Investigation of IAQ in Mechanically Ventilated Kindergartens and Elementary Schools in Korea

Hyeun Jun Moon, Seung Ho Ryu, and Jeong Tai Kim

***Abstract*—This study investigates the indoor pollutant levels in school buildings according to the operation of mechanical ventilation system. Three classrooms at two different elementary schools and four classrooms at two children's day care center in Korea were chosen for investigation of indoor air quality with mechanical ventilation systems. Measurements were conducted for particulate matter, formaldehyde, total volatile organic compounds, carbon monoxide, carbon dioxide, nitrogen dioxide, ozone, radon, and total bacteria counts. Differences in indoor pollutants concentrations with and without operation of ventilation systems in each classroom were analyzed. The results show that operation of ventilation systems could decrease the levels of indoor pollutants in the classrooms, especially showing the reduction of HCHO concentrations by 14.9–62.3%.**

***Index Terms*—Day care centers, elementary schools, indoor air quality, ventilation system.**

I. Introduction

Indoor air quality is an increasing public health concern due to the amount of time spent indoors. (70–90%) [1]. Poor indoor air quality can cause many adverse health effects such as respiratory symptoms and asthma [2], [3]. School children spend about 6–8h per weekday in classrooms, which is the second most time-spent indoor environment after homes [4]. Moreover children are more susceptible to indoor pollutants, including airborne particles, volatile organic compounds since their organs are in developing stage and they breathe more air relative to their body size than adults [5], [6]. Thus, good indoor air quality should be maintained in schools for children's health. Several studies have reported that the indoor air problems can increase the chance of long-term and short-term health problems for students and teachers in terms of comfort and productivity [7], [8].

Several studies have been conducted during the past decades to investigate the indoor air quality in school buildings such as children's day care center and elementary schools. Roda *et al*. [9] have investigated the indoor environment in 28 Paris child day care centers. They reported that the child day care centers indoor/outdoor ratio for most chemical pollutants was above unity except for NO_2, the levels for NO_2 being significantly higher than those measured in homes. Zuraimi and Tham [10] have investigated indoor pollutants concentrations in child care centers and evaluated their determinants involving representative samples in Singapore. This study reported that indoor CO_2 concentration levels were lower in Singapore child care centers when compared to child care centers from other cold climate countries due to the higher ventilation rate of child care centers in Singapore. St-Jean *et al*. [11] have assessed indoor air quality in 21 day care centers in Montréal, Canada and determined association between building characteristics and IAQ. They reported that over 85% of the day care centers had a mean CO_2 concentration higher than 1000 ppm. The mean formaldehyde concentration was 22.9 μg/m^3. They also reported that the presence of a mechanical ventilation system and a large surface of play are per child were significantly associated with lower CO_2 levels. Chitra and Nagendra [4] have investigated indoor air quality parameters in a naturally ventilated school building located near an urban roadway in India. This study reported that the mean value of indoor PM_{10}, $PM_{2.5}$, PM_1 and CO concentrations were found to be 149 ± 69, 61 ± 29, 43 ± 24, 0.10 ± 0.18 and 95 ± 61, 32 ± 16, 18 ± 9 μg/m^3, 0.11 ± 0.14 ppm, respectively for winter and summer seasons. Norback *et al*. [12] have studied the relationship between VOCs, respirable dust, and personal factors to prevalence and incidence of sick building syndrome in six primary schools. They reported that the average CO_2 concentrations in all sites were greater than 800 ppm and indicated inadequate ventilation. Lee and Chang [13] investigated IAQ of five classrooms in Hong Kong. This study showed that the average respirable suspended particulate matter (RSPM) concentrations were higher than the Hong Kong air quality objective (annual average, 55 μg/m^3) and the maximum indoor PM_{10} level exceeded 1000 μg/m^3. Yang *et al*. [14] characterized the concentrations of different indoor air pollutants within Korean schools and to compare their indoor levels within schools according to the age of school buildings. The I/O ratio for HCHO was 6.32 during the autumn, and the indoor HCHO concentrations (mean=0.16 ppm) in schools constructed within 1 year were significantly higher than the Korean Indoor Air Standard, indicating that schools have indoor sources of HCHO. FROMME *et al*. [15] evaluated indoor air quality in 64 schools in the city of Munich and a neighboring district outside the city boundary. They reported that the median indoor CO_2 concentration in a classroom was 1603 ppm in winter and 405 ppm in summer. Median $PM_{2.5}$ concentrations of 19.8 μg/m^3 and PM_{10} concentrations of 91.5 μg/m^3 were observed during winter period. In summer, a reduced PM concentrations were reported (median $PM_{2.5}$=12.7 μg/m^3, median PM_{10}=64.9 μg/m^3).

