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Survey of Volatile Organic Compounds found in Indoor and Outdoor Air Samples from Japan

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Indoor air quality is currently a growing concern, mainly due to the incidence of sick building syndrome and building related illness. To better understand indoor air quality in Japan, both indoor and outdoor air samples were collected from 50 residences in Iwate, Yamanashi, Shiga, Hyogo, Kochi and Fukuoka Prefectures. More than 100 volatile organic compounds (VOCs) were analyzed by thermal desorption-gas chromatography/mass spectrometry method. The most abundant class of compounds present in the indoor air samples were identified (i.e. alkanes, alkylbenzenes and terpenes). For 30% of the indoor air samples, the sum of each VOC exceeded the current provisional guideline value for total VOC (TVOC, 400 μg/m^3). The major component of these samples included linear and branched-chain alkanes (possibly derived from fossil fuels), 1,4-dichlorobenzene (a moth repellent), α-pinene (emission from woody building materials) and limonene (probably derived from aroma products). As an unexpected result, one residence was polluted with an extremely high concentration of 1,1,1,2-tetrafluoroethane (720 μg/m^3), suggesting accidental leakage from a household appliance such as a refrigerator. The results presented in this paper are important in establishing the Japanese target compound list for TVOC analysis, as well as defining the current status of indoor air quality in Japan.

Key Words: indoor air quality, sick building syndrome, guideline value, volatile organic compound, thermal desorption-gas chromatography/mass spectrometry

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Introduction

Indoor air quality is of growing concern, mainly because of the increased incidence of sick building syndrome and building related illness[1,2]. To achieve and maintain healthy air quality, the Ministry of Health, Labour and Welfare of Japan (MHLW) has established guidelines for 13 organic compounds in indoor air, including formaldehyde (guideline value, 100 μg/m^3), acetaldehyde (48 μg/m^3), tetradecane (330 μg/m^3), toluene (260 μg/m^3), xylene (870 μg/m^3), ethylbenzene (3,800 μg/m^3), styrene (220 μg/m^3), 1,4-dichlorobenzene (240 μg/m^3), chlorpyrifos (1 μg/m^3), diazinon (0.29 μg/m^3), fenobucarb (33 μg/m^3), di-(2-ethylhexyl) phthalate (120 μg/m^3) and di-(*n*-butyl) phthalate (220 μg/m^3) (http://www.nihs.go.jp/mhlw/chemical/situnai/kentoukai/rep-eng4.html). There have been several pioneering reports on the indoor air concentrations for these compounds[3~5]. In addition to the guidelines for each compound, the MHLW has proposed total volatile organic compounds (TVOC) of 400 μg/m^3 as an advisable value based on the concept of *As Low As Reasonably Achievable* from the investigations on the indoor VOC concentrations in Japan. The analytical procedure of TVOC, however, has not been fully defined. For instance, the list of target compounds, or the VOCs which should be identified and quantified in the TVOC analysis, remains to be established. Furthermore, it will be necessary to refine the air sampling method (e.g. an

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alternative sorbent to Tenax TA, change the air sampling volume/rate) for the quantitative analysis of TVOC.

In this study, we investigated the 132 VOCs in the 50 indoor and outdoor air samples by the thermal desorption-gas chromatography/mass spectrometry (TD-GC/MS) method. The data is critical for defining the candidate compounds to be included in the target compound list for Japan.

Materials and methods

Reagents

All the analytical standards, listed in Table 1, were obtained from Wako Pure Chemicals (Osaka, Japan).

Air sampling

The residences used in this investigation were chosen without consideration of the age of the houses. The Indoor and outdoor air samples were collected from 50 residences in Iwate, Yamanashi, Shiga, Hyogo, Kochi and Fukuoka Prefectures in January and February, 2005. Active sampling was carried out for 24 h at a flow rate of 5 ml/min, using a five-line mass flow controller (Toyo Riko, Tokyo, Japan) and a vacuum pump Linicon LV-140 (Nitto Koki, Tokyo, Japan). Typical sample volumes of 7.2 L were passed through the in-house-made 4-bed sorbent tube (3 graphitized carbon sorbents and one carbon molecular sieve). The sorbent tubes were preconditioned using a Markes TC-20 (ENV Science Trading, Chiba, Japan) at 310℃ for 24 h with a stream of 20 ml/min helium.

