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Indoor Air Monitoring of Volatile Organic Compounds and Evaluation of Their Emission from Various Building Materials and Common Products by Gas Chromatography-Mass Spectrometry

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1. Introduction

In recent years, increased numbers of people entering modern buildings complain of various symptoms such as dry mucous membranes and skin; irritation of eyes, nose, and throat; chest tightness; headache; and mental fatigue (Kirkeskov et al., 2009). These nonspecific health problems related to indoor environments are caused by volatile organic compounds (VOCs) emitted from various sources such as building materials (Haghighat et al., 2002; Lee et al., 2005; Claeson et al., 2007; Nicolle et al., 2008; Han et al., 2010; Jia et al., 2010), household materials (Kwon et al. 2008), and combusted materials (Liu et al., 2003; Ye, 2008; Fromme et al., 2009; Kabir & Kim, 2011). VOCs are widely used in many household products and are emitted by paints (Afshari et al., 2003; Wieslander & Norbäck, 2010; Chang et al., 2011), adhesives (Wilke et al., 2004), waxes, solvents, detergents, woods (Jensen et al., 2001; Kirkeskov et al., 2009), and items containing them, including carpets (Katsoyiannis et al., 2008), vinyl flooring (Cox et al., 2001 and 2002), air-conditioners (Tham et al., 2004), newspapers (Caselli et al. 2009), printers and photocopiers (Lee et al., 2006). VOCs emitted by these materials can be classified as primary or secondary. Primary emissions are emissions of non-bound or free VOCs within building materials; these are generally low molecular weight compounds utilized in additives, solvents and unreacted raw materials like monomers. Secondary emissions refer to VOCs that were originally chemically or physically bound, and are usually generated following decomposition, oxidation, chain scission, sorption processes, maintenance, or microbial action, followed by their emission (Pedersen et al., 2003; Lee et al., 2005; Wady & Larsson, 2005; Araki et al., 2009 and 2010).

Indoor air quality (Tumbiolo et al., 2005; Salthammer, 2011) has been assessed in various environments, including non-residential buildings (Abbritti & Muzi, 2006; Bruno et al., 2008; Barro et al., 2009; Massolo et al., 2010), residences (Son et al., 2003; Hippelein, 2004; Sax et al., 2004; Ohura et al., 2006; Yamaguchi et al., 2006; Dodson et al., 2009; Liu et al., 2008; Takigawa et al., 2010; Logue et al., 2011), schools (Adgate et al., 2004a; Sohn et al., 2009), hospitals (Takigawa et al., 2004), stores and restaurants (Vainiotalo et al., 2008; Loh et al., 2009). VOCs are regarded as one of the main causes of "sick building syndrome (SBS)" (Harada et al., 2007; Glas et al., 2008; Takeda et al., 2009), and exposure to high concentrations of VOCs can lead to adverse health effects such as acute and chronic respiratory effects, functional alterations of the central nervous system, mucous and dermal irritations, chromosome aberrations, and cancer (Boeglin et al., 2006; Rumchev et al., 2007; Sarigiannis et al., 2011; Zhou et al., 2011). SBS is a serious problem in Japan, and the Ministry of Health, Labour and Welfare (MHLW) of Japan (2002) has advised that total VOC (TVOC) be limited to 400 μg/m^3. This TVOC value, however, was not based on the possible effects of long-term exposure on chronic toxicity. Furthermore, air concentrations of VOCs are generally lower in the home than in the workplace (Larroque et al., 2006; LeBouf et al., 2010), and symptoms related to these low indoor VOC levels and their emission sources are not sufficiently clear. To systematically evaluate the relationship between indoor air pollution and human exposure to VOCs (Gokhale et al., 2008; Delgado-Saborit et al., 2011), it is important to measure VOCs in indoor environments, to assess their possible sources and to determine the source strengths of VOCs to which humans are exposed during working, commuting and rest times. In this chapter, we describe a sensitive and reliable method for the simultaneous determination of VOCs by gas chromatography-mass spectrometry (GC-MS). Using this method, we measured the VOC levels in indoor air of a new building, and we characterized the VOCs emitted from various building materials and common household products.

2. Experimental

2.1 Reagents

A 1 mg/mL standard solution of 39 VOCs (Table 1) in carbon disulfide (CS_2) was purchased from Kanto Kagaku (Tokyo, Japan). All other chemicals were of analytical-reagent grade.

2.2 Gas chromatography-mass spectrometry

GC-MS analysis was performed using a Shimadzu Model QP-2010 gas chromatograph-mass spectrometer in conjunction with a GCMS solution Ver.2 workstation. A fused-silica capillary column of cross-linked DB-1 (J&W, Folsom, CA, USA: 60 m × 0.25 mm i.d., 1.0 μm film thickness) was used. The GC operating conditions included injection and detector temperatures of 260°C; a column temperature of 40°C for 10 min, increasing to 280°C at 8°C/min; an inlet helium carrier gas flow rate of 1.0 mL/min maintained with an electronic pressure controller; and a split ratio of 10:1. The electro impact (EI)-MS conditions included an ion-source temperature of 200°C; ionizing voltage of 70 eV; and selected ion monitoring (SIM) mode detection for each compound in each time fraction. Selected ions and peak numbers of each VOC are shown in Table 1. The 39 VOCs were separated into 8 functional groups (A-H), and the results obtained by an average of duplicate analyses were reported as the total concentrations of target VOCs in each group.

Table 1. VOCs used in this study

Peak	Retention time (min)	Selected ion (m/z)	VOCs	Group[1)]	Peak	Retention time (min)	Selected ion (m/z)	VOCs	Group[1)]
1	12-13.5	61	Ethyl acetate	E	20	22.5-25	91	*m*-Xylene + *p*-Xylene	A
2		57	*n*-Hexane	B	21		104	Styrene	A
3		83	Chloroform	C	22		91	*o*-Xylene	A
4	13.5-16	62	1,2-Dichloroethane	C	23		43	*n*-Nonane	B
5		43	2,4-Dimethyl-pentane	B	24	25-28.5	93	α-Pinene	H
6		97	1,1,1-Trichloroethane	C	25		105	1,2,3-Trimethyl-benzene	A
7		56	*n*-Butanol	D	26		43	*n*-Decane	B
8		78	Benzene	A	27		146	*p*-Dichloro-benzene	C
9		117	Carbon tetrachloride	C	28		105	1,2,4-Trimethyl-benzene	A
10	16-19	63	1,2-Dichloro-propane	C	29		68	Limonene	H
11		57	2,2,4-Trimethyl-pentane	B	30	28.5-30.5	41	*n*-Nonanal	F
12		43	*n*-Heptane	B	31		43	*n*-Undecane	B
13		43	Methyli-sobutylketone	G	32		119	1,2,4,5-Tetramethyl-benzene	A
14	19-22.5	91	Toluene	A	33	30.5-40	43	*n*-Decanal	F
15		129	Chlorodibromomethane	C	34		43	*n*-Dodecane	B
16		43	Butyl acetate	E	35		43	*n*-Tridecane	B
17		43	*n*-Octane	B	36		43	*n*-Tetra-decane	B
18		166	Tetrachloro-ethylene	C	37		57	*n*-Penta-decane	B
19	22.5-25	91	Ethylbenzene	A	38		57	*n*-Hexa-decane	B

[1)] A: aromatic hydrocarbon, B: aliphatic hydrocarbon, C: halocarbon, D: alcohol, E: ester, F: aldehyde, G: ketone, H: terpene.

