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Research Article

Exposure Assessments for Children in Homes and in Daycare Centers to NO_2, PMs and Black Carbon

Jae Young Lee, Changhyeok Kim[1)], Jongbum Kim[1)], Sung Hee Ryu[2)], Gwi-Nam Bae[1),*]

Institute of Health and Environment and Graduate School of Public Health, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, Republic of Korea
[1)]Center for Environment, Health and Welfare Research, Korea Institute of Science and Technology (KIST), Hwarangno 14-gil 5, Seongbuk-gu, Seoul 02792, Republic of Korea
[2)]Research Management Team, R&D Center for Green Patrol Technologies, 120 Neungdong-ro, Gwangjin-gu, Seoul, Republic of Korea

***Corresponding author.**
Tel: +82-2-958-5676
E-mail: gnbae@kist.re.kr

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ABSTRACT Indoor air quality was investigated in homes and daycares located in areas with heavy traffic in Seoul, South Korea from November 2013 to January 2014. Indoor and outdoor air quality measurements were collected for 48 hours in four children's homes and daycare centers. The I/O ratio (Indoor to outdoor ratio) for each major air pollutant (NO_2, black carbon, PM_{10}, and $PM_{2.5}$) was calculated, and NO_2 and PM_{10} concentration profiles were analyzed based on indoor activity diaries recorded during the 48 hours. Most I/O ratios for NO_2, black carbon, PM_{10}, and $PM_{2.5}$ at daycare centers were less than one. At homes, I/O ratios for black carbon, PM_{10}, and $PM_{2.5}$ were less than one; however, most I/O ratios for NO_2 were greater than one due to the usage of gas stoves. The children's exposure to indoor air pollutants was calculated using a time-weighted average exposure method, and the daily intake level for each pollutant was determined.

KEY WORDS Indoor air quality, Air pollutants, Children, I/O ratio, Exposure assessment

1. INTRODUCTION

Air pollutants are known to influence allergic diseases, respiratory illnesses, and cardiovascular diseases (Zanobetti *et al.*, 2011). Traffic related emissions are one of the major outdoor sources of pollutants that affect human health. Thus, it is important to investigate indoor and outdoor air quality in areas with heavy traffic.

Among traffic related air pollutants, NO_2, black carbon, and particulate matter have been frequently studied due to their impacts on human health (Buonanno *et al.*, 2013; Habil *et al.*, 2013; Massey *et al.*, 2013, 2012, 2009; Tian *et al.*, 2012; Pénard-Morand *et al.*, 2010; Lee *et al.*, 2008; Martuzevicius *et al.*, 2008; Hwang *et al.*, 2005; Janssen *et al.*, 2003; Brauer *et al.*, 2002; Fisher *et al.*, 2000; Studnicka *et al.*, 1997; van Vliet *et al.*, 1997). NO_2 is the most effective indicator of proximity to traffic. The exposure to NO_2 has received a lot of attention due to its toxicity in humans. Previous studies demonstrated how indoor and outdoor NO_2 concentrations change and affect personal exposure (Kornartit *et al.*, 2010). In a study conducted by Vanderstraeten *et al.* (2011), black carbon was a more effective indicator of local traffic than particulate matter, and showed a strong correlation with NO. Janssen *et al.* (2011) also reported that black carbon is an important indicator of air quality with regard to health risks. For particulate matter, previous studies reported that PM_{10} and $PM_{2.5}$ are capable of carrying allergens and polycyclic aromatic hydrocarbons (PAHs), and can penetrate deep lung tissue (Krugly *et al.*, 2014; Liu *et al.*, 2004; Ormstad, 2000). Therefore, particulate matter can cause adverse respiratory effects (Happo *et al.*, 2013). Liu *et al.* (2004) and Hassanvand *et al.* (2014) reported that particulates in indoor air primarily originate from outdoor sources, such as heavy traffic and construction activities; thus, particulate concentrations can also be used to elucidate the relationship between outdoor and indoor air quality. Based on previous studies, this study focused on indoor and outdoor levels of NO_2, black carbon, PM_{10}, and $PM_{2.5}$.

