A study on the evaluation of indoor air quality in small scale apartment house in South Korea

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Abstract. The purpose of this study is to measure and evaluate indoor air quality in small-scale apartment houses which are not included in construction standard of Clean-Healthy house in Korea. This study is measured the formaldehyde, acetaldehyde, benzene, toluene, ethylbenzene, xylene and styrene included in the indoor air quality guideline of Korea. As a result, high concentrations of formaldehyde and acetaldehyde were detected in some of the houses measured, and in particular, there were some homes that exceeded the guidelines of the World Health Organization by more than six times the guideline of acetaldehyde. Some of the measured houses were found to contain volatile organic compounds such as toluene, styrene, and xylene at a high concentration and exceeded the indoor air quality in Korea guidelines. Therefore, the construction standards of Clean-Healthy house should be applied not only to large-scale apartment of 1,000 or more, but also to single-family houses and small-scale apartment houses.

1. Introduction

The pollution of Indoor air is a contributory factor to the social problem known as “sick house syndrome”. [1]. In 2003, the South Korean Ministry of Environment provided the IAQ (Indoor Air Quality) Management Act for newly built apartments [2]. In 2005, the IAQ guidelines in newly built apartment were revised [3]. The guidelines of South Korean on IAQ in apartment blocks cover formaldehyde, styrene, toluene, ethylbenzene, xylene and benzene [4]. Besides, to enable construction contractors and consumers to select building materials with low emissions of formaldehyde, the guidelines recommend attaching a Healthy Building Mark in accordance with the formaldehyde emission rate [5]. However, despite these efforts on the part of the South Korean government, there has not been change in the IAQ in newly built apartments [6, 7]. Accordingly, in 2010, the South Korean Ministry of Land, Infrastructure, and Transport took steps to resolve the issue by issuing the Clean Healthy House Standard, effective from that year [8]. The standard of Clean Healthy House building is designed to ensure a certain level of indoor air quality and ventilation in order to provide residents with a healthy, comfortable indoor environment. Newly built or renovated apartment developments of 1,000 or more residences are required to be based on the standard. Construction companies must create a Clean Healthy House Standard Evaluation Report themselves and submit it to a government office. The report is divided between the minimum standard and the recommended standard. Newly built apartment blocks should apply all of the minimum standard items, and if at least three of the seven recommended standard items are applied, then the building is recognized as a Clean-Healthy House.

In this study, Indoor air quality was measured and evaluated for single-family houses and small-scale houses which are not included in construction standard of Clean Healthy House.
2. Measurement method

Table 1 shows an overview of the houses. This study measured seven different houses to evaluate indoor air quality. The total floor area of houses ranged from 20.3 to 38.3 (m²), and the houses are where one person or two people can live. These houses were built in April and May in the year of 2018. The measurement period ranged from August 15 to 17 in 2018 for three days.

| Type of house         | Sample name | Floor area [m²] | Volume [m³] | Completion date | Measurement period   |
|-----------------------|-------------|-----------------|-------------|-----------------|---------------------|
| Multi-Family House    | A           | 22.3            | 55.75       | April 15, 2018  | August 15~17, 2018  |
|                       | B           | 20.3            | 50.75       |                 |                     |
|                       | C           | 39.0            | 97.50       | May 13, 2018    |                     |
|                       | D           | 32.6            | 81.52       |                 |                     |
|                       | E           | 36.0            | 90.00       |                 |                     |
|                       | F           | 38.3            | 95.70       |                 |                     |
|                       | G           | 38.3            | 95.70       |                 |                     |

2.1 Measurement methods

Figure 1 shows the measurement schedule. Table 2 shows the indoor air sampling devices and samplers and the volume of air sampled. In accordance with the official experimental method published by the South Korean Ministry of Environment (2004) [4], indoor air quality for each type of residence was measured. Before collecting indoor air samples, all windows and doors connecting with the outside were opened. In addition, all internal doors and furniture doors were also opened, and the residence was left to ventilate for 30 minutes. Next, all the windows and doors connecting with the outside were closed while the furniture doors and kitchen under-sink cupboards were left open and the residence was left in this state for five hours. During this five-hour period in which the residence was sealed, indoor air was sampled for 30 minutes. Formaldehyde and acetaldehyde were sampled using a 2, 4- dinitrophenylhydrazine (DNPH) cartridge, with an ozone scrubber attached to the front section to remove ozone from the sample. The air-sampling device was a SIBATA (Japan) MP-Σ100H. VOCs were sampled using a Tenax TA tube with a SIBATA (Japan) MP-Σ30H. The measurement position was in the center of the living room at a height of 1.2 - 1.5 m above the floor. A travel blank was used to check for contamination of the sampler.

