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Effects of Legal Regulation on Indoor Air Quality in Facilities for Sensitive Populations – A Field Study in Seoul, Korea

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Abstract

Facilities for sensitive populations have increased in Korea; and its indoor air quality (IAQ) was strictly regulated by the Korean government compared to other facilities. However, merely public facilities on certain level of total floor area were lawfully regulated. This study aims to characterize the indoor environment at facilities for sensitive populations in Korea and investigate the effects of legal regulation on IAQ throughout the duration of 1 year. Sixty facilities for sensitive populations were investigated. Particulate matter (PM_{10}), nitrogen dioxide (NO_2), carbon dioxide (CO_2), carbon monoxide (CO), total bacteria count (TBC), total volatile organic compound (TVOC), formaldehyde (HCHO), radon (Rn), ozone (O_3), asbestos, fine particulate matter ($PM_{2.5}$), and volatile organic compounds (VOCs) were target pollutants. As a result, none of the rooms' concentration of CO, NO_2, O_3, Rn, asbestos, and VOCs exceeded the Korean Standard of Indoor Air Quality, while some rooms' concentration of other pollutants exceeded the KSIAQ. Statutory facilities had lower indoor pollutant concentrations and exceedance rates due to efficient ventilation system and the lack of kitchen location within the building, as opposed to non-statutory facilities. In addition, the VOCs had significant differences depending on the number of years it took for the building to be constructed. To reduce the indoor pollutants concentrations, efficient ventilation systems should be installed while controlling the main sources of pollutants. In addition, construction and remodeling using eco-friendly materials should be considered. The standards of IAQ for small size facilities should be included in the KSIAQ in the future.

Keywords Indoor air quality · Legal regulation · Sensitive population · Statutory facility · Seoul

Introduction

Indoor environments in residential area and workplaces have caught the attention of scientists and public institutions (Lee and Chang 2000), since indoor air quality and thermal environment are a prominent risk factor of relevance to health and comfort of humans (Mendes et al. 2013), as most people spend an average of 87% of their time indoors and 5–6% in vehicles (Klepeis et al. 2001). Continuous monitoring of the levels and relevant types of indoor air pollutants is important to understand the contemporary and contributing factors to indoor environments (Weschler 2009). The range of activities of people in indoor spaces have increased due to industrialization and urbanization. This transition to indoor space has elicited a significant change of indoor air quality for people. As time spent indoors increased, the amount of exposure to inhalant indoor air pollutions of low concentrations became larger than exposure to outdoor air pollutants of higher concentration; thus, emerging as a very important national health issue (Nam Goung et al. 2015).

The indoor air quality of buildings, where most people spend a great part of their time, is an essential determinant of healthy life and welfare (Branco et al. 2014). In particular, children and the elderly are the most exposed population to indoor air pollutants, due to the fact that they spend most of their time indoors (Almeida et al. 2011; Mendes et al. 2014). Children have greater vulnerability to air pollutants than adults because of the higher amount of air

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inhalation per body weight unit, growing tissues and organs (Mendell and Heath 2005). In addition, the elderly are more susceptible to health problems that arise from problems in indoor environments, because their immune systems are not as strong as those of younger adults (Ginaldi et al. 1999). Especially, during the year of 2013 to 2014 in Korea, 3.4% of people under the age of 20, and 25.7% of people over the age of 70 suffer from asthma (Choi et al. 2017). Therefore, indoor air quality of the facilities occupied by children and the elderly is of greater concern than that of facilities occupied by other populations.

