Measuring Degree of Contamination by Semi-volatile Organic Compounds (SVOC) in Interiors of Korean Homes and Kindergartens

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Abstract

PVC floor material is widely used in Korean homes, and people customarily sit or lie on the floor surface. This could potentially put residents of such homes at high risk of exposure to semi-volatile organic compounds (SVOCs). However, there is a current lack of information regarding the degree of SVOC contamination in Korean homes. Therefore, this study was implemented to measure SVOC concentration in the air and house dust in homes and kindergartens, places where children spend long periods of time. The substances analyzed were 2E1H, D6, TBP, TCEP, DBP, TPP, DOA, and DEHP. Amounts of 2E1H, D6, DEP, DBP, and DEHP were detected in the air of the homes included in the study, and the average air concentrations of DBP and DEHP were 0.53 μg/m^3 and 0.28 μg/m^3, respectively. The average dust DEHP concentrations in the rooms of homes and kindergartens were 2,800 μg/g and 4,350 μg/g, respectively, showing that higher values were measured in kindergartens. The measured DEHP concentrations in the dust of both homes and kindergartens where PVC floor materials are used were high.

Keywords: plasticizer; house dust; SVOC; PVC sheet

1. Background and Purpose

For modern people, who spend more than 90% of each day indoors, the quality of the interior air seriously affects not only their health, but also their comfort and productivity (Kleppe et al. 2001; Brown et al. 1994; Molhave et al. 1991; Saltheimmer et al. 2010; Nielsen et al. 2007; Wlokoff et al. 2001). Organic chemical substances inside rooms are emitted from building materials such as wallpaper, flooring, and adhesives, and from sofas, cabinets, desks, and other items used daily (Risto 1997; Guo et al. 2000a; Bouhamra et al. 1997; Plaisance et al. 2014; Ye et al. 2014). Furthermore, it has been reported that the use of heating devices, such as gas stoves, inside rooms has a serious impact on contamination caused by volatile organic compounds (VOCs) (Gou et al. 2009b; Lee et al. 2002; Garrett et al. 1997; Jia et al. 1993). Investigations of homes occupied by smokers have shown that the degree of VOC contamination is extremely high (Edwards et al. 2001; Guerin et al. 1992).

In Korea, a 'sick house' problem has appeared in newly constructed collective dwellings (WHO, 1993; Molhave et al. 1997; Mendell et al. 1993). Typical chemical substances contaminating rooms include formaldehyde, toluene, and styrene, amongst others (Du et al. 2014; Zhu et al. 2005; Park et al. 2004; Sawant et al. 2004; Lai et al. 2004; Kim et al. 2001; Guo et al. 2003c). The Government of Korea has enforced the Indoor Air Quality Management Act in newly constructed collective dwellings and enacted a Guideline to Room Interior Air Quality in order to resolve the 'sick house' problem (Korea, 2003a, 2010b).

Recent attention has also been focused on Semi-Volatile Organic Compound (SVOC) contamination inside rooms. SVOCs characteristically adhere to house dust, windows, the surfaces of furniture, and air inside rooms, and have been reported to exist in high concentrations in house dust inside rooms (VDI, 2004; Wensing et al. 2005; Fromme et al. 2004). A typical SVOC substance that contaminates rooms is plasticizer, which is widely used not only in daily-use products, but also in interior materials such as flooring or wallpaper, medical treatment equipment, home appliances, children's toys, and stationary products (Bergh et al. 2010; Fay et al. 1999).

Amongst substances found in house dust, contamination by lead and other heavy metals or by fungi, ticks, and other microorganisms are considered to be problems, but the growing use of plastic products inside rooms has aroused fears of contamination by...
phthalate esters or phosphoric acid esters (Gou et al. 2011d; Langer et al. 2010; Abb et al. 2009; Bornehag et al. 2005; Becker et al. 2004). A link between phthalate esters in house dust and asthma or allergies in toddlers has been reported (Mendell et al. 2007; Bornehag et al. 2004; Bonvallot et al. 2010; Larsson et al. 2010). It is reported that in particular, toddlers ingest more than 10 times as much house dust per kilogram of body weight than adults (Wensing et al. 2005), and they have a habit of putting their hands in their mouth; hence, the health risk to them is higher than it is to adults (Xue et al. 2007; USEPA, 1997; Harrad et al. 2010; Lioy et al. 2002; Whitehead et al. 2011). It is also reported that of the total DEHP a toddler ingests in one day, about 54% is derived from house dust (Clark et al. 2003).

The people of Korea widely adopted western lifestyles, such as the use of sofas, dining tables, beds, a long time ago, but Korean people traditionally spend most of their time indoors sitting or lying on the floor after removing their shoes at the entrance of their homes before entering the rooms. Toddlers are often in contact with the floor, where they crawl, play, or sleep, and in many homes in Korea, PVC sheets are used as floor surface heaters or floor coverings; hence, it is assumed that toddlers are at a high risk of SVOC exposure. However, there has not been sufficient research to quantify SVOC contamination in rooms in Korean homes or kindergartens.