2.3 Sampling and analysis of indoor air VOCs

Indoor air quality in 13 rooms in a newly built hospital was assessed by active air sampling and VOC analysis before the hospital was opened (in March) and after one year later (in May). In addition, indoor air VOC monitoring was performed in another newly constructed hospital and in a newly constructed school (in March). This new hospital was built without using adhesives in all floors and walls. The mean room temperature and relative humidity of the rooms were 14°C and 65%, respectively, in March and 25.0°C and 42%, respectively, in May. Active sampling was performed using charcoal sorbent tubes (glass tubes with two sections, 130 mg in front and 65 mg in back; Shibata Kagaku, Tokyo, Japan) and a sampling pump (SP-208 Dual, GL Science Inc., Tokyo, Japan), using the standard method of the MHLW. To enable measuring maximum indoor chemical concentrations, sampling was performed in a room that had been closed for more than 5 h following ventilation. From when ventilation occurred to sampling, all doors of built-in furniture in the room were open. In the center of the room (more than 1 m from the wall and 1.2-1.5 m above the floor), VOCs were collected from air onto charcoal sorbent tubes in duplicate, at a flow-rate of 0.2 L/min for 0.5 h in newly constructed building (before occupation) and at a flow-rate of 6 L/h for 24 h after occupation for one year. As controls, VOCs in the air were also trapped outside, 2-5 m from the building and 1.2-1.5 m above the ground. All samples were sealed in a container with an activated carbon bed, stored in an insulated container, and shipped to our laboratory. The front charcoal sorbent was desorbed with 1 mL of CS_2 by shaking and standing for 1 h. After centrifugation at 3000 rpm for 1 min, the supernatant CS_2 solution was transferred to an autosampler vial, and 1 µL of this solution was injected into the GC-MS system. Outlines of indoor air sampling and the analytical procedure are illustrated in Fig. 1.

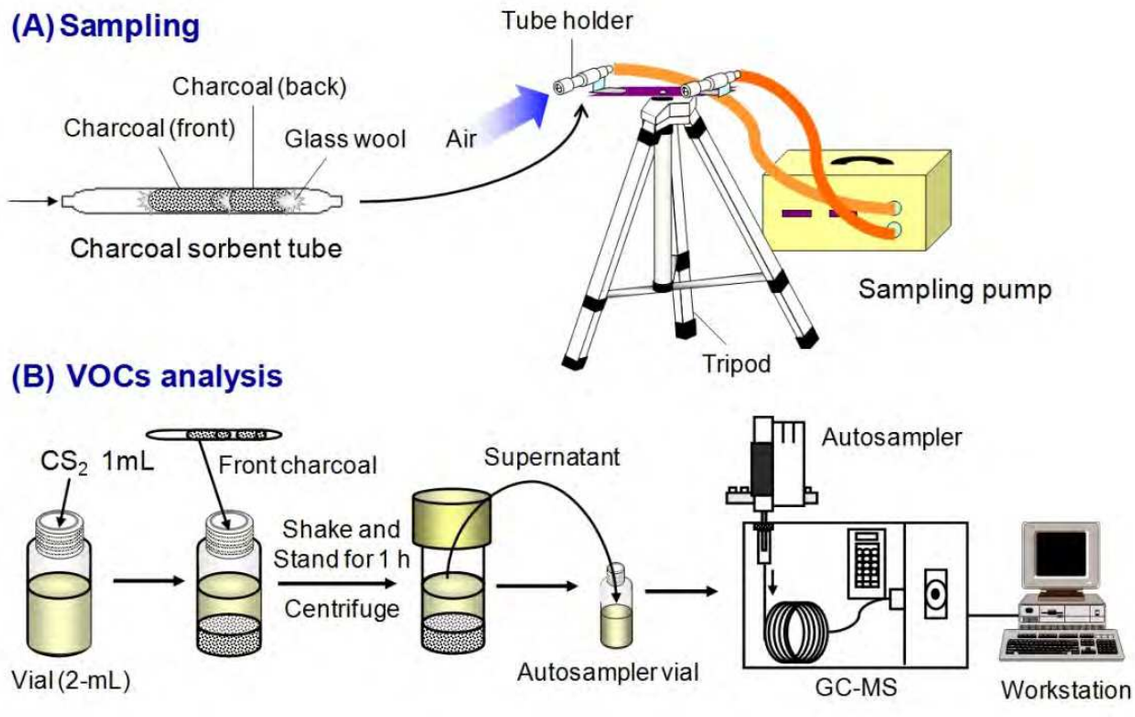

Fig. 1. Outline of indoor air sampling and VOC analysis.

2.4 Sampling and analysis of VOCs emitted from various building materials and common products

VOC emission tests were performed on 16 building materials and 31 common household products, including school supplies, purchased from a local market. Some photographs of these materials are shown in Fig. 2. Woods and hard plastic products were sawn and the sawdust was used for emission tests. Other dry materials, such as carpet, wall paper, newspaper and soft plastic products, were cut finely with scissors or a knife, and the cut pieces were used for emission tests. Wet materials, such as paint, wax, shampoo, glue, paste and ink, were used directly for emission test. Fifteen g of each material were placed in a cleaned small chamber (500-mL volume), and the emitted VOCs were collected onto charcoal sorbent tubes (Shibata Kagaku) by absorption of headspace air using an air sampling pump at a flow-rate of 500 mL/min for 6 h. The adsorbed VOCs on charcoal sorbent were desorbed with 1 mL of CS_2 as described in section 2.3 and analyzed by GC-MS. The VOCs emitted by each material were reported per 180 L. An outline of the emission test is illustrated in Fig. 3.

Fig. 2. Several building materials and common products used for emission test.

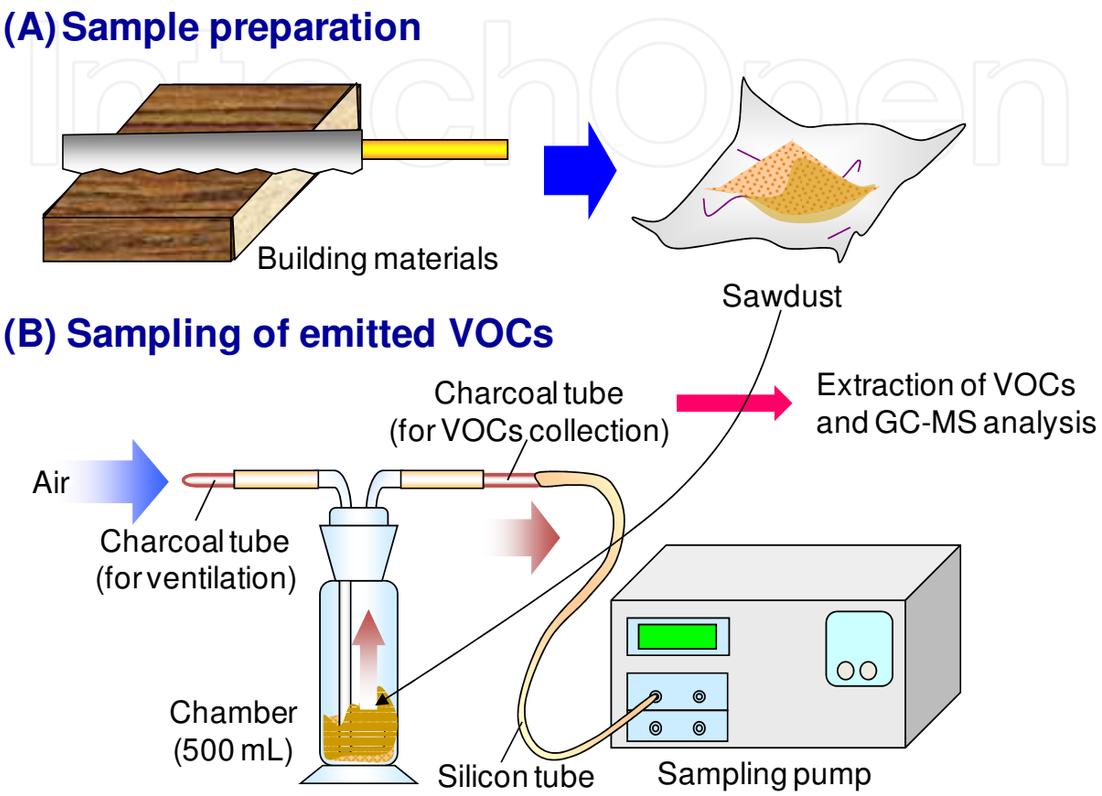

Fig. 3. Outline of emission test.

3. Results and discussion

3.1 GC-MS analysis of VOCs

Mass spectra of VOCs were confirmed by scan mode detection. Although molecular ion peaks of each VOC were observed, the base ion peaks shown in Table 1 were selected for SIM mode detection. The GC-MS method was selective and sensitive, with all 39 VOCs separated on a DB-1 capillary column within 40 min. A typical total ion chromatogram of the VOCs is shown in Fig. 4. The calibration curve for each VOC was linear ($r>0.9992$) in a range from 0.1 to 10 μg/mL CS_2, and the limits of detection (LOD) that gave a signal-to-noise ratio of 3 were 0.4-13.4 ng/mL CS_2 (Table 2).