The Korea Ministry of Environment (MOE) enacted the 'Indoor Air Quality Control in Public Facilities', since controlling the indoor air quality in publicly used facilities helps people recognize its significance. The purpose of KSIAQ is to protect the health of general and sensitive population using the following facilities to prevent possible environmental risks. Recently, there are many studies regarding indoor air quality, public health, and especially studies regarding the increase of sensitive population. Based on these researches, $PM_{2.5}$ and fungi were included in KSIAQ for only sensitive population in 2018 by MOE. This program was implemented in 21 public facilities. These facilities were regulated by being divided into three groups: general facilities, facilities for sensitive population, and indoor parking lots. General facilities include underground subway, underground shopping areas, airport, port waiting rooms, theaters, museums, libraries, and game rooms. Facilities for sensitivity population include hospitals, elderly care centers, child care centers, and postnatal care centers. Indoor air quality regulation of facilities for sensitive population was particularly stricter than the other groups. The elderly, children, and pregnant women are defined as sensitive populations in exposure to environmentally hazardous factors that need special controls, according to the 'Environmental Health Act' of Korea. In addition, volatile organic compounds were regulated for only newly-built collective housing. However, only publicly used facilities over certain levels of total floor area were prescribed by the law. The certain levels of elderly care centers and nursery schools are 430 m^2 and 1000 m^2, respectively.

According to the Korea Ministry of Health and Welfare, elderly care centers and nursery schools have increased promptly solve the problem of sensitive populations. The number of children and child care centers (CCCs) have more than doubled between 2000 and 2013. In addition, the increased rates of the elderly and elderly care centers (ECCs) between 2008 and 2013 are 21.5 and 87.5%, respectively. Although investigation of indoor air quality of the environment inhabited by sensitive populations such as the elderly and children has recently increased, these studies were limited to facilities that were operating under compulsory regulations. Thus, this study is carried out through field investigation of indoor air quality (IAQ) at ECCs and CCCs, in order to characterize the indoor environment at facilities for sensitive populations in Korea and to assess the effects of legal regulation on IAQ comparing the difference between statutory and non-statutory facilities and providing indoor environment methods for improving public health and environment.

Methods

Study Target

The measurement considered 60 randomly selected facilities (30 elderly care centers and 30 child care centers) in Seoul, South Korea. The number of statutory and non-statutory facilities are 27 and 33, respectively. Measurements were conducted outdoors and in two representative rooms in each facility. One-day monitoring was performed at each facility during the occupied time, from 09:00 to 16:00, from April 2013 to March 2014. In addition, the investigation was carried out once each season for a total of four seasons. The investigation parameter included 11 pollutants and volatile organic compounds (VOCs), which are regulated or controlled by the MOE: particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), carbon dioxide (CO_2), carbon monoxide (CO), total bacteria count (TBC), total volatile organic compounds (TVOC), formaldehyde (HCHO), radon (Rn), ozone (O_3), asbestos, benzene, toluene, ethylbenzene, xylene, and styrene.

Measuring Methods

Temperature and relative humidity were investigated by an NTC/capacitive humidity sensor (testo 175 H1, Testo, Germany) with a minute interval. The PM_{10} and $PM_{2.5}$ were sampled on 47 mm PTFE membrane filters with 0.45 μm pore size (TF-450, Pall Corporation, United States) using a MiniVol portable air sampler (TAS, Airmetrics, United States). Filter mass was weighed before and after sampling, by averaging three measurements made on an electronic micro balance (CPA2P, Sartorius, Germany) after being conditioned in dry air (20 °C and 50%) using a desiccator (MCU 201, McDry, United States) for 48 hours. An analyzer connected by 4 instruments (Model 200E, 300E, 360E, and 400E, Teledyne, United States), which are continuous monitoring equipment that use a chemiluminescence method for NO_2, a non-dispersive infrared (NDIR) for CO and CO_2, and an ultraviolet photometric method for O_3 was used for investigating these 4 pollutants with the interval of one-minute. Radon was measured by using continuous radon monitor (Model 1027, Sun Nuclear Co. USA). Bacteria were collected on trypcase soy agar (TSA) three times at 20 min intervals by a sampler (Buck, Bio-Culture, United States), which used the inertial impaction principle with a flow rate of 100 L min^{-1} for 2 min. The colonies were counted after the TSA plates were incubated at 35 °C for 48 h with one field blank per batch of samples. The volatile organic compounds (VOCs) samples were collected simultaneously at two places in each room using Tenax-TA tubes by a portable minipump (MP-∑300, SIBATA, Japan) with a flow rate of 0.1 L min^{-1} for 30 min, and were analyzed using gas-chromatography mass spectrum (GC/MS) (Model 6890 N, Agilent, United States). A portable minipump (MP-∑100 H, SIBATA, Japan) with a 2,4-dinitrohydrazine(DNPH) (SUPELCO, USA) connected to an ozone scrubber (SUPELCO, USA) was used to sample HCHO with a flow rate of 1 L min^{-1} for 30 min at two places per room, simultaneously. The DNPH-HCHO eluted with 5 ml of acetonitrile (ACN) was analyzed by high-performance liquid chromatography (HPLC) (Model 2695, Waters, United States). To measure asbestos concentration, an absorption pump connected to a filter holder in which membrane filter with 0.8 μm pore size and 25 mm diameter was used with flow rate of 20 L min^{-1} for 1 h. The sampled filter was analyzed using a phase-contrast microscope (CX42RF, Olympus).