2.2 Method of analyzing target chemicals

The chemicals analyzed included indoor pollutants, which are listed in the South Korean Ministry of Environment’s indoor air quality guidelines (2005) for newly built apartments[4] and the World Health Organization (WHO) guidelines (1999) [9]. The chemicals analyzed were formaldehyde, acetaldehyde, benzene, toluene, ethylbenzene, xylene, and styrene. Formaldehyde and acetaldehyde...
Table 2. Indoor Air Sampling Devices, Samplers and Air Sample Volumes

| Measurement item                  | Sampling device, sampler used                 | Sampled air volume (L) |
|-----------------------------------|-----------------------------------------------|------------------------|
| Formaldehyde, acetaldehyde        | MP-Σ100H (SIBATA, Japan) Ozone scrubber + DNPH cartridge | 15 L (0.5 L/min)       |
| Volatile Organic Compounds (VOCs) | MP-Σ30H (SIBATA, Japan) Tenax TA tube (Gerstel) | 6 L (0.2 L/min)        |

Table 3. HPLC Conditions

|                      | Agilent 1100                                      |
|----------------------|---------------------------------------------------|
| Column               | GL Science/Inertsil Acrolein C18 4.6 x 150 mm (5μm) |
| Mobile phases        | Water/Acetonitrile = 60:40                        |
| UV detector          | Agilent 1100 Variable Wavelength Detector (VWD)   |
| Injection volume     | 10 μL (1.2 mL/min)                               |
| Oven temperature     | 40°C                                             |
| Detection wavelength | 360 nm                                           |

Table 4. GC/MS Conditions

|                      | PerkinElmer Turbo Matrix ATD                      |
|----------------------|---------------------------------------------------|
| Desorption temperature, (Time) | 260°C (10 min)                                           |
| Second desorption temperature, (Time) | 5°C→280°C (45 min)                                   |
| GC oven temperature  | HP- VOC 60 m x 0.32 mm, df = 1.8μm                |
| Split ratio          | 7:1                                               |
| MS analysis mode     | SCAN                                              |
| MS range             | m/z 35 (low) – 550 (high)                         |
| Ion source temperature | 250°C                                            |

were recovered from the DNPH cartridge by solvent extraction with acetonitrile and extracts were analyzed via high-performance liquid chromatography (HPLC). VOCs collected by the Tenax TA tube were analyzed using a gas chromatography/mass spectrometer (GC/MS). Tables 3 and 4 show the conditions for HPLC and GC/MS analysis, respectively.

3. Measurement results

Table 5 shows the concentration of formaldehyde and acetaldehyde in indoor air and guideline. Table 6 shows the concentration of formaldehyde and acetaldehyde in indoor air and guideline. In the case of the house measured in this study, the concentration of formaldehyde in the indoor air was measured to be in the range of 49.3-198.3 [ug/m³]. None of the six houses measured exceeded the Korean indoor air quality guidelines. However, among the measured homes, three homes exceeded the indoor air quality guideline of the World Health Organization and Japan. The concentration of acetaldehyde was measured in the range of 14.4-371.0 [ug/m³]. Korea does not yet have guidelines for acetaldehyde. Therefore, it is compared with the guidelines of Japan and the World Health Organization. In particular, the concentrations of acetaldehyde in houses D and E were 324.0 and 371.0 [ug/m³], respectively, which was 6.5-7.4 times higher than the World Health Organization standard. Of the six homes surveyed, three homes exceeded the guideline of Japan and the World Health Organization. The concentration of benzene measured in the house was 1.2-2.7 [ug/m³], and all the measured houses were not exceeded the indoor air quality guidelines in Korea. The concentration of toluene was detected to be 20.0-1000 or more [ug/m³], and the Concentration of toluene in indoor air showed a great difference according to housing. In particular, D and E housing were exceeded the guidelines of Korea.
and the World Health Organization. The concentration of ethylbenzene was measured in the range of 10.5-372.0 [µg/m³].

