) exceeded the US EPA guidelines of 0.01 fibers/cubic centimeter (f/cc), whereas all outdoor samples were below or near the detection limit of 0.001 f/cc. Urban indoor fiber concentrations were higher (0.006±0.006 f/cc) than rural indoor concentrations (0.003±0.003 f/cc; p=0.02).

Table 1 Total suspended particulate and respirable dust concentrations

		Particulate	No. of samples	Airborne concentration, μg/m^3			I/O ratio
				AM(SD)	GM (GSD)	Range	
Urban	Indoor*	Total	54	71.01 (38.36)	62.07 (1.70)	15.04–217.33	1.37
		Respirable	54	29.87 (16.86)	25.65 (1.76)	8.09–80.63	1.06
	Outdoor*	Total	13	51.89 (25.75)	45.56 (1.74)	18.12–95.10	
		Respirable	13	28.15 (14.10)	24.64 (1.75)	9.72–51.73	
Rural	Indoor*	Total	17	52.17 (15.07)	49.49 (1.44)	16.92–69.92	1.35
		Respirable	17	29.54 (10.07)	26.85 (1.71)	4.66–41.54	1.60
	Outdoor*	Total	4	38.69 (22.49)	33.34 (1.92)	16.63–59.88	
		Respirable	4	18.46 (8.33)	16.36 (1.89)	6.39–25.50	

Level of detection (LOD): 1.0 μg/m^3

AM arithmetic mean, *SD* standard deviation, *GM* geometric mean, *GSD* geometric standard deviation

* p<0.001 for both total and respirable particulate with location

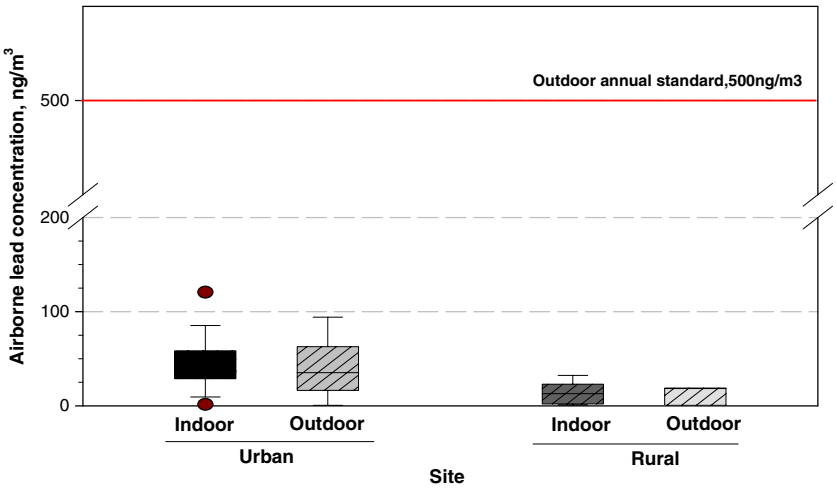

Fig. 1 Airborne lead concentrations by sampling site. Whisker cap stands for 5/95 percentile and dots stand for outliers

Among 20 suspicious asbestos-containing materials (ACM), five bulk samples (25%), all of the ceiling boards, contained 1~3% chrysotile. There were no significant differences in airborne concentrations between the schools that had ACM and those that did not (0.006±0.005 vs. 0.003±0.003 f/cc; p=0.20; Fig. 2).

4. Formaldehyde concentrations

Formaldehyde concentrations are shown in Table 3. Indoor formaldehyde concentrations of urban preschools (36.3±31.3 ppb) were higher than urban outdoor concentrations (21.5±29.4 ppb), but the difference was not significant (p=0.12). Indoor formaldehyde concentrations in rural preschools (32.1±20.9 ppb) were significantly higher than outdoor concentrations (6.2±2.2 ppb; p=0.03). Indoor levels did not differ between urban and rural areas (p=0.61). Formaldehyde in rural areas had the highest I/O ratio (5.18), because rural outdoor concentrations of formaldehyde are much lower than indoor concentrations, as shown in Table 3.

5. Concentrations of TVOCs and eight individual aromatic compounds

TVOC concentrations are summarized in Table 4. The concentrations differed significantly among sampling sites (p=0.004). Urban indoor TVOC concentrations were highest (591.2±419.4 μg/m^3), followed by rural indoor (351.0±303.3 μg/m^3), urban outdoor (258.3±37.4 μg/m^3), and rural outdoor concentrations (118.2±97.7 μg/m^3; Table 4).