Therefore, the purposes of the present study are to investigate SVOC pollution levels in preschools and Korean housing by measuring the concentration of SVOC such as plasticizer in air and indoor dust; and to compare it with the previous studies.

2. Method

2.1 Outline of Measurements

The SVOC concentrations of air and house dust in homes of the Pusan and Daegu regions of Korea were measured. The measurements were made in 4 homes in Pusan and in 4 homes in Daegu. Measurements were also made in 6 kindergarten classrooms in the Pusan region. In homes, room air was collected from the center of living rooms, while in kindergarten facilities; air was collected from the center of ordinary classrooms. To obtain house dust, dust accumulated on the floor surfaces of living rooms and other rooms in the measured homes was collected. In measured houses where the floor materials of the living room and the other rooms differed, house dust was collected separately from each type of floor material. In the kindergarten facilities, dust accumulated on the floor surface of ordinary classrooms was collected. All measured houses are equipped with a third-class ventilation system. The ceilings and walls are all finished with PVC wallpaper. In addition, the Kindergartens in the present study have third-class ventilation systems, and the walls and ceilings are finished with paint and gypsum boards, respectively. Tables 1. and 2. outline the measurement sampling of homes and kindergartens, respectively.

Table 1. Outline of Measurement Sampling in Homes

| Home | Indoor air | House dust | Measurement location | Floor material | Structure | Region | Dates of measurements |
|------|------------|------------|---------------------|----------------|-----------|--------|------------------------|
| PS1  | PA1        | P1R        | Other room          | PVC sheet      | Wooden    | Pusan  | 2013.8.7 to 8.14       |
|      |            | P1L        | Living room         |                |           | Korea   |                        |
| PS2  | PA2        | P2R        | Other room          | PVC sheet      | Wooden    | Daegu  | 2014.4.17 to 4.23      |
|      |            | P2L        | Living room         |                |           | Korea   |                        |
| PS3  | PA3        | P3R        | Other room          | PVC sheet      | Wooden    |        |                        |
|      |            | P3L        | Living room         |                |           |        |                        |
| PS4  | PA4        | P4R        | Other room          | PVC sheet      | Wooden    |        |                        |
|      |            | P4L        | Living room         |                |           |        |                        |
| DG1  | DA1        | D1R        | Other room          | PVC sheet      |           |        |                        |
|      |            | D1L        | Living room         |                |           |        |                        |
| DG2  | DA2        | D2R        | Other room          | PVC sheet      | Wooden    |        |                        |
|      |            | D2L        | Living room         |                |           |        |                        |
| DG3  | DA3        | D3         | Other room          | Living room    | PVC sheet |        |                        |
|      |            |            |                     |                |           |        |                        |
| DG4  | DA4        | D4         | Other room          | Living room    |           |        |                        |

Table 2. Outline of Measurement Sampling in Kindergarten Facilities

| Kindergartens facility | Indoor air | Dust | Measurement location | Floor material | Structure | Region | Dates of measurements |
|------------------------|------------|------|----------------------|----------------|-----------|--------|------------------------|
| PS-K1                  | PK1        | PD1  | Ordinay classroom    | PVC sheet      | RC        | Pusan  | 2014.8.10 ~ 8.18       |
| PS-K2                  | PK2        | PD2  |                      |                |           | Korea   |                        |
| PS-K3                  | PK3        | PD3  |                      |                |           |        |                        |
| PS-K4                  | PK4        | PD4  |                      |                |           |        |                        |
| PS-K5                  | PK5        | PD5  |                      |                |           |        |                        |
| PS-K6                  | PK6        | PD6  |                      |                |           |        |                        |
2.2 Measurement Methods

1) Room interior air collection method

The SVOC concentration in the room interior air was measured with Tenax TA (180 mg). The samples were collected between 100 and 120 cm above the floor at a rate of 200 mL/min, for 150 minutes. A total of 30 L of air was collected. Since it has been reported that SVOC concentration in indoor air is low in any space, it is not considered to be measured in each room. In this study, for the purpose of confirming the trend of the past studies, it was measured.

2) Dust collection

In both the homes and kindergartens, only dust accumulated on the floor was collected. To collect house dust that accumulated on the floors of the homes for a 3-day period, on the first day, a household vacuum cleaner was used to remove all the house dust that had accumulated on the floor surfaces of each home that was measured. Then the occupants were asked to live their normal daily lives for three days without cleaning their home. On the third day, the house dust of each home was collected. In the case of the kindergarten rooms, assuming that cleaning was done once a day, after lessons were over, dust accumulated on the floor surfaces in ordinary classrooms was collected. The house dust was collected using a collection nozzle developed by the authors. See Reference (Hyun-tae Kim et al. 2010) for the details of this collection nozzle. The collected house dust was filtered to separate all dust particles having diameters smaller than 63 μm, and the SVOC concentration of these dust particles was measured. After dust less than 63 μm was placed in a centrifugal tube, 5 ml of dichloromethane was injected into the separated dust (having diameters smaller than 63 μm) and ultrasonic waves were used to perform solvent extraction for 30 minutes. Afterwards, a syringe filter unit (GL Science: Liquid chro disk (15C)) was used to filter the house dust, and qualitative and quantitative analyses were done using a GC/MS.