VOCs	Range [1] (μg/mL CS_2)	Correlation coefficient	LOD [2] (ng/mL CS_2)	LOQ [3] (μg/m^3 for 30 min)
Ethyl acetate	0.1-2.0	0.9993	13.4	21.1
n-Hexane	0.1-2.0	0.9996	4.4	11.5
Chloroform	0.1-2.0	0.9995	4.5	31.3
1,2-Dichloroethane	0.1-2.0	0.9994	2.3	34.7
2,4-Dimethylpentane	0.1-2.0	0.9995	0.7	10.9
1,1,1-Trichloroethane	0.1-2.0	0.9994	8.0	35.7
n-Butanol	0.1-2.0	0.9994	12.4	28.5
Benzene	0.1-2.0	0.9998	2.0	19.4
Carbon tetrachloride	0.1-2.0	0.9992	3.9	44.8
1,2-Dichloropropane	0.1-2.0	0.9992	0.5	25.0
2,2,4-Trimethylpentane	0.1-2.0	0.9996	0.9	11.7
n-Heptane	0.1-2.0	0.9995	0.2	13.7
Methylisobutylketone	0.1-2.0	0.9998	1.3	17.3
Toluene	0.1-10	0.9994	0.4	24.6
Chlorodibromomethane	0.1-2.0	0.9997	1.3	87.5
Butyl acetate	0.1-2.0	0.9997	1.1	19.5
n-Octane	0.1-2.0	0.9994	1.6	15.6
Tetrachloroethylene	0.1-2.0	0.9996	1.8	50.5
Ethylbenzene	0.1-10	0.9996	0.6	27.9
m-Xylene + *p*-Xylene	0.1-10	0.9997	0.7	18.0
Styrene	0.1-2.0	0.9997	0.6	30.4
o-Xylene	0.1-10	0.9997	0.4	29.2
n-Nonane	0.1-2.0	0.9998	1.5	16.1
a-Pinene	0.1-2.0	0.9998	0.8	27.3
1,2,3-Trimethylbenzene	0.1-2.0	0.9998	0.4	31.3
n-Decane	0.1-2.0	0.9996	1.4	13.2
p-Dichlorobenzene	0.1-2.0	0.9998	0.5	42.6
1,2,4-Trimethylbenzene	0.1-2.0	0.9998	0.5	38.6
Limonene	0.1-2.0	0.9998	1.1	25.6
n-Nonanal	0.1-2.0	0.9998	2.8	31.0
n-Undecane	0.1-2.0	0.9995	1.5	17.9
1,2,4,5-Tetramethylbenzene	0.1-2.0	0.9998	0.6	34.7
n-Decanal	0.1-2.0	0.9994	3.9	32.0
n-Dodecane	0.1-2.0	0.9994	1.0	16.7
n-Tridecane	0.1-2.0	0.9992	2.1	17.2
n-Tetradecane	0.1-2.0	0.9994	1.4	18.0
n-Pentadecane	0.1-2.0	0.9996	2.4	19.5
n-Hexadecane	0.1-2.0	0.9995	2.3	20.2

[1] Range 0.1-2.0 μg/mL (*n*=12), range 0.1-10 μg/mL (*n*=18); [2] S/N=3; [3] S/N=10.

Table 2. Linearity of calibration, limits of detection and limits of quantitation of target VOCs

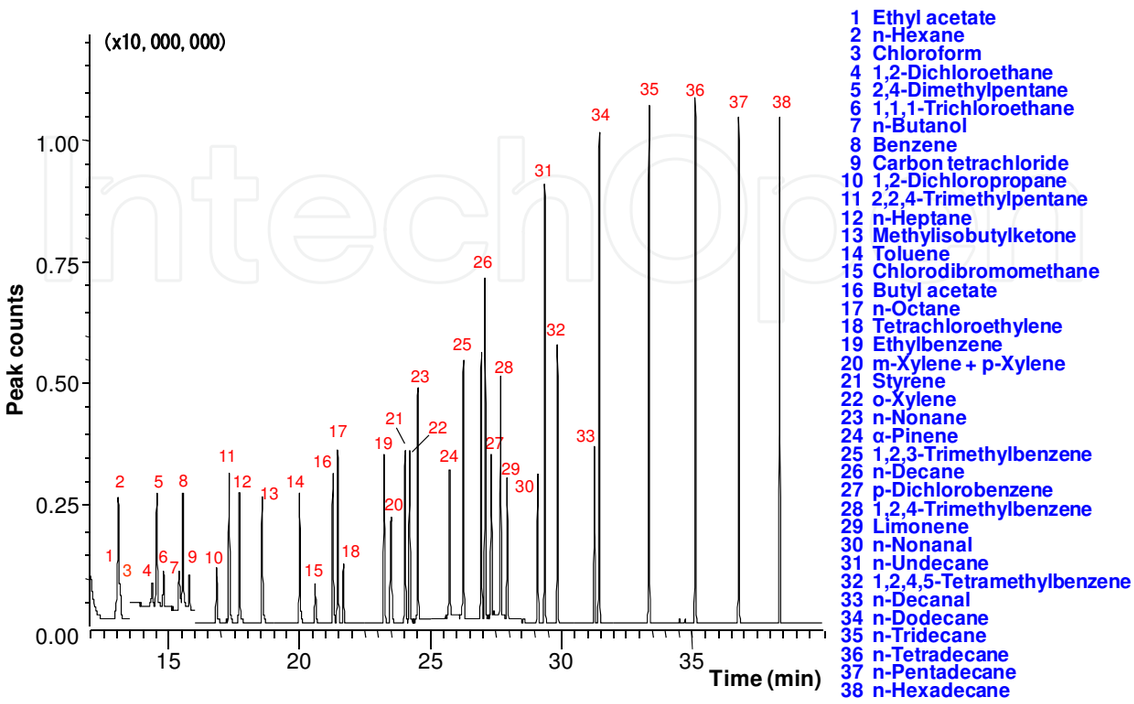

Fig. 4. Typical total ion chromatogram obtained from standard VOCs including 1 μg/mL of each compound.

3.2 Indoor air monitoring of VOCs in newly built buildings

Indoor air VOCs were easily trapped onto charcoal sorbent by the MHLW standard method, with limits of quantitation (LOQ) of VOCs being 10.9-87.5 μg/m^3 for 30 min (Table 2). Using this method, we measured the indoor air VOC concentrations in 13 rooms in a newly built, 10 story hospital before occupation and after occupation for one year (Tables 3 and 4). VOC levels varied depending on the presence of indoor building materials, such as paint and furniture. VOCs were not detected, in air sampling obtained once daily from one site outside the hospital. Prior to the building being occupied, aromatic hydrocarbons (toluene, xylenes and ethylbenzene), aliphatic hydrocarbons (mainly *n*-hexane) and esters (ethyl acetate and butyl acetate) were detected with TVOC concentrations exceeding the recommended maximum concentration (400 μg/m^3) in 12 of 13 rooms (Fig. 5). Particularly, toluene was detected in all rooms and its concentration exceeded the MHLW recommended maximum concentration (260 μg/m^3) in 12 rooms. One year after occupation, however, the TVOC concentrations in the same rooms were below 80 μg/m^3, and the indoor levels of toluene and *n*-hexane decreased dramatically, to about 1/100 and 1/60, respectively, of their previous values. **Table 3.** Indoor air VOC amounts in 13 rooms of newly built hospital prior to occupation.