Because children are more susceptible to the adverse health effects of air pollution than adults, studies concerning indoor air quality in daycares and schools have been conducted. Krugly *et al.* (2014) investigated indoor and outdoor concentrations of PAHs in primary schools during winter, and showed that indoor PAHs originated from outdoor sources. Pegas *et al.* (2012) reported that outdoor NO_2 concentrations were higher than those indoors, while indoor PM_{10} and volatile organic compound (VOC) concentrations were lower than those outdoors on weekdays in both suburban and city center elementary schools in Aveiro, Portugal. Tippayawong *et al.* (2009) showed that in school classrooms with natural ventilation, the presence of indoor particulates was attributed to penetration of outdoor particles. Habil and Taneja (2011) also reported that particulate matter concentrations inside of classrooms were higher than those outside of classrooms in India. Zuraimi and Tham (2008) investigated the indoor air quality of childcare centers in Singapore, and determined that outdoor concentrations of $PM_{2.5}$, floor type, toy type, presence of curtains, renovation, and cleaning frequency were directly related to indoor $PM_{2.5}$ levels. Demirel *et al.* (2014) showed that personal, indoor, and outdoor concentrations of NO_2 and benzene, toluene, ethylbenzene, and xylene (BTEX) were higher in primary schools located in urban areas with heavier traffic than those in suburban areas with less traffic in Turkey. Janssen *et al.* (2001) also reported that concentrations of $PM_{2.5}$, NO_2, and benzene inside and outside of schools in the Netherlands increased as traffic around the school increased.

A few studies examined indoor air quality in homes and daycare centers simultaneously. Roda *et al.* (2011) measured endotoxin and NO_2 concentrations in child daycare centers and homes in Paris, and found that the concentrations were higher in daycare centers than in homes, while VOC concentrations were higher in homes than in daycare centers. Langer *et al.* (2010) measured phthalates and PAHs in Danish daycare centers and in homes. They reported that phthalate concentrations were higher in daycare centers, and PAH concentrations were similar in homes and daycare centers. In addition, Wichmann *et al.* (2010) measured indoor $PM_{2.5}$, soot, and NO_2 concentrations in homes, preschools, and schools in Sweden. They found that NO_2 concentrations were highest in preschools, while soot and $PM_{2.5}$ concentrations were highest in homes. However, there is still

Table 1. Child, home, and daycare center information.

Child	Gender	Age (years)	Degree of symptoms	Daycare		Home		
				# of Classroom	Area (m^2/child)	Type of home	Area (m^2)	Cooking type and smoker
A	Female	3	Moderate	5	0.28	2-story residence (1st floor)*	90	Gas stove; non-smoking
B	Female	4	Severe to moderate	13	0.29	High-rise apartment (25th floor)*	84	Gas stove; non-smoking
C	Male	2	Moderate to weak	6	0.15	High-rise apartment (18th floor)*	109	Gas stove; non-smoking
D	Male	2	Moderate to weak	4	0.31	High-rise apartment (19th floor)*	115	Gas stove; non-smoking

*Parenthesis indicates the actual floor where the child is living.

a dearth of studies measuring indoor air quality of daycare centers and homes simultaneously, and estimating the total exposure levels for children.

This study examined indoor air quality of homes and daycare centers where four children with atopic dermatitis were living and attending. Based on the outdoor and indoor air pollutant concentrations, the relationship between the indoor and outdoor environment at homes and daycares located in traffic-concentrated areas in Seoul were investigated. Lastly, a time-weighted averaging method was used to assess the exposure for each child, and daily intake levels of pollutants were calculated.

2. METHODS

2.1 Subject Information

Four children with atopic dermatitis were screened and tested by dermatologists at the Samsung Medical Center in Seoul, Korea. The children lived in homes and attended daycare centers near main roads with heavy traffic in Seoul. Children were selected based on availability for measuring indoor air quality both in their homes and in the daycare centers they attended. Table 1 displays general information about the children, their homes, and the daycare centers. The severity of atopic dermatitis symptoms was divided into three categories: weak, moderate, and severe. As shown in Table 1, three of the four children lived in high-rise apartments, which are the most common type of accommodation in Seoul. The locations of the homes and daycare centers were marked on a map of Seoul as shown in Fig. S1. The locations of air quality monitoring stations (AQMS) in Seoul are also identified in Fig. S1.

2.2 Measurements of NO_2, Black Carbon, and Particulate Matter (PM_{10} and $PM_{2.5}$)

Forty-eight-hour measurements were conducted at each home and daycare center from November 12, 2013 to January 23, 2014. The measurement schedule is detailed in Table 2. For each period, the indoor and outdoor measurements were taken simultaneously. At the high-rise apartments, the measurement devices for

Table 2. Meteorological parameters at each site.