As shown in Fig. 3, the eight most common aromatic hydrocarbons, benzene, toluene, ethyl benzene, xylene, styrene, 1,3,5-trimethylbenzene, 1,2,4-trimethylbenzene, and naphthalene, comprised 36.9% of the TVOCs in urban indoor settings, 49.7% in urban outdoor settings, 41.8% in rural indoor areas, and 35.4% in rural outdoor areas. The mean contribution of these eight aromatic hydrocarbons to TVOC was 39.7% (Figs. 3 and 4).

The concentrations of the eight quantified aromatic compounds are shown in Fig. 4. Among these compounds, benzene, toluene, ethyl benzene, and xylene (BTEX)

Table 2 Lead concentrations in wipe samples

	Sampling site	No. of samples	Concentration, μg/100cm^2	
			AM (SD)	Range
Urban classrooms	Desk surface	12	3.80 (7.26)	0.11–25.62
	Wall surface	17	3.39 (3.58)	0.05–12.38
	Floor surface	23	1.13 (0.79)	0.12–2.75
	Other[a]	8	5.49 (3.37)	0.05–8.92
	Subtotal	60	2.89 (4.15)	0.05–25.62
Rural classrooms	Desk surface	9	1.93 (3.60)	0.05–8.29
	Wall surface	4	0.94 (1.29)	0.08–2.84
	Floor surface	9	0.24 (0.21)	0.02–0.67
	Other[a]	2	7.82 (0.85)	7.21–8.42
	Subtotal	24	1.62 (3.00)	0.05–8.42

[a] Other includes dust on window sills, storage cabinets, toy surfaces, wood blocks, and the surface of air blowers.

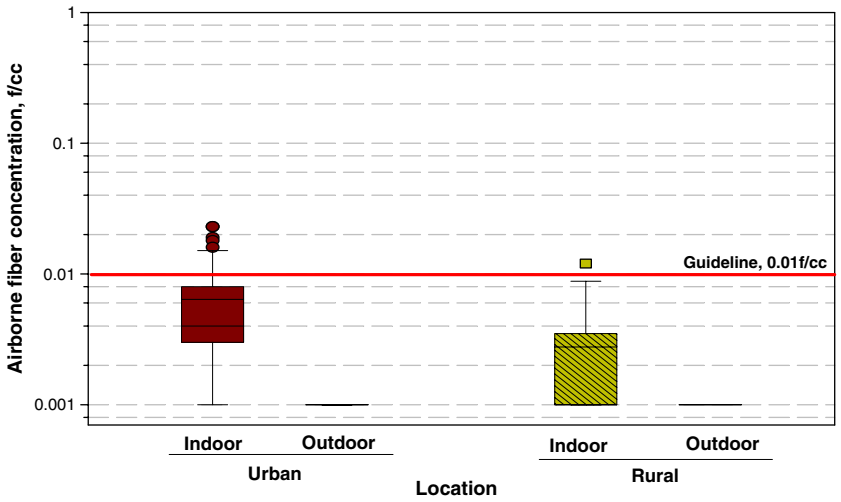

Fig. 2 Airborne fiber concentrations by sampling site. Whisker cap stands for 5/95 percentile and dots stand for outliers

concentrations and their percentages were higher in urban than in rural areas, and in indoor air than in outdoor air. The concentration and percentage of BTEX was greatest in urban indoor air and lowest in rural outdoor air. BTEX comprised 25.4% of TVOCs and 86.9% of quantified VOCs in urban indoor settings, and 23.6% and 85.4% in urban outdoor air, respectively. It comprised 20.1% of TVOCs and 81.8% of quantified VOCs in rural indoor settings and 24.1% and 76.4% in rural outdoor air, respectively. The mean percentage of BTEX was 24.5% of TVOCs and 86.2% of quantified VOCs.

Levels of benzene, a human carcinogen, are summarized in Table 5. Benzene concentrations in urban samples (8.96± 7.24 μg/m^3) were higher than those in rural samples (5.18± 3.20 μg/m^3; p=0.02), while no significant difference was seen between indoor and outdoor samples in urban (p=0.52) or rural areas (p=0.57; Table 5).