VOCs	VOC amounts in indoor air (μg/ m³) [1]/ sampling at 0.2 L/ min for 30 min											
	Guidance room	Doctor office	Radiograph room	10F Lounge	6A Nurse station	6B Nurse station	7A Nurse station	8A Nurse station	8B Nurse station	9A Nurse station	9B Nurse station	10A Nurse station	10B Nurse station
Ethyl acetate	ND[2]	ND	255	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Hexane	ND	263	ND	ND	ND	111	ND	ND	ND	ND	ND	362	417
Chloroform	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-Dimethylpentane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Butanol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Carbon tetrachloride	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloropropane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2,4-Trimethylpentane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Heptane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methylisobutylketone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	218	682	605	640	355	785	1051	420	1733	847	934	850	1494
Chlorodibromomethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Butyl acetate	ND	ND	ND	ND	618	272	ND	ND	ND	ND	ND	ND	ND
n-Octane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene	ND	186	ND	ND	712	317	160	ND	ND	ND	ND	ND	ND
m-Xylene + *p*-Xylene	ND	ND	ND	ND	744	476	460	ND	ND	ND	ND	ND	ND
Styrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
o-Xylene	ND	ND	ND	ND	250	ND	ND	ND	ND	ND	ND	ND	ND
n-Nonane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
α-Pinene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2,3-Trimethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Decane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
p-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2,4-Trimethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Limonene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Nonanal	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Undecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2,4,5-Tetramethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Decanal	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Dodecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Tridecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Tetradecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Pentadecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Hexadecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[1] Mean of duplicate analysis; [2] Not detectable.

Table 3. Indoor air VOC amounts in 13 rooms of newly built hospital prior to occupation.

VOCs	VOC amounts in indoor air (μg/ m³) [1]/ sampling at 0.2 L/ min for 30 min											
	Guidance room	Doctor office	Radiograph room	10F Lounge	6A Nurse station	6B Nurse station	7A Nurse station	8A Nurse station	8B Nurse station	9A Nurse station	9B Nurse station	10A Nurse station	10B Nurse station
Ethyl acetate	9.0	6.9	7.1	11.7	5.32	11.5	10.8	2.1	ND	3.5	3.1	6.1	8.5
n-Hexane	2.5	ND	1.9	6.0	ND	47.4	22.7	ND	ND	2.3	1.0	1.9	5.9
Chloroform	ND[2]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-Dimethylpentane	ND	ND	0.9	0.8	ND	3.0	1.8	ND	ND	0.5	ND	0.8	1.0
1,1,1-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Butanol	4.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	2.7	ND	2.0	2.3	ND	ND	ND	1.2	0.9	1.1	1.1	1.1	2.2
Carbon tetrachloride	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloropropane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2,4-Trimethylpentane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Heptane	1.1	ND	ND	1.3	ND	ND	ND	ND	ND	ND	ND	ND	1.2
Methylisobutylketone	2.2	ND	ND	1.6	1.6	1.8	2.1	ND	ND	ND	ND	ND	ND
Toluene	12.9	8.8	8.5	9.8	4.7	8.7	10.0	5.3	5.6	4.6	3.8	7.5	15.6
Chlorodibromomethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Butyl acetate	2.1	2.8	1.4	1.9	0.7	1.4	1.4	ND	ND	ND	ND	1.5	2.2
n-Octane	ND	ND	ND	1.4	ND	ND	ND	ND	ND	ND	ND	ND	1.3
Tetrachloroethylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene	3.4	2.3	3.0	3.3	ND	2.0	1.8	1.3	1.9	1.1	1.5	1.7	4.3
m-Xylene + *p*-Xylene	3.9	3.8	2.5	3.2	ND	1.4	2.1	2.1	2.2	1.7	1.9	2.4	4.6
Styrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
o-Xylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.8
n-Nonane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
α-Pinene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2,3-Trimethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Decane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.1
p-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2,4-Trimethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Limonene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Nonanal	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Undecane	ND	ND	ND	1.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2,4,5-Tetramethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Decanal	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Dodecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Tridecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Tetradecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Pentadecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Hexadecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[1] Mean of duplicate analysis; [2] Not detectable.

Table 4. Indoor air VOC amounts in 13 rooms of newly built hospital after occupation for one year.

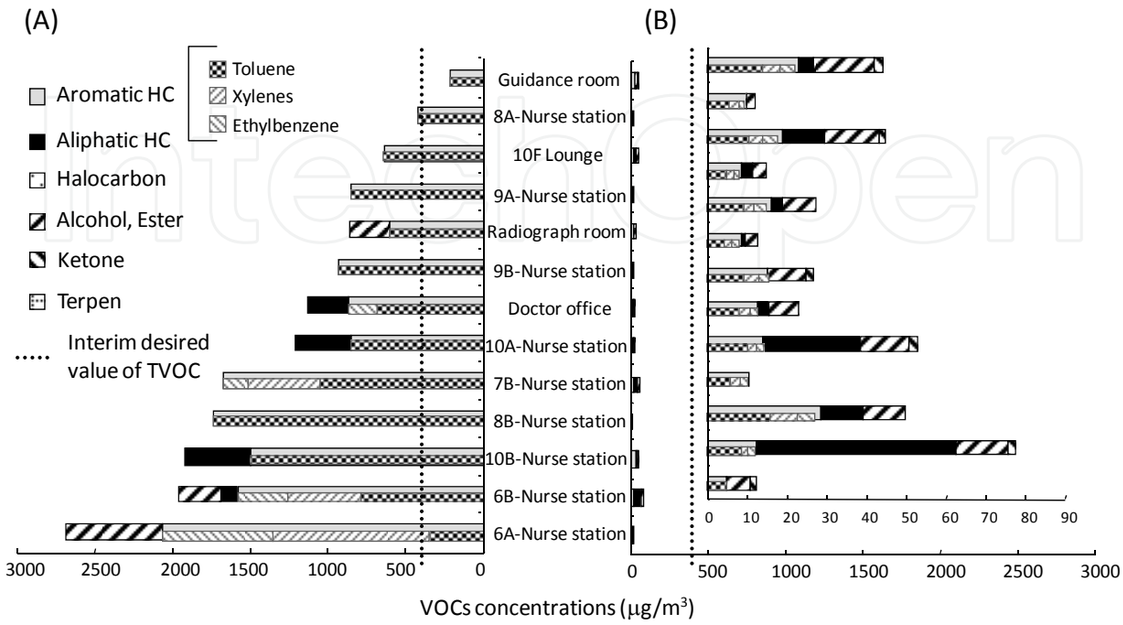

Fig. 5. Comparison of indoor air VOC amounts in 13 rooms of a newly built hospital (A) prior to occupation and (B) after occupation for one year. Air sampling: (A) 0.2 L/min × 30 min and (B) 6 L/h × 24 h.

We also evaluated the relationships among environmental, personal, and occupational factors and changes in the subjective health symptoms in 214 hospital employees (Takigawa et al., 2004). Multiple logistic regression analysis was applied to select variables significantly associated with subjective symptoms that can be induced by SBS. Subjective symptoms of deterioration in the skin, eyes, ears, throat, chest, central nervous system, autonomic system, musculoskeletal system, and digestive system among employees were associated mainly with gender differences and high TVOC concentrations (>1200 μg/m^3). These findings suggest the importance of reducing indoor air VOCs in new buildings to protect employees from the risks of indoor environment-related adverse health effects.

Indoor air VOCs were also measured in unoccupied new buildings, including another newly built hospital that attempted to reduce SBS by not using adhesives in all floors and walls. As shown in Fig. 6A, VOCs were not detected in any rooms or corridors of this hospital. In contrast, TVOC concentrations exceeded the recommended maximum value (400 μg/m^3) in 4 of 10 rooms of a newly built school (Fig. 6B), whereas VOCs were not detected in the other 4 rooms. In 4 rooms, the concentrations of toluene were high, and exceeding the guideline value (260 μg/m^3) of the MHLW. Furthermore, relatively high concentrations of esters (ethyl acetate and butyl acetate) were detected in 4 rooms.