Child	Site	Date	Average temp (°C)	Precipitation (mm)	Relative humidity (%)	Average wind speed (m/s)
A	Daycare	Nov. 12~14, 2013	3.4	–	36.1	2.7
			4.8	–	43.5	1.7
			6.7	1	55.1	1.9
	Home	Nov. 19~21, 2013	1.1	–	5.9	4.4
			1.5	–	38.8	3.2
			2.6	1.6	48.8	2.4
B	Daycare	Nov. 26~28 2013	2.1	1.5	60.9	2.5
			0.0	1.7	66.8	3.4
			−3.8	–	48.9	2.9
	Home	Dec. 3~5, 2013	6.7	–	62.6	1.6
			5.5	–	72.8	1.8
			5.5	–	73.4	2.4
C	Daycare	Dec. 16~18, 2013	−3.6	–	52.6	1.8
			−0.3	–	52.4	1.5
			2.2	0.8	65.1	2.4
	Home*	Jan. 6~7, 2014	0.8	–	50.4	1.6
			3.0	–	56.0	1.7
D	Daycare	Jan. 14~16, 2014	−4.3	–	33.8	2.2
			−2.9	–	42.0	1.7
			0.1	–	59.9	1.9
	Home	Jan. 21~23, 2014	−5.5	0.7	62.6	2.4
			−3.9	–	60.0	1.6
			−0.8	–	65.6	2.1

*Due to an undisclosed issue, measurements were collected for 24 hours.

outdoor air quality were located on a front balcony, which was assumed to be the nearest place exposed to outdoor air. At the 2-story residence, they were located in the front yard. Indoor air quality measurement devices were placed in the middle of the living room.

To measure NO_2 concentrations, an NO-NO_2-NO_x analyzer (Thermo 42i, USA) was used inside, and an NH_3 analyzer (Teledyne Technologies 201E, USA) was used outside. The analyzer monitored NO, NO_2, and NO_x concentrations in real time with a recording interval of 1 minute. An aethalometer (Magee Scientific AE51, USA) and a dust monitor (Grimm Technologies 1.109, Germany) were used to measure black carbon concentrations and particulate concentrations, respectively. These monitors also reported the real-time concentrations every minute. All measurement systems were placed on a tray at 1 m above the floor.

Meteorological parameters, such as temperature, precipitation, relative humidity, and wind velocity, were obtained from the Korea Meteorological Administration for each day that measurements were taken. They are summarized in Table 2.

2.3 Time-weighted Average Exposure

To determine the child's exposure over two days, we used a time-weighted average micro-environmental exposure method (Eq. (1)) (Kornartit *et al.*, 2010). The child's home, daycare, and outside of these areas were used as the microenvironments; the time the child spent in each microenvironment was used to calculate the exposure level for two days. We assumed that two consecutive days were sufficient to represent the typical pollutant concentration trends at the home and daycare.

$$E_i = \sum_{j}^{J} C_j t_{ij} \qquad (1)$$

where E_i = time-weighted average exposure for person i over the specified time period; C_j = pollutant concentration in microenvironment j; t_{ij} = time that person i spends in microenvironment j; J = total number of microenvironments.

On weekdays, children were generally at the daycare from 9 am to 5 pm, and spent the rest of the time at home. We assumed that all of the children followed this time schedule, and calculated the NO_2, black carbon, and particulate matter concentrations that the children could potentially be exposed to for 48 hours at daycare centers and at homes. The time for outdoor activities, such as commute and play time, was not considered in this study.

2.4 Daily Intake

In this study, we calculated each child's daily intake of NO_2, black carbon, PM_{10}, and $PM_{2.5}$ using the following equation.

$$DI = \frac{C_{air} \cdot IR \cdot ET}{BW} \qquad (2)$$

where C_{air} = contaminant concentration in air (μg/m^3); IR = inhalation rate (m^3/h), for a 1-3-year-old child IR = 7.6 m^3/h; ET = exposure time (h/d); BW = body weight (kg), for a 1-3-year-old child BW = 19 kg. The inhalation rate and body weight for a 1-3-year-old child were obtained from Guo and Kannan (2011) and Zhang *et al.* (2014).

3. RESULTS AND DISCUSSION

3.1 Relationship between Indoor and Outdoor Air Pollution Levels at Daycare Centers and Homes

As seen in Table 3, most I/O ratios of indoor pollutants in daycare centers were less than one, with the exception of NO_2 concentrations in child D's daycare center. In child D's daycare center, the indoor concentration of NO_2 was higher than the average outdoor NO_2 concentration. For the children's homes shown in Table 4, I/O ratios for black carbon, PM_{10}, and $PM_{2.5}$ were less than one, while I/O ratios for NO_2 were greater than one, with the exception of child B's home. This indicates that there was an indoor source of NO_2 in the homes. The use of gas stoves and candle burning are potential indoor sources of NO_2.

Fig. 1 and Fig. 2 show the indoor and outdoor NO_2 concentrations that were measured at daycares and homes, along with the hourly NO_2 concentrations reported from urban AQMS. To analyze the relationship between indoor activities and indoor air quality, we consulted the indoor activity diaries recorded by the children's parents, and denoted the indoor activities carried out during the measurement period in the figures. The indoor peak concentrations of NO_2 generally occur when gas stoves are on, and when doors are open

Table 3. Pollutant concentrations and I/O ratios at daycare centers.

