

測定方法の開発及び日本標準規格(JIS)などの整備に必要な情報を提供することを目的とした。

B. 研究方法

室内空気測定方法に関する日本標準規格(JIS)と国際規格(IS)を比較し、IS に対応されている JIS の室内空気測定方法を調べた。また、JIS 対応が確立されていない IS や ISO/DIS(国際規格案)と AWI(作業草案)の中、室内空気中殺虫剤や SVOC 濃度測定方法と関連する規格・規格案について情報提供を行う。日本における室内空気質測定方法は JIS ハンドブック -シックハウス-(2015)、JIS ハンドブック -シックハウス-(2008)を参考した。また、国際規格は JIS ハンドブック -国際標準化-(2014)と ISO-16000/TC146/SC6を参考した。

C. 結果

JIS と IS における室内空気質と関連する測定方法を調べた。日本の室内空気質測定方法は日本規格協会から出版された JIS ハンドブック -シックハウス-(2008, 2015)を参考した。以下に室内空気質と関連する JIS を示す。

1)JIS 室内空気測定規格

- JIS A 1960:2015 室内空気のサンプリング方法 通則
- JIS A 1961:2015 室内空気中のホルムアルデヒドのサンプリング方法
- JIS A 1962:2015 室内空気中のホルムアルデヒド及び他のカルボニル化合物の定量-ポンプサンプリング
- JIS A 1963:2015 室内空気中のホルムアルデヒドの定量-パッシブサンプリング
- JIS A 1964:2015 室内空気中の揮発性有機化合物(VOC)の測定方法通則
- JIS A 1965:2015 室内及び放散試験チャンバー内空気中揮発性有機化合物の Tenax TA 吸着剤を用いたポンプサンプリング, 加熱脱離及び MS/FID を用いたガスクロマトグラフィーによる定量
- JIS A 1966:2015 室内空気中の揮発性有機化合物(VOC)の吸着捕集/加熱脱離/キャピラリーガスクロマトグラフ法によるサンプリング及び分析-ポンプサンプリング
- JIS A 1967:2015 室内空気中の揮発性有機化合物(VOC)の吸着捕集/加熱脱離/キャピラリーガスクロマトグラフ法によるサンプリング及び分析-パッシブサンプリング
- JIS A 1968:2015 室内空気中の揮発性有機化合物(VOC)の吸着捕集/溶媒抽出/キャピラリーガスクロマトグラフ法によるサンプリング及び分析-ポンプサンプリング
- JIS A 1969:2015 室内空気中の揮発性有機化合物(VOC)の吸着捕集/溶媒抽出/キャピラリーガスクロマトグラフ法によるサンプリング及び分析-パッシブサンプリング
- JIS A 1901:2015 建築材料の揮発性有機化合物(VOC), ホルムアルデヒド及び他のカルボニル化合物放散測定方法—小形チャンバー法
- JIS A 1902-1:2015 建築材料の揮発性有機化合物(VOC), ホルムアルデヒド及び他のカルボニル化合物放散量測定におけるサンプル採取, 試験片作製及び試験条件—第1部: ボード類, 壁紙及び床材
- JIS A 1902-2:2015 建築材料の揮発性有機化合物(VOC), ホルムアルデヒド及び他のカルボニル化合物放散量測定におけるサンプル採取, 試験片作製及び試験条件—第2部: 接着剤
- JIS A 1902-3:2015 建築材料の揮発性有機化合物(VOC), ホルムアルデヒド及び他のカルボニル化合物放散量測定におけるサンプル採取, 試験片作製及び試験条件—第3部: 塗料及び建築用仕上塗材
- JIS A 1902-4:2015 建築材料の揮発性有機化合物(VOC), ホルムアルデヒド及び他の