2.3 Substances Analyzed and Analysis Method

1) Substances analyzed

Table 3. shows the chemical substances that were analyzed. The chemical substances selected for analysis were SVOC substances that are widely used in plastic products and in building materials. In addition, 2E1H, one of the volatile organic compounds, is included as an analysis substance since it is known to be produced by hydrolysis of DEHP.

Table 3. Outline of Analyzed Chemical Substances

| Substance analyzed | Molecular weight (g/mol) | Molecular structure | Boiling point (°C) | CAS number |
|--------------------|--------------------------|-------------------|-------------------|------------|
| 2-Ethyl-1-Hezanol (2E1H) | 130.3 | C₈H₁₆O | 184~185 | 104-76-7 |
| Dodecamethyl cyclonexasiloxane (D6) | 444.9 | C₁₂H₃₀O₅Si₁₀ | 245 | 540-97-6 |
| Diethyl phthalate (DEP) | 222.2 | C₁₀H₁₀O₄ | 295 | 84-66-2 |
| Tributyl phosphate (TBP) | 266.3 | C₁₀H₁₆P | 289 | 126-73-8 |
| Tris (2-chloroethyl) phosphate (TCEP) | 285.5 | C₆H₁₂ClO₃P | 300 | 115-96-8 |
| Diethyl phthalate (DBP) | 278.3 | C₁₀H₁₀O₄ | 340 | 84-74-2 |
| Triphenyl phosphate (TPP) | 326.3 | C₁₅H₉₃O₅P | 370 | 115-86-6 |
| Dioctyl adipate (DOA) | 370.5 | C₁₂H₂₈O₄ | 335 | 103-23-1 |
| Di (2-ethylhexyl) phthalate (DEHP) | 390.5 | C₁₄H₂₉O₄ | 385 | 117-81-7 |

Table 4. Thermal Desorption Conditions of Tenax TA

| Instrument used | GERSTEL TDS A |
|-----------------|---------------|
| Thermal desorption conditions | 280°C x 10 min. |
| Trap temperature | -60°C |
| Injection temperature | 325°C x 5 min |

Table 5. GC/MS Analysis Conditions

| Instrument used | Agilent 6890N/5973inert |
|-----------------|--------------------------|
| Column | InertCap1MS30mx0.25mm, df=0.25μm |
| Temperature | 50°C(2min)→10°C/min→320°C(5min) |
| GC injection quantity | 1 μL |
| Split ratio | Splitless |
| Measurement mode | SCAN |
| Detector temperature | 230°C |
| SCAN parameter | m/z 29 (Low) – 550 (high) |

Table 6. House Dust GC/MS Conditions

| GC/MS | Shimadzu (Japan) GCMS-QP2010Plus |
|-----------------|----------------------------------|
| Column | InertCap1MS30mx0.25mm, df=0.25μm |
| Temperature | 50°C(2min)→10°C/min→320°C(15min) |
| Injection temp. | 280°C |
| GC injection temperature | 1 μL |
| Split ratio | Splitless |
| Measurement mode | SCAN |
| SCAN parameter | m/z 29 (Low) – 550 (high) |
| Detector temp. | 230°C |

Table 7. Quantification Ion, Confirmation Ion, and Average Recovery Rate of Analyzed Chemical Substances

| Substance | Quantification Ion (m/z) | Confirmation Ion (m/z) | Average recovery rate (%) |
|-----------------|--------------------------|-----------------------|---------------------------|
| 2E1H | 57 | 43 | 100.1 |
| D6 | 73 | 341 | 84.2 |
| DEP | 149 | 177 | 99.7 |
| TBP | 99 | 155 | 107.8 |
| TCEP | 63 | 249 | 96.1 |
| DBP | 149 | - | 101.7 |
| TPP | 326 | 325 | 111.2 |
| DOA | 129 | 57 | 106.7 |
| DEHP | 149 | 167 | 99.5 |
2) Analysis method

Table 4. shows the thermal desorption conditions of the Tenax TA tube used to collect the room interior air, and Table 5. shows the GC/MS conditions. Table 6. shows the GC/MS conditions for the house dust. Table 7. shows the quantification Ion (m/z), confirmation Ion (m/z), and the average recovery rate of each analyzed substance. As standard dust, testing use dust stipulated by Japan Industrial Standard JIS Z 8901 was used. For the recovery rate test, five 0.05 g standard dust samples were prepared, and 4 μL of a standard solution of each analyzed substance (1,000 μg/mL) was added to each sample. Afterwards, the recovery rate of each analyzed substance was confirmed.