6. Carbon dioxide and carbon monoxide concentrations

CO_2 and CO concentrations are summarized in Table 6. CO_2 concentrations differed with sampling location ($p<$ 0.001) and were highest in urban indoor settings (847.1± 328.3 ppm), followed by rural indoor (607.8±101.8 ppm), urban outdoor (478.2±36.3 ppm), and rural outdoor settings (454.8±18.3 ppm). Urban indoor and rural indoor CO_2 concentrations differed (p=0.005), but urban outdoor and rural outdoor levels did not (p=0.24).

Concentrations and standard deviations of CO_2 concentrations were also greater in indoor classroom air than in outdoor air because CO_2 concentrations were affected by the number of students and space confinement of the classroom. CO concentration was below 1.6 ppm, although it varied with sampling site (p=0.008). Of the measured values, 16% was below the detection limit and 40% was below 0.5 ppm. A possible CO source in indoor air was the preschool kitchenette stove; the outdoor source was likely traffic. Urban indoor and rural indoor CO concentrations differed, as did urban outdoor and rural outdoor CO concentrations (p=0.02 and 0.08, respectively; Table 6).

7. Correlation between measured hazardous agents

Pearson correlation coefficients of measured pollutants are summarized in Table 7. Many individual VOCs had correlation coefficients greater than 0.5, and total dust and respirable dust had a correlation coefficients of 0.60. Among the individual VOCs, toluene was correlated with ethylbenzene (r=0.74), xylene (r=0.73), styrene (r=0.56), quantified VOCs (r=0.98), and TVOCs (r=0.84). Ethyl-

Table 3 Formaldehyde concentrations in preschools

		No. of samples	Airborne formaldehyde concentration, ppb			National and International standards exceeding percentage, %		I/O ratio	*P* value
			AM (SD)	GM (GSD)	Range	Korea	WHO		
Urban	Indoor	54	36.3 (31.3)	25.5 (2.4)	4.6–126.9	5.6	13.0	1.69	0.10
	Outdoor	13	21.5 (26.9)	13.0 (2.7)	3.2–100.9	7.7	7.7		
Rural	Indoor	17	32.1 (20.9)	26.4 (1.9)	7.1–91.2	0.0	5.9	5.18	
	Outdoor	4	6.2 (2.2)	5.9 (1.5)	3.3–8.0	0.0	0.0		

Indoor air quality standard: Korea 100 ppb, World Health Organization (WHO) 80 ppb

Table 4 Concentrations of total volatile organic compounds (TVOC) in preschool facilities

		No. of Samples	Concentration, μg/m^3			Percentage exceeding guidelines[a]	I/O ratio	*p* Value
			AM (SD)	GM (GSD)	Range			
Urban	Indoor	54	591.2 (419.4)	432.8 (2.4)	73.3–1927.7	57.4	2.29	0.005
	Outdoor	13	258.3 (370.4)	153.4 (2.5)	58.6–1322.9	15.4		
Rural	Indoor	17	351.0 (303.3)	233.0 (2.7)	61.7–1103.1	41.2	2.52	
	Outdoor	4	139.4 (97.7)	118.2 (1.9)	60.3–281.2	0.0		

[a] Indoor air quality standard of Ministry of Environment and Ministry of Education in Korea: 400 μg/m^3

benzene was correlated with xylene (r=0.87), 1,3,5-trimethylbenzene (r=0.55), 1,2,4-trimethylbenzene (r=0.59), quantified VOCs (r=0.84), and TVOCs (r=0.79). No correlation coefficients over 0.50 were found between particulates and gaseous materials, except between asbestos and CO_2 (r=0.56; Table 7).

4 Discussion

We investigated the concentrations of airborne particulates and gaseous materials in preschools, where the microenvironment and occupant activities are expected differ from those in the home.