TD-GC/MS analysis of 132 VOCs

All the TD-GC/MS analysis was carried out at Green Blue Corporation (Tokyo, Japan) and a detailed method will be published elsewhere (Ando. et al., unpublished results). Briefly, analyses were performed using a QP-5050A GC/MS (Shimadzu, Kyoto, Japan) equipped with a thermal desorption unit ATD-400 (Perkin-Elmer, Yokohama, Japan). Thermal desorption was carried out by heating the tube at 300℃ for 20 min and applying a stream of helium of 20 ml/min. The analytes were subsequently focused at −10℃ on a Tenax TA trap, and then the trap was heated at 300℃ for 2 min. The outlet splitter of the unit was fixed at 1:19. The column used was a CP-SIL 5CB fused silica capillary, 60 m × 0.25 mm × 1.0 μm film thickness (Varian, Palo Alto, CA, USA). The oven of the chromatograph was programmed from 40℃ (hold 10 min) to 140℃ at 3℃/min, to 200℃ at 5℃/min and finally up to 300℃ at 10℃/min. The carrier gas was high purity helium at a flow rate of 1 ml/min.

Results and discussion

Indoor and outdoor air samples were collected from 50 different residences in January - February, 2005, and their VOC constituents were analyzed by the TD-GC/MS method. Table 1 summarizes the indoor and outdoor air concentrations for 132 VOCs. When compared in terms of the median values, the most abundant VOCs were ethanol (520 $\mu g/m^3$), followed by acetone (16 $\mu g/m^3$), toluene (14 $\mu g/m^3$), limonene (13 $\mu g/m^3$), *n*-nonane (6.8 $\mu g/m^3$), *n*-decane (6.4 $\mu g/m^3$), *m*,*p*-xylene (6.1 $\mu g/m^3$), *n*-undecane (5.5 $\mu g/m^3$), *n*-dodecane (4.4 $\mu g/m^3$), 2-propanol (3.8 $\mu g/m^3$) and *n*-octane (3.7 $\mu g/m^3$). In addition to the ubiquitously detected compounds in indoor air (ethanol, *n*-undecane, acetone, naphthalene and benzene), VOCs that found with high frequencies (≥80%) were *n*-alkanes (C7 to C16), branched-chain alkanes (C7 to C10), cycloalkanes (cyclohexane, methylcyclopentane and methylcyclohexane), alkylbenzenes (toluene, xylene isomers, ethylbenzene, *n*-propylbenzene, 2-ethyltoluene, trimethylbenzene isomers and 1,2,4,5-tetramethylbenzene), terpenes (limonene and α-pinene), halocarbons (dichloromethane, chloroform, carbon tetrachloride, 1,4-dichlorobenzene and 1,3,5-trichlorobenzene), styrene, 2-propanol, ethylacetate and methylisobutylketone. Among each VOC included in the guideline for indoor air quality in Japan, only 1,4-dichlorobenzene was found at the concentrations exceeding the guideline value (240 $\mu g/m^3$): two residences at the levels of 320 and 360 $\mu g/m^3$.