Child	NO_2 (ppb)			Black carbon (μg/m^3)			PM_{10} (μg/m^3)			$PM_{2.5}$ (μg/m^3)		
	Indoor	Outdoor	I/O	Indoor	Outdoor	I/O	Indoor	Outdoor	I/O	Indoor	Outdoor	I/O
A	36.11±9.20	40.38±11.77	0.89	3.11±1.74	4.39±2.65	0.71	42.12±24.64	54.27±20.82	0.78	24.61±9.13	36.24±13.89	0.68
B	21.11±6.12	21.27±7.42	0.99	0.97±0.33	1.97±1.97	0.49	21.42±20.67	–*	–*	9.64±4.19	36.24±13.89	0.27
C[1]	37.59±5.78	44.33±9.20	0.85	2.74±1.24	4.78±2.22	0.57	33.21±15.90	72.05±22.83	0.46	24.95±8.50	64.54±20.85	0.39
D	54.58±20.88	42.02±10.03	1.30	1.89±0.80	3.12±1.80	0.61	30.93±14.55	58.53±31.54	0.53	25.67±11.00	50.50±27.21	0.51

*Measurements were not available due to equipment malfunction.

Table 4. Pollutant concentrations and I/O ratios at homes.

Child	NO_2 (ppb)			Black carbon (μg/m^3)			PM_{10} (μg/m^3)			$PM_{2.5}$ (μg/m^3)		
	Indoor	Outdoor	I/O	Indoor	Outdoor	I/O	Indoor	Outdoor	I/O	Indoor	Outdoor	I/O
A	23.52±11.11	17.92±5.52	1.31	0.80±0.31	1.35±0.75	0.59	17.35±24.24	26.14±5.75	0.66	9.08±7.68	17.82±4.84	0.51
B	22.51±5.65	47.50±7.03	0.47	2.67±1.12	6.24±3.29	0.43	39.16±8.11	77.52±15.63	0.51	34.62±5.79	71.33±15.36	0.49
C[1]	61.40±21.72	52.87±8.25	1.16	3.83±1.39	6.38±2.11	0.6	44.88±12.60	102.95±9.06	0.44	38.42±8.99	86.49±6.22	0.44
D	73.72±30.98	69.05±58.13	1.07	2.10±1.12	3.30±2.01	0.64	36.17±16.04	62.28±21.11	0.58	32.15±12.98	61.20±23.70	0.53

[1]Twenty-four-hour measurements taken due to an undisclosed issue.

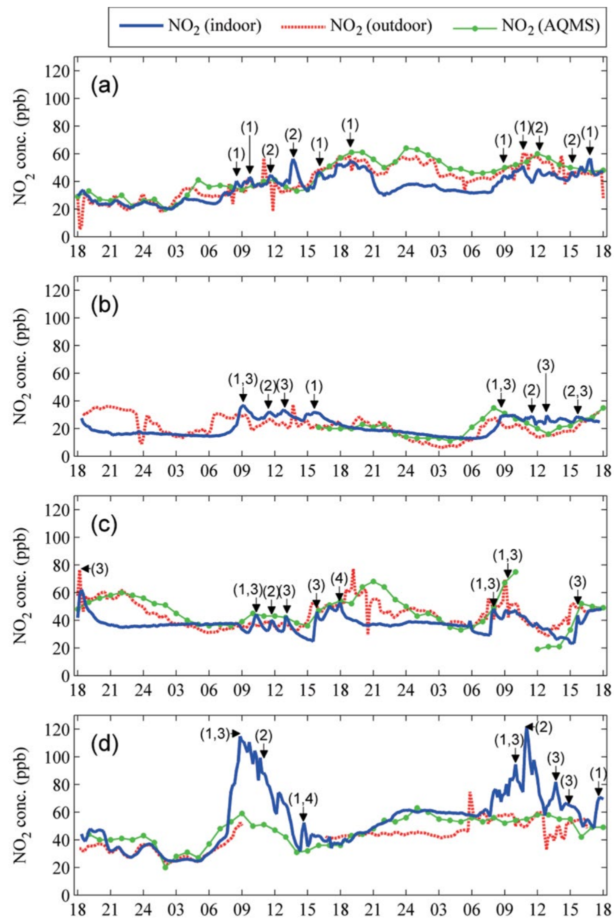

Fig. 1. Profile of NO_2 concentrations over 48 hours at each daycare center. Missing data points are due to equipment malfunction. (1), (2), (3), and (4) represent major indoor activities such as opening/closing the main door for entering or leaving, cooking for lunch or snacks, opening/closing windows for ventilation, and vacuum cleaning, respectively.

for ventilation. In South Korea, the usage of gas stoves is much more common than that of electric stoves. Combustion from cooking processes is one of the dominant causes of increased NO_2 concentrations indoors. Garrett *et al.* (1998), Smith *et al.* (2000), and Belanger *et al.* (2006) reported that NO_2 exposure due to the usage of gas stoves was positively associated with respiratory symptoms and asthma.