One of the strategies to maintain good indoor air quality in buildings is to use mechanical ventilation systems. Adequate ventilation systems should not only provide thermal comfort but also distribute fresh air to occupants and remove

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pollutants. This study aims to investigate the indoor pollutant levels in school classrooms according to the operation of mechanical ventilation system. Differences in indoor pollutants concentrations with and without operation of mechanical ventilation systems in each classroom are analyzed. Investigation of indoor air quality in classrooms helps us to characterize pollutant levels and effects of ventilation systems.

II. Methods

A. Field Measurements Design

A field study was conducted in seven classrooms at two different kindergartens and two elementary schools located in Korea. Detailed description of the selected day care centers and elementary schools is shown in Table I. Mechanical ventilation systems were installed in all selected classrooms, as shown Fig. 1. The measurements were taken in two different ventilation operation modes (before and after operation of ventilation system), with the aim of investing the effect of ventilation system on the indoor air pollutants concentrations.

TABLE I: Description of the Selected School Buildings and Classrooms

Target buildings		Selected classrooms	Construction years
Day care center	DCC-A	2 (DCC-A1, DCC-A2)	11 years
	DCC-B	2 (DCC-B1, DCC-B2)	3 years
Elementary school	ES-A	1 (ES-A1)	7 years
	ES-B	2 (ES-B1, ES-B2)	2 years

Fig. 1. Ventilation systems in selected classrooms.

B. Measurement of the Indoor air Pollutants

One-day indoor air quality investigations at each school were performed. The indoor pollutants were monitored for particle matter (PM_{10}), Carbon monoxide (CO), Carbon dioxide (CO_2), Nitrogen dioxide (NO_2), Ozone (O_3), Radon (Rn), total bacteria count, Formaldehyde (HCHO) and Volatile Organic Compounds (VOCs). Indoor air temperature and relative humidity were also monitored during the field measurement. Samplings were performed in the middle of classroom near the breathing zone of children.

Measurement methods for each indoor pollutant were referred to the Indoor air quality control in public use facilities, an act provided by the Ministry of Environment, Korea [16]. PM_{10} samples were collected on a pall flex membrane filter using mini volume air sampler. CO and CO_2 were measured by means of a non-dispersive infrared (NDIR) analyzer (CO Analyzer 300E and CD 98 Plus). NO_2 was measured by means of a chemiluminescence analyzer (NO_2 Analyzer 200E). O_3 was measured by means of an ultraviolet photometric analyzer (O_3 Analyzer 400E). Radon was measured based on continuous radon monitoring method using the RAD7. The sampling method employed for the total bacteria count was a MAS impactor, which used the centrifugal impaction principle. HCHO was collected by pulling air through a 2,4-DNPH cartridge (MP-∑100). The DNPH-HCHO derivative eluted with acetonitrile was determined by a reverse-phase high-performance liquid chromatography (HPLC). TVOCs' samples were collected using Tenax-TA tubes, which were analyzed by gas chromatography with flame ionization detection and a modified thermal desorption cold trap injector.

III. Results and Discussions

A. Indoor Air Quality in the Selected Elementary Schools According to Ventilation Mode

A field study in elementary school was conducted in three class rooms (ES-A1, ES-B1 and ES-B2) at two different elementary schools (ES-A and ES-B). Indoor air pollutants levels in ES-A1 were monitored while the classroom was unoccupied. The measurements were conducted before and after the operation of ventilation system while an air-conditioner system was not operated. Table II shows the level of indoor air pollutants measured at ES-A1 according to operation of mechanical ventilation system.

