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Report

Analysis of Volatile Organic Compounds Emitted from Bedding Products

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In this study, we analyzed the volatile organic compounds (VOCs) emitted from a sample of bedding products. These items are intended for long-term use indoors and therefore will be present for long periods of time in the breathing zone of household occupants. Forty bedding products (20 pillows and 20 mattresses) were obtained from the Japanese domestic market for analysis. We have pioneered the measurement of VOCs from bedding products using the sampling bag method, and our measurements showed that a variety of VOCs were emitted from the items. In the pillow sample, polyethylene pillows emitted the most aliphatic hydrocarbons, while buckwheat hull pillows emitted fewer chemicals overall. All pillows emitted tetradecane, toluene, and xylene. VOCs emissions from the mattresses tended to be higher than from the pillows. The mattresses emitted 2-ethyl-1-hexanoic acid frequently and at high concentrations. To further understand the effects of indoor air pollution, it is necessary to continue research into testing the emissions from bedding products and other household items.

Key words indoor air, emission test, sampling bag method, volatile organic compounds, aldehydes

INTRODUCTION

Volatile organic compounds (VOCs) emitted from indoor household items are known to contribute to health problems, such as sick building syndrome, in occupants of residential spaces. The negative health effects of VOCs exposure have promoted interest in understanding and improving indoor air quality. However, there is limited information on the indoor air pollution caused by household items introduced by residents, in particular bedding items, which will be present for a long time in the resident's breathing zone. Therefore, to minimize the health effects of indoor air pollution, it is important to identify the chemical substances emitted from these household items. Although there have been studies measuring VOC emissions from mattresses using the chamber method,[1,2] to the best of our knowledge, there are no published studies using the sampling bag method.

For this study, we obtained a sample of pillows and mattresses that had been marketed and distributed in Japan. VOCs emitted from the bedding items were collected using the sampling bag method, and were quantified using thermal desorption-gas chromatography/mass spectrometry (TD-GC/MS). Aldehydes, one of the group of VOCs, were quantified using high-performance liquid chromatography (HPLC).

MATERIALS AND METHODS

Chemicals The target substances for analysis for every group are listed in Table 1. 48 Component Indoor Air Standard and TO11/IP-6A Aldehyde/Ketone-DNPH Mix were purchased from Supelco, Inc. 2-Ethyl-1-hexanol (98%) was purchased from Wako Pure Chemical Industries, Ltd. 3-Hydroxy-2,2,4-trimethylpentyl isobutyrate (Texanol; contains ca. 40% 2,2,4-trimethyl-1,3-pentanediol 3-monoisobutyrate) and 2,2,4-trimethyl-1,3-pentanediol diisobutyrate (TXIB; > 97.0%) were purchased from Tokyo Chemical Industry Co., Ltd. Toluene-d_8, purchased from Wako Pure Chemical Industries, Ltd., was used as an internal standard in the GC/MS analysis in this study.

Instruments TD-GC/MS analysis was performed using a TD-100xr (MARKES International Ltd.) equipped with Agilent 7890B/5977B GC/MSD series (Agilent Technologies, Inc.). MP-Σ30 NII sampling pumps (Sibata Scientific Technology Ltd.) was used for collection of VOCs except that MP-Σ300 NII sampling pumps (Sibata Scientific Technology Ltd.) was for aldehyde group. The sampling bag method was conducted using Skypia® bags (GL Sciences Inc.). Tenax® TA 60/80 (Camsco Co.) collection tubes were used for VOCs whereas InertSep® mini AERO DNPH (GL Sciences Inc.) collection tubes was for aldehyde group.

Product Samples We purchased 20 pillows and 20 mattresses from Japanese domestic internet markets. The pillows were composed of the following materials: polyester (**P-1–P-7**) in 7, urethane foam (**P-8–P-14**) in 7, polyethylene (pipe) (**P-15–P-18**) in 4, and buckwheat hull (**P-19**, **P-20**) in 2. All 20 mattresses were composed of urethane foam (**M-1–M-20**).

Emissions Tests As recommended by the Japanese Automotive Standards Organization M902 (JASO M902), 2018 edition,[3] the sampling bag method was used to collect emitted chemical substances. For each test, one item of bedding was properly stored at room temperature until it was opened. Immediately after opening the package, we sealed in a sampling bag (100 L for pillows, 2,000 L for mattresses), alongside pure air (50 L for pillows, 1,000 L for mattresses). The sampling bag

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Table 1. Information of Target Substances

Groups	Analytical methods	Total number	Target substances
Aliphatic hydrocarbons	TD-GC/MS	12	Hexane, 2,4-Dimethylpentane, Isooctane, Heptane, Octane, Nonane, Decane, Undecane, Dodecane, Tridecane, Pentadecane, Hexadecane
Aromatic hydrocarbons	TD-GC/MS	12	Benzene, Toluene, Ethylbenzene, Xylene, Styrene, *m*-Ethyltoluene, *p*-Ethyltoluene, 1,3,5-Trimethylbenzene, *o*-Ethyltoluene, 1,2,4-Trimethylbenzene, 1,2,3-Trimethylbenzene, 1,2,4,5-Tetramethylbenzene,
Terpenes	TD-GC/MS	3	α-Pinene, β-Pinene, D-Limonene
Halogenated hydrocarbons	TD-GC/MS	9	Dichloromethane, Chloroform, 1,2-Dichloroethane, Trichloroethylene, 1,2-Dichloropropane, Bromodichloromethane, Dibromochloromethane, Tetrachloroethylene, 1,4-Dichlorobenzene
Esters/Ketones	TD-GC/MS	6	Ethyl acetate, Butyl acetate, Methyl ethyl ketone, Methyl isobutyl ketone, Nonanal, Decanal
Alcohols	TD-GC/MS	6	Isopropylalcohol, 1-Propanol, 1-Butanol, 2-Ethyl-1-hexanol, 2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate, 2,2,4-Trimethyl-1,3-pentanediol diisobutyrate
Aldehydes	HPLC	11	Formaldehyde, Acetaldehyde, Propionaldehyde, Crotonaldehyde, Butyraldehyde, Benzaldehyde, Isovaleraldehyde, Valeraldehyde, Tolualdehyde, Hexaldehyde, 2,5-Dimethylbenzaldehyde

was then placed in a thermostat chamber at 40°C for 2 h. Subsequently, emitted VOCs were collected at a rate of 100 mL/min (2 L), and emitted aldehydes at a rate of 1,000 mL/min (20 L). A blank sample measurement was obtained by repeating this procedure without a test product in the bag.

Analytical Methods

TD-GC/MS The TD conditions: Desorb temperature (time) was set at 270°C (10 min). Stripping temperature was held 5°C, increased at 280°C and held 11.5 min. Trap flow was 30 mL/min. Tenax® (a porous polymer based on 2,6-diphenylphenol) was used as cryofocusing trap devise.