In Fig. 1(d), based on the indoor activity diaries, the peak concentrations of NO_2 at daycares occurred when windows were opened and closed for ventilation. Since the classroom where the indoor measurement systems were located was near a loading zone for trucks, the increase of NO_2 concentrations when the windows opened could have been caused by exhaust gases from

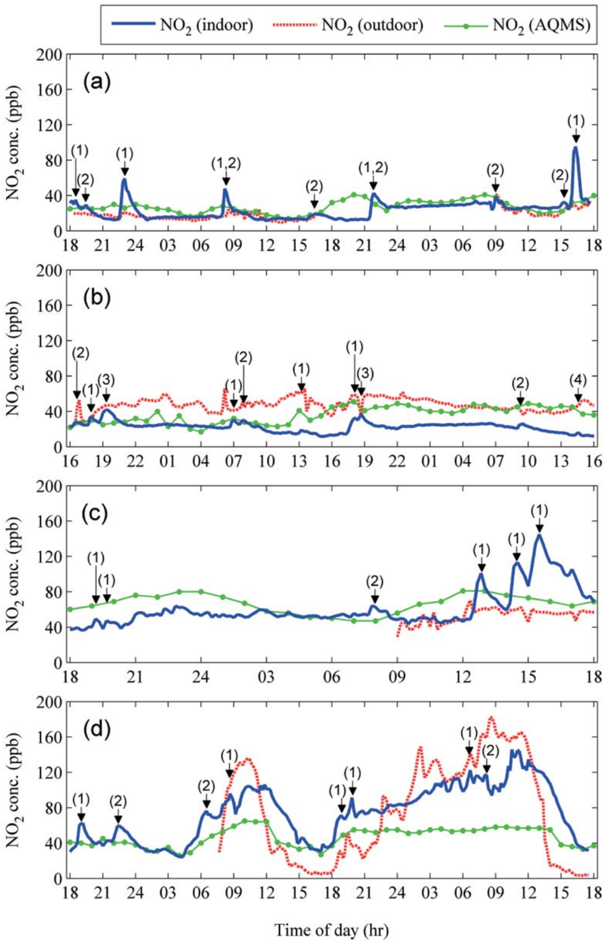

Fig. 2. Profile of NO_2 concentrations over 48 hours at each child's home. Blue solid line indicates indoor NO_2 concentrations and red dotted line indicates outdoor NO_2 concentrations. Green line with circles indicates NO_2 concentrations reported from urban AQMS. Missing data points are due to equipment malfunction. (1), (2), (3), and (4) represent major indoor activities such as cooking (gas stove), opening/closing the main door, incense burning, and vacuum cleaning, respectively.

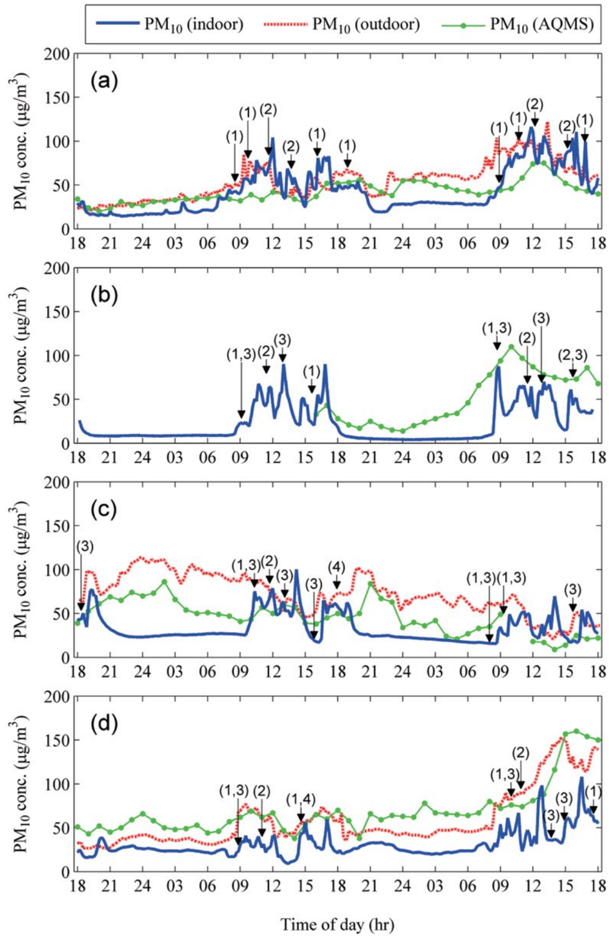

Fig. 3. Profile of PM_{10} concentrations over 48 hours at each child's daycare. Blue solid line indicates indoor PM_{10} concentrations and red dotted line indicates outdoor PM_{10} concentrations. Green line with circles indicates PM_{10} concentrations reported from regional AQMS. Missing data points are due to equipment malfunction. (1), (2), (3), and (4) represent major indoor activities such as opening/closing the main door for entering or leaving, cooking for lunch or snacks, opening/closing windows for ventilation, and vacuum cleaning, respectively.