In terms of the sum of each VOC, 15 of 50 residences (30%) exceeded the provisional guideline value for TVOC (400 $\mu g/m^3$) (Fig.1). Figure 2 depicts the composition of each chemical class for these 15 indoor air samples. For residence A, linear and branched-chain alkanes accounted for 70% of the indoor VOCs. These compounds were also a major component for residences D, F, I, J, K, L and M (35-55%). The alkanes were probably derived from fossil fuels because all of these residences used unvented kerosene heaters during the air sampling procedure. The predominant VOC detected in residences B and N was 1,4-dichlorobenzene (27% and 39%, respectively). This moth repellent was also abundant in the indoor air sample from F (31%), and thus alkanes and 1,4-dichlorobenzene represented almost 75% of the combined VOCs. Terpenes were major constituents (54-84%) of the indoor air samples from residences C, E, G and O, although the

Table 1 VOC concentrations in the indoor and outdoor air

Compounds		Indoor Air Concentration (μg/m³)					Outdoor Air Concentration (μg/m³)				
		Mean	Median	Minimum	Max	Frequency	Mean	Median	Minimum	Max	Frequency
Aromatic Hydrocarbons	Benzene	3.2	2.7	0.71	17	50 / 50	1.9	1.7	0.63	5.2	50 / 50
	Toluene	16	14	<LOQ[b]	50	49 / 50	9.4	6.6	0.68	42	50 / 50
	Ethylbenzene	5.3	3.3	<LOQ	26	49 / 50	4.2	1.3	0.09	120	50 / 50
	m , *p* -Xylene	9.3	6.1	<LOQ	49	49 / 50	3.9	2.1	0.25	68	50 / 50
	o -Xylene	4.1	2.4	<LOQ	24	49 / 50	1.2	0.72	<LOQ	16	48 / 50
	n -Propylbenzene	1.6	0.79	<LOQ	10	49 / 50	0.47	0.44	<LOQ	2.4	44 / 50
	Isopropylbenzene	0.53	0.22	<LOQ	3.9	37 / 50	0.05	<LOQ	<LOQ	0.88	12 / 50
	2-Ethyltoluene	2.8	0.87	<LOQ	22	49 / 50	0.41	0.28	<LOQ	3.5	43 / 50
	1,2,3-Trimethylbenzene	2.8	0.90	<LOQ	24	46 / 50	0.35	0.24	<LOQ	2.1	42 / 50
	1,2,4-Trimethylbenzene	10	3.7	<LOQ	96	49 / 50	2.0	1.3	0.09	16	50 / 50
	1,3,5-Trimethylbenzene	2.7	0.99	<LOQ	21	48 / 50	0.61	0.45	<LOQ	5.1	49 / 50
	n -Butylbenzene	0.77	0.22	<LOQ	8.1	35 / 50	0.03	<LOQ	<LOQ	0.30	7 / 50
	1-Methyl-3-propylbenzene	1.2	<LOQ	<LOQ	13	23 / 50	0.02	<LOQ	<LOQ	0.49	2 / 50
	1,2,4,5-Tetramethylbenzene	0.71	0.29	<LOQ	6.8	40 / 50	0.04	<LOQ	<LOQ	0.38	9 / 50
	1,3-Diisopropylbenzene	0.01	<LOQ	<LOQ	0.53	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	1,4-Diisopropylbenzene	—[a]	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Styrene	2.3	0.71	<LOQ	40	49 / 50	0.26	0.18	<LOQ	1.1	38 / 50
	α-Methylstyrene	0.01	<LOQ	<LOQ	0.42	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	p -Methylstyrene	0.01	<LOQ	<LOQ	0.30	3 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Ethynylbenzene	0.04	<LOQ	<LOQ	0.75	3 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	4-Phenylcyclohexene	0.01	<LOQ	<LOQ	0.39	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Naphthalene	2.6	0.48	0.15	58	50 / 50	0.21	0.20	<LOQ	0.68	39 / 50
Aliphatic Hydrocarbons	*n* -Hexane	3.0	1.9	<LOQ	14	32 / 50	1.2	<LOQ	<LOQ	21	17 / 50
	2-Methylpentane	3.0	2.2	<LOQ	25	45 / 50	2.1	1.7	<LOQ	17	41 / 50
	3-Methylpentane	1.9	1.5	<LOQ	18	36 / 50	1.3	1.4	<LOQ	12	27 / 50