Sampling was done during late June and early September which represents typical summer weather condition. The mean temperature and humidity in indoors during sampling period were not significantly different from outdoors both in the morning (25.7±1.8 vs. 25.7±2.3°C, p=0.98; 73.2±8.8 vs. 76.1±13.3%, p=0.32, respectively), and in the afternoon (26.9±2.0 vs. 28.1±3.0°C, p=0.08; 70.0±13.5 vs. 66.9±17.4%, p=0.48, respectively). Each preschool was surveyed within a day. Sampling was done during normal schedule on class so that all activities such as sitting on the chair, playing, eating, cleaning, as well as napping under age 5 were included. Average number of windows was 3.6 per classroom and all classrooms were naturally ventilated during sampling. Most Korean school depends on natural ventilation rather than mechanical ventilation (Kim et al. 2007)

The differences of measured pollutant concentrations between indoor and outdoor might be well explained by indoor/outdoor (I/O) ratios (Tables 1, 2, 3, 4, 5 and 6).

The I/O relationships of pollutant concentrations are important because indoor levels can be influenced by both outdoor levels and indoor sources such as construction materials and human activities. The levels of some contaminants may be significantly higher in indoors than outdoors (Godish 1989). The I/O ratios are summarized in Fig. 5. We found that all pollutant concentrations, except benzene in rural areas, were higher in indoor air than in outdoor air, with I/O ratios ranging from 0.83 to 5.18. The mean I/O ratio of all pollutants was 1.96 (SD 0.76), indicating that the indoor level of pollutants measured in this study was almost two times the outdoor level.

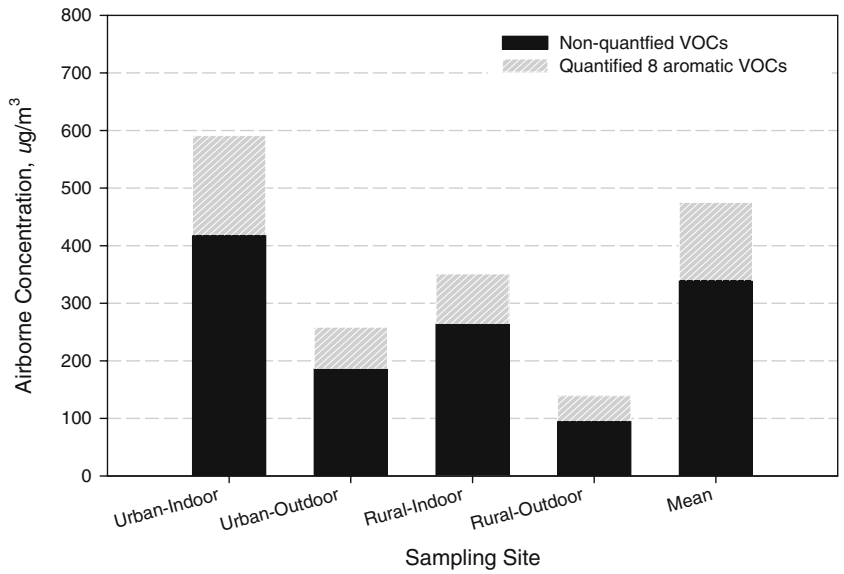

Fig. 3 The proportions of quantified eight aromatic VOCs in TVOCs

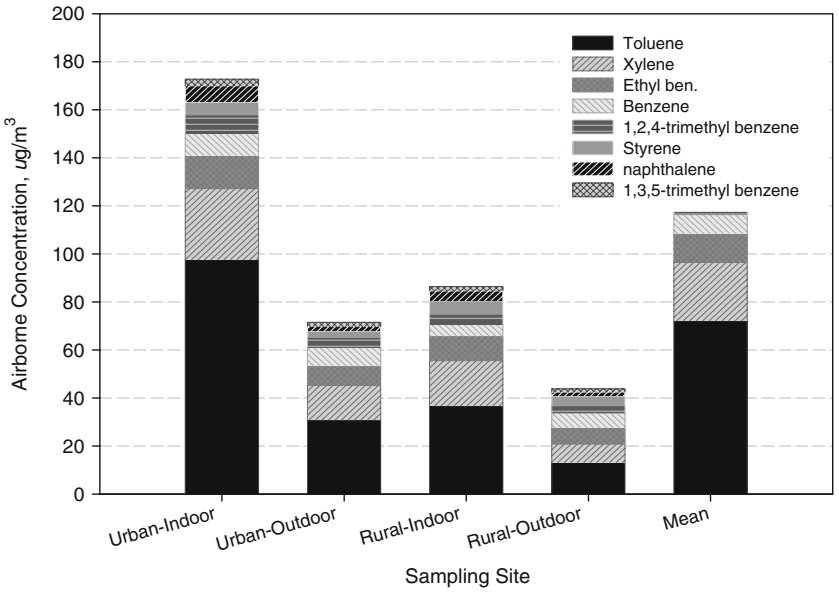

Fig. 4 Concentrations of benzene, toluene, ethyl benzene, xylene, styrene, 1,3,5-trimethylbenzene, 1,2,4-trimethylbenzene, and naphthalene by sampling site