3. Measurement Results

3.1 SVOC Concentration in Air

1) SVOC concentration in home air

Table 8. shows the SVOC concentrations in the air of homes that was measured. The TCEP and DOA values were below the detection limit. The detection frequency of TBP was 37% and the detection frequency of TPP was 25%. The substances, 2E1H, D6, DEP, DBP, and DEHP, on the other hand were detected in the air of all measured homes. The average concentration of 2E1H in air was 4.43 μg/m³, and the average concentrations of D6 and DEP in air were 3.14 μg/m³ and 0.19 μg/m³, respectively. The concentration of DBP in the air ranged from 0.22-0.72 μg/m³, and its average concentration was 0.53 μg/m³. The minimum concentration, maximum concentration, and average concentration of DEHP in air were 0.11 μg/m³, 0.50 μg/m³, and 0.28 μg/m³, respectively.

2) SVOC concentrations in kindergarten air

Table 9. shows the SVOC concentrations in the air of kindergartens. The concentrations of TBP, TCEP, TPP, and DOA in the air were below the detection limit. The detection frequencies of 2E1H, D6, DBP, and DEHP on the other hand were 100%. The detection frequency

| Chemical substance | PA1   | PA2   | PA3   | PA4   | DA1   | DA2   | DA3   | DA4   | Min.   | Max.   | Average [%]* |
|--------------------|-------|-------|-------|-------|-------|-------|-------|-------|--------|--------|-------------|
| 2E1H               | 8.26  | 6.00  | 7.13  | 6.67  | 2.57  | 0.91  | 1.65  | 2.28  | 0.91   | 8.26   | 4.43 100   |
| D6                 | 2.72  | 4.67  | 3.69  | 1.47  | 4.33  | 1.48  | 2.42  | 4.33  | 1.47   | 4.67   | 3.14 100   |
| DEP                | 0.12  | 0.31  | 0.21  | 0.09  | 0.38  | 0.07  | 0.16  | 0.13  | 0.07   | 0.38   | 0.19 100   |
| TBP                | 0.14  | 0.18  |       |       | 0.12  |       |       |       | 0.18   | 0.15  37   |
| TCEP               |       |       |       |       |       |       |       |       |        |        0     |
| DBP                | 0.72  | 0.71  | 0.71  | 0.27  | 0.68  | 0.22  | 0.66  | 0.30  | 0.22   | 0.72   | 0.53 100   |
| TPP                |       | 0.12  |       |       |       | 0.15  |       |       | 0.15   | 0.14  25   |
| DOA                |       |       |       |       |       |       |       |       |        |        0     |
| DEHP               | 0.50  | 0.17  | 0.34  | 0.11  | 0.30  | 0.11  | 0.26  | 0.44  | 0.11   | 0.50   | 0.28 100   |

*: Detection frequency
-: Detection limit [<2 ng]

| Chemical substance | PK1   | PK2   | PK3   | PK4   | PK5   | PK6   | Min.   | Max.   | Average [%]|
|--------------------|-------|-------|-------|-------|-------|-------|--------|--------|-------------|
| 2E1H               | 2.04  | 4.00  | 3.33  | 2.67  | 0.64  | 2.11  | 0.64   | 4.00   | 2.46 100   |
| D6                 | 3.33  | 1.97  | 6.00  | 2.83  | 3.33  | 3.05  | 1.97   | 6.00   | 3.42 100   |
| DEP                | 0.25  | 0.27  | 0.11  | 0.14  | 0.09  |       | -      | 0.27   | 0.17 83    |
| TBP                |       |       |       |       |       |       |        |        |            |
| TCEP               |       |       |       |       |       |       |        |        |            |
| DBP                | 0.45  | 0.26  | 0.25  | 0.41  | 0.38  | 0.14  | 0.14   | 0.45   | 0.31 100   |
| TPP                |       |       |       |       |       |       |        |        |            |
| DOA                |       |       |       |       |       |       |        |        |            |
| DEHP               | 0.11  | 0.46  | 0.40  | 0.14  | 0.17  | 0.17  | 0.11   | 0.46   | 0.24 100   |

*: Detection frequency
-: detection limit [<2 ng]

| Chemical substances | P1R   | P1L   | P2R   | P2L   | P3R   | P3L   | P4R   | P4L   | D1R   | D1L   | D2R   | D2L   | D3   | D4   |
|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|
| 2E1H                |       |       |       |       |       |       |       |       |       |       |       |       |      |      |
| D6                  |       |       |       |       |       |       |       |       |       |       |       |       |      |      |
| DEP                 |       |       |       |       |       |       |       |       |       |       |       |       |      |      |
| TBP                 | 25    | 30    | 26    | -     | 20    | 8     | -     | 12    | -     | -     |       |       |      |      |
| TCEP                | 27    | 36    | 29    | 15    | 12    | 10    | 10    | 13    | 38    | 43    | 17    | 14    | 30   | 25   |
| DBP                 | 24    | 20    | 35    | 20    | 30    | 25    | 35    | 25    | 35    | 28    | 58    | 20    | 40   | 35   |
| TPP                 | 15    | 12    | 13    | -     | -     | 25    | 30    | -     | -     | -     | -     |       |      |      |
| DOA                 | 16    | 30    | 25    | 20    | 19    | 15    | 18    | 15    | 30    | 10    | 38    | 30    | 25   | 45   |
| DEHP                | 4500  | 800   | 3900  | 400   | 2800  | 450   | 6700  | 1300  | 4500  | 1100  | 2700  | 660  | 4100 | 5800 |