**Table 5.** The concentration of formaldehyde and acetaldehyde in indoor air and guideline

| Chemicals | House name | Concentration [µg/m³] | Guideline |
|------------|------------|-----------------------|-----------|
| Formaldehyde | A | 168.0 | 210(Korea*) |
|              | B | 127.0 | 100(WHO**, Japan***) |
|              | C | 49.3  |            |
|              | D | 198.3 |            |
|              | E | 89.7  |            |
|              | F | 56.5  |            |
|              | G | 57.1  |            |
| Acetaldehyde | A | 37.9 | 50(WHO) |
|              | B | 21.8 | 48(Japan) |
|              | C | 13.0 |            |
|              | D | 324.0 |            |
|              | E | 371.0 |            |
|              | F | 77.8 |            |
|              | G | 14.4 |            |

*: Ministry Environment, Korea: 2005[4]
**: World Health Organization (WHO):1999[9]
***: Ministry of Health, Labour and Welfare, Japan: 2002[10]

**Table 6.** The concentration of formaldehyde and acetaldehyde in indoor air and guideline

| Chemicals | House name | Concentration [µg/m³] | Guideline |
|------------|------------|-----------------------|-----------|
| Benzene    | A | 1.2 | 30(Korea) |
|            | B | 1.5 |            |
|            | C | 1.3 |            |
|            | D | 2.7 |            |
|            | E | 2.3 |            |
|            | F | 1.2 |            |
|            | G | 1.6 |            |
| Toluene    | A | 388.0 | 1000(Korea, WHO) |
|            | B | 177.0 | 260(Japan) |
|            | C | 166.0 |            |
|            | D | >1000 |            |
|            | E | >1000 |            |
|            | F | 43.0 |            |
|            | G | 20.0 |            |
| Ethylbenzene | A | 25.4 | 360(Korea) |
|             | B | 19.0 | 3800(Japan) |
|             | C | 28.1 | 22000(WHO) |
|             | D | 358.0 |            |
|             | E | 372.0 |            |
|             | F | 50.6 |            |
|             | G | 10.5 |            |
| Xylene     | A | 58.4 | 700(Korea) |
|            | B | 40.7 | 870(Japan, WHO) |
|            | C | 66.3 |            |
|            | D | 159.0 |            |
|            | E | 123.0 |            |
|            | F | 193.0 |            |
|            | G | 30.9 |            |
| Styrene    | A | 120.0 | 300(Korea) |
|            | B | 47.1 | 220(Japan) |
|            | C | 5.7 | 260(WHO) |
|            | D | >1000 |            |
|            | E | >1000 |            |
|            | F | 508.0 |            |
|            | G | 97.8 |            |
The measured D housing was exceeded the Korean guidelines. In the case of xylene, the measured concentrations in indoor was 30.9-159.0 [ug/m^3], which were not exceeded the guidelines of Korea, the World Health Organization and Japan. The concentration of styrene was measured in the range of 5.7-1000 or more [ug/m^3], and the difference in concentration was large among houses. D, E, and F housing were exceeded guidelines not only the guidelines in Korea but also in Japan and the World Health Organization. In particular, D and E housing were measured at more than three times the guidelines of Korea.

4. Discussion
In the case of houses measured in this study, the concentrations of formaldehyde in indoor air were not exceeded the guidelines in Korea. However, some homes have exceeded the guidelines of WHO and Japan. The guideline of formaldehyde in Korea is 210 [ug/m^3], twice as high as those in Japan and WHO. It is necessary to lower the guideline of formaldehyde applied to Korea to the level of Japan and WHO. The guideline of acetaldehyde has not yet designated as substances subject to indoor air quality regulation in Korea. Because the concentration of acetaldehyde in the house was measured at a high level, it is recommended to establish a guideline for acetaldehyde. In the case of volatile organic compounds, all the homes measured were not exceeded the benzene guideline. However, the concentrations of toluene, styrene, and xylene were exceeded the Korea’s guidelines in some homes. Therefore, it is considered that countermeasures against indoor air quality will be needed in single-family houses and small-scale apartment houses.

5. Conclusion
This study was conducted to measure the indoor air quality of small houses not included in the construction standards of clean-healthy house. Some of the houses were detected to contain high levels of formaldehyde and acetaldehyde. In addition, there were houses where volatile organic compounds such as toluene, styrene, and xylene were detected at high concentrations. Therefore, it is hoped that the criteria for the construction of clean health housing will be applied not only to new housing units over 1000 households, but also to single-family homes or small-scale apartment houses.

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