Statistical Analysis

All statistical analyses were performed using SPSS software (ver. 23; IBM SPSS) at a significance level of 0.05. T-test and One-way analysis of variance (ANOVA) with a Bonferroni correction were used to analyze differences in indoor air quality by legal regulation, season, using air purifier, and construction year.

Results

The Characteristics of Indoor Environments in Facilities for Sensitive Populations

Table 1 shows the concentrations of ten indoor air pollutants, which are lawfully regulated by the MOE, and $PM_{2.5}$ investigated in facilities for sensitive populations throughout a year. In addition, temperature and relative humidity were measured. Table 2 shows indoor temperature and relative humidity (RH) according to the season. The indoor temperature showed difference of average and range between seasons. RH in summer was higher than other seasons, and other seasons showed similar range.

Mean concentrations of PM_{10}, $PM_{2.5}$, CO_2, CO, NO_2, and TBC in statutory facilities were significantly lower than

Table 1 The difference of indoor air quality between statutory and non-statutory facilities for sensitive populations

Pollutants	KSIAQ	Facilities	Min	Median	Max	Mean	S.D	*p*-value	I/O ratio
PM_{10}	100	SF	20.1	47.5	82.2	46.0	11.4	**0.008**	1.52
[μg m^{-3}]	–	Non-SF	21.4	50.1	111.9	49.0	12.8	–	1.69
$PM_{2.5}$	–	SF	3.9	15.8	28.9	16.0	5.2	**0.049**	0.86
[μg m^{-3}]	–	Non-SF	3.9	17.5	32.5	16.9	5.1	–	0.92
CO_2	1000	SF	454.7	784.2	1842.0	813.5	208.1	**0.013**	2.11
[ppm]	–	Non-SF	495.3	815.9	1842.2	864.3	232.1	–	1.96
CO	10	SF	0.30	1.00	2.70	1.08	0.42	**0.034**	0.92
[ppm]	–	Non-SF	0.30	1.10	4.20	1.17	0.47	–	0.95
NO_2	0.05	SF	0.001	0.013	0.029	0.013	0.006	**0.037**	0.51
[ppm]	–	Non-SF	0.001	0.015	0.037	0.015	0.006	–	0.58
O_3	0.06	SF	0.001	0.009	0.029	0.010	0.006	0.990	0.40
[ppm]	–	Non-SF	0.001	0.009	0.032	0.010	0.007	–	0.42
HCHO	100	SF	6.1	34.9	168.6	40.2	23.6	0.781	2.01
[μg m^{-3}]		Non-SF	7.3	34.3	110.5	40.8	23.6		2.12
TVOC	400	SF	11.5	202.9	1427.0	298.7	269.0	0.543	1.74
[μg m^{-3}]		Non-SF	12.2	197.15	1880.7	314.6	302.5		1.70
TBC	800	SF	38.6	256.8	832.5	289.7	175.2	**0.048**	3.31
[CFU m^{-3}]		Non-SF	55.7	280.1	1176.2	323.7	195.3		3.02
Rn	4.0	SF	0.04	0.31	1.26	0.34	0.22	0.369	1.31
[pCi m^{-3}]		Non-SF	0.04	0.35	1.05	0.36	0.19		1.32

KSIAQ Korea Standard of indoor air quality of facilities for sensitive population, *I/O ratio* indoor/outdoor ratio, *SF* statutory facility

Bold values mean statistical significance ($p < 0.05$)

non-statutory facilities ($p < 0.05$). O_3's mean concentration had no difference between statutory and non-statutory facilities and asbestos was not detected in any of the facilities. There were no significant differences in the average concentrations of HCHO, TVOC, and Rn between statutory and non-statutory facilities, however, mean values in statutory facilities were lower than that of the non-statutory facilities.