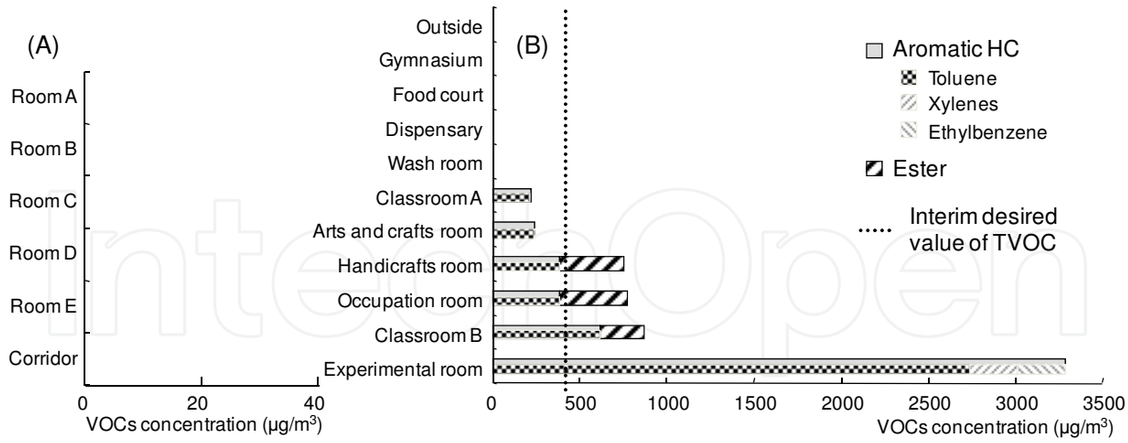

Fig. 6. Indoor air VOC concentrations in rooms of the unoccupied new buildings, (A) a newly built hospital designed to prevent SBS and (B) a newly built school. Air sampling: 0.2 L/min × 30 min

The occurrence and concentrations of VOCs in indoor environments can be affected by outdoor atmospheric conditions, indoor sources, indoor volume, human activities, chemical reactions, ventilation rates, and seasonal factors (Son et al., 2003; Schlink et al., 2004; Massolo et al., 2010). Indoor VOC concentrations have decreased recently in Japan and may be easily reduced by sufficient ventilation and SBS measures. However, measurement of VOC exposure in households with children (Adgate et al., 2004a, b; Sohn et al., 2009) suggested a significant association between VOC exposure and respiratory symptoms such as childhood asthma (Khalequzzaman et al., 2007; Hulin et al., 2010). These findings indicate the necessity of frequent monitoring of VOC exposure in children.

3.3 Emission of VOCs from various building materials and household products

Although various VOCs were detected in newly constructed buildings, they were not detected in the building that took measures to avoid SBS. Therefore, to determine the causal relationship between VOC exposure and SBS onset, it is important to determine the types of building materials and household products that emit VOCs, and the type and quality of VOCs emitted. We therefore collected the VOCs emitted by 16 building materials and 31 household products by a small chamber sampling method (Fig. 3). These emitted VOCs were quantitatively collected onto charcoal sorbent tubes at a flow-rate of 0.5 L/min for 6 h and analyzed by GC-MS.

While there was little emission of VOCs from rush floor mats and ceiling board materials, toluene, chloroform, ethyl acetate, and *n*-hexane were detected in wood chipboard, vinyl wall paper, and vinyl floor mats (Table 5 and Fig. 7). These VOCs may have originated from adhesives and painting materials, which are used to manufacture these products. We found that water-based paints emitted significant amounts of toluene, xylenes, *n*-butanol and high-molecular weight aliphatic hydrocarbons. These quantities emitted may depend on the thickness of the paint layer (Afshari et al., 2003). Some components in these emissions are also highly reactive and may contribute to the health damage.

VOCs	Amounts of VOCs from sample (μg/ 180 L/ 15 g) [1]/ sampling at 0.5 L/ min for 6 h														
	Ceiling board	Gypsum board	Laminated lumber	Plywood	Wood chipboard	Wall paper	Vinyl wall paper (A)	Vinyl wall paper (B)	Rush floor mats	Vinyl floor mats (A)	Vinyl floor mats (B)	Polyester carpets	Floor wax (A)	Floor wax (B)	Adhesive	Water-based paint
Ethyl acetate	ND [2]	1.07	ND	ND	19.59	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Hexane	ND	1.91	ND	1.17	ND	5.18	0.91	ND	ND	1.51	1.56	1.18	N.D.	5.74	0.56	ND
Chloroform	ND	1.32	ND	1.37	ND	ND	2.80	0.91	ND	ND	ND	3.06	2.35	ND	1.23	ND
1,2-Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-Dimethylpentane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-Trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Butanol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	176.55
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.28	ND	ND	ND	ND	ND	ND
Carbon tetrachloride	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloropropane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2,4-Trimethylpentane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Heptane	ND	ND	ND	ND	ND	ND	ND	0.46	ND	ND	ND	ND	ND	ND	ND	8.67
Methylisobutylketone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	73.50
Toluene	ND	ND	ND	197	13.91	ND	1.32	0.71	ND	0.93	1.49	0.54	ND	ND	ND	649.64
Chlorodibromomethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Butyl acetate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Octane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	67.94
m-Xylene + *p*-Xylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	58.89
Styrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
o-Xylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.31	ND	ND	ND	ND	23.68
n-Nonane	ND	ND	ND	ND	ND	ND	ND	8.94	ND	ND	ND	ND	ND	ND	ND	27.08
α-Pinene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.81	9.66	ND	ND	ND	ND
1,2,3-Trimethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Decane	ND	ND	ND	ND	ND	ND	ND	32.21	ND	ND	ND	ND	ND	ND	ND	88.04
p-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2,4-Trimethylbenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Limonene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Nonanal	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Undecane	ND	ND	ND	ND	ND	ND	ND	6.38	ND	ND	ND	ND	ND	ND	ND	ND
1,2,4,5-Tetramethylbenzene	ND	ND	ND	ND	ND	ND	ND	4.11	ND	ND	ND	ND	ND	ND	ND	ND
n-Decanal	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Dodecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.41	ND	ND	ND
n-Tridecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.68	ND	ND	9.44	ND	ND
n-Tetradecane	ND	ND	ND	ND	ND	ND	ND	1.25	ND	ND	ND	ND	1.56	18.62	ND	ND
n-Pentadecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	27.35	ND	ND
n-Hexadecane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	27.59	ND	ND

[1] Mean of duplicate analysis; [2] Not detectable.

Table 5. Amounts of VOCs emitted from various building materials.

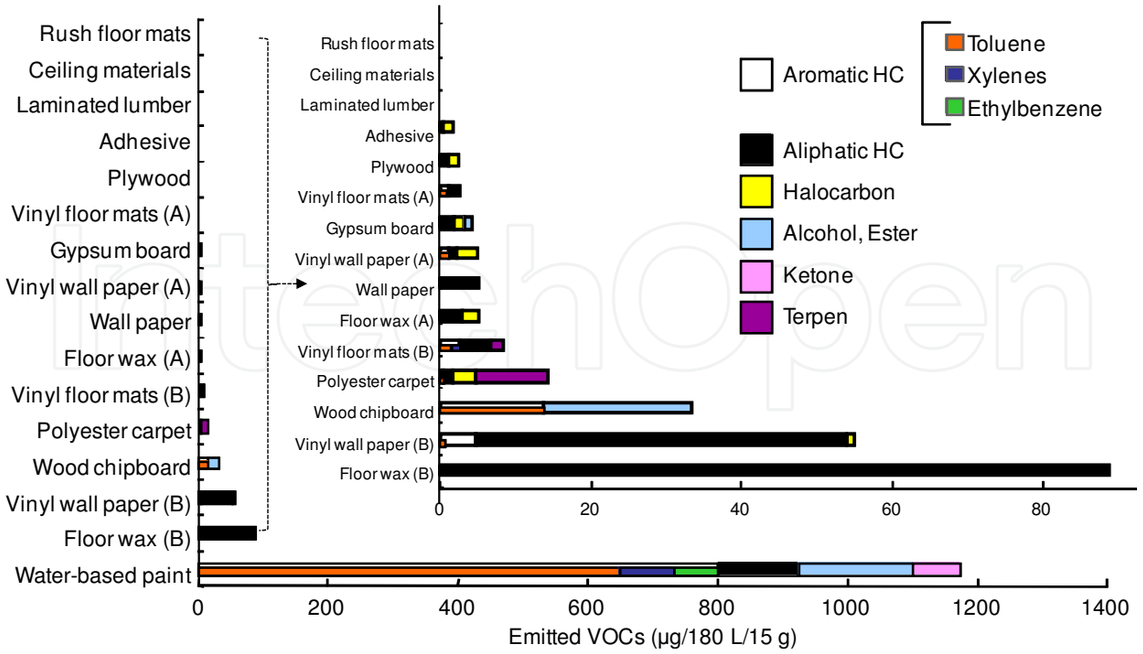

Fig. 7. VOCs emitted from various building materials.