trucks. Generally, the loading zones were full of trucks during the morning (approximately 9 am to 12 pm), and the indoor NO_2 concentrations in the classroom increased more at that time. Outdoor measurement systems were located on the opposite side of the daycare from the loading zone due to limitations of the measurement system installation; thus, our measured outdoor NO_2 concentrations could not represent the degree of NO_2 pollution at the loading zone. In this case, even though the I/O ratio was greater than one, we cannot specify that outdoor sources affected the elevated indoor NO_2 concentrations.

In Fig. 1 and Fig. 2, most trends of outdoor NO_2 concentrations closely followed that of the AQMS NO_2 concentrations, with the exception of child D's home. At child D's home, outdoor NO_2 concentrations measured on the balcony were higher than those measured at the nearest AQMS. Possible reasons for this phenomenon may be the traffic characteristics and wind direction near the residence.

To observe the effects of indoor activities on particulate matter concentrations, Fig. 3 and Fig. 4 illustrate the indoor and outdoor PM_{10} concentrations at daycare centers and homes. Concentration data exported from the AQMS are also shown in these figures. At daycare centers, PM_{10} concentrations were only elevated during the opening hours (approximately 9 am to 7-8 pm). This might have been due to the children's indoor activities, which could keep the particles suspended in the air. However, at homes, several indoor activities, such as cooking, opening main doors, and cleaning, caused elevated indoor PM_{10} concentrations. Interestingly, unlike the NO_2 concentration profile at homes and daycares, the indoor PM_{10} concentrations were lower than the outdoor concentrations and the AQMS data, despite the occurrence of indoor activities.

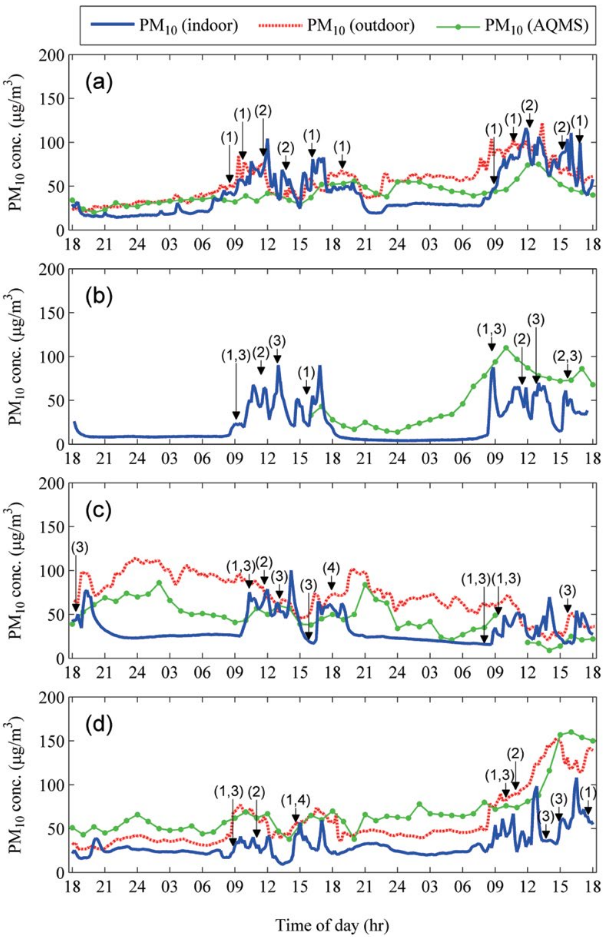

Fig. 4. Profile of PM_{10} concentrations over 48 hours at each child's home. Blue solid line indicates indoor PM_{10} concentrations and red dotted line indicates outdoor PM_{10} concentrations. Green line with circles indicates PM_{10} concentrations reported from regional AQMS. Missing data points are due to equipment malfunction. (1), (2), (3), and (4) represent major indoor activities such as cooking (gas stove), opening/closing the main door, incense burning, and vacuum cleaning, respectively.