*: Detection limit [<2 μg]
of DEP was 83%. The concentration of 2E1H in the air ranged from 0.64 - 4.00 μg/m³, and its average concentration was 2.46 μg/m³. The concentration of D6 in air ranged from 1.97 μg/m³ to 6.00 μg/m³, and its average concentration was 3.42 μg/m³. The average concentration of DEP in the air was 0.17 μg/m³. The concentration of DBP in the air ranged from 0.14 μg/m³ to 0.45 μg/m³, and its average concentration was 0.31 μg/m³. The minimum, maximum and average concentration of DEHP in the air were 0.11 μg/m³, 0.46 μg/m³, and 0.24 μg/m³, respectively.

### 3.2 SVOC Concentration in Dust

1) SVOC concentration in house dust of homes

Table 10. shows the SVOC concentrations in the house dust of homes. 2E1H, D6, and DEP were all below the detection limit. The detection frequencies of TBP and TPP were 50% and 43%, respectively. TCEP, DBP, DOA, and DEHP on the other hand, were detected in all house dust. The concentration of TBP and TPP in house dust was 8-30 μg/g and 12-30 μg/g, respectively. The concentration of TCEP in house dust was 10-43 μg/g, and the average concentration was 22.7 μg/g. The concentration of DEHP in house dust ranged from 20-58 μg/g and its average concentration was 31 μg/g. The maximum and average concentrations of DOA in house dust were 45 μg/g and 24 μg/g, respectively. The concentration of DEHP in house dust ranged from 400-6,700 μg/g, and its average concentration was 2,800 μg/g.

2) SVOC concentrations in dust of kindergartens

Table 11. shows the SVOC concentrations in dust from kindergarten rooms. 2E1H, D6, and DEP concentrations were all below the detection limit. TCEP and TPP were detected only in dust from 1 of the 6 sampled kindergarten facilities. TBP and DOA were detected in dust from 4 of the 6 sampled kindergarten facilities. DBP and DEHP, on the other hand, were detected from dust in all kindergarten facilities at a detection frequency of 100%. The concentrations of TBP and DOA in the dust ranged from 18-30 μg/g and from 11-45 μg/g, respectively. The average concentration of DBP in the dust was 61 μg/g. The concentration of DEHP in the dust ranged from 2,500-6,500 μg/g and its average concentration was 4,350 μg/g.

### 4. Discussions

#### 4.1 SVOC Concentrations in Air

The substances, 2E1H, D6, DEP, DBP, and DEHP were detected at high frequencies in the homes and kindergarten rooms measured in this study. Fig. 1. shows the average air concentrations of each chemical substance. 2E1H was measured at a higher concentration in the air of homes than that of kindergarten rooms, but the concentrations of other chemical substances were almost the same. Additionally, the measurements were compared with similar measurements taken in homes and kindergarten facilities in Japan, a country with lifestyles and home environments similar to those of Korea. In the case of newly constructed homes in Japan, as reported by Sakai et al. (2006), the average 2E1H concentration in air was 16.5 μg/m³, an amount about 4 times as high as that found in the results of this study. This suggests that the 2E1H concentration in air might be higher in new homes than in existing homes. Kanazawa et al. (2006) reported medium DBP and DEHP concentrations of 0.88 μg/m³ and 0.49 μg/m³ in the air of ordinary homes in the Tokyo region of Japan. These values did not differ greatly from the corresponding values of this study. Hatano et al. (2014) reported DBP and DEHP concentrations of 0.14 μg/m³ and 0.16 μg/m³, respectively, in air measured from kindergarten rooms in Japan, which are lower than the Korean kindergarten measurements taken in this study.

#### 4.2 SVOC Concentrations in Dust

1) SVOC concentrations in house dust of homes

2E1H, D6, and DEP had measurable concentrations in air, but their house dust concentrations were below the detection limits. Conversely, the concentrations of TBP, TCEP, TPP, and DOA were below the detection limits in air, but were detectable in house dust. However, it was later learned that DBP and DEHP exist in both air and dust. During this fact-finding survey, the authors collected house dust samples according to the type of floor material and analyzed the SVOC concentrations of these samples. They compared the SVOC concentrations of TCEP, DBP, DOA, and DEHP in house dust, which were the frequently detected chemical substances amongst those that were analyzed. Figs. 2.-5. show the concentrations of each

| Chemical substance | PD1 | PD2 | PD3 | PD4 | PD5 | PD6 |
|--------------------|-----|-----|-----|-----|-----|-----|
| 2E1H               | -   | -   | -   | -   | -   | -   |
| D6                 | -   | -   | -   | -   | -   | -   |
| DEP                | -   | -   | -   | -   | -   | -   |
| TBP                | 18  | 20  | -   | 25  | 30  | -   |
| TCEP               | -   | 11  | -   | -   | -   | -   |
| DBP                | 75  | 68  | 70  | 60  | 50  | 45  |
| TPP                | -   | -   | -   | 20  | -   | -   |
| DOA                | 45  | 11  | 11  | 40  | -   | -   |
| DEHP               | 4500| 5600| 3800| 6500| 2500| 3200|