カルボニル化合物放散量測定におけるサンプル採取，試験片作製及び試験条件—第4部：断熱材

- JIS A 1903:2015 建築材料の揮発性有機化合物(VOC)のフラックス発生量測定法—パッシブ法
- JIS A 1904:2015 建築材料の準揮発性有機化合物(SVOC)の放散測定方法—マイクロチャンバー法
- JIS A 1905-1:2015 小形チャンバー法による室内空気汚染濃度低減材の低減性能試験法—第1部：一定ホルムアルデヒド濃度供給
- JIS A 1905-2:2015 小形チャンバー法による室内空気汚染濃度低減材の低減性能試験法—第2部：ホルムアルデヒド放散建材を用いた吸着速度測定
- JIS A 1906:2015 小形チャンバー法による室内空気汚染濃度低減材の低減性能試験法—一定揮発性有機化合物(VOC)，及びホルムアルデヒドを除く他のカルボニル化合物濃度供給法による吸着速度測定
- JIS A 1911:2015 建築材料などからのホルムアルデヒド放散測定方法—大形チャンバー法
- JIS A 1912:2015 建築材料などからの揮発性有機化合物(VOC)，及びホルムアルデヒドを除く他のカルボニル化合物放散測定方法—大形チャンバー法

2)国際規格(ISO)の室内空気測定規格

ISO-16000 の専門委員会(TC)146(大気質)の中、分科委員会(SC)6 が室内空気質として構成されている。表1に TC146/SC1~6 を示す。以下は室内空気質関連の国際規格やこれからの規格について述べた。

- ISO 16000-1 (General aspects)General aspects of sampling strategy (ISO EN)
- ISO 16000-2 (Sampling strategy)

Sampling strategy for formaldehyde (ISO EN)

- ISO 16000-3 (Active sampling) Active sampling method for formaldehyde and other carbonyl compounds in indoor and test chamber air (2011-10-15)
- ISO 16000-4 (Diffuse sampling) Diffusive sampling method for formaldehyde (2011-12-01)
- ISO 16000-5 (Sampling strategy) Sampling strategy for volatile organic compounds (VOCs) (ISO EN)
- ISO 16000-6 (GC/MS) Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas chromatography using MS or MS-FID (2011-12-01)
- ISO 16000-7 (Sampling strategy) Sampling strategy for determination of airborne asbestos fibre concentrations (ISO EN)
- ISO 16000-8 (Local mean ages of air) Determination of local mean ages of air in buildings for characterizing ventilation conditions
- ISO 16000-9 (Emission test chamber) Determination of the emission of volatile organic compounds from building products and furnishing – Emission test chamber method (ISO EN)
- ISO 16000-10 (Emission test cell) Determination of the emission of volatile organic compounds from building products and furnishing – Emission test cell method (ISO EN)
- ISO 16000-11 (Sample handling) Determination of the emission of volatile

- organic compounds from building products and furnishing – Sampling, storage of samples and preparation of test specimens (ISO EN)
- ISO 16000-12 (Sampling strategy) Sampling strategy for polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzo-furans (PCDFs) and polycyclic aromatic hydrocarbons (PAHs) (ISO EN)
 - ISO 16000-13 (Filter sampling) Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDDs/PCDFs) – Collection on sorbent-backed filters
 - ISO 16000-14 (HR-GC/MS) Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDDs/PCDFs) – Extraction, clean-up and analysis by high-resolution gas chromatography and mass spectrometry
 - ISO 16000-15 (Sampling strategy NO₂) Sampling strategy for nitrogen dioxide (NO₂) (ISO EN)
 - ISO 16000-16 (Sampling by filtration) Detection and enumeration of moulds - Sampling by filtration
 - ISO 16000-17 (Culture-based method) Detection and enumeration of moulds - Culture based method
 - ISO 16000-18 (Sampling by impaction) Detection and enumeration of moulds – Sampling by impaction (2011-07-01)
 - ISO 16000-19 (Sampling strategy) Sampling strategy for moulds (2012-06-01)
 - ISO 16000-20 (Total spore count) * Detection and enumeration of moulds - Determination of total spore count → DIS
 - ISO 16000-21 (Sampling from materials) Detection and enumeration of moulds - Sampling from materials
 - ISO 16000-23 (HCHO sorptive material) Performance test for evaluating the reduction of formaldehyde concentrations by sorptive building materials
 - ISO 16000-24 (VOC sorptive material) Performance test for evaluating the reduction of volatile organic compounds (except formaldehyde) concentrations by sorptive building materials
 - ISO 16000-25 (SVOC, micro-chamber) Determination of the emission of semi-volatile organic compounds by building products - Micro chamber method (2011-07-01)
 - ISO 16000-26 (NO₂) Sampling strategy for carbon dioxide (CO₂) (ISO EN) (2012-08-01)
 - ISO 16000-27 (Settled fibrous dust) Determination of settled fibrous dust on surfaces by SEM (scanning electron microscopy) (direct method)
 - ISO 16000-29 (VOC detectors) Test method for VOC detectors
 - ISO 16000-30 Sensory test of indoor air
 - ISO 16000-31 (Phosphoric acid esters) Measurement of flame retardants and plasticizers based on organophosphorus compounds – Phosphoric acid ester
 - ISO 16000-32 (Investigation of buildings) Investigation of buildings for occurrence of