3.2 Time-weighted Average Exposure for Children with Atopic Dermatitis

As shown in Table 5, time-weighted average exposures of NO_2, black carbon, PM_{10}, and $PM_{2.5}$ for each child were calculated. The average concentrations at home are displayed from 5 pm to 9 am, while the concentrations at daycares are displayed from 9 am to 5 pm. Note that at child C's home, air pollutant concentrations were measured for only 24 hours, and the data was used twice to calculate the time-weighted average exposures for 48 hours; therefore, the total calculated exposure concentrations may be overestimated or underestimated. Child D had the highest estimated NO_2 exposure among all of the children, followed by child C, child A, and child B. Child C had the highest estimated black carbon exposure, followed by child B, child A, and child D. Child C also had the highest estimated PM_{10} exposure, followed child B, child D, and child A. Child B had the highest estimated exposure to $PM_{2.5}$, followed by child C, child D, and child A.

Based on the estimated exposure levels in Table 5, we calculated each child's daily intake of NO_2, black carbon, PM_{10}, and $PM_{2.5}$ and summarized in Table 6 (Demirel *et al.*, 2014; Krol *et al.*, 2014; Zhang *et al.*, 2014). Based on the exposure assessments, the severity of atopic dermatitis symptoms in the four children (Table 1) was not proportional to the estimated exposure levels. This may be because there are many other factors that determine the severity of atopic dermatitis. Such factors may include age, sex, and parental history. In addition, there were limitations in this exposure study. First, the pollutant con-

Table 5. Time-weighted average exposure for each child.

Child	NO_2 (ppb)			Black carbon (μg/m³)			PM_{10} (μg/m³)			$PM_{2.5}$ (μg/m³)		
	Home	Daycare	Total	Home	Daycare	Total	Home	Daycare	Total	Home	Daycare	Total
A	23.31	43.14	29.92	0.73	4.15	1.87	18.77	70.07	35.87	9.35	31.55	16.75
B	24.15	28.23	25.51	3.04	1.06	2.38	39.3	44.01	40.87	34.55	28.07	32.39
C*	54.21	35.79	48.07	3.21	2.55	2.99	40.96	42.1	41.34	35.38	23.41	31.39
D	66.99	68.88	67.62	1.46	2.54	1.82	37.04	40.34	38.14	32.2	28.03	30.81

*For C's home, measurements were collected for 24 hours due to an undisclosed issue.

Table 6. Daily pollutant intake for each child.

Pollutant (μg/(kg·d))	Child A	Child B	Child C	Child D
NO_2	548.6	467.8	881.4	1239.9
Black carbon	18.0	22.8	28.7	17.5
PM_{10}	344.4	392.4	396.9	366.1
$PM_{2.5}$	160.8	310.9	301.3	295.8

centrations were measured for only 48 hours. For a more reliable assessment of the exposure level, concentrations should be measured for a longer period. Second, the air quality measurements in daycare centers and homes took place on different days because of the limited amount of equipment. As a result, the exposure could have been affected by the daily fluctuation in air pollution levels. In order to accurately compare the exposure levels of children, the measurements should be taken simultaneously.

4. DISCUSSION

In this study, indoor and outdoor levels of NO_2, PMs and black carbon were measured at four children's homes and daycare centers. Based on the measurement data, we calculated time-weighted average exposures and daily intakes of air pollutants for four children. In addition, we calculated the I/O ratio for each air pollutant and analyzed NO_2 and PM_{10} concentration profiles based on indoor activity diaries. According to the result, the I/O ratios of NO_2, $PM_{2.5}$, PM_{10} and black carbon were typically less than one. This result indicates that those indoor air pollutants were originated from outdoor sources, and thus it is better to keep doors and windows closed for indoor air quality. However, the I/O ratios of NO_2 at children's homes were typically more than one due to indoor sources such as gas stoves. To reduce the indoor NO_2 levels, it is better to use electric stoves instead of gas stoves. In addition, a proper ventilation is necessary during cooking and vacuum cleaning.

This study has a few limitations. First, this study only aimed to measure indoor and outdoor air concentrations for the atopic dermatitis patients. Thus, it is not possible to compare the environments for children with and without atopic dermatitis. In addition, the measurements were conducted during fall and winter. Therefore, it is not possible to examine the seasonal variations in the air pollutant concentrations. Lastly, this study only measured homes and daycare centers of four children. The exposure characteristics for those children may not represent the exposure for children in Seoul.