Indoor urban and rural respirable dust concentrations were similar, as shown Table 1, while outdoor levels in rural areas were much lower than those in urban areas. The reason why indoor RSP concentrations between urban and rural preschools are similar is not clear. One reason might be that two preschools (ten classrooms) in rural area used kerosene oil for intermittent hot water supply. Mean indoor RSP concentration in these preschools was 36.4±3.5 μg/m^3 while it was 19.7±7.7 μg/m^3 in other rural indoor air ($p<$ 0.01). Many classroom floors (60%) have been swept by broom which might cause more particulate to suspend than vacuum or wet cleaning.

The I/O ratio for rural areas was thus higher than that for urban areas. This may be due to low sources of respirable dust in rural outdoor air, whereas vehicle exhaust may be a major source of respirable dust in urban areas. Even though the I/O ratios for lead were similar in urban and rural areas, indoor and outdoor urban lead concentrations were much higher than those in rural areas, as shown in Fig. 1.

Most VOC components had I/O ratios above 1, in part due to the presence of many VOC-emitting materials in preschool buildings, including painted walls, coloring books, dolls, adhesives, and dyes. In Korea, almost all walls in preschool classrooms are painted with fairy tale characters. All rural pollutant levels, except that of benzene, were higher indoors than outside, indicating that children are more exposed when they are in the classroom. The mean I/O ratio of gaseous material (2.13) was higher than that of particulates (1.27), but the difference was not significant (p=0.08; Fig. 5).

Several studies have reported I/O ratios in schools and homes, but there have been no consistent results because there are many possible contamination sources and influencing factors. Cavallo et al. (1993) reported that average NO_2, PM_{10}, and asbestos dust concentrations were roughly the same indoors and outdoors, whereas the I/O ratios for TOVCs and formaldehyde varied from 1 to 15 and 3 to 5, respectively. Blondeau et al. (2005) found that the I/O ratio of airborne particles was greater than 1 and emphasized the strong influence of human occupancy on indoor airborne particulate concentrations. We can assume that resuspension of deposited particulates in preschools is much higher than that in elementary or middle schools because of the greater activity levels of preschool children. Fromme et al. (2005) reported that RSP concentration in nursery schools was about two times higher than that in non-smoker homes in Germany and discussed that resuspension of particles during permanent movement in the classroom might be one reason. Monn et al. (1997) reported that human activity was an important factor in high indoor levels in homes. Large

Table 5 Benzene concentrations in preschools

		No. of samples	Concentration, μg/m^3			I/O ratio	p Value
			AM (SD)	GM (GSD)	Range		
Urban	Indoor	54	9.24 (7.16)	6.55 (2.45)	2–33.18	1.18	0.13
	Outdoor	13	7.78 (7.70)	5.71 (2.16)	2–30.36		
Rural	Indoor	17	4.98 (3.46)	3.95 (2.02)	2–12.71	0.83	
	Outdoor	4	6.03 (1.78)	5.81 (1.38)	3.78–7.65		

Level of detection (LOD) of benzene; 2 μg/m^3, UK guideline 16.25 μg/m^3 =5 ppb.

Table 6 Carbon dioxide and carbon monoxide concentrations

		No. of samples	CO_2 concentration, ppm		I/O Ratio	CO concentration, ppm		I/O ratio
			AM (SD)	Range		AM (SD)	Range	
Urban	Indoor	54	847.1 (328.3)	443.8–1593.3	1.77	0.7 (0.4)	<0.1–1.6	1.17
	Outdoor	13	478.2 (36.3)	437.0–542.5		0.6 (0.5)	<0.1–1.5	
Rural	Indoor	17	607.8 (101.8)	427.3–870.3	1.34	0.4 (0.4)	<0.1–1.3	4.00
	Outdoor	4	454.8 (18.3)	438.0–472.0		0.1 (0.1)	<0.1–0.2	

particle I/O ratios were reported to be higher during children's activity time than during unoccupied periods.