- pollutants (ISO EN)
- ISO 16000-33* (GC/MS) Determination of phthalates with GC/MS
 - ISO 16000-34* (Sampling strategy) Strategies for the measurement of airborne particles
 - ISO 16000-35* (Brominated substances) Measurement of polybrominated diphenylether, hexabromocyclododecane and hexabromobenzene (*:Standard under development)
 - ISO 16000-36 (Air Purifiers) * Test method for the reduction rate of airborne bacteria by air purifiers using a test chamber
 - ISO 16000-37* (PM_{2.5}) Strategies for the measurement of PM_{2.5}
 - ISO 16017-1 (Pumped sampling) Indoor, ambient air and workplace air – Sampling and analysis • ISO of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography – part 1 : Pumped sampling (ISO EN)
 - ISO 16017-2 (Diffusive sampling) Indoor, ambient air and workplace air – Sampling and analysis • ISO of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography – part 2 : Diffusive sampling (ISO EN)

D. 考察

室内空気質測定方法と関連する IS・これからの IS と JIS 対応を表 2 に示す。室内空気のサンプリング方法通則をはじめ、サンプリング方法などが IS に対応されている。IS の中には日本から提案された規格もある。図 1 に JIS の ISO の関係(その 1—建材などからの放散<13 規格：経産省所管>)を、図 2 に JIS の ISO の関係(その 2—室内空気<10 規格：国交省所管>)を

示す。

しかし、ISO/DIS(国際規格案)に基づいて JIS 化した規格も少なくはないため、2011 年 7 月、財団法人建材試験センター内に JIS 改正委員会が組織され、関連 ISO 規格との整合性を図り、かつ JIS Z 8301(規格票の様式及び作成方法)に対応した JIS 原案を作成した。改正内容としては JIS と対応国際規格との対比表を作成し、改正内容と理由、改正趣旨などを明らかにしている。2015 年に改正された規格は日本規格協会から出版(JIS ハンドブック -シックハウス-(2015))されている。

一方、ホルムアルデヒドなどの揮発性有機化合物に関する測定方法は IS に対応する JIS が定められているが、近年 IS や ISO/DIS(国際規格案)と AWI(作業草案)になっている規格の場合、JIS 対応ができていない状況である。特に、この研究グループでは室内空気中殺虫剤やフタル酸エステル類など、新たな汚染物質に関する測定方法の JIS 原案を作成し、または IS との整合性を図り、室内空気中 SVOC などの測定方法の開発を目指している。

そのため、室内空気中殺虫剤や SVOC 濃度測定方法と関連する IS または ISO/DIS、AWI などの規格情報を提供した。

IS の中で、殺虫剤、難燃剤、可塑剤などに関連する測定・分析方法は、ISO 16000-13 (Filter sampling)、ISO 16000-31 (Phosphoric acid esters)、ISO 16000-33 (GC/MS)、ISO 16000-35 (Brominated substances)であることが分かった。ここで、ISO-16000-13、31 は規格になっているが、33 は委員会原案(CD)として、35 は作業草案として提案され、ている。そのため、今後規格案の修正・変更などがある場合、この研究グループに新たな情報提供が必要とされる。