The GC conditions: InertCap 1 column with an inner diameter of 0.25 mm × 60 m and a film thickness of 1.5 µm (GL Sciences, Inc.). Helium was used as the carrier gas. The flow rate was 1.3 mL/min as a constant pressure. GC Oven temperature sequence was held 35°C for 2 min, increased at 15°C/min to 65°C, then increased at 5°C/min to 95°C, increased at 2.5°C/min to 105°C, increased at 10°C/min and held 10 min to 280°C. Split ratio was 6:1. Transfer line temperature was set at 280°C.

The MS conditions: EI was used as an ionization type. Source temperature was set at 260°C. Quad temperature was set at 260°C. Acquisition type was Scan mode (*m/z* 35–450).

The concentration range of the calibration curve was 0.5–20 ng. Extrapolated values were calculated when this range was exceeded. Toluene-d_8 was used as an internal standard. The total VOC (TVOC) concentration was calculated as a toluene equivalent value, using the sum of the peak areas of the total ion current chromatogram of scan mode eluting at the retention time between hexane and hexadecane. The 10 most intense VOC peaks each sample for scan measurements were identified using a similarity search of the GC/MS library (NIST 11.lib).

HPLC Quantification was performed using an external standard method with 2,4-dinitrophenylhydrazine (DNPH) derivatized standards. The concentration range of the calibration curve was 0.15–15 ng. Extrapolated values were calculated when this range was exceeded. The HPLC conditions were as follows: column, Inertsil ODS-3 (4.6 mm i.d. × 250 mm, 5 µm; GL Sciences, Inc); mobile phase, ultra-pure water (A) and acetonitrile (B) in the gradient mode: 60% B (0 min) → 60% B (14 min) → 100% B (40 min); injection volume, 10 µL; flow rate, 1.0 mL/min; detection, ultraviolet (360 nm).

Formula for calculating the bag VOC concentration

$$W = \frac{(Ps - Pb) \times Vs}{u}$$

W: Quantitative value (µg/unit)
*P*s: Test concentration (µg/m³)
*P*b: Blank concentration (µg/m³)
*V*s: Gas inclusion amount (m³)
u: Number of test samples (unit)

RESULTS AND DISCUSSION

Pillow Emissions We characterized and quantified the VOCs emitted from 20 pillows. The results are summarized in Table 2. When comparing the mean TVOC emissions from each pillow material, showed that the emissions from the polyethylene products (475 µg/unit) were more than twice as high as from the urethane foam products (203 µg/unit). However, there was no notable difference in the median value for the polyethylene products (144 µg/unit) compared with the urethane foam products (121 µg/unit). These facts indicated that there was a polyethylene sample producing significantly higher emissions compared with the other samples. It was the case for **P-18**, which produced the highest TVOC emissions of the pillow samples at 1,570 µg/unit. Decane, undecane, and dodecane were emitted from **P-18** at levels of 162 µg/unit, 60 µg/unit, and 48 µg/unit, respectively. We hypothesize that the source of these chemical species is the rigid carbon pipe within these pillows. The sample emitting the most formaldehyde (51 µg/unit) was **P-7** from the polyester products. The sample emitting the most ethylbenzene (55 µg/unit) was **P-8** from the urethane foam products. Overall, buckwheat hull pillows produced lower emissions compared with the other materials (Table 2D).

Table 3 shows that there were three VOCs emitted by all 20 of our pillow samples: tetradecane, toluene, and xylene. 1,4-Dichlorobenzene, which is often used as an insect repellent, was detected in 50% of the pillow samples. To identify chemical substances beyond the indoor air quality guideline substances that may have a considerable contribution to indoor air pollution, we identified compounds with a toluene equivalent value > 400 µg/m³ and a high emission frequency of

Table 2. VOCs Emissions from Pillow Samples (μg/unit) (A) Polyester Products (**P-1**–**P-7**), (B) Urethane Foam Products (**P-8**–**P-14**), (C) Polyethylene Products (**P-15**–**P-18**) and (D) Buckwheat Hull Products (**P-19**–**P-20**)

(A)

		Polyester							Max.	Min.	Mean	Median
		P-1	**P-2**	**P-3**	**P-4**	**P-5**	**P-6**	**P-7**				
Aliphatic hydrocarbons	Hexane	0.0	0.0	0.0	0.1	0.1	0.2	0.0	0.2	0.0	0.1	0.0
	2,4-Dimethylpentane#	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Isooctane#	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heptane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Octane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Nonane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Decane	0.0	0.0	0.0	0.0	0.2	0.9	0.0	0.9	0.0	0.2	0.0
	Undecane	0.0	0.0	0.0	0.0	0.2	0.9	0.0	0.9	0.0	0.2	0.0
	Dodecane	0.0	0.7	0.1	0.0	0.4	1.6	0.0	1.6	0.0	0.4	0.1
	Tridecane	0.0	0.2	0.4	0.0	0.6	0.3	0.0	0.6	0.0	0.2	0.2
	Tetradecane*	0.2	0.6	0.4	0.2	1.0	0.4	0.3	1.0	0.2	0.4	0.4
	Pentadecane	0.0	0.2	0.2	0.1	0.0	0.1	0.1	0.2	0.0	0.1	0.1
	Hexadecane	0.1	0.2	0.2	0.2	0.0	0.1	0.5	0.5	0.0	0.2	0.2
Aromatic hydrocarbons	Benzene	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.0	0.0	0.0
	Toluene*	0.6	0.9	0.5	0.8	0.6	1.1	0.5	1.1	0.5	0.7	0.6
	Ethylbenzene*	0.1	0.5	0.2	0.3	0.3	1.3	0.2	1.3	0.1	0.4	0.3
	Xylene*	0.1	0.7	0.3	0.2	0.2	1.2	0.2	1.2	0.1	0.4	0.2
	Styrene*	1.2	2.5	1.7	2.1	4.3	3.9	2.0	4.3	1.2	2.5	2.1
	m-Ethyltoluene	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0
	p-Ethyltoluene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,3,5-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	o-Ethyltoluene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2,4-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0
	1,2,3-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2,4,5-Tetramethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Terpenes	α-Pinene	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0
	β-Pinene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	D-Limonene	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0
Halogenated hydrocarbons	Dichloromethane#	0.3	0.6	0.3	0.6	0.5	0.3	0.5	0.6	0.3	0.4	0.5
	Chloroform	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloroethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tricholoroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloropropane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bromodichloromethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dibromochloromethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tetracholoroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,4-Dicholorobenzene*	0.0	0.0	0.3	0.0	0.1	0.1	2.2	2.2	0.0	0.4	0.1
Esters/Ketones	Ethyl acetate	0.2	0.3	0.2	0.3	0.3	0.3	0.4	0.4	0.2	0.3	0.3
	Butyl acetate	0.0	0.2	0.1	0.1	0.1	0.4	0.2	0.4	0.0	0.2	0.1
	Methyl ethyl ketone	0.1	0.3	0.1	0.2	0.2	1.2	0.3	1.2	0.1	0.3	0.2
	Methyl isobutyl ketone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Nonanal	7.4	0.3	1.2	2.8	1.8	0.0	1.8	7.4	0.0	2.2	1.8
	Decanal	0.8	0.0	0.1	0.3	0.3	0.0	0.3	0.8	0.0	0.2	0.3
Alcohols	Isopropylalcohol#	0.0	0.2	0.0	0.1	0.5	0.3	0.1	0.5	0.0	0.2	0.1
	1-Propanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1-Butanol	0.2	2.5	1.1	0.4	1.3	3.6	0.9	3.6	0.2	1.4	1.1
	2-Ethyl-1-hexanol	0.3	0.8	0.5	0.5	2.0	3.3	0.6	3.3	0.3	1.1	0.6
	2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	0.3	0.7	0.7	0.3	0.0	0.5	0.5	0.7	0.0	0.4	0.5
	2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	0.3	0.3	0.0	0.2	0.2	0.4	0.3	0.4	0.0	0.2	0.3
Aldehydes	Formaldehyde*	0.6	0.2	0.3	0.2	0.8	0.3	50.8	50.8	0.2	7.6	0.3
	Acetaldehyde	0.5	1.4	0.4	0.8	0.3	0.7	1.5	1.5	0.3	0.8	0.7
	Propionaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Crotonaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Butyraldehyde	0.0	0.2	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0
	Benzaldehyde	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.3	0.0	0.1	0.0
	Isovaleraldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Valeraldehyde	0.0	0.2	0.0	0.0	0.0	0.1	0.2	0.2	0.0	0.1	0.0
	Tolualdehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hexaldehyde	0.4	0.6	0.2	0.3	0.5	0.4	0.7	0.7	0.2	0.5	0.4
	2,5-Dimethylbenzaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TVOC	25	44	32	19	249	96	47	249	19	73	44