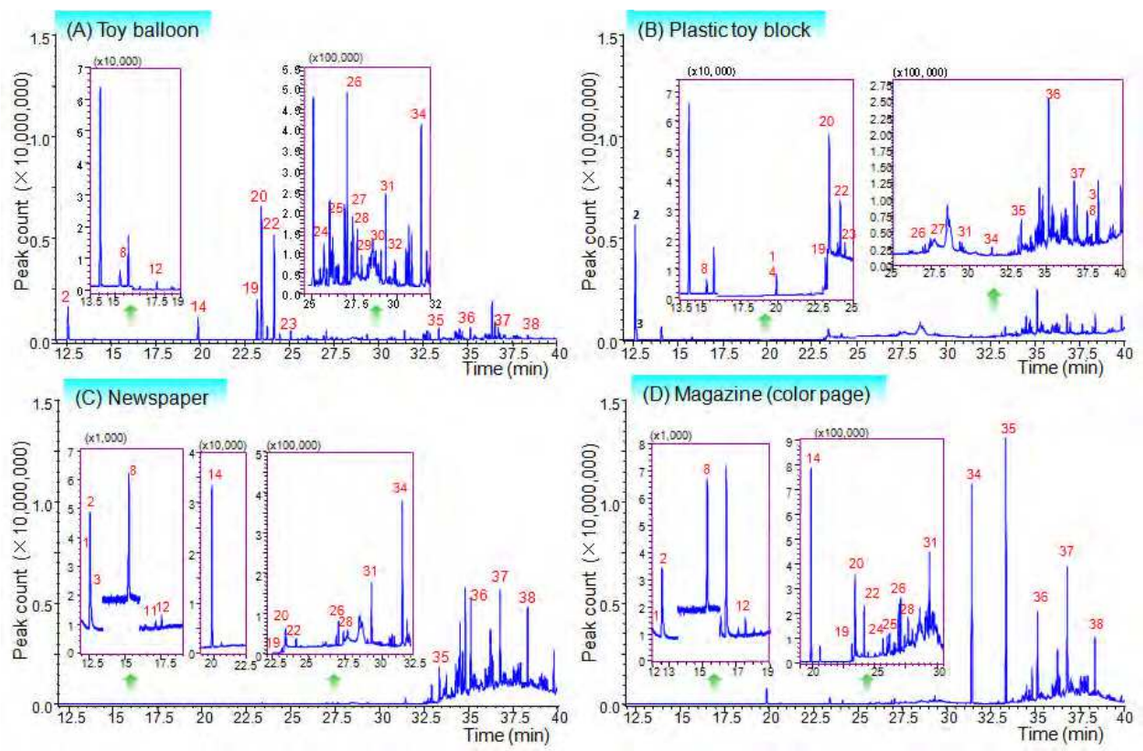

Fig. 8. Typical total ion chromatograms of VOCs emitted from some common products. Peak numbers appear in Fig. 4.

Typical total ion chromatograms of VOCs emitted from some household products are shown in Fig. 8. High concentrations of *n*-hexane, toluene, ethylbenzene and xylenes were detected in a toy rubber balloon (Table 6 and Fig. 9). In addition to toluene, *n*-hexane and chloroform, high concentrations of high-molecular weight aliphatic hydrocarbons were also detected from printed materials such as newspapers and magazines. These are doubtless the main sources of indoor air VOCs at newspaper stands, printing shops, and bookstores (Lee et al., 2006; Barro et al., 2008; Caselli et al., 2009). Evidence has indicated a close relationship between occupational VOC exposure and adverse health effects on workers in the printing industry and in copy centers (Yu et al., 2004). Furthermore, various VOCs were detected in school supplies, including clay, India ink, paint, crayons, glue, and pencils printed with colored paint (Table 7 and Fig. 10). Particularly, paint coating materials are recognized as a major source of VOC exposures (Zhang & Niu, 2002).

These findings may provide semiquantitative estimations of inhalation exposure to VOCs in indoor environments and may allow the selection of safer household products. In particular, the emissions from school supplies are of importance, because they affect the health of children.

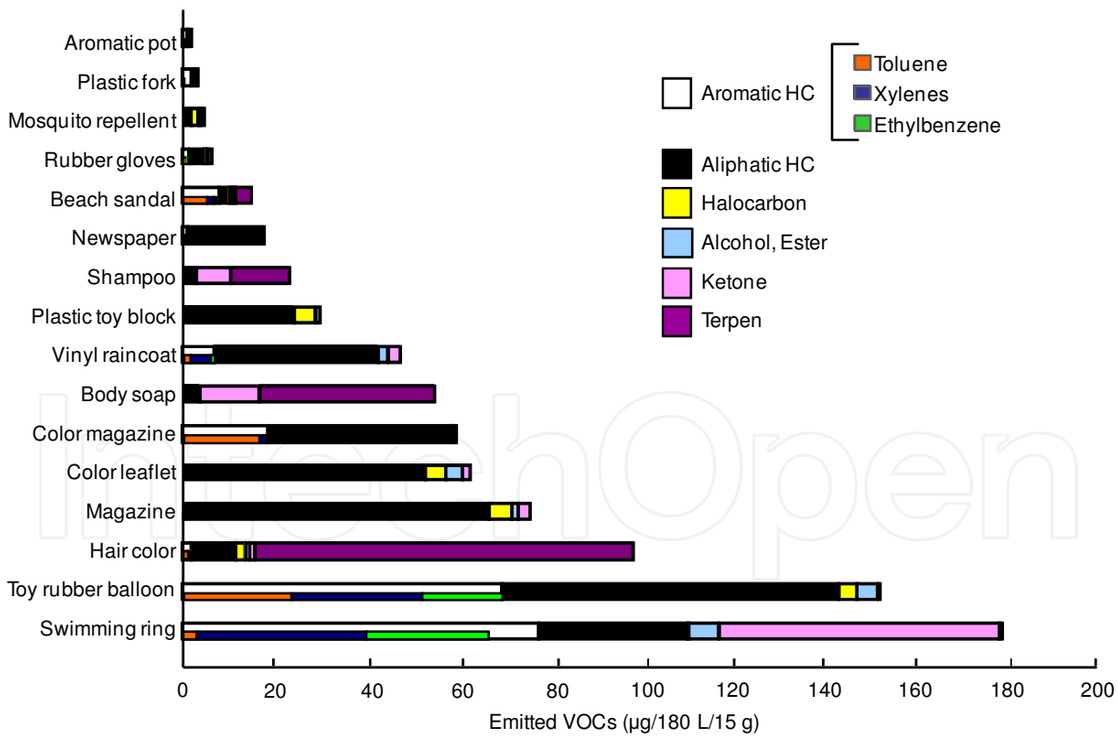

Fig. 9. VOCs emitted from various common products.

Table 6. Amounts of VOCs emitted from various household products.