< detection limit [<2 μg]

![Fig.1. Average SVOC Concentrations in Air of Each Chemical Substance](image)
chemical substance in house dust according to type of floor material. The average concentration of TCEP in house dust accumulated on the surfaces of PVC floor material was 23 μg/g, and the average concentration of TCEP in house dust accumulated on wooden type floor materials was 22 μg/g. The average DBP concentrations in house dust were 37 μg/g (PVC) and 23 μg/g (wood), and the average DOA concentrations in house dust were 27 μg/g (PVC) and 20 μg/g (wood). This shows that almost no difference was found between the concentrations of TCEP, DBP, and DOA in house dust according to the type of floor material. On the other hand, the average concentration of DEHP in house dust collected on PVC floor material was 4,310 μg/g, and the average concentration of DEHP in house dust collected on wood floor material was 790 μg/g, thereby showing that the concentration of DEHP in house dust collected from PVC floor material was about 5.5 times higher than the concentration of DEHP in house dust collected from wooden floor material. In addition, the SPSS statistical program analyzed the correlation between the kind of material used on floors and SVOC concentration in house dust; as a result, the p-value of DBP and DEHP were 0.04 and 0.01, respectively; and the correlation between them was high. The study also found that DOA (p-value; 0.09) and TCEP (p-value; 0.39) have a low correlation with the floor material. The findings of the authors' research on the DEHP concentrations in house dust in Japanese homes revealed that the DEHP concentration in house dust is higher in homes with PVC floors than in homes with wood floors, consistent with the trends identified in this study (Kim et al. 2016). Also, it has been widely known that floor materials containing plasticizers have more impact on the dust settled on the floor surface than indoor air; therefore, Koreans who have a tendency to lie and sit directly on the floor are more likely to have a higher risk of SVOC contamination.

2) SVOC concentration in dust of kindergartens

Similar to the results for homes, DBP and DEHP detection frequencies in house dust were 100%. However, although 2E1H, D6, and DEP had detectable concentrations in air, their concentrations in house dust were below the detection limits. Additionally, the detection frequencies of TBP, TCEP, TPP, and DOA in the house dust of homes were low.

As shown in Table 2., PVC building materials are used for PS-K1 in 4 kindergarten classrooms, and wood building materials are used for PS-K5 in 6 kindergarten classrooms. The average concentration of DEHP in dust of kindergarten rooms with PVC floors was 5,100 μg/g, and the average concentration of DEHP in dust of kindergarten rooms with wood floors was 2,850 μg/g. In kindergarten facilities where PVC floor materials were used, the concentration of DEHP in dust was higher than where wood floor materials were used. A comparison of the DEHP concentration in house dust of homes measured in this study shows
that the DEHP concentration of house dust was higher in kindergarten facilities than in homes. The average DEHP concentration of house dust in homes that use wood floor materials in particular was 790 µg/g, but in the case of kindergartens, even when wood floor materials were used, the DEHP concentration of dust was measured to be about 3.6 times as high as that of homes. This difference required an explanation; hence, an analysis was conducted to compare this study with a study that measured the DEHP concentration in dust in Japanese kindergartens (Hatano et al. 2014). Fig. 6 shows the types of floor materials used in various kindergarten facilities and their respective DEHP dust concentrations. From this, it can be seen that concentrations of DEHP in dust in Japanese and Korean kindergartens with PVC floors were high.

5. Conclusions
This study was a fact-finding survey of the SVOC concentration in air and house dust in ordinary homes and in kindergarten facilities in Korea. The substances, 2E1H, D6, and DEP were detected in air, but TBP, TCEP, TPF, and DOA in air were below the detection limit. However, DBP and DEHP were detected in both air and house dust at high detection frequencies. The DEHP concentration in dust was higher than that of the other substances that were analyzed, and the DEHP concentration in the dust of homes and kindergartens with PVC floor materials was higher than in homes and kindergartens with wood floor materials. However, in the case of kindergartens, even those with wood floor materials had high DEHP concentrations, thereby identifying the importance of clarifying the sources of emission in rooms. In the future, it will be necessary to carry out wide-ranging fact-finding surveys of lifestyles, homes, and kindergartens in Korea, in order to evaluate the risk of exposure to SVOCs in rooms.