TABLE II: Concentrations of Indoor Air Pollutants Measured in ES-A1

Pollutants	Standard*	Before the operation of vent.	After the operation of vent.
T (°C)	–	23.2	22.5
RH (%)	–	34.5	31.1
PM_{10} (μg/m^3)	100	33.3	16.7
CO (ppm)	10	0.03	0.03
CO_2 (ppm)	1000	519	467
NO_2 (ppb)	50	26.5	23.7
O_3 (ppb)	60	N.D.**	N.D.
Rn (pCi/l)	4.0	0.5	0.3
TBC (CFU/m^3)	800	150	40
HCHO (μg/m^3)	100	52.8	19.9
TVOC (μg/m^3)	400	189.4	101.4

* Korean Indoor Air Standard [16]

** Not detected

Indoor air pollutants levels in ES-B1 and ES-B2 were monitored while the classrooms were unoccupied. The measurements in ES-B1 and ES-B2 were conducted before and after the operation of ventilation system while air-conditioner systems were turned on. In case of the elementary school B, measurement of the indoor pollutants were focused on particle matter (PM_{10}), carbon dioxide (CO_2), formaldehyde (HCHO) and volatile organic compounds (VOCs) excluding other pollutants since other pollutants were measured significantly lower from pre-test. Table III–IV show the level of indoor air pollutants measured at elementary school B according to operation of mechanical ventilation system.

B. Indoor Air Quality in the Selected Day Care Centers According to Ventilation Mode

A field study in day care center was conducted in four class rooms (DCC-A1, DCC-A2, DCC-B1 and DCC-B2) at two different day care centers (DCC-A and DCC-B). In case of

day care centers, measurements of the indoor pollutants were focused on particle matter (PM_{10}), carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde (HCHO) and volatile Organic Compounds (VOCs). Table V–VIII show the level of indoor air pollutants measured at each day care center according to operation of mechanical ventilation system.

TABLE III: CONCENTRATIONS OF INDOOR AIR POLLUTANTS MEASURED IN ES-B1

Pollutants	Standard*	Before the operation of vent.	After the operation of vent.
T (°C)	–	21.7	21.8
RH (%)	–	30.9	26.3
PM_{10} (μg/m^3)	100	75.7	65.2
CO_2 (ppm)	1000	470	350
HCHO (μg/m^3)	100	43.0	34.0
TVOC (μg/m^3)	400	360.0	205.5

TABLE IV: CONCENTRATIONS OF INDOOR AIR POLLUTANTS MEASURED IN ES-B2

Pollutants	Standard*	Before the operation of vent.	After the operation of vent.
T (°C)	–	23.2	22.3
RH (%)	–	24.1	15.7
PM_{10} (μg/m^3)	100	87.5	25.0
CO_2 (ppm)	1000	510	360
HCHO (μg/m^3)	100	32.7	27.7
TVOC (μg/m^3)	400	259.4	191.3

TABLE V: CONCENTRATIONS OF INDOOR AIR POLLUTANTS MEASURED IN DCC-A1

Pollutants	Standard*	Before the operation of vent.	After the operation of vent.
PM_{10} (μg/m^3)	100	104.2	71.5
CO (ppm)	10	0.23	0.06
CO_2 (ppm)	1000	437	934
HCHO (μg/m^3)	100	75.1	63.9
TVOC (μg/m^3)	400	379.4	66.2

TABLE VI: CONCENTRATIONS OF INDOOR AIR POLLUTANTS MEASURED IN DCC-A2

Pollutants	Standard*	Before the operation of vent.	After the operation of vent.
PM_{10} (μg/m^3)	100	184.2	77.4
CO (ppm)	10	0.02	0.04
CO_2 (ppm)	1000	561	991
HCHO (μg/m^3)	100	73.2	59.7
TVOC (μg/m^3)	400	282.7	45.5

TABLE VII: CONCENTRATIONS OF INDOOR AIR POLLUTANTS MEASURED IN DCC-B1

Pollutants	Standard*	Before the operation of vent.	After the operation of vent.
PM_{10} (μg/m^3)	100	82.9	65.5
CO (ppm)	10	0.66	0.02
CO_2 (ppm)	1000	643	623
HCHO (μg/m^3)	100	60.1	26.6
TVOC (μg/m^3)	400	348	31.1

C. Indoor Air Pollutants Levels by Operation of the Mechanical Ventilation System

The indoor PM_{10} concentrations in the elementary school A, elementary school B, day care center A and day care center B, on average, decreased by 49.8, 42.6, 44.7 and 23.2%, respectively by operation of the mechanical ventilation systems. The mean of decreasing rates of indoor CO_2 concentrations were 10.0, 27.5 and 26.8% in the elementary school A, elementary school B and day care center B, respectively. In contrast, CO_2 concentrations in the day care center A increased by 95.2%. It is assumed that because of the change in number of children and increase of outdoor CO_2 concentration (from 277 to 435 ppm) during the filed measurements. The mean of decreasing rates of indoor HCHO concentrations were 62.3, 18.1, 16.7 and 58.2% in the elementary school A, elementary school B, day care center A and day care center B, respectively. The indoor TVOC concentrations in the elementary school A, elementary school B, day care center A and day care center B, on average, decreased by 46.5, 34.6, 83.2 and 82.1%, respectively.