Table 2. (Continue)
(B)

		Urethane foam							Max.	Min.	Mean	Median
		P-8	**P-9**	**P-10**	**P-11**	**P-12**	**P-13**	**P-14**				
Aliphatic hydrocarbons	Hexane	2.2	0.1	0.2	0.1	2.0	0.0	0.2	2.2	0.0	0.7	0.2
	2,4-Dimethylpentane#	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Isooctane#	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heptane	0.1	0.0	0.0	0.0	6.4	0.0	0.0	6.4	0.0	0.9	0.0
	Octane	0.0	0.0	0.0	0.0	4.8	0.0	0.0	4.8	0.0	0.7	0.0
	Nonane	0.0	0.0	0.0	0.0	2.1	0.0	0.0	2.1	0.0	0.3	0.0
	Decane	0.2	0.2	0.0	0.0	14	0.0	0.6	14	0.0	2.1	0.2
	Undecane	0.2	0.0	0.0	0.0	18	0.0	3.3	18	0.0	3.1	0.0
	Dodecane	0.5	0.0	0.0	0.2	11	0.2	1.5	11	0.0	1.9	0.2
	Tridecane	0.3	0.2	0.3	0.2	5.1	0.2	0.6	5.1	0.2	1.0	0.3
	Tetradecane*	0.3	0.4	0.7	0.9	1.1	0.2	0.5	1.1	0.2	0.6	0.5
	Pentadecane	0.0	0.0	0.0	0.2	0.2	0.0	0.1	0.2	0.0	0.1	0.0
	Hexadecane	0.1	0.0	0.0	0.3	0.0	0.0	0.2	0.3	0.0	0.1	0.0
Aromatic hydrocarbons	Benzene	2.3	0.1	0.0	0.4	4.7	0.2	0.0	4.7	0.0	1.1	0.2
	Toluene*	1.4	0.8	0.8	0.7	2.5	0.3	1.0	2.5	0.3	1.1	0.8
	Ethylbenzene*	55	0.3	0.3	0.3	1.0	0.1	0.5	55	0.1	8.2	0.3
	Xylene*	2.5	0.3	0.3	0.3	0.9	0.1	0.7	2.5	0.1	0.7	0.3
	Styrene*	12	2.5	2.9	1.9	1.3	0.2	4.1	12	0.2	3.5	2.5
	m-Ethyltoluene	0.6	0.0	0.0	0.0	0.0	0.0	0.1	0.6	0.0	0.1	0.0
	p-Ethyltoluene	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.1	0.0
	1,3,5-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	o-Ethyltoluene	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	1,2,4-Trimethylbenzene	0.1	0.0	0.1	0.1	0.0	0.0	0.2	0.2	0.0	0.1	0.1
	1,2,3-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2,4,5-Tetramethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Terpenes	α-Pinene	0.3	0.0	0.1	0.0	0.6	0.0	0.0	0.6	0.0	0.1	0.0
	β-Pinene	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0
	D-Limonene	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.0
Halogenated hydrocarbons	Dichloromethane#	0.3	0.6	0.3	0.5	0.1	0.2	0.4	0.6	0.1	0.3	0.3
	Chloroform	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloroethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tricholoroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloropropane	0.0	0.0	0.0	0.0	9.1	0.0	0.0	9.1	0.0	1.3	0.0
	Bromodichloromethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dibromochloromethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tetracholoroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,4-Dicholorobenzene*	0.0	0.1	0.2	0.1	0.0	0.0	0.1	0.2	0.0	0.1	0.1
Esters/Ketones	Ethyl acetate	0.4	0.5	0.4	0.4	9.7	0.1	0.4	9.7	0.1	1.7	0.4
	Butyl acetate	0.2	0.2	0.2	0.1	0.1	0.0	0.5	0.5	0.0	0.2	0.2
	Methyl ethyl ketone	0.4	0.3	0.2	0.2	3.4	0.1	0.2	3.4	0.1	0.7	0.2
	Methyl isobutyl ketone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Nonanal	0.5	1.5	0.0	1.8	0.1	1.4	0.0	1.8	0.0	0.8	0.5
	Decanal	0.0	0.2	0.2	0.3	0.0	0.6	0.0	0.6	0.0	0.2	0.2
Alcohols	Isopropylalcohol#	0.7	0.4	0.6	0.4	12	0.0	0.2	12	0.0	2.1	0.4
	1-Propanol	0.2	0.0	0.0	0.0	2.5	0.0	0.0	2.5	0.0	0.4	0.0
	1-Butanol	0.6	2.8	3.1	1.7	2.9	0.2	2.9	3.1	0.2	2.0	2.8
	2-Ethyl-1-hexanol	7.8	0.0	5.9	3.1	1.9	1.3	2.5	7.8	0.0	3.2	2.5
	2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	0.2	0.7	3.6	1.5	0.0	0.7	2.6	3.6	0.0	1.3	0.7
	2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	0.0	0.3	32.6	9.4	0.2	0.4	0.0	32.6	0.0	6.1	0.3
	Formaldehyde*	0.2	0.3	0.2	7.7	0.3	0.7	0.6	7.7	0.2	1.4	0.3
	Acetaldehyde	1.2	0.3	1.1	1.0	6.6	0.4	0.5	6.6	0.3	1.6	1.0
	Propionaldehyde	7.1	0.1	0.4	0.0	2.8	0.0	1.0	7.1	0.0	1.6	0.4
	Crotonaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Butyraldehyde	0.2	0.5	0.1	0.0	1.8	0.0	0.0	1.8	0.0	0.4	0.1
	Benzaldehyde	6.4	0.2	0.1	0.1	0.0	0.0	0.2	6.4	0.0	1.0	0.1
	Isovaleraldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Valeraldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tolualdehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hexaldehyde	0.2	0.2	0.3	0.2	0.2	0.0	0.4	0.4	0.0	0.2	0.2
	2,5-Dimethylbenzaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TVOC	188	285	112	42	645	24	121	645	24	203	121