Indoor air quality in over 70% of the facilities for sensitive populations did not exceed the KSIAQ. None of the rooms' concentration of CO, NO_2, O_3, Rn, asbestos, and VOCs exceeded the KSIAQ. The PM_{10} concentration did not exceed the KSIAQ in all the rooms except for one. HCHO in a CCC exceeded the KSIAQ in 2 seasons and ECC exceeded the KSIAQ in one season. TBC exceeded the KSIAQ in only one season in 2 CCCs. The exceedance rate of TVOC was 66.6% in the facilities; a CCC exceeded in four seasons, a CCC and 4 ECCs exceeded in three seasons, 5 ECCs and 4 CCCs exceeded in two seasons, and 11 CCCs and 14 ECCs exceeded in one season. The number of facilities exceeding CO_2 concentration of KSIAQ is 26: 2 CCCs exceeded in three seasons, 10 CCCs exceeded in two seasons and 10 CCCs and 4 ECCs exceeded in one season. All of the rooms exceeding the standard of PM_{10} and HCHO were non-statutory facilities. Also, the 70.0%, 67.8%, and 70.5% of rooms exceeding the standard of TBC, TVOC, and CO_2 were the rooms of non-statutory facilities.

The mean I/O ratio of PM_{10}, CO_2, HCHO, TVOC, TBC, and radon were >1. In addition, the minimum I/O ratio of CO_2, HCHO, and TBC were 1.52, 1.33, and 1.40, respectively. 84.8% and 86.0% of the number of measurements showed that indoor PM_{10} and TVOC concentrations were higher than that of outdoor PM_{10} and TVOC concentrations, respectively.

Table 2 Difference of indoor environment according to season

Season	Temp. (°C)			RH (%)		
	Min	Mean (SD)	Max	Min	Mean (SD)	Max
Summer	25.0	27.8 (1.23)	31.2	31.7	60.0 (1.23)	75.1
Autumn	14.9	21.1 (2.67)	26.4	22.5	36.7 (8.20)	65.3
Winter	12.0	18.9 (2.64)	26.8	20.3	37.2 (9.86)	67.3
Spring	21.8	25.4 (1.48)	298.5	23.2	32.5 (3.60)	44.2

Volatile Organic Compounds Levels in Facilities for Sensitive Populations

The concentrations of VOCs, such as benzene, toluene, ethylbenzene, xylene, and styrene, in facilities for sensitive population were shown in Table 3. The VOCs were regulated for only newly-built collective housing by the law: standards of HCHO, benzene, toluene, ethylbenzene, xylene, and styrene are 210 μg/m^3, 30 μg/m^3, 1000 μg/m^3, 360 μg/m^3, 700 μg/m^3, and 300 μg/m^3, respectively. The concentrations of VOCs did not exceed the standard of VOCs in newly-built collective housing. The VOCs were detected in over 90% of rooms investigated.

Discussion

Characteristics of Indoor Air Quality Management

The KSIAQ was enacted by the MOE based on examples from developed nations, field study, and health risk assessment. Health risk assessment was performed using human toxicity of indoor air pollutants, exposure, carcinogenesis and so on. To measure accurately, this standard regulated the number of measuring sites according to the facility. For example, if the building area is under 10,000 m^3, two measuring sites are necessary. Indoor air quality standards and guidelines of US EPA and WHO are similar to that of Korean standards and guidelines; however, there are low differences regarding some pollutants. For example, CO_2 standard of WHO, US EPA, and Korea is 1000, 800, and 1000 ppm, respectively (Abdul-Wahab et al. 2015).