	n -Heptane	4.7	2.8	<LOQ	20	48 / 50	0.87	0.56	<LOQ	18	40 / 50
	2-Methylhexane	1.5	1.3	<LOQ	4.9	48 / 50	0.59	0.37	<LOQ	5.2	37 / 50
	3-Methylhexane	1.7	1.5	<LOQ	5.7	48 / 50	0.70	0.52	<LOQ	5.8	39 / 50
	2,4-Dimethylpentane	0.18	0.16	<LOQ	0.76	40 / 50	0.06	<LOQ	<LOQ	0.31	21 / 50
	n -Octane	7.9	3.7	<LOQ	45	48 / 50	0.46	0.45	<LOQ	1.8	28 / 50
	2,2,4-Trimethylpentane	0.17	0.16	<LOQ	0.70	29 / 50	0.18	0.15	<LOQ	0.66	31 / 50
	n -Nonane	20	6.8	<LOQ	160	49 / 50	1.2	0.79	<LOQ	7.6	44 / 50
	2-Methyloctane	3.2	1.4	<LOQ	25	34 / 50	0.13	<LOQ	<LOQ	1.6	8 / 50
	3-Methyloctane	3.5	1.4	<LOQ	25	46 / 50	0.18	0.04	<LOQ	1.1	25 / 50
	n -Decane	23	6.3	<LOQ	250	49 / 50	1.2	0.72	<LOQ	7.9	43 / 50
	2-Methylnonane	4.1	1.1	<LOQ	32	47 / 50	0.22	<LOQ	<LOQ	1.5	22 / 50
	3,5-Dimethyloctane	1.3	0.37	<LOQ	9.9	32 / 50	0.02	<LOQ	<LOQ	0.69	4 / 50
	n -Undecane	20	5.5	0.41	290	50 / 50	0.85	0.54	<LOQ	7.0	40 / 50
	n -Dodecane	13	4.3	<LOQ	210	48 / 50	0.51	<LOQ	<LOQ	5.6	19 / 50
	n -Tridecane	10	3.0	<LOQ	150	48 / 50	0.53	<LOQ	<LOQ	7.0	21 / 50
	n -Tetradecane	5.5	2.5	<LOQ	62	47 / 50	0.23	<LOQ	<LOQ	2.1	14 / 50
	n -Pentadecane	2.3	1.2	<LOQ	15	47 / 50	0.06	<LOQ	<LOQ	1.2	5 / 50
	n -Hexadecane	1.2	1.1	<LOQ	6.5	41 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	1-Octene	0.03	<LOQ	<LOQ	0.88	2 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	1-Decene	0.81	<LOQ	<LOQ	8.3	16 / 50	0.01	<LOQ	<LOQ	0.45	1 / 50
Cycloalkanes	Cyclohexane	3.9	1.5	<LOQ	39	47 / 50	0.27	0.17	<LOQ	1.8	30 / 50
	Methylcyclopentane	1.3	1.1	<LOQ	8.0	46 / 50	0.54	0.47	<LOQ	4.6	40 / 50
	Methylcyclohexane	3.8	2.2	<LOQ	23	48 / 50	0.71	0.39	<LOQ	16	41 / 50
	1,4-Dimethylcyclohexane	4.7	2.2	<LOQ	37	31 / 50	0.02	<LOQ	<LOQ	1.0	1 / 50
	cis -1-Methyl-4-isopropyl-cyclohexane	0.31	<LOQ	<LOQ	8.1	6 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	trans -1-Methyl-4-isopropyl-cyclohexane	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
Terpenes	(+/-)-Camphene	4.9	<LOQ	<LOQ	120	22 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Camphor	0.90	<LOQ	<LOQ	9.3	22 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	3-Carene	4.2	<LOQ	<LOQ	75	21 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	α-Cedrene	0.02	<LOQ	<LOQ	1.1	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Limonene	30	13	<LOQ	250	49 / 50	0.09	<LOQ	<LOQ	0.78	11 / 50
	Longifolene	0.22	<LOQ	<LOQ	4.7	5 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Menthol	0.25	<LOQ	<LOQ	13	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	α-Pinene	47	2.5	<LOQ	650	49 / 50	0.30	0.17	<LOQ	1.5	27 / 50
	β-Pinene	1.9	<LOQ	<LOQ	27	19 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
Alcohols	Ethanol	920	520	99	8600	50 / 50	16	11	<LOQ	120	38 / 50
	1-Propanol	0.22	<LOQ	<LOQ	8.7	3 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	2-Propanol	8.9	3.8	<LOQ	64	46 / 50	1.5	<LOQ	<LOQ	34	17 / 50
	2-Methyl-1-propanol	0.28	<LOQ	<LOQ	12	4 / 50	0.05	<LOQ	<LOQ	1.5	2 / 50
	2-Methyl-2-propanol	0.13	<LOQ	<LOQ	1.7	9 / 50	0.12	<LOQ	<LOQ	6.2	1 / 50
	1-Butanol	0.73	0.48	<LOQ	7.6	28 / 50	0.44	<LOQ	<LOQ	22	2 / 50