Table 2. (Continue)
(C)

		Polyester				Max.	Min.	Mean	Median
		P-15	**P-16**	**P-17**	**P-18**				
Aliphatic hydrocarbons	Hexane	0.2	0.3	0.3	0.3	0.3	0.2	0.3	0.3
	2,4-Dimethylpentane#	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Isooctane#	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heptane	0.0	0.0	0.1	0.3	0.3	0.0	0.1	0.1
	Octane	0.0	0.0	0.0	5.0	5.0	0.0	1.3	0.0
	Nonane	0.1	0.0	0.0	0.3	0.3	0.0	0.1	0.1
	Decane	1.9	0.3	0.3	162	162	0.3	41	1.1
	Undecane	3.7	0.3	0.3	60	60	0.3	16	2.0
	Dodecane	5.6	1.5	0.9	48	48	0.9	14	3.5
	Tridecane	1.1	0.5	0.6	0.0	1.1	0.0	0.5	0.5
	Tetradecane*	1.0	0.9	0.9	5.3	5.3	0.9	2.0	0.9
	Pentadecane	0.1	0.1	0.2	0.0	0.2	0.0	0.1	0.1
	Hexadecane	0.2	0.0	0.0	0.2	0.2	0.0	0.1	0.1
Aromatic hydrocarbons	Benzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Toluene*	0.7	0.5	0.5	0.2	0.7	0.2	0.5	0.5
	Ethylbenzene*	0.3	0.2	0.2	0.0	0.3	0.0	0.2	0.2
	Xylene*	0.4	0.2	0.2	0.2	0.4	0.2	0.3	0.2
	Styrene*	2.2	0.1	0.2	0.0	2.2	0.0	0.6	0.1
	m-Ethyltoluene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	p-Ethyltoluene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,3,5-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	o-Ethyltoluene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2,4-Trimethylbenzene	0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.1
	1,2,3-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2,4,5-Tetramethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Terpenes	α-Pinene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	β-Pinene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	D-Limonene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Halogenated hydrocarbons	Dichloromethane#	0.4	0.0	0.0	0.0	0.4	0.0	0.1	0.0
	Chloroform	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloroethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tricholoroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloropropane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bromodichloromethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dibromochloromethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tetracholoroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,4-Dicholorobenzene*	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Esters/Ketones	Ethyl acetate	0.4	0.4	0.3	0.0	0.4	0.0	0.3	0.4
	Butyl acetate	0.2	0.0	0.1	0.0	0.2	0.0	0.1	0.1
	Methyl ethyl ketone	0.3	0.7	0.2	0.0	0.7	0.0	0.3	0.2
	Methyl isobutyl ketone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Nonanal	1.4	2.1	3.1	0.0	3.1	0.0	1.6	1.7
	Decanal	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0
Alcohols	Isopropylalcohol#	0.3	0.0	0.0	0.1	0.3	0.0	0.1	0.1
	1-Propanol	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0
	1-Butanol	2.0	0.0	0.1	0.0	2.0	0.0	0.5	0.1
	2-Ethyl-1-hexanol	0.0	0.5	0.9	0.0	0.9	0.0	0.4	0.3
	2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	0.0	1.7	1.2	0.0	1.7	0.0	0.7	0.6
	2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	0.0	0.3	0.3	0.0	0.3	0.0	0.2	0.2
Aldehydes	Formaldehyde*	3.8	0.0	0.3	0.2	3.8	0.0	1.1	0.2
	Acetaldehyde	0.6	0.0	0.2	0.3	0.6	0.0	0.3	0.3
	Propionaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Crotonaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Butyraldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Benzaldehyde	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
	Isovaleraldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Valeraldehyde	0.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
	Tolualdehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hexaldehyde	0.6	0.0	0.1	0.0	0.6	0.0	0.2	0.1
	2,5-Dimethylbenzaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TVOC	226	42	63	1,570	1,570	42	475	144

Table 2. (Continue)
(D)