VOCs	Amounts of VOCs from sample (μg/ 180 L/ 15 g) [1]/ sampling at 0.5 L/ min for 6 h															
	Newspaper	Magazine	Color magazine	Color leaflet	Plastic toy block	Rubber balloon	Swimming ring	Beach sandal	Vinyl raincoat	Plastic fork	Rubber gloves	Mosquito repellent	Aromatic pot	Shampoo	Body soap	Hair color
Ethyl acetate	0.19	1.87	0.04	2.37	1.03	3.83	1.10	0.07	1.50	0.08	0.28	0.06	0.09	0.07	ND	0.34
n-Hexane	0.06	39.27	0.06	47.71	23.63	70.68	23.59	1.43	33.94	0.72	2.88	0.70	0.28	0.82	0.63	2.73
Chloroform	0.01	4.96	ND	4.39	4.56	3.71	ND	ND	ND	ND	ND	ND	ND	0.12	0.10	0.19
1,2-Dichloroethane	ND [2]	0.19	ND	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-Dimethylpentane	ND	0.39	ND	0.27	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-Trichloroethane	ND	0.28	ND	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Butanol	0.07	1.24	0.03	1.24	ND	0.04	5.57	0.20	0.08	0.00	0.00	0.09	ND	0.04	ND	0.50
Benzene	0.04	0.11	0.06	0.07	0.01	0.01	0.23	0.13	0.31	0.07	0.09	0.08	0.08	0.07	0.07	0.19
Carbon tetrachloride	ND	0.23	ND	0.02	0.04	0.03	0.05	0.01	0.05	ND	ND	ND	ND	0.02	ND	1.84
1,2-Dichloropropane	ND	0.19	ND	ND	ND	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2,4-Trimethylpentane	0.01	0.19	0.01	ND	ND	0.01	0.02	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Heptane	ND	0.18	0.01	0.01	ND	0.06	0.03	ND	0.04	ND	ND	ND	ND	ND	ND	0.08
Methylisobutylketone	ND	0.26	ND	0.01	ND	0.03	57.65	ND	0.06	ND	0.04	ND	0.24	ND	ND	0.09
Toluene	0.64	0.18	16.23	0.05	0.12	23.51	2.86	5.38	1.28	0.05	0.74	0.04	0.10	0.17	0.09	0.93
Chlorodibromomethane	ND	0.12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Butyl acetate	ND	0.29	ND	0.01	ND	0.34	ND	0.39	0.67	0.05	0.52	0.16	0.10	0.02	0.02	0.05
n-Octane	ND	0.14	0.02	0.01	ND	0.27	ND	0.04	0.05	ND	ND	ND	ND	ND	ND	0.23
Tetrachloroethylene	ND	0.07	ND	ND	ND	0.27	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene	0.08	0.11	0.6	0.05	0.08	17.54	26.52	0.34	1.01	0.18	0.20	0.07	0.10	0.07	0.04	0.28
m-Xylene + *p*-Xylene	0.13	0.21	0.99	0.08	0.1	19.93	27.04	1.12	2.71	0.19	0.38	0.11	0.22	0.11	0.08	0.44
Styrene	ND	0.14	0.01	ND	0.01	0.17	0.06	0.03	0.01	1.38	0.01	ND	0.02	0.02	ND	0.01
o-Xylene	0.04	0.11	0.34	0.02	0.03	8.55	10.31	0.33	1.63	0.05	0.11	0.04	0.05	0.03	0.02	0.12
n-Nonane	0.01	0.01	0.03	0.01	0.01	0.56	0.69	0.08	0.05	ND	0.01	ND	0.11	ND	0.01	0.06
α-Pinene	ND	0.09	0.17	ND	ND	0.24	0.13	0.09	0.27	0.01	0.16	0.19	0.28	1.02	0.33	10.54
1,2,3-Trimethylbenzene	0.01	0.11	0.11	0.02	ND	0.1	4.70	0.06	0.05	ND	0.02	0.01	0.16	ND	ND	0.02
n-Decane	0.08	0.05	0.31	0.02	0.01	0.66	2.61	0.19	0.65	0.01	0.03	0.04	ND	0.02	0.04	0.06
p-Dichlorobenzene	ND	0.33	0.01	0.19	0.03	0.24	0.05	0.08	0.12	0.01	0.06	1.47	ND	0.02	0.02	0.07
1,2,4-Trimethylbenzene	0.02	0.14	0.1	0.06	ND	0.12	4.99	0.12	0.04	ND	0.02	0.02	ND	0.05	0.05	0.02
Limonene	0.01	0.15	0.1	0.01	0.01	0.17	0.12	3.76	0.10	0.03	0.48	0.84	ND	11.80	38.65	72.48
n-Nonanal	0.03	2.84	0.52	1.80	ND	0.06	2.12	0.22	2.39	0.02	0.02	0.03	ND	7.27	12.97	1.16
n-Undecane	0.18	0.49	0.39	0.10	0.01	0.25	3.53	0.21	0.18	0.01	0.02	0.06	ND	0.03	1.40	0.17
1,2,4,5-Tetramethylbenzene	0.01	0.13	0.02	0.03	ND	0.06	1.82	0.04	0.02	ND	0.02	0.01	ND	0.03	0.03	0.01
n-Decanal	ND	0.40	0.03	0.14	ND	ND	2.04	0.22	0.09	ND	ND	0.11	ND	0.29	0.16	0.28
n-Dodecane	0.4	2.55	12.18	0.06	0.01	0.44	1.91	0.25	0.98	0.02	0.03	0.08	ND	0.39	0.53	4.63
n-Tridecane	1.83	1.09	13.62	0.14	0.04	0.61	0.35	0.13	0.12	0.02	0.03	0.17	ND	0.63	0.22	0.28
n-Tetradecane	4.85	5.62	4.56	2.20	0.21	0.57	0.08	0.20	0.49	0.06	0.07	0.26	ND	0.11	0.24	0.97
n-Pentadecane	5.15	14.62	6.77	1.49	0.09	0.25	0.02	0.08	0.05	0.03	0.04	0.08	ND	0.04	0.08	0.23
n-Hexadecane	4.05	4.04	2.96	0.85	0.07	0.11	0.02	0.04	0.08	0.02	0.03	0.05	ND	0.03	0.06	0.10

[1] Mean of duplicate analysis; [2] Not detectable.

VOCs	Amounts of VOCs from sample (μg/ 180 L/ 15 g) [1]/ sampling at 0.5 L/ min for 6 h												
	Pencil	Fluid paste	Glue	Adhesive tape	Clay	Rubber band	Indian ink	Stamp ink	Paint (white)	Paint (black)	Paint (red)	Crayon (black)	Crayon (blue)	Crayon (yellow)	Crayon (red)
Ethyl acetate	10.84	0.07	11.13	1.42	1.50	2.31	0.30	ND	0.33	0.27	1.88	0.08	0.07	0.19	3.13
n-Hexane	1.27	0.66	110.16	15.07	33.94	70.52	9.48	0.53	2.25	2.42	36.17	3.12	2.78	6.14	37.33
Chloroform	7.47	ND	0.44	0.03	ND	5.58	4.71	0.10	1.27	1.63	ND	ND	ND	ND	16.17
1,2-Dichloroethane	0.05	ND	0.01	ND	ND	0.02	0.02	0.00	0.01	0.01	ND	ND	ND	ND	0.04
2,4-Dimethylpentane	0.01	ND	ND	0.02	ND	0.02	ND	ND	ND	ND	ND	ND	ND	ND	0.01
1,1,1-Trichloroethane	0.01	ND	0.01	ND	ND	0.01	0.01	ND	ND	ND	ND	ND	ND	ND	0.01
n-Butanol	206.77	ND	0.08	ND	0.08	0.04	ND	0.44	0.07	4.11	0.10	ND	ND	ND	0.44
Benzene	0.08	0.07	0.08	0.01	0.31	0.14	0.08	0.06	0.06	0.09	0.16	0.08	0.08	0.11	0.21
Carbon tetrachloride	0.02	ND	0.02	0.01	0.05	0.04	0.04	ND	0.01	0.01	ND	ND	ND	ND	0.02
1,2-Dichloropropane	ND [2]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,2,4-Trimethylpentane	ND	ND	0.01	0.03	ND	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND
n-Heptane	0.01	ND	0.35	8.16	0.04	0.04	ND	ND	ND	0.05	ND	ND	0.04	ND	0.02
Methylisobutylketone	0.08	ND	ND	0.29	0.06	0.06	0.01	ND	ND	0.01	ND	ND	ND	ND	0.01
Toluene	14.81	0.03	0.14	62.35	1.28	1.65	0.12	0.03	0.05	0.10	0.37	0.16	0.15	0.20	0.53
Chlorodibromomethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Butyl acetate	83.91	0.33	ND	0.68	0.67	0.14	ND	0.54	0.02	0.02	0.03	0.02	0.02	0.04	0.03
n-Octane	84.34	ND	ND	0.64	0.05	0.02	ND	ND	ND	ND	ND	0.03	0.10	0.03	0.05
Tetrachloroethylene	ND	ND	ND	ND	ND	0.01	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene	6.03	0.05	0.05	0.32	1.01	1.11	0.08	0.04	0.04	0.05	0.27	0.13	0.12	0.16	0.31
m-Xylene + *p*-Xylene	7.15	0.07	0.08	0.98	2.71	1.53	0.08	0.07	0.06	0.08	0.39	0.28	0.30	0.32	0.55
Styrene	0.01	ND	ND	ND	0.01	0.02	ND	ND	ND	ND	0.01	ND	ND	ND	ND
o-Xylene	3.10	0.02	0.02	0.01	1.63	0.41	0.02	0.02	0.02	0.03	0.11	0.11	0.13	0.13	0.17
n-Nonane	0.02	ND	ND	ND	0.05	0.03	ND	ND	0.01	0.01	0.01	0.62	0.95	0.69	0.60
α-Pinene	0.03	ND	0.02	ND	0.27	0.09	0.36	ND	ND	0.01	0.03	0.02	0.03	0.03	0.03
1,2,3-Trimethylbenzene	0.19	ND	ND	ND	0.05	0.09	ND	ND	ND	ND	0.01	0.45	0.59	0.49	0.32
n-Decane	0.13	0.01	0.01	ND	0.65	0.10	0.01	0.01	0.01	0.02	0.02	3.85	4.60	4.41	3.08
p-Dichlorobenzene	0.01	ND	0.01	ND	0.12	0.13	ND	0.01	ND	ND	0.02	0.09	0.09	0.16	0.10
1,2,4-Trimethylbenzene	2.23	ND	ND	ND	0.04	0.24	ND	ND	ND	ND	0.01	0.53	0.66	0.58	0.37
Limonene	0.02	0.02	0.04	ND	0.10	0.21	0.02	0.03	ND	0.04	0.02	0.05	0.07	0.06	0.05
n-Nonanal	1.69	ND	5.67	ND	2.39	0.02	0.01	ND	0.01	0.02	0.02	0.55	0.59	0.54	0.24
n-Undecane	0.15	0.01	0.02	ND	0.18	0.16	0.01	0.01	0.01	0.01	0.02	4.32	5.50	5.49	3.58
1,2,4,5-Tetramethylbenzene	2.89	ND	ND	ND	0.02	0.01	ND	ND	ND	ND	ND	0.23	0.29	0.28	0.16
n-Decanal	0.12	ND	0.11	ND	0.09	0.02	1.70	ND	ND	ND	0.05	0.12	ND	9.10	2.80
n-Dodecane	0.08	0.01	0.02	ND	0.98	0.15	0.22	0.01	0.01	0.01	0.02	1.91	2.83	2.80	1.85
n-Tridecane	0.06	0.01	0.05	ND	0.12	0.11	2.08	0.02	0.02	0.04	0.04	0.43	0.70	0.71	0.41
n-Tetradecane	0.08	0.04	0.08	ND	0.49	0.13	0.05	0.04	0.05	0.09	0.09	0.77	1.16	1.36	0.77
n-Pentadecane	0.06	0.02	0.04	ND	0.05	0.07	0.03	0.03	0.04	0.04	0.05	0.18	0.24	0.32	0.16
n-Hexadecane	0.03	0.02	0.03	ND	0.08	0.04	0.02	0.02	0.03	0.03	0.05	0.34	0.43	0.72	0.30