5. CONCLUSIONS

In this paper, indoor air qualities of homes and daycare centers were measured, and the exposure assessment of children with atopic dermatitis was studied. The major findings of this work can be summarized as follows:

- At daycare centers and homes located in traffic-concentrated areas, I/O ratios for black carbon, PM_{10}, and $PM_{2.5}$ were all less than one. However, I/O ratios for NO_2 at homes were mostly greater than one due to the usage of gas stoves for cooking.
- According to the real-time air quality measurements conducted at homes and daycare centers, indoor activities such as cooking and door opening contribute to the indoor pollutant concentrations.
- Children's exposures were estimated using the time-weighted average exposure method, and the daily intake of pollutants was calculated. We found that the exposure amount was not proportional to the severity of atopic dermatitis symptoms. This may be due to other confounding factors such as age, sex, and parental history.

In this study, an exposure assessment was conducted by measuring the indoor air quality in microenvironments (homes and daycare centers), and applying the time-weighted average exposure method. This process can help to accurately estimate the pollutant exposure of children, and to further analyze the association between exposure and diseases in children.

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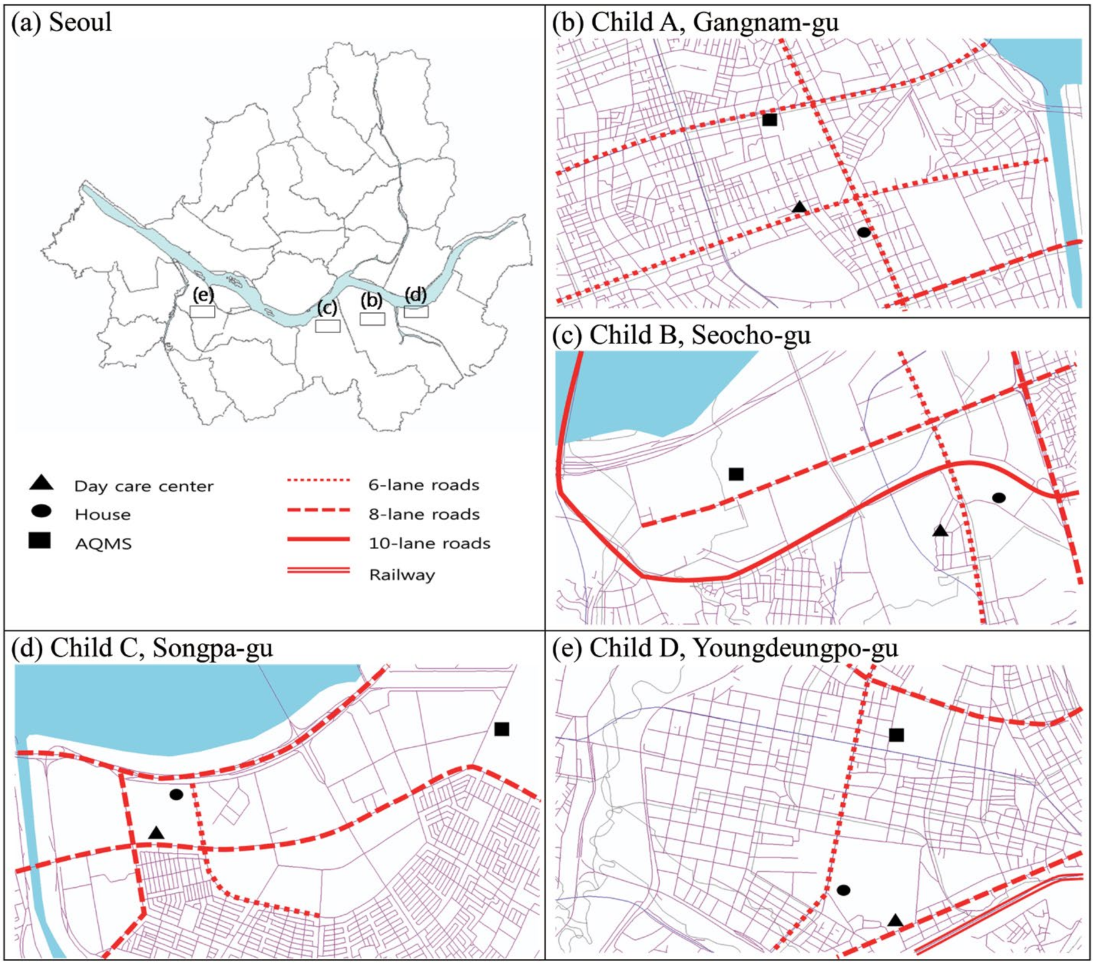

Fig. S1. The locations of target homes, daycare centers and AQMSs respectively marked using circles, triangles and squares. (a) A map of Seoul is shown along with the four boxes each of which indicates the area where each child is living. (b)-(e) Enlarged maps of the boxed area shown in (a), where Child A-D are living, respectively (scale of map - 1:11399). Gangnam-go, Seocho-gu, Songpa-gu, and Youngdeungpo-gu are the name of the borough the child A-D are living, respectively. Red lines indicate the nearby major roads and railroad.