[a] Could not be calculated because all samples were below the limit of quantitation.

[b] Below the limit of quantitation.

Table 1 VOC concentrations in the indoor and outdoor air (continued)

Compounds		Indoor Air Concentration (μg/m³)					Outdoor Air Concentration (μg/m³)				
		Mean	Median	Minimum	Max	Frequency	Mean	Median	Minimum	Max	Frequency
Alcohols	1-Pentanol	—[a]	<LOQ[b]	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	1-Hexanol	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Cyclohexanol	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	1-Octanol	8.5	<LOQ	<LOQ	240	3 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	2-Ethyl-1-hexanol	6.3	<LOQ	<LOQ	110	10 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Texanol	0.34	<LOQ	<LOQ	17	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
Glycols/ Glycolethers	Propylene glycol	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Dimethoxymethane	0.09	<LOQ	<LOQ	4.5	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Dimethoxyethane	—	<LOQ	<LOQ	<LOQ	0 / 50	0.12	<LOQ	<LOQ	4.0	2 / 50
	2-Methoxyethanol	0.33	<LOQ	<LOQ	16	1 / 50	0.60	<LOQ	<LOQ	13	3 / 50
	2-Ethoxyethanol	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	2-Butoxyethanol	0.49	<LOQ	<LOQ	24	1 / 50	0.41	<LOQ	<LOQ	21	1 / 50
	1-Methoxy-2-propanol	2.9	0.48	<LOQ	47	34 / 50	0.07	<LOQ	<LOQ	1.3	4 / 50
	2-(2-Ethoxyethoxy)ethanol	1.3	<LOQ	<LOQ	22	3 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	2-Butoxyethoxyethanol	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
Ketones	Acetone	22	16	2.6	98	50 / 50	6.6	4.9	0.90	19	50 / 50
	3-Methyl-2-butanone	0.03	<LOQ	<LOQ	0.37	6 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Methylethylketone	2.0	0.71	<LOQ	23	38 / 50	1.1	0.21	<LOQ	12	27 / 50
	Methylisobutylketone	2.9	0.66	<LOQ	59	43 / 50	0.84	0.38	<LOQ	18	39 / 50
	Acetophenone	0.23	<LOQ	<LOQ	3.6	8 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
Halocarbons	Chloromethane	0.15	<LOQ	<LOQ	1.4	18 / 50	0.05	<LOQ	<LOQ	1.1	5 / 50
	Bromomethane	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Dichloromethane	3.9	1.2	<LOQ	72	48 / 50	1.2	0.47	<LOQ	6.3	41 / 50
	Chloroform	0.59	0.33	<LOQ	4.9	47 / 50	0.19	<LOQ	<LOQ	3.4	10 / 50
	Chlorodibromomethane	0.05	<LOQ	<LOQ	0.84	6 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Carbon tetrachloride	0.68	0.61	<LOQ	1.9	48 / 50	0.75	0.73	<LOQ	2.0	43 / 50
	1,2-Dichloroethane	0.01	<LOQ	<LOQ	0.20	6 / 50	—	<LOQ	<LOQ	0.17	1 / 50
	1,1,1-Trichloroethane	0.21	<LOQ	<LOQ	4.8	19 / 50	0.02	<LOQ	<LOQ	0.30	6 / 50
	1,1,2,2-Tetrachloroethane	0.01	<LOQ	<LOQ	0.39	1 / 50	0.03	<LOQ	<LOQ	0.97	2 / 50
	Trichloroethene	0.44	0.11	<LOQ	2.6	29 / 50	0.44	<LOQ	<LOQ	2.9	23 / 50
	Tetrachloroethene	0.28	0.11	<LOQ	4.3	27 / 50	0.13	<LOQ	<LOQ	1.3	10 / 50