[1] Mean of duplicate analysis; [2] Not detectable.

Table 7. Amounts of VOCs emitted from various school items.

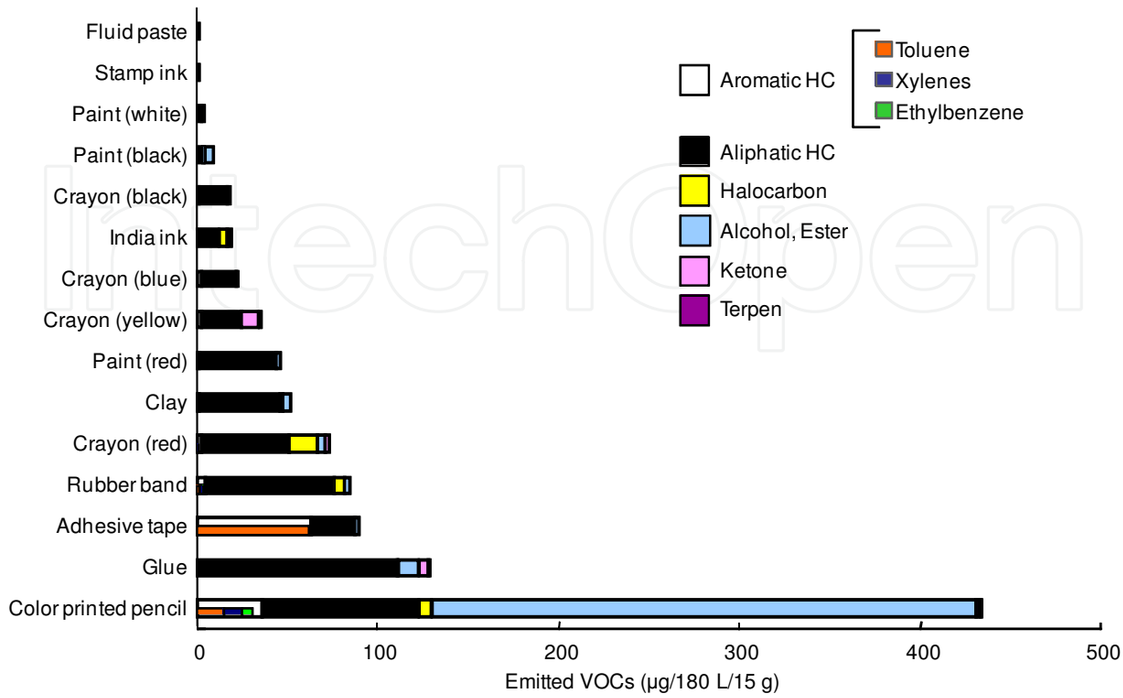

Fig. 10. VOCs emitted from various school items.

4. Conclusion

This chapter provides an analytical method for the determination of VOCs in environmental air samples by GC-MS. This GC-MS method is convenient and reliable, and is useful in evaluating indoor air quality and the sources of VOCs emitted in indoor environments. Indoor air VOC levels in newly constructed buildings exceeded those set by the MHLW. Since humans spend most of their lives indoors, it is necessary to minimize exposure to VOCs affecting human health. Furthermore, we found that various building materials and household products were emission sources of VOCs. Indoor VOC levels associated with these sources can be reduced by increasing outdoor air ventilation, but this entails increased costs in building construction, operation, and energy (Cox et al., 2010). Low VOC-emitting materials are being developed and are used more widely in buildings to help achieve healthier and more productive indoor environments. While VOC-exposure from household products is less than that from building materials, children hypersensitive to these chemicals may be at high risk from directly touching toys and school supplies. Sufficient assessment of the hazards and risks of indoor environments and the regulation of indoor air pollutants such as VOCs are necessary to protect human health, especially children and people who are sensitive to these chemicals. Finally, we hope that this chapter will be beneficial and informative for scientists and students studying environmental pollution and related research fields.

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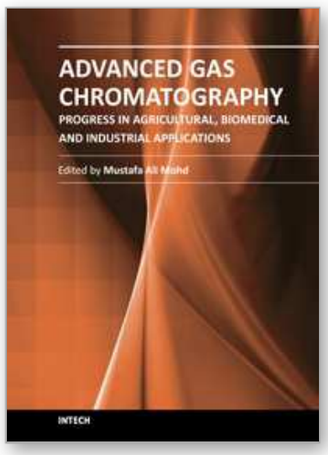

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Progress in agricultural, biomedical and industrial applications' is a compilation of recent advances and developments in gas chromatography and its applications. The chapters cover various aspects of applications ranging from basic biological, biomedical applications to industrial applications. Book chapters analyze new developments in chromatographic columns, microextraction techniques, derivatisation techniques and pyrolysis techniques. The book also includes several aspects of basic chromatography techniques and is suitable for both young and advanced chromatographers. It includes some new developments in chromatography such as multidimensional chromatography, inverse chromatography and some discussions on two-dimensional chromatography. The topics covered include analysis of volatiles, toxicants, indoor air, petroleum hydrocarbons, organometallic compounds and natural products. The chapters were written by experts from various fields and clearly assisted by simple diagrams and tables. This book is highly recommended for chemists as well as non-chemists working in gas chromatography.

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