		Polyester		Max.	Min.	Mean	Median
		P-19	**P-20**				
Aliphatic hydrocarbons	Hexane	0.0	0.0	0.0	0.0	0.0	0.0
	2,4-Dimethylpentane[#]	0.0	0.0	0.0	0.0	0.0	0.0
	Isooctane[#]	0.0	0.0	0.0	0.0	0.0	0.0
	Heptane	0.0	0.0	0.0	0.0	0.0	0.0
	Octane	0.0	0.0	0.0	0.0	0.0	0.0
	Nonane	0.0	0.0	0.0	0.0	0.0	0.0
	Decane	0.2	0.2	0.2	0.2	0.2	0.2
	Undecane	0.0	0.0	0.0	0.0	0.0	0.0
	Dodecane	0.1	0.6	0.6	0.1	0.4	0.4
	Tridecane	0.0	0.2	0.2	0.0	0.1	0.1
	Tetradecane*	0.3	0.8	0.8	0.3	0.5	0.5
	Pentadecane	0.2	0.4	0.4	0.2	0.3	0.3
	Hexadecane	0.3	0.4	0.4	0.3	0.3	0.3
Aromatic hydrocarbons	Benzene	0.3	0.7	0.7	0.3	0.5	0.5
	Toluene*	0.4	0.8	0.8	0.4	0.6	0.6
	Ethylbenzene*	0.1	0.4	0.4	0.1	0.2	0.2
	Xylene*	0.2	0.5	0.5	0.2	0.3	0.3
	Styrene*	0.5	2.9	2.9	0.5	1.7	1.7
	m-Ethyltoluene	0.0	0.0	0.0	0.0	0.0	0.0
	p-Ethyltoluene	0.0	0.0	0.0	0.0	0.0	0.0
	1,3,5-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0
	o-Ethyltoluene	0.0	0.0	0.0	0.0	0.0	0.0
	1,2,4-Trimethylbenzene	0.0	0.1	0.1	0.0	0.1	0.1
	1,2,3-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0
	1,2,4,5-Tetramethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0
Terpenes	α-Pinene	0.0	0.0	0.0	0.0	0.0	0.0
	β-Pinene	0.0	0.0	0.0	0.0	0.0	0.0
	D-Limonene	0.0	0.0	0.0	0.0	0.0	0.0
Halogenated hydrocarbons	Dichloromethane[#]	0.1	0.4	0.4	0.1	0.3	0.3
	Chloroform	0.0	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloroethane	0.0	0.0	0.0	0.0	0.0	0.0
	Tricholoroethylene	0.0	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloropropane	0.0	0.0	0.0	0.0	0.0	0.0
	Bromodichloromethane	0.0	0.0	0.0	0.0	0.0	0.0
	Dibromochloromethane	0.0	0.0	0.0	0.0	0.0	0.0
	Tetracholoroethylene	0.0	0.0	0.0	0.0	0.0	0.0
	1,4-Dicholorobenzene*	0.0	0.1	0.1	0.0	0.1	0.1
Esters/Ketones	Ethyl acetate	0.7	0.7	0.7	0.7	0.7	0.7
	Butyl acetate	0.0	0.0	0.0	0.0	0.0	0.0
	Methyl ethyl ketone	0.8	0.6	0.8	0.6	0.7	0.7
	Methyl isobutyl ketone	0.0	0.0	0.0	0.0	0.0	0.0
	Nonanal	0.4	0.3	0.4	0.3	0.3	0.3
	Decanal	0.0	0.0	0.0	0.0	0.0	0.0
Alcohols	Isopropylalcohol[#]	1.1	1.3	1.3	1.1	1.2	1.2
	1-Propanol	0.6	0.3	0.6	0.3	0.5	0.5
	1-Butanol	2.3	2.0	2.3	2.0	2.1	2.1
	2-Ethyl-1-hexanol	0.6	1.5	1.5	0.6	1.1	1.1
	2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	0.0	0.0	0.0	0.0	0.0	0.0
	2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	0.0	0.1	0.1	0.0	0.1	0.1
Aldehydes	Formaldehyde*	0.3	0.3	0.3	0.3	0.3	0.3
	Acetaldehyde	5.5	3.4	5.5	3.4	4.4	4.4
	Propionaldehyde	0.4	0.2	0.4	0.2	0.3	0.3
	Crotonaldehyde	0.0	0.0	0.0	0.0	0.0	0.0
	Butyraldehyde	0.2	0.3	0.3	0.2	0.3	0.3
	Benzaldehyde	0.1	0.2	0.2	0.1	0.2	0.2
	Isovaleraldehyde	0.0	0.0	0.0	0.0	0.0	0.0
	Valeraldehyde	0.2	0.2	0.2	0.2	0.2	0.2
	Tolualdehyde	0.0	0.0	0.0	0.0	0.0	0.0
	Hexaldehyde	0.5	0.6	0.6	0.5	0.5	0.5
	2,5-Dimethylbenzaldehyde	0.0	0.0	0.0	0.0	0.0	0.0
	TVOC	16	51	51	16	34	34

[*]: Indoor air quality guideline substances established by the Ministry of Health, Labour and Welfare
[#]: This value is for reference since the retention of the adsorbent filler for this compound is weak.
TVOC is the value obtained by converting all compounds detected in the range between hexane and hexadecane to Toluene

Table 3. Maximum, Minimum, Mean and Median Emission Values and Detection Rate for the Pillow Samples

		Max. (μg/unit)	Min. (μg/unit)	Mean (μg/unit)	Median (μg/unit)	Detection rate (%)
Aliphatic hydrocarbons	Hexane	2.2	0.0	0.3	0.1	65
	2,4-Dimethylpentane	0.0	0.0	0.0	0.0	0.0
	Isooctane	0.0	0.0	0.0	0.0	0.0
	Heptane	6.4	0.0	0.3	0.0	20
	Octane	5.0	0.0	0.5	0.0	10
	Nonane	2.1	0.0	0.1	0.0	15
	Decane	162	0.0	9.0	0.2	60
	Undecane	60	0.0	4.3	0.0	45
	Dodecane	48	0.0	3.6	0.4	75
	Tridecane	5.1	0.0	0.5	0.2	75
	Tetradecane	5.3	0.2	0.8	0.6	100
	Pentadecane	0.4	0.0	0.1	0.1	65
	Hexadecane	0.5	0.0	0.1	0.1	65
Aromatic hydrocarbons	Benzene	4.7	0.0	0.4	0.0	45
	Toluene	2.5	0.2	0.8	0.7	100
	Ethylbenzene	55	0.0	3.1	0.3	95
	Xylene	2.5	0.1	0.5	0.3	100
	Styrene	12	0.0	2.4	2.0	95
	m-Ethyltoluene	0.6	0.0	0.0	0.0	15
	p-Ethyltoluene	0.4	0.0	0.0	0.0	5.0
	1,3,5-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0
	o-Ethyltoluene	0.1	0.0	0.0	0.0	5.0
	1,2,4-Trimethylbenzene	0.2	0.0	0.1	0.0	40
	1,2,3-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0
	1,2,4,5-Tetramethylbenzene	0.0	0.0	0.0	0.0	0.0
Terpenes	α-Pinene	0.6	0.0	0.1	0.0	20
	β-Pinene	0.1	0.0	0.0	0.0	5.0
	D-Limonene	0.2	0.0	0.0	0.0	10
Halogenated hydrocarbons	Dichloromethane	0.6	0.0	0.3	0.3	85.0
	Chloroform	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloroethane	0.0	0.0	0.0	0.0	0.0
	Trichloroethylene	0.0	0.0	0.0	0.0	0.0
	1,2-Dicholoropropane	9.1	0.0	0.5	0.0	5.0
	Bromodichloromethane	0.0	0.0	0.0	0.0	0.0
	Dibromochloromethane	0.0	0.0	0.0	0.0	0.0
	Tetrachloroethylene	0.0	0.0	0.0	0.0	0.0
	1,4-Dichlorobenzene	2.2	0.0	0.2	0.1	50
Esters/Ketones	Ethyl acetate	9.7	0.0	0.8	0.4	95
	Butyl acetate	0.5	0.0	0.1	0.1	70
	Methyl ethyl ketone	3.4	0.0	0.5	0.2	95
	Methyl isobutyl ketone	0.0	0.0	0.0	0.0	0.0
	Nonanal	7.4	0.0	1.4	1.3	80
	Decanal	0.8	0.0	0.2	0.1	50
Alcohols	Isopropylalcohol	12	0.0	0.9	0.2	75
	1-Propanol	2.5	0.0	0.2	0.0	25
	1-Butanol	3.6	0.0	1.5	1.5	90
	2-Ethyl-hexanol	7.8	0.0	1.7	0.9	85
	2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	3.6	0.0	0.8	0.5	70
	2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	33	0.0	2.3	0.2	70
Aldehydes	Folmaldehyde	51	0.0	3.4	0.3	95
	Acetaldehyde	6.6	0.0	1.3	0.6	95
	Propionaldehyde	7.1	0.0	0.6	0.0	35
	Crotonaldehyde	0.0	0.0	0.0	0.0	0.0
	Butyraldehyde	1.8	0.0	0.2	0.0	40
	Benzaldehyde	6.4	0.0	0.4	0.1	50
	Isovaleraldehyde	0.0	0.0	0.0	0.0	0.0
	Valeraldehyde	0.2	0.0	0.1	0.0	30
	Tolualdehyde	0.0	0.0	0.0	0.0	0.0
	Hexaldehyde	0.7	0.0	0.3	0.3	85
	2,5-Dimethylbenzaldehyde	0.0	0.0	0.0	0.0	0.0
	TVOC	1,570	16	195	57	–

> 50%. This assessment identified the compound hexamethylcyclotrisiloxane as a compound of interest (data not shown).