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References
1) Abb, M, Heinrich, T, Sorkau, E. and Lorenz W. (2009) Phthalates in house dust, Environ. Int., Vol. 35, pp.965-970.
2) Becker, K, Seiwert, M, Angerer, J, Heger, W, Koch, H.M, Nagorka, R, Rosskamp, E, Schluter, C, Seifert, B, and Ullrich, D. (2004) DEHP metabolites in urine of children and DEHP in house dust, Int. J. Hyg. Environ. Health, 207, pp.409-417.
3) Bergh C, Torgrip R, Emeenius G, Östman C. (2010) Organophosphate and phthalate esters in air and settled dust – a multi-location indoor study, Indoor Air, 21, pp.67-76.
4) Bonvallot, N, Mandin, C, Mercier, F, Le Bot, B and Glorennec, P. (2010) Health ranking of ingested semi-volatile organic compounds in house dust, Indoor Air, 20, pp.458-472.
5) Bornenhag, C, Sundell, J. and Weschler, C.J. (2004) The association between asthma and allergic symptoms in children and phthalates in house dust: a nested case-control study, Environ Health Persp., 112, pp.1393-1397.
6) Bornenhag, C.G, Lundgren, B, Weschler, C.J, Sigsgaard, T, Hagerhed-Engman, L. and Sundell, J. (2005) Phthalates in indoor dust and their association with building characteristics, Environ. Health. Persp., 113, pp.1399-1404.
7) Bouhamra, W.S, Bulhamra, S.S. and Thomson, M.S. (1997) Determination of volatile organic compounds in indoor and ambient air of residences in Kuwait, Environ. Int., 23, pp.197-204.
8) Brown, S.K., Sim, M.R., Abramson, M.J., Gray, C.N. (1994) Concentrations of volatile organic compounds in indoor air: a review, Indoor Air, 4, pp.123-134.
9) Clark, K, Cousins, I. and Mackay, D. (2003) Assessment of Critical Exposure Pathways. In: C.A. Staples (Editor) Phthalate Esters: The Handbook of Environmental Chemistry. Vol. 3, Part Q, pp.227-262.
10) Du, Z.J., Mo, J.H., Zhang, Y.P., Xu, Q.J. (2014) Benzene, toluene and xylenes in newly renovated homes and associated health risk in Guangzhou, China, Building and Environ., 72, pp.75-81.
11) Edwards, R.D., Jurvelin, J., Saarela, K. and Jantunen, M. (2001) VOC concentrations measured in personal samples and residential indoor, outdoor, and workplace microenvironments in EXPLIS-Helsinki, Finland, Atoms. Environ., 35, pp.4531-4543.
12) Fay, M, Donohue, J.M. and De Rosa, C. (1999) ATSCR evaluation of health effects of chemicals. VI. Di (2-ethylhexyl) phthalate. Agency for toxic substances and disease registry, Toxic. Ind. Health, 15, pp.651-746.
13) Fromme H, Lahrz T, Piloty M, Gebhart H, Odday A, Ruden H. (2004) Occurrence of phthalates and musk fragrances in indoor air and dust from apartments and kindergartens in Berlin(Germany), Indoor air, 14, pp.188-195.
14) Garrett, M.H., Hooper, M.A. and Hooper, B.M. (1997) Formaldehyde in Australian homes: levels and sources, Clean Air, 31, pp.28-32.
15) Gl sciences Inc.: http://www.gls.co.jp/index.html [Assessed 10 July 2015]
16) Guerin, M, Jenkins, R and Thomkinst, B. (1992) The Chemistry of Environmental Tobacco Smoke, Michigan, Lewis Publisher.
17) Guo, H., Murray, F. and Wilkinson, S. (2000a) Evaluation of total volatile organic compounds emissions form adhesives based on chamber test, J. Air Waste Manage. Assoc., 50, pp.199-206.
18) Guo, H., Kwok, N.H., Cheng, H.R., Lee, S.C., Hung, W.T. and Li, Y.S. (2009b) Formaldehyde and volatile organic compounds in Hong Kong homes: concentration and impact factors, Indoor Air, 19, pp.206-217.
19) Guo, H., Lee, S.C., Li, W.M. and Cao, J.J. (2003c) Source characterization of BTEX in indoor microenvironments in Hong Kong, Atmos. Environ., 37, pp.73-82.
20) Guo, Y. and Kannan, K. (2011) Comparative assessment of human exposure to phthalate esters from dust from house dust in China and the United States, Environ. Sci. Technol, 45, pp.3788-3794.
21) Harrad, S, Gooshey, E, Desborough, J, Abdallah, M.A.E, Roosens, L. and Covaci, A. (2010) Dust from U.K. primary school classrooms and daycare centers: the significance of dust as a pathway of exposure of young U.K. children to brominated flame retardants and polychlorinated biphenyls, Environ. Sci. Technol., 44, pp.4198-4202.
22) Hatano H., Kim H.T., and Tanabe S. (2014) Measurement of SVOC concentration in dust of four child welfare facilities, J. Environ., AII, 79(699), pp.429-434.
23) Japanese Industrial Standards (JIS Z 8901): http://www.jisc.go.jp/app/page/id=2505090, 2006 [Assessed 20 May 2015]
24) Jia, M.L. and Yao, Y.H. (1993) Formaldehyde in conventional homes in Taiwan, Environ. Int., 19, pp.561-568.
25) Kanzawa A. and Kishi R. (2006) Potential risk of indoor Semivolatile Organic Compounds indoors to human health, Jpn. J. Hyg., 64, pp.672-682.
26) Kim H.T., and Tanabe S. (2016) Field measurement of SVOC in indoor air and house dust in residential building, Journal of Environmental Engineering, Architectural institute of Japan, 81(720), pp.199-207.