Guo et al. (2003) consider an I/O ratio greater than 1 to be an indicator of additional indoor sources as well as outdoor sources. They reported that outdoor vehicle and industrial emissions as well as indoor sources contributed to overall indoor levels. We conclude that many indoor pollutant sources exist in preschools. There are usually more chemical-emitting materials in preschool classrooms than in elementary school classrooms in Korea. In addition, we found that most classroom walls were painted every year during the vacation season (summer or winter), which could be a possible VOC source.

No generalized patterns were found between measured pollutants, although many correlation coefficients were statistically significant, as shown in Table 7. The weak relationships among particulates or between particulates and gaseous materials suggest that the pollutant sources may be diverse. Some pollutants may come from outdoor sources, some from indoors, and others from both outdoor and indoor sources. Ozone, though we did not measure it, can be used as the indirect indicative of air filtration or absence of indoor source (Stranger et al. 2007; Blondeau et al. 2005).

The respirable fraction of total suspended particulates was 49.7±19.4%. The total suspended particulate concentration was higher in urban than in rural indoor classrooms (p=0.05), while no difference was seen in respirable dust between urban and rural indoor settings (p=0.93). RSP, which is defined to have a median cut point of 3.5 μm, had a correlation coefficient of 0.60 with TSP and occupied nearly 50% of TSP. The remaining 50% of TSP consisted of relative large particle, larger than median cut point of 3.5 μm, which might be resuspended from the settled coarse particles by human activities such as cleaning or children activities on floor.

In this study, the airborne asbestos concentration was higher in urban than in rural areas. This pattern has been reported previously in Europe and America (Howitt et al. 1993; Burdett et al. 1994), and may in part be due to the asbestos-containing brake linings found in vehicles and auto repair shops (Lim et al. 2004).

We analyzed airborne asbestos fibers under phase contrast microscopy, which presented difficulties in precisely distinguishing between asbestos and non-asbestos fibers when analyzing very thin fibers (i.e., 0.2 μm diameter; Howitt et al. 1993). This method is likely to lead to overestimations if non-asbestos fibers are present. Lim et al. (2004) reported that non-asbestos fiber concentrations were much higher than asbestos fiber concentrations in non-occupational environments based on transmission electron microscopy and energy dispersive X-ray analysis. In their study, airborne asbestos and non-asbestos fiber concentrations were 0.0006 and 0.067 and 0.0003 and 0.017 f/L in urban and rural areas, respectively. Predominant non-asbestos fiber presence in the environmental air might explain why airborne fiber concentration at the classroom with ACM was not significantly higher than those in classroom without ACM in this study. Another reason might be that ACM presence was not significantly correlated with the asbestos concentration in air (Corn et al. 1991).

Non-asbestos fiber, which is dominant in residential areas, can mask real asbestos fiber concentrations. This may partially explain why airborne asbestos concentrations in preschools where ACM was detected are not high. Another limitation with regard to ACM is that we subjectively collected suspected ACM.

Urban and rural indoor formaldehyde concentrations were very similar even though outdoor levels differed between urban and rural areas. This means that the major potential formaldehyde sources are inside the classrooms. Other study reported that outdoor contribution to indoor formaldehyde concentration was low (Zhang et al. 2006). Various teaching materials, dolls, synthetic wood materials, and carpets may be sources of formaldehyde. Urban outdoor formaldehyde concentrations in this study seem high because one outdoor sample taken very close to a garment factory was 110.9 ppb. The second highest concentration was 47.8 ppb in which we could not find any possible source. Without these two data, the AM was 11.94 ppb which is similar or within the range reported in France and Mexico (Marchand et al. 2006; Baéz et al. 2003).