The higher occupancy and human activities in the rooms cause the higher indoor particle, bioaerosol, and CO_2 concentrations. In addition, ambient air pollution caused by traffic in outdoor affect the indoor particle levels (Fromme et al. 2007; Mullen et al. 2011; Scheff et al. 2000; Yang et al. 2009). Aerosol includes a lot of organic compounds which is toxic or carcinogenic, such as formaldehyde,

Table 3 Volatile organic compounds concentrations and detection frequency in facilities for sensitive populations

Pollutats	Min	Median	Max	Mean	S.D	Detection frequency (%)
Benzene [μg/m^3]	0.10	2.00	15.90	2.26	1.79	91.2
Toluene [μg/m^3]	0.30	8.9	291.30	20.06	32.29	99.6
Ethylbenzene [μg/m^3]	0.10	2.9	118.60	4.78	9.87	98.7
m&p-xylene [μg/m^3]	0.30	3.50	207.60	6.34	14.62	96.2
o-xylene [μg/m^3]	0.10	1.40	101.00	2.66	6.77	95.6
Σ xylene [μg/m^3]	0.30	5.20	308.60	10.04	22.32	96.9
styrene [μg/m^3]	0.10	0.80	89.90	2.57	11.76	92.3

benzene, and polyaromatic hydrocarbons (Smith et al. 2000). The combustion-generated pollutants such as CO and NO_2 are emitted by the heater and vehicles outdoor, and indoor concentration is firmly affected (Alberts, 1994; Chithra and Nagendra, 2012), however, most of the recent heating systems are not combustion systems. VOCs are generally emitted from building materials and consumer products (Blondel and Plaisance, 2011; Wallace et al. 1987). The main sources of indoor radon are soil and regular building materials (Cosma et al. 2013). The ozone is generated by consumer appliances and photochemical reaction (Morrison et al. 2011; Park and Rhee, 2015). In general, the main reasons for higher indoor pollutants concentrations are poor ventilation (Godwin and Batterman, 2007; Yang et al. 2009). However, there is potential for an increase in concentration of indoor pollutants through ventilation; because of pollutants originating from outdoor sources.

In order to compare the result of this study to another place where high concentration level of pollutants exist, places such as screen golf courses and schools in Korea were taken into consideration (Nam Goung et al. 2015; Yang et al. 2009). Therefore, the results of this study reveals that indoor air levels in facilities for sensitive populations were lower than other facilities because they are consistently controlled by the government; further induced by increased public perception of importance in IAQ management (Yang et al. 2015).

Adequate ventilation is an efficient method for improving IAQ (Nam Goung et al. 2015; Yang et al. 2015) and all facilities are recommended to use ventilation systems such as mechanical ventilation system, natural ventilation, and an air purifier. Natural ventilation is effective in decreasing the level of indoor air pollutant, especially for CO_2 and VOCs (Wong et al. 2004; Meininghaus et al. 2000). Furthermore, air purifiers are very efficient in decreasing the levels of PM_{10}, $PM_{2.5}$, and bioaerosol (Oh et al. 2014). Table 4 shows difference of using ventilation system between statutory and non-statutory facilities. In Korea, most of the non-statutory facilities are in apartments and row houses which are remodeled to care for the elderly and children. Therefore, most of these are small in size and care only a handful of men. In addition, there are not any mechanical ventilation system in most of the room for activity and these facilities performed cross natural ventilation. Whereas, the rooms of the statutory facility used mechanical ventilation more than cross natural ventilation due to the fact that windows are sealed for prevention of falling accidents. Natural ventilation in these facilities was performed through only aisle-side windows and doors. In addition, the number of the rooms of statutory facilities that used both cross natural ventilation and mechanical ventilation system were more than that of non-statutory facilities. Generally, cross natural ventilation and mechanical ventilation are more efficient in improving IAQ than the regular ventilation system. However, this would only be true if the outdoor pollutant concentration was less than that of the indoor pollutant concentration. Mechanical ventilation system has filters, but did not filter gaseous pollutants; while natural ventilation did not block outdoor pollutants.