27) Kim H.T., and Tanabe S., and Okada K. (2010) Measurement of DEHP concentration in house dust in Japan and Korea, Journal of Environmental Engineering, Architectural institute of Japan, 75(654), pp.713-720.

28) Kim, Y.M., Harrad, S. and Harrison, R.M. (2001) Concentration and sources of VOCs in urban domestic and public microenvironments, Environ. Sci. Technol., 35, pp.997-1004.

29) Klepeis, N.E., Nelson, W.C., Ott, W.R., Robinson, J.P., Tsang, A.M., Switzer, P., Behar, J.V., Herr, S.C., Engelmann, W.H. (2001) The national human activity pattern survey (NHAPS): a resource for assessing exposure to environmental pollutants, J Exposure Anal Environ Epidemiol., 11, pp.231-252.

30) Korea, (2003a) Indoor Air Quality Management Act.

31) Korea, (2010b) Ministry of Land, Infrastructure and Transport; http://www.molit.go.kr/ [Assessed 10 July 2013]

32) Lai, H.K., Kendall, M., Ferrier, H., Lindup, I., Aln, S., Haminen, O., Jantunen, M., Mathys, P., Colville, R., Ashmore, M.R., Cullinan, P. and Nieuwenhuijzen, M.J. (2004) Personal exposures and microenvironment concentration of PM2.5, VOC, NO2 and CO in Oxford UK, Atmos. Environ., 38, pp.6399-6410.

33) Larsson, M, Hagerhed-Engman, L, Kolarik, B, James, P, Lundin, F, Clausen, G. (2010) Phthalate and PAH concentrations in dust collected from Danish homes and daycare centers, Atmos. Environ., 44, pp.2294-2301.

34) Larson, M, Hagerhed-Engman, L, Kolarik, B, James, P, Lundin, F, Janson, S, Sundell, J. and Bornehag, C.G. (2010) PVC-as flooring material- and its association with incident asthma in a Swedish child cohort study, Indoor Air, 20, pp.494-501.

35) Lee, S.C., Li, W.M. and Ao, C.H. (2002) Investigation of indoor volatile organic compounds (TVOC) in indoor air quality investigation, Indoor Air, 10, pp.96-101.

36) Lioy, P.J, Freeman, N.C.G. and Millette, J.R. (2002) Dust: a metric for use in residential and building exposure assessment and source characterization, Environ. Health Persp., 110, pp.969-983.

37) Mendell, M.J. (2007) Indoor residential chemical emissions as risk factors for respiratory and allergic effects in children: a review, Indoor Air, 17, pp.259-277.

38) Mendell, M.J. (1993) Non-specific symptoms in office workers. A review and summary of the epidemiologic literature, Indoor Air, 3, pp.227-236.

39) Molhave, L. (1991) Volatile organic compounds, indoor air quality and health, Indoor Air, 1, pp.357-376.

40) Molhave, L., Clausen, G., Berglund, B., De Ceaurriz, J., Ketrup, A., Lindvall, T., Maroni, M., Pickering, A.C., Risse, H., Rothweiler, H., Seifert, B. and Younes, M. (1997) Total volatile organic compounds (TVOC) in indoor air quality investigation, Indoor Air, 7, pp.225-240.

41) Nielsen, G.D., Larsen, S.T., Ols, E., Pavl, M., Poulsen, L.K., Glue, C., Wolff, P. (2007) Do indoor chemicals promote development of airway allergy?, Indoor Air, 17, pp.236-255.

42) Park, J.S., and Ikeda, K. (2004) Exposure to mixtures of organic compounds in homes in Japan, Indoor Air, 14, pp.413-420.

43) Plaisance, H., Blondel, A., Desauziers, V., Meho, P. (2014) Hierarchical cluster analysis of carbonyl compounds emission profiles from building and furniture materials, Building and Environ., 75, pp.40-45.

44) Risto, K. (1997) Volatile organic compounds in the indoor air of normal and sick house, Atmos. Environ., 29, pp.693-702.

45) Sakai, K., Kamijima, M., Shibata, E., Ohno, H. and Nakajima, T. (2006) Indoor air pollution by 2-ethyl-1-hexanol in non-domestic building in Nagoya Japan, J. Environ. Monit., 8, pp.1122-1128.

46) Salzhammer, T., Mentese, S., Marutzky, R. (2010) Formaldehyde in the indoor environment, Chem Rev., 110, pp.2536-2572.