	1,2-Dichloropropane	0.01	<LOQ	<LOQ	0.15	3 / 50	—	<LOQ	<LOQ	0.12	2 / 50
	Chlorobenzene	0.01	<LOQ	<LOQ	0.37	2 / 50	0.01	<LOQ	<LOQ	0.37	1 / 50
	1,4-Dichlorobenzene	25	2.0	<LOQ	360	49 / 50	0.47	0.33	<LOQ	2.4	42 / 50
	1,2,4-Trichlorobenzene	0.01	<LOQ	<LOQ	0.57	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	1,3,5-Trichlorobenzene	2.7	0.99	<LOQ	21	48 / 50	0.61	0.45	<LOQ	5.1	49 / 50
	Vinylchloride	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	1,1,1,2-Tetrafluoroethane (134a)	16	<LOQ	<LOQ	720	4 / 50	—	<LOQ	<LOQ	0.08	1 / 50
	Hexachlorocyclopentadiene	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
Esters	Butyl formate	0.07	<LOQ	<LOQ	3.3	2 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Methyl acetate	2.1	0.46	<LOQ	49	27 / 50	0.02	<LOQ	<LOQ	0.91	1 / 50
	Ethyl acetate	5.1	3.2	<LOQ	60	44 / 50	1.7	<LOQ	<LOQ	19	19 / 50
	Vinyl acetate	0.29	<LOQ	<LOQ	3.4	13 / 50	0.01	<LOQ	<LOQ	0.34	1 / 50
	Propyl acetate	0.13	<LOQ	<LOQ	0.98	11 / 50	0.08	<LOQ	<LOQ	1.2	5 / 50
	Butyl acetate	3.1	1.3	<LOQ	46	38 / 50	0.50	<LOQ	<LOQ	3.2	19 / 50
	Isobutyl acetate	0.59	0.20	<LOQ	4.6	27 / 50	0.16	<LOQ	<LOQ	3.5	14 / 50
	Isopropyl acetate	0.01	<LOQ	<LOQ	0.72	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	2-Methoxyethyl acetate	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	2-Ethoxyethyl acetate	0.51	<LOQ	<LOQ	16	6 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	2-Ethylhexyl acetate	0.05	<LOQ	<LOQ	2.4	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Linalyl acetate	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Methacrylic acid methyl ester	0.08	<LOQ	<LOQ	2.0	4 / 50	0.02	<LOQ	<LOQ	0.83	1 / 50
	TXIB	0.02	<LOQ	<LOQ	0.82	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
Other	Methyl-*tert*-butylether	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	0.19	1 / 50
	Tetrahydrofuran (THF)	0.20	<LOQ	<LOQ	3.1	12 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	2-Pentylfuran	0.03	<LOQ	<LOQ	0.81	3 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	1,4-Dioxane	0.02	<LOQ	<LOQ	0.39	3 / 50	0.01	<LOQ	<LOQ	0.50	1 / 50
	Phenol	0.23	<LOQ	<LOQ	2.3	14 / 50	0.07	<LOQ	<LOQ	3.4	1 / 50
	Cresol	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	2,6-Di-*tert*-buty-l-4-methylphenol	—	<LOQ	<LOQ	<LOQ	0 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Acrylonitrile	0.04	<LOQ	<LOQ	0.87	3 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Caprolactam	0.12	<LOQ	<LOQ	5.8	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Carbon disulfide	0.48	<LOQ	<LOQ	17	2 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Indene	—	<LOQ	<LOQ	0.13	1 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50
	Isophorone	0.02	<LOQ	<LOQ	0.42	4 / 50	—	<LOQ	<LOQ	<LOQ	0 / 50