The rooms of statutory facilities use air purifier more than non-statutory. The particulate matter (PM_{10} and $PM_{2.5}$) and bioaerosol (bacteria and fungi) were removed by air purifier and removal efficiency of these pollutants during three weeks was over 50% (Oh et al. 2014). In this study, air purifiers are used in 149 rooms and Fig. 1 shows the concentrations of PM_{10}, $PM_{2.5}$, and TBC in the rooms using air purifier and none. The concentrations of PM_{10}, $PM_{2.5}$, and TBC in the using air purifier are $41.9 \pm 11.3\ \mu g\ m^{-3}$, $14.0 \pm 5.3\ \mu g\ m^{-3}$, and 281.8 ± 187.9 CFU m^{-3}, respectively. Also, the concentrations of PM_{10}, $PM_{2.5}$ and TBC in the no using air purifier are $50.2 \pm 11.8\ \mu g\ m^{-3}$, $17.6 \pm 4.7\ \mu g\ m^{-3}$, and 320.3 ± 185.7 CFU m^{-3}, respectively. The concentrations of

Table 4 The number of rooms using ventilation systems

Facility	MV	CNV	MV + CNV	Air purifier
Statutory facility	157	105	75	98
Non-statutory facility	95	166	33	51

MV mechanical ventilation system, *CNV* cross natural ventilation

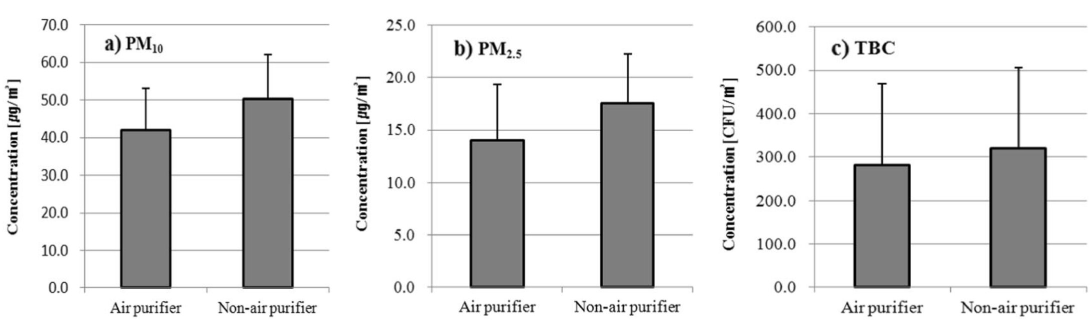

Fig. 1 The difference of indoor PM_{10}, $PM_{2.5}$, and TBC concentrations between rooms using air purifier and none

PM_{10}, $PM_{2.5}$, and TBC in using air purifier are significantly lower than none ($p < 0.05$).

The cooking process emit indoor air pollutants and these pollutants are related to health of the occupants (Huang et al. 2011; Kim et al. 2011; Yu et al. 2015; Zhao et al. 2014). Cooking has correlations with indoor air quality, especially with concentrations of CO_2, CO, PM_{10}, $PM_{2.5}$, and VOCs that increase in the dining area (Lee et al. 2001). There is a kitchen in all of the facilities for cooking of meals and snacks. Kitchens in most of the statutory facilities are situated in different floors from the rooms used for education and recess. However, most of the non-statutory facilities have them situated in the same floor. Because most of the statutory facilities are constructed with several floors and the non-statutory facilities are a single flat.

Natural episodes, such as yellow sand, smog, and rainy season, which are different in each season, made characteristics of outdoor air quality distinguishable in each season. Outdoor air pollutant concentrations were important variables in predicting indoor air quality, because the fraction of those particles infiltrating the indoors were ranged from 30 to 66% (Meier et al. 2015). In this study, indoor air pollutants displayed significant differences seasonally. The particle concentration in yellow sand season was significantly higher than other seasons, however TBC in rainy season was significantly higher than other seasons ($p < 0.05$). In general, the indoor and outdoor bioaerosol concentrations during summer are higher than winter due to high temperature and relative humidity since summer in Korea is a rainy season (Jo and Seo, 2005; Ren et al. 1999). In addition, there are the seasonal differences of indoor and outdoor activity program and in the natural ventilation rate due to air conditioning, heating, temperature, humidity, weather, and episodes.