Since pillows are used for a longer time in the resident's breathing zone than other bedding items, further continuous monitoring is necessary, especially for polyethylene pillows, which showed relatively high emissions.

Mattress Emissions Twenty mattresses were subjected to the same emissions tests as the pillow samples. The results are shown in Table 4. **M-1**, a low-resilience urethane mattress, produced the highest TVOC emissions (11,200 μg/unit, toluene equivalent). Relatively high emissions of hexane (52 μg/unit), toluene (513 μg/unit), trichloroethylene (68 μg/unit), and tetrachloroethylene (13,400 μg/unit) were also detected from **M-1. M-10** produced the highest emissions of xylene (92 μg/unit), 1,2-dichloroethane (54 μg/unit) and ethyl acetate (120 μg/unit). Relatively high emissions of dichloromethane from **M-12**, 1-butanol from **M-16,** and α-pinene from **M-20** were also detected.

Ten compounds were emitted by all 20 of the mattresses: decane, dodecane, tetradecane, toluene, ethyl benzoate, xylene, styrene, ethyl acetate, butyl acetate, 1-butanol (Table 5).

As with the pillows, we surveyed the mattress emission results for chemical substances detected at a high concentration (> 400 μg/m^3) and with a high emission frequency (> 50%). This assessment highlighted the compounds octamethyltetrasiloxane, 2-ethyl-1-hexanoic acid, and decamethylcyclopentasiloxane. 2-Ethyl-1-hexanoic acid is an oxide of 2-ethyl-1-hexanol, a possible causative chemical for sick building symptoms[4–6] that needs to be continuously monitored.

In conclusion, we reported the VOCs emissions from a sample of bedding products (20 pillows and 20 mattress) using the sampling bag method for the first time. This sample represented items that are commonly present indoors for long periods of time and in the breathing zone of occupants. The emissions from these items therefore pose a potential health risk to the residents. Our results showed that a wide variety of VOCs are emitted by these items. The results from the polyethylene pillow sample showed higher TVOC emissions compared with the other pillow types tested, while buckwheat hull pillows produced lower emissions overall. Tetradecane, toluene and xylene were frequently emitted from our pillow sample. The mattresses showed an overall trend of higher emissions compared with the pillows. High concentrations of tetrachloroethylene, dichloromethane, 1-butanol and toluene were also detected. 2-Ethyl-1-hexnoic acid was detected at a high frequency and a high concentration from the mattress samples. The results of this study provide important evidence that can be used in the development of measures combatting the negative health effects of indoor air pollution, such as sick building syndrome. To further understand the effects of indoor air pollution, it is necessary to continue research into testing the emissions from bedding products and other household items.

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Conflict of interest The authors declare no conflict of interest.

REFERENCES

1) Boor BE, Jarnstrom H, Novoselac A, Xu Y. Infant exposure to emissions of volatile organic compounds from crib mattresses. *Environ. Sci. Technol.*, **48**, 3541–3549 (2014).
2) OZ K. Merav B, Sara S, Yael D. Volatile Organic Compound Emissions from Polyurethane Mattresses under Variable Environmental Conditions. *Environ. Sci. Technol.*, **53**, 9171–9180 (2019).
3) JASO M902. Road vehicles-interior parts and materials-measurement methods of diffused volatile organic compounds (VOCs). Tokyo, Japan: Japanese Automobile Standards Organization, 2018.
4) Wakayama T, Ito Y, Sakai K, Miyake M, Shibata E, Ohno H, Kamijima M. Comprehensive review of 2-ethyl-1-hexanol as an indoor air pollutant. *J. Occup. Health*, **61**, 19–35 (2019).
5) Sakai K, Kamijima M, Shibata E, Ohno H, Nakajima T. Indoor air pollution by 2-ethyl-1-hexanol in non-domestic buildings in Nagoya, Japan. *J. Environ. Monit.*, **8**, 1122–1128 (2006).
6) Sakai K, Kamijima M, Shibata E, Ohno H, Nakajima T. Annual transition and seasonal variation of indoor air pollution levels of 2-ethyl1-hexanol in large-scale buildings in Nagoya, Japan. *J. Environ. Monit.*, **11**, 2068–2076 (2009).

Table 4. VOCs Emissions from Mattress Samples (μg/unit) (A) **M-1**–**M-10**, (B) **M-11**–**M-20**
(A)