Our results clearly showed that indoor air pollutants' level after operation of the ventilation system were lower than before operation of the ventilation system expect in the case of CO_2 concentrations at the day care center A. These results could be explained by the adequate ventilation by means of a mechanical ventilation system. Fig. 2 shows the TVOC concentration changes in classrooms according to operation of the mechanical ventilation system.

TABLE VIII: CONCENTRATIONS OF INDOOR AIR POLLUTANTS MEASURED IN DCC-B2

Pollutants	Standard*	Before the operation of vent.	After the operation of vent.
PM_{10} (μg/m^3)	100	86.7	64.7
CO (ppm)	10	0.64	0.01
CO_2 (ppm)	1000	1013	502
HCHO (μg/m^3)	100	58.6	23.1
TVOC (μg/m^3)	400	170.2	45.6

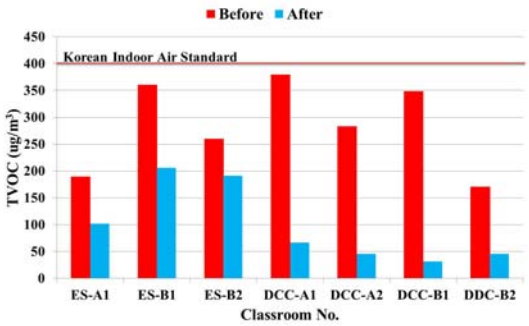

Fig. 2. TVOC concentrations in classrooms according to operation of the mechanical ventilation system.

Zuraimi and Tham [17] have documented the relation between indoor pollutant levels and child day care center ventilation mode such as naturally ventilated, hybrid ventilated and air conditioning with or without mechanical ventilation. They found that the level in hybrid ventilation systems lower than other systems by means of increased dilution of pollutants. Smedje and Norback [18] have conducted a study in Swedish schools and found that schools in which a new ventilation system was installed had higher exchange rates and reduced exposure to several pollutants including CO_2, HCHO and VOCs.

There were slight differences between the decreasing rates of each school buildings. An explanation might be the difference of outdoor pollutants concentrations at the

boundary with each school buildings, efficiencies of the mechanical ventilation system, number of occupants, operation of air-conditioners and location of diffusers.

The indoor air concentrations of all measured pollutants after operation of ventilation system in the selected school buildings complied with the Korean Indoor Air Standard, although measurements were conducted for one-day only. The mean of the PM_{10} concentrations were 16.7, 45.1, 74.5 and 65.1 μg/m^3 in the ES-A, ES-B, DCC-A and DCC-B, respectively. The mean of the CO_2 concentrations were 467, 355, 963 and 563 ppm in the ES-A, ES-B, DCC-A and DCC-B, respectively. The mean of the HCHO concentrations were 19.9, 30.9, 61.8 and 24.9 μg/m^3 in the ES-A, ES-B, DCC-A and DCC-B, respectively. The mean of the TVOC concentrations were 101.4, 198.4, 55.9 and 38.4 μg/m^3 in the ES-A, ES-B, DCC-A and DCC-B, respectively.

IV. Conclusion

In this study, we analyzed the indoor air quality parameters in four different school buildings with mechanical ventilation system to characterize pollutant levels and effects of ventilation systems. The results had shown remarkable difference in indoor air pollutants' level according to the operation of mechanical ventilation system. Operation of ventilation systems could decrease the levels of indoor pollutants in most of the selected classrooms, especially showing the reduction of chemical pollutants, HCHO and TVOC concentrations by 35.5 and 65.5%, respectively. Therefore, adequate ventilation by means of a mechanical ventilation system can play key roles in improving the indoor air quality within school buildings.

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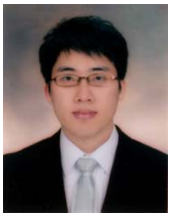

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