VOCs Concentrations According to Construction Year

The TVOC and individual VOCs, including HCHO, levels are related to SBS (sick building syndrome) and have adverse health effects. In particular, exposure to VOCs causes acute and chronic diseases in eyes, respiratory organs, and central nervous system (Hodgson et al. 1991; Logue et al. 2011; Maroni et al. 1995).

Figure 2 shows the VOCs according to construction year. In this study, the construction year of target buildings ranged from 1 to 19. Maximum construction year of buildings where TVOC and HCHO concentration exceed KSIAQ were 9 and 2, respectively, because of new furniture. The result of this study showed that VOCs levels decreased and had significant difference according to construction year of buildings ($p < 0.05$). The VOCs concentrations of new buildings decreased rapidly after a year, similar to the results of previous studies (Park and Ikeda, 2006; Yang et al. 2015). In addition, the VOCs concentrations of buildings constructed under the duration of one year had a wider range, because of difference in management and materials. In new buildings, emissions from the building materials and contents have been shown to elevate VOC levels compared to the levels observed in old buildings (Brown et al. 1994). VOCs concentrations are associated with the renovation and aging of buildings (Jia et al. 2008; Zhao et al. 2004).

The main indoor sources of VOCs are consumer products, building materials, furnishing, and combustion appliances (Nam Goung et al. 2015). Concrete and cement emitting high VOCs are used as building materials for most of buildings in Korea. In particular, the cement-based building materials emit higher VOCs compared to other substance-based building materials, dominated by neopentyl glycol which is a material used as an additive in the building materials industry (Katsoyiannis et al. 2012; Claeson et al. 2007). In addition, outdoor VOCs concentrations, particularly emitted by motor vehicles, are known to contribute to indoor VOCs levels (Hinwood et al. 2007; Jia et al. 2008; Lawson et al. 2011). Since these outdoor sources release high concentrations of VOCs, ventilation raises the indoor concentration of VOCs.

The results of this study reveal that the newer construction, the higher VOCs concentration, therefore strict management is needed in new facilities. However, there were only a few new buildings in this study. The number of new building was only 3, and buildings constructed under the 3 years was 13. More research is needed to control the VOCs efficiently and for health of the occupants in more buildings from pre-occupancy to the oldest.

Conclusions

Korea Ministry of Health and Welfare reported that elderly care centers and nursery schools have increased. In addition, the Korea Ministry of Environment regulated the indoor air quality of facilities for sensitive population strictly compared with other facilities. However, only public facilities which are over certain level of total floor area were regulated by the law.

In this study, indoor air quality in 60 facilities for sensitive populations (30 elderly care centers and 30 child care centers/27 statutory facilities and 33 non-statutory facilities) was investigated throughout one year to provide the effects of legal regulation and basic data for legal control of IAQ in small size facilities. The measurement was performed indoor where two representative rooms were selected in each facility and outdoor. The parameters investigated were ten pollutants that are legally regulated, $PM_{2.5}$, and VOCs.