		M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	M-9	M-10
Aliphatic hydrocarbons	Hexane	52	3.1	1.7	2.0	3.9	1.4	0.0	1.3	8.7	12
	2,4-Dimethylpentane[#]	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Isooctane[#]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heptane	14	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Octane	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Nonane	16	3.5	1.4	0.0	0.0	0.0	0.0	0.0	1.0	1.2
	Decane	22	13	3.9	1.4	1.4	2.4	2.4	1.5	2.0	2.9
	Undecane	7.6	15	4.3	2.1	1.0	1.5	2.1	2.2	0.0	3.8
	Dodecane	13	24	6.1	6.1	1.9	8.3	8.6	8.8	1.1	6.7
	Tridecane	2.7	11	0.0	2.2	0.0	0.0	3.5	0.0	0.0	3.3
	Tetradecane*	5.8	2.5	2.2	1.3	4.1	7.2	18	19	2.8	3.6
	Pentadecane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hexadecane	1.3	1.1	0.0	0.0	0.0	1.5	2.7	4.4	0.0	1.1
Aromatic hydrocarbons	Benzene	13	4.4	2.8	1.5	1.6	1.5	1.6	1.3	2.0	1.9
	Toluene*	513	36	44	15	20	12	19	19	21	31
	Ethylbenzene*	7.7	11	8.1	9.4	6.7	4.0	6.2	5.9	5.9	24
	Xylene*	19	14	7.0	8.6	7.8	3.6	5.8	6.1	5.8	92
	Styrene*	14	21	3.2	29	18	18	31	62	19	6.1
	m-Ethyltoluene	6.6	1.8	1.2	1.2	1.3	0.0	1.2	1.3	0.0	0.0
	p-Ethyltoluene	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,3,5-Trimethylbenzene	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	o-Ethyltoluene	3.1	2.3	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
	1,2,4-Trimethylbenzene	8.1	2.6	2.2	1.7	2.6	1.6	2.4	2.3	1.9	2.1
	1,2,3-Trimethylbenzene	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2,4,5-Tetramethylbenzene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Terpenes	α-Pinene	19	2.9	2.3	0.0	24	0.0	34	12	1.1	0.0
	β-Pinene	7.5	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	1.6
	D-Limonene	6.1	1.4	0.0	0.0	0.0	0.0	1.5	1.1	0.0	2.3
Halogenated hydrocarbons	Dichloromethane[#]	44	142	4.7	1.8	1.5	0.0	0.0	1.8	2.6	5.5
	Chloroform	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloroethane	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54
	Trichloroethylene	68	2.2	3.4	1.3	0.0	0.0	1.0	1.2	1.6	2.6
	1,2-Dichloropropane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Bromodichloromethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dibromochloromethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tetrachloroethylene	13,400	55.9	6.3	6.0	5.5	4.3	8.6	7.0	7.3	3.2
	1,4-Dichlorobenzene*	0.0	0.0	0.0	1.2	1.3	0.0	1.1	0.0	0.0	0.0
Esters/Ketones	Ethyl acetate	17	12	12	7.3	9.2	4.1	9.8	14	14	120
	Butyl acetate	11	5.0	4.8	2.3	9.1	3.8	7.6	6.2	11	4.7
	Methyl ethyl ketone	6.1	4.6	5.8	5.1	11	2.7	5.2	6.1	6.4	13
	Methyl isobutyl ketone	0.0	2.3	1.7	0.0	2.4	0.0	1.1	0.0	1.2	1.5
	Nonanal	30	14	3.0	2.3	3.5	2.2	2.6	2.2	3.7	5.7
	Decanal	0.0	0.0	1.9	10.5	0.0	1.1	1.6	2.8	1.9	0.0
Alcohols	Isopropylalcohol[#]	2.4	1.5	2.6	2.8	9.5	1.2	2.9	3.3	4.7	5.4
	1-Propanol	0.0	0.0	0.0	0.0	10.4	0.0	0.0	1.2	1.4	0.0
	1-Butanol	8.5	14	14	23	38	23	105	20	29	5.3
	2-Ethyl-1-hexanol	10	10	2.8	180	67	4.0	28	52	38	6.2
	2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	0.0	1.6	1.3	0.0	3.2	0.0	8.1	3.1	2.0	1.3
	2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	0.0	0.0	1.2	0.0	0.0	0.0	0.0	4.2	1.1	0.0
Aldehydes	Formaldehyde*	0.2	0.6	0.2	0.2	0.0	0.2	0.1	0.0	0.2	0.4
	Acetaldehyde	2.7	2.5	0.3	0.4	0.7	0.5	0.1	0.2	0.3	0.3
	Propionaldehyde	0.2	0.8	0.9	0.6	4.8	1.2	0.4	0.5	0.0	2.3
	Crotonaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Butyraldehyde	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
	Benzaldehyde	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.1	0.0
	Isovaleraldehyde	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.2	0.1	0.0
	Valeraldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	Tolualdehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hexaldehyde	0.2	0.1	0.0	0.1	0.1	0.0	0.1	0.1	0.3	0.0
	2,5-Dimethylbenzaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TVOC	11,200	2,860	1,260	3,390	2,510	1,430	1,190	2,780	1,110	1,370

Table 4. (Continue)
(B)

		M-11	M-12	M-13	M-14	M-15	M-16	M-17	M-18	M-19	M-20
Aliphatic hydrocarbons	Hexane	0.0	1.4	0.0	1.0	4.1	2.1	5.0	4.6	0.0	0.0
	2,4-Dimethylpentane[#]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Isooctane[#]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heptane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Octane	0.0	4.5	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0
	Nonane	1.2	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0
	Decane	7.9	22.8	5.9	3.7	6.3	22	2.1	2.9	1.3	3.2
	Undecane	9.0	6.2	4.0	6.8	6.3	17	2.9	14	1.5	5.1
	Dodecane	16	22	153	10	32	21	5.4	28	4.1	8.7
	Tridecane	3.5	1.2	1.7	5.7	7.7	4.5	3.9	22	0.0	4.3
	Tetradecane*	3.4	6.6	57	13	12	13	4.7	7.7	5.7	5.3
	Pentadecane	0.0	0.0	1.4	1.7	0.0	3.0	1.2	1.2	0.0	2.1
	Hexadecane	0.0	0.0	5.1	3.5	1.6	3.7	1.2	1.7	0.0	3.0
Aromatic hydrocarbons	Benzene	0.0	2.6	0.0	1.1	0.0	2.4	0.0	1.1	0.0	0.0
	Toluene*	11	93	8.5	19	27	66	12	16	9.4	20
	Ethylbenzene*	17	13	5.4	23	11	15	7.0	3.4	3.6	16
	Xylene*	36	24	10	41	18	27	13	6.2	5.4	82
	Styrene*	8.8	80	3.8	8.2	11	11	6.2	41	2.7	12
	m-Ethyltoluene	1.4	0.0	0.0	1.6	1.1	3.1	1.0	0.0	0.0	1.5
	p-Ethyltoluene	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0
	1,3,5-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	1.2
	o-Ethyltoluene	0.0	0.0	1.2	0.0	3.7	1.6	0.0	0.0	0.0	1.1
	1,2,4-Trimethylbenzene	3.0	0.0	1.8	3.2	1.7	3.1	2.1	1.5	0.0	3.3
	1,2,3-Trimethylbenzene	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	1.2
	1,2,4,5-Tetramethylbenzene	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0
Terpenes	α-Pinene	1.4	6.3	2.5	12.8	3.8	9.7	3.1	0.0	0.0	347
	β-Pinene	0.0	3.1	0.0	0.0	0.0	3.0	2.2	0.0	0.0	28
	D-Limonene	1.1	1.7	0.0	1.4	1.4	6.4	2.3	1.9	0.0	11
Halogenated hydrocarbons	Dichloromethane[#]	0.0	8,860	5.1	1.1	85	346	0.0	2.2	0.0	0.0
	Chloroform	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
	1,2-Dichloroethane	0.0	2.6	0.0	0.0	1.5	2.0	0.0	0.0	0.0	0.0
	Trichloroethylene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1,2-Dichloropropane	0.0	5.2	0.0	0.0	4.0	13	0.0	0.0	0.0	0.0
	Bromodichloromethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Dibromochloromethane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Tetrachloroethylene	0.0	2.6	0.0	0.0	4.1	18	0.0	0.0	0.0	0.0
	1,4-Dichlorobenzene*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Esters/Ketones	Ethyl acetate	1.2	15	14	5.4	11	7.4	5.1	3.7	2.5	3.8
	Butyl acetate	1.1	6.7	2.2	6.0	5.7	13	8.5	6.3	3.0	11
	Methyl ethyl ketone	0.0	6.8	3.5	3.0	6.1	19	2.9	1.5	2.1	6.1
	Methyl isobutyl ketone	0.0	0.0	0.0	1.6	0.0	1.3	1.3	0.0	0.0	2.1
	Nonanal	37	0.0	27	26	0.0	0.0	13	93	2.0	16
	Decanal	1.2	0.0	0.0	1.1	0.0	0.0	0.0	1.7	0.0	0.0
Alcohols	Isopropylalcohol[#]	0.0	4.8	0.0	1.2	3.0	13	1.4	0.0	2.9	3.7
	1-Propanol	0.0	0.0	0.0	0.0	0.0	11	0.0	0.0	0.0	1.1
	1-Butanol	83	13	2.9	15	17	576	45	20	5.6	26.3
	2-Ethyl-1-hexanol	87	6.5	38	25	0.0	64	18	0.0	1.2	0.0
	2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	35	0.0	39	11	0.0	0.0	0.0	0.0	0.0	0.0
	2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	0.0	0.0	1.4	1.1	0.0	2.1	0.0	0.0	0.0	0.0
Aldehydes	Formaldehyde*	0.2	0.7	0.2	0.5	1.0	1.9	0.2	0.7	0.0	0.2
	Acetaldehyde	0.0	2.2	0.2	0.1	2.2	0.4	0.1	0.2	0.1	0.2
	Propionaldehyde	0.3	13	1.0	0.0	6.5	0.8	0.1	0.0	0.5	0.2
	Crotonaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Butyraldehyde	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
	Benzaldehyde	0.0	0.1	0.0	0.0	0.1	0.2	0.1	0.1	0.0	0.0
	Isovaleraldehyde	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.2
	Valeraldehyde	0.0	0.0	0.0	0.0	0.2	0.4	0.0	0.0	0.0	0.3
	Tolualdehyde	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Hexaldehyde	0.2	0.2	0.0	0.2	0.3	0.6	0.5	0.3	0.0	0.9
	2,5-Dimethylbenzaldehyde	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TVOC	816	4,280	1,810	2,140	3,550	4,950	828	4,060	687	1,660