There were many possible sources of VOCs, including formaldehyde, inside preschools. Examples include paint, lacquers, paint stripers, cleaning supplies, pesticides, building materials, new furnishings, spray repellents,

Table 7 Pearson correlation coefficients for the concentrations of measured particulate and gaseous pollutants

	Total dust	Respirable dust	Lead	Asbestos	CO2	CO	HCHO	Benzene	Toluene	EEthyl benzene.	Xylene	Styrene	1,3,5-trimethyl benzene	1,2,4-trimethyl benzene	Naphth-alene	8 Quantified VOCs	TVOCs
Total dust	1.00																
Respirable dust	0.60*	1.00															
Lead	0.19*	0.24*	1.00														
Asbestos	0.40*	0.09	0.12	1.00													
CO2	0.31*	0.03	0.27*	0.56*	1.00												
CO	0.24*	0.10	0.12	0.18*	0.40*	1.00											
HCHO	−0.04	−0.18*	0.26*	0.24*	0.48*	0.29*	1.00										
Benzene	0.22*	−0.02	0.03	0.12	−0.19*	−0.06	−0.15	1.00									
Toluene	0.31*	0.04	0.08	0.38*	0.34*	0.02	0.03	0.42*	1.00								
Ethyl benzene	0.36*	−0.04	−0.02	0.42*	0.39*	0.29*	0.11	0.43*	0.74*	1.00							
Xylene	0.26*	−0.03	−0.03	0.36*	0.22*	0.31*	0.13	0.40*	0.73*	0.87*	1.00						
Styrene	0.26*	0.15	−0.01	0.32*	0.34*	0.03	0.01	−0.01	0.56*	0.38*	0.28*	1.00					
1,3,5-trimethyl benzene	0.22*	−0.19*	0.12	0.41*	0.48*	0.36*	0.45*	0.17*	0.34*	0.55*	0.48*	0.14	1.00				
1,2,4-trimethyl benzene	0.21*	−0.16*	0.20*	0.43*	0.51*	0.44*	0.45*	0.09	0.44*	0.59*	0.58*	0.29*	0.80*	1.00			
Naphthalene	0.18*	−0.01	0.09	0.36*	0.46*	0.23*	0.04	−0.23*	0.48*	0.40*	0.35*	0.52*	0.20*	0.47*	1.00		
8 Quantified VOCs	0.33*	0.01	0.07	0.42*	0.35*	0.12	0.07	0.46*	0.98*	0.84*	0.84*	0.54*	0.44*	0.55*	0.50 *	1.00	
TVOCs	0.25*	−0.12	−0.03	0.34*	0.22*	0.12	0.00	0.53*	0.84*	0.79*	0.79*	0.40*	0.36*	0.53*	0.47*	0.89*	1.00

*$p<0.05$

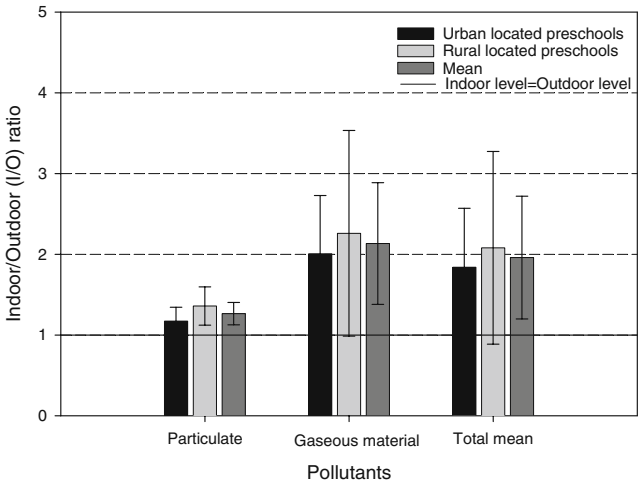

Fig. 5 Indoor/Outdoor (I/O) ratios of particulate and gaseous materials

waxes, adhesives, glues, and compressed wood furnishings. It is important to increase ventilation when using products that emit VOCs (Yoon et al. 2004). Previous studies have found that outdoor sources such as petroleum hydrocarbons and vehicle exhaust may contribute significantly to indoor pollution (Keady and Mainquist 2000; Saarelaa et al. 2003). Several efforts to identify and control emissions from these possible sources have been undertaken (Yang et al. 2004) and various models may help to predict possible sources (Guo 2002; Choi 1997).