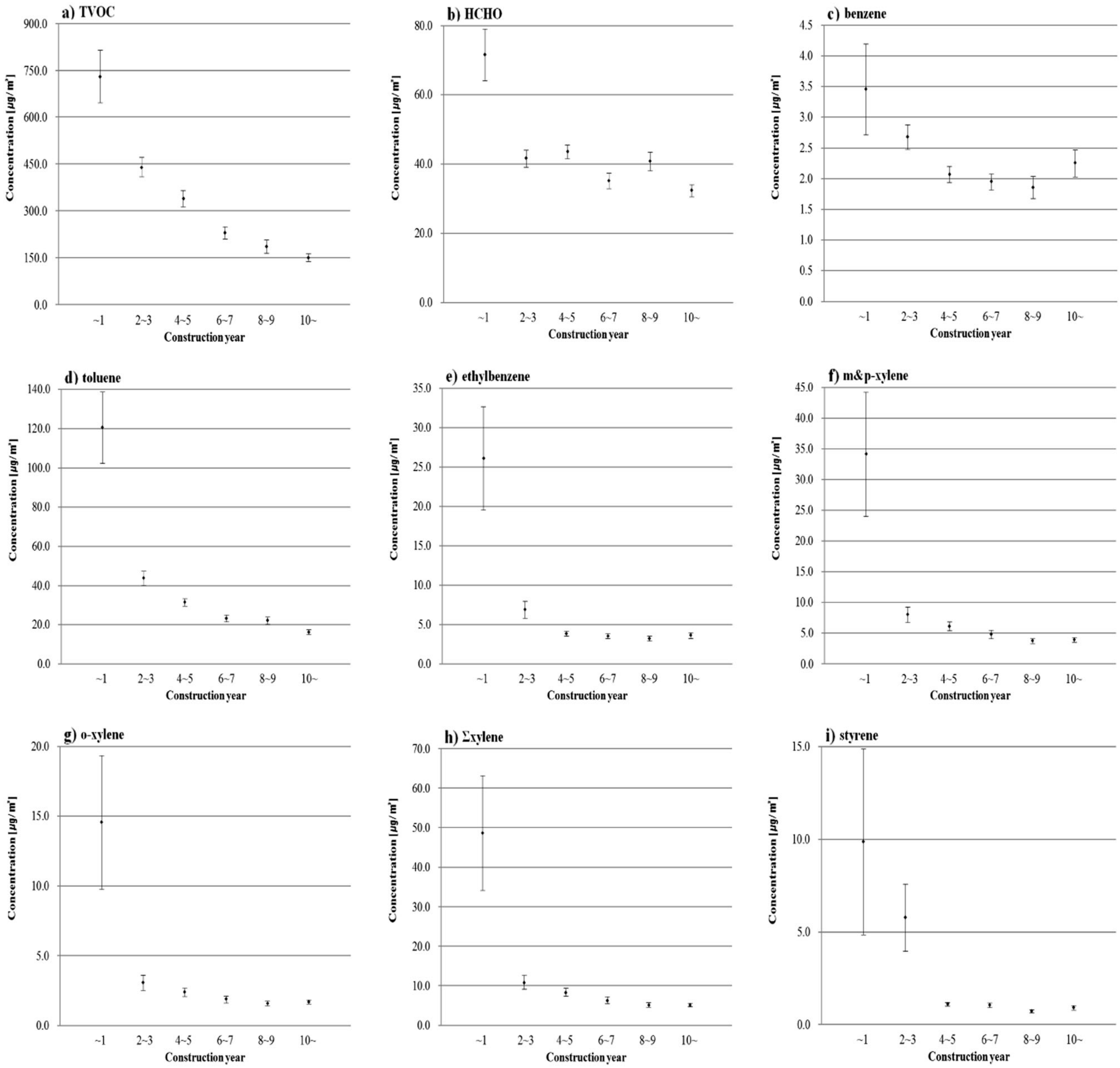

Fig. 2 The difference of indoor volatile organic compounds levels according to construction years

None of the rooms' concentration of CO, NO_2, O_3, Rn, asbestos, and VOCs exceeded the KSIAQ, while other pollutant concentrations exceeded the KSIAQ in some rooms. Statutory facilities had lower indoor pollutant concentrations and exceedance rates than non-statutory facilities. The investigation of ventilation system was carried out to provide the difference of IAQ management between statutory and non-statutory facilities. The results suggested that more statutory facilities were ventilated by using both cross natural ventilation and mechanical ventilation system, and an air purifier. In addition, kitchens in most of the non-statutory facilities are situated in the same floor with rooms for education program and rest. Statutory facilities had efficient ventilation system and non-statutory facilities had kitchens for cooking which is a main indoor pollutant source. The concentrations of VOCs did not exceed the standard of VOCs in newly-built collective housing. However, VOCs concentrations decreased consistently and had significant difference according to construction years.

To reduce the indoor air pollutant concentrations, an efficient ventilation system should be installed and the main source should be carefully controlled. In addition, construction and remodeling using eco-friendly materials should be considered. The result of this study revealed that these methods for reducing indoor air pollutant levels in non-statutory facilities were insufficient; therefore, non-statutory facilities for sensitive populations need consistent IAQ management through legal regulation. The additional studies on allowable and suitable IAQ standard for small size facilities for sensitive populations should be carried out for legal regulation. The standards of IAQ for small sized facilities should be included in KSIAQ in the future, based on such studies.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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