[a] Could not be calculated because all samples were below the limit of quantitation.

[b] Below the limit of quantitation.

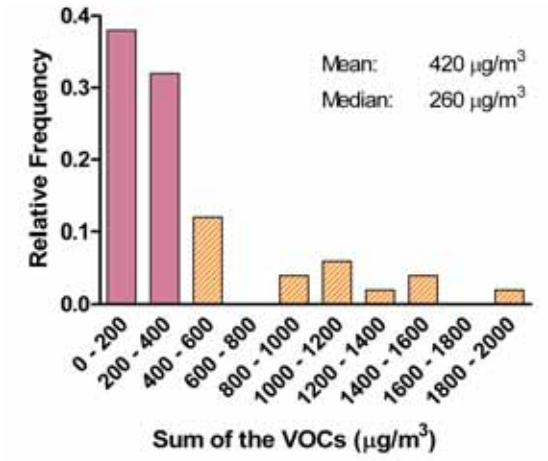

Fig. 1 Frequency distribution of the sum of indoor air VOCs. The oblique bars indicate those data exceeding the provisional guideline value for TVOC.

most abundant terpene did vary: α-pinene for C, E and G and limonene for O. Interestingly, residences C, E and G were less than one-year old at the time of air sampling. Therefore, the rather high concentrations of α-pinene might be attributable to emission from the woody building materials. In contrast, residence O was a ten-year old building, and the high limonene concentration was not associated with elevated levels of other terpenes. We believe the limonene detected in residence O might be derived from aroma products. Finally, residence H was primarily polluted with 1,1,1,2-tetrafluoroethane (74%), suggesting accidental leakage from a household appliance such as a refrigerator.

In conclusion, we have analyzed 132 VOCs in indoor and outdoor air samples collected from 50 residences in Japan, and identified the most abundant chemical classes (i.e. linear and branched-chain alkanes, alkylbenzenes and terpenes). The results presented here are important in establishing the target compound list for TVOC analysis in Japan, as well as assessing the current status of indoor air quality.

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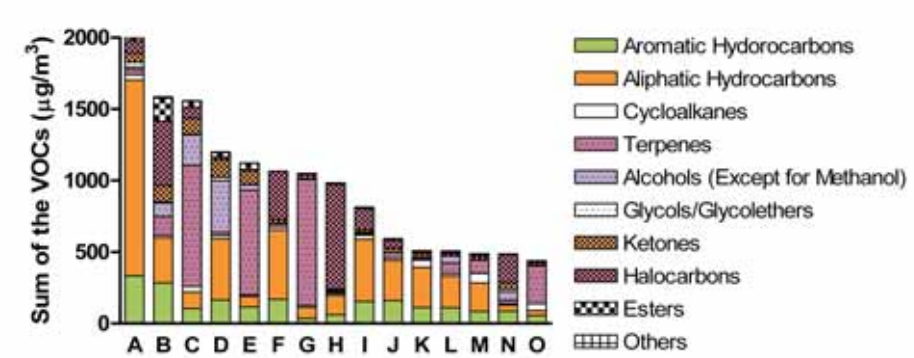

Fig. 2 Chemical classes of the VOCs for the samples that exceeded the provisional guideline value for TVOC.