CO_2 concentrations are often used as a surrogate for the rate of outdoor air supply, or IAQ index. An indoor IAQ index of 1,000 ppm is generally regarded as indicative of adequate ventilation and good IAQ. In this study, CO_2 concentrations in 16 of 54 (29.6%) urban classrooms exceeded 1,000 ppm, whereas concentrations in all rural classrooms were below 1,000 ppm, as shown in Table 6. The Spearman correlation coefficient between the number of classroom occupants and CO_2 concentration was 0.32 in this study, indicating that other factors such as ventilation and infiltration may affect CO_2 concentration. Relative high concentration of CO_2 in outdoor in this study and other study implies that there are many anthropogenic emissions like vehicles, fossil fuel, and human activities(Kim et al. 2007; George et al. 2007; Idso et al. 2001; Gratani and Varone 2005)

CO_2 concentrations below 1,000 ppm do not guarantee adequate IAQ. For example, 41% of TVOC concentrations in rural areas exceeded the Korean IAQ standard, as shown in Table 4, even though CO_2 concentrations in these areas were all below 1,000 ppm. Other researchers have also mentioned that the ventilation rate required to maintain CO_2 concentrations below 1,000 ppm is not always adequate for the removal of air pollutants from indoor sources (Apte et al. 2000; Daisey et al. 2003).

It should be emphasized that not only are children exposed to higher levels of contaminants indoors than outdoors, but they are indoors for a much longer period of time (up to 90% of the day; Godish 1989). During the survey, the preschool teachers completed open questionnaires. Most were concerned about the health effects of poor IAQ on children and themselves. The most frequent symptoms listed on the questionnaires were related to respiratory problems such as flu, bronchitis, rhinitis, tonsillitis, irritation of throat, nose, and epidemic conjunctivitis. All of these symptoms are known to be related to IAQ (Meininghaus et al. 2003). Some published data on the level of indoor and outdoor pollutants in Korea were similar to this study (Baek et al. 1997; Jo et al. 2003) while others are somewhat higher (Bae et al. 2004; Son et al. 2003) depending on the sampling protocol, local area and year.

There could be seasonal variations on measured pollutant levels. IAQ in winter season was reported to be aggravated more than in summer season because of many factors like limited natural ventilation, more fossil fuel use, emission from heating system (Fromme et al. 2007). This study was undertaken during the late spring and summer when natural ventilation through windows occurs. We expect that IAQ deteriorates during the winter in most Korean preschools where natural ventilation predominates, because windows are usually closed during this season. Adequate ventilation was reported to be a major factor in improving IAQ (Daisey et al. 2003; Zuraimi et al. 2007). This study did not investigate some factors such as geographical and metrological factors (e.g., wind direction and speed) which were known to be important to explain outdoor pollutant levels (Demirci and Cuhadaroglu 2000)

The reason why so many preschools (83 out of 100) refused to participate was unclear. But some principals complained that these types of survey often lead to enforced regulation later. There could be some selection bias because we evaluated the preschools which agree to participate in this study. But as far as we know, there was nothing particular in these preschools in terms of environmental policy, location, construction year, and construction material as well as size. Further research in regarding the source assortment investigation of both indoor and outdoor pollutants would be of great help to the public and policy makers to implement effective control measure.

Based on the fact that children in preschool have more airway infection symptoms than those in home care in Sweden (Hagerhed-Engman et al. 2006), IAQ in preschool should be improved. In a developing country such as Korea, the number of two-income families is increasing rapidly and results in children spending more time in preschool (Korean National Statistical Office (KNSO) 2006). As described in the Section 1, the preschool age in Korea was expanded in 2008 from 3–5 to 0–5, and the

government provides monetary incentives to preschools to remain open after their regular session in order to accommodate these children. Thus, preschool children are expected to spend more time inside preschool facilities and therefore to be more exposed to pollutants.

5 Conclusion

We found that indoor and urban concentration profiles of the studied pollutants were higher than those in outdoor and rural areas. Concentrations of particulates such as total dust, respirable dust, and asbestos were highest in urban preschool indoor air, followed by rural preschool indoor, urban outdoor, and rural outdoor air, in that order. But both indoor and outdoor urban lead levels were higher than those in rural preschools, while indoor lead concentrations were much higher than outdoor lead concentrations. Indoor concentrations of gaseous material such as formaldehyde, TVOCs, and CO were higher in both urban and rural classrooms than outdoors. All pollutant concentrations except that of benzene were higher indoors than outdoors, with a mean I/O ratio of 1.96 (SD 0.76). Since an I/O ratio greater than 1 implies the presence of indoor sources, we conclude that there are many indoor sources of pollutants as well as outdoor air in preschools. High concentration profiles in urban indoor and outdoor implies that natural ventilation can aggregate the indoor air quality in preschool classrooms in urban area.

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