[*]: Indoor air quality guideline substances established by the Ministry of Health, Labour and Welfare
[#]: This value is for reference since the retention of the adsorbent filler for this compound is weak.
TVOC is the value obtained by converting all compounds detected in the range between hexane and hexadecane to Toluene

Table 5. Maximum, Minimum, Mean and Median Emission Values and Detection Rate for the Mattress Samples

		Max. (μg/unit)	Min. (μg/unit)	Mean (μg/unit)	Median (μg/unit)	Detection rate (%)
Aliphatic hydrocarbons	Hexane	52	0.0	5.2	1.9	75
	2,4-Dimethylpentane	9.3	0.0	0.5	0.0	5.0
	Isooctane	0.0	0.0	0.0	0.0	0.0
	Heptane	14	0.0	0.7	0.0	10
	Octane	4.5	0.0	0.4	0.0	15
	Nonane	16	0.0	1.3	0.0	35
	Decane	23	1.3	6.5	3.0	100
	Undecane	17	0.0	5.6	4.2	95
	Dodecane	153	1.1	19	8.8	100
	Tridecane	22	0.0	3.8	3.0	70
	Tetradecane	57	1.3	9.7	5.7	100
	Pentadecane	3.0	0.0	0.5	0.0	30
	Hexadecane	5.1	0.0	1.6	1.2	65
Aromatic hydrocarbons	Benzene	13	0.0	2.0	1.5	70
	Toluene	513	8.5	51	20	100
	Ethylbenzene	24	3.4	10	7.9	100
	Xylene	92	3.6	22	12	100
	Styrene	80	2.7	20	13	100
	m-Ethyltoluene	6.6	0.0	1.2	1.2	65
	p-Ethyltoluene	3.4	0.0	0.2	0.0	10
	1,3,5-Trimethylbenzene	2.9	0.0	0.3	0.0	15
	o-Ethyltoluene	3.7	0.0	0.7	0.0	35
	1,2,4-Trimethylbenzene	8.1	0.0	2.4	2.2	90
	1,2,3-Trimethylbenzene	3.0	0.0	0.3	0.0	15
	1,2,4,5-Tetramethylbenzene	1.6	0.0	0.1	0.0	5.0
Terpenes	α-Pinene	347	0.0	24	3.0	75
	β-Pinene	28	0.0	2.3	0.0	35
	D-Limonene	11	0.0	2.0	1.4	65
Halogenated hydrocarbons	Dichloromethane	8,860	0.0	475	2.0	70
	Chloroform	1.7	0.0	0.1	0.0	10
	1,2-Dichloroethane	54	0.0	3.1	0.0	25
	Trichloroethylene	68	0.0	4.1	0.0	40
	1,2-Dichloropropane	13	0.0	1.1	0.0	15
	Bromodichloromethane	0.0	0.0	0.0	0.0	0.0
	Dibromochloromethane	0.0	0.0	0.0	0.0	0.0
	Tetrachloroethylene	13,400	0.0	676	4.2	65
	1,4-Dichlorobenzene	1.3	0.0	0.2	0.0	15
Esters/Ketones	Ethyl acetate	120	1.2	14	9.5	100
	Butyl acetate	13	1.1	6.4	6.1	100
	Methyl ethyl ketone	19	0.0	5.8	5.5	95
	Methyl isobutyl ketone	2.4	0.0	0.8	0.6	50
	Nonanal	93	0.0	14	3.6	85
	Decanal	11	0.0	1.2	0.0	45
Alcohols	Isopropylalcohol	13	0.0	3.3	2.9	85
	1-Propanol	11	0.0	1.3	0.0	25
	1-Butanol	576	2.9	54	20	100
	2-Ethyl-1-hexanol	180	0.0	32	14	85
	2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	39	0.0	5.3	0.7	50
	2,2,4-Trimethyl-1,3-pentanediol diisobutyrate	4.2	0.0	0.6	0.0	30
Aldehydes	Formaldehyde	1.9	0.0	0.4	0.2	85
	Acetaldehyde	2.7	0.0	0.7	0.3	95
	Propionaldehyde	13	0.0	1.7	0.5	85
	Crotonaldehyde	0.0	0.0	0.0	0.0	0.0
	Butyraldehyde	0.2	0.0	0.0	0.0	25
	Benzaldehyde	0.2	0.0	0.1	0.0	35
	Isovaleraldehyde	0.3	0.0	0.1	0.0	30
	Valeraldehyde	0.4	0.0	0.1	0.0	20
	Tolualdehyde	0.2	0.0	0.0	0.0	5.0
	Hexaldehyde	0.9	0.0	0.2	0.2	75
	2,5-Dimethylbenzaldehyde	0.0	0.0	0.0	0.0	0.0
	TVOC	11,200	687	2,694	1,975	-