E. 結論

厚生労働省のシックハウス(室内空気汚染)問

題検討会が再開され、室内濃度指針値の見直し作業が進められている。しかし、室内空気中の揮発性有機化合物(Volatile Organic Compound、VOC)や準揮発性有機化合物(Semi-Volatile Organic Compound、SVOC)の測定方法が必ずしも十分に統一されておらず、室内濃度指針値を策定するため、新たな室内汚染物質の測定方法の開発及び妥当性評価が必要とされる。そこで、本研究は国際規格をはじめとする諸外国の空気試験法に関する情報を収集し、ISに対応するJISなどを調べた。また、最近注目を浴びている殺虫剤、難燃剤、可塑剤のようなSVOCに関する室内空気中測定・分析方法の開発が求められているため、関連するISとISO/DIS、AWIなどの情報を提供した。

しかし、ISO/DIS、AWIは国際規格になる前の段階であるため、今後規格案の改正・修正が行った場合、その内容を研究グループに情報提供する予定である。現在、ISO TC146/SC6の議長を務めている。

「参考文献」

- 1) 日本規格協会：JIS ハンドブック -シックハウス-, 2008
- 2) 日本規格協会：JIS ハンドブック -シックハウス-, 2015
- 3) 日本規格協会：JIS ハンドブック-国際標準化-, 2014
- 4) 日本規格協会：JIS 総目録, 2015
- 5) ISO-16000:
<http://www.iso.org/iso/home.htm>

F. 健康危険情報

なし

G. 研究発表

1. 論文発表

- 1) 金 炫兌, 田辺新一：マイクロチャンバーを用いた PVC 建材及び用品からの SVOC 放散量の測定. 日本建築学会環境系論文集, 2016; 81(720): 印刷中.
- 2) 金 炫兌, 田辺新一：住宅における空気・ハウスダスト中 SVOC 濃度測定. 日本建築学会環境系論文集, 2016; 81(720): 印刷中.

2. 学会発表

- 1) Kim, H, Tanabe, S.: Concentration of bis (2-ethyhexyl) phthalate on the surface of polyvinyl chloride flooring. Healthy Buildings Europe 2015 (2015.5)
- 2) 金 炫兌, 田辺新一：半揮発性有機化合物 (SVOC) の測定法に関する研究 その 25) 家庭用殺虫剤の再放散と残留量の測定. 日本建築学会大会学術講演 (2015.9)

H. 知的財産権の出願・登録状況

1. 特許取得

なし

2. 実用新案登録

なし

3. その他

なし

表 1 ISO-16000/TC146 の分類

ISO-16000 TC146:大気の質、事務局(DIN:Deutsches Institut fur Normung)	
SC1	Stationary source emission(固定発生源大気の測定)
	事務局(NEN:Netherlands Standardization Institute)
SC2	Workplace atmospheres(作業環境大気の測定)
	事務局(ANSI:American National Standards Institute)
SC3	Ambient atmospheres(環境大気の測定)
	事務局(ANSI)
SC4	General aspects (環境大気の一般事項)
	事務局(DIN)
SC5	Meteorology(気象)
	事務局(DIN)
SC6	Indoor Air(室内空気)
	事務局(DIN)

表2 IS規格と対応JIS

IS規格とこれからのIS	対応JIS
ISO-16000-1 General aspects of sampling strategy (ISO EN)	A 1960 (2015)
ISO-16000-2 Sampling strategy for formaldehyde (ISO EN)	A 1961 (2015)
ISO-16000-3 Active sampling method for formaldehyde and other carbonyl compounds in indoor and test chamber air (2011-10-15)	A 1962 (2015)
ISO-16000-4 Diffusive sampling method for formaldehyde (2011-12-01)	A 1963 (2015)
ISO-16000-5 Sampling strategy for volatile organic compounds (VOCs) (ISO EN)	A 1964 (2015)
ISO-16000-6 Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA® sorbent, thermal desorption and gas chromatography using MS or MS-FID (2011-12-01)	A 1965 (2015)
ISO-16000-7 Sampling strategy for determination of airborne asbestos fibre concentrations (ISO EN)	
ISO-16000-8 Determination of local mean ages of air in buildings for characterizing ventilation conditions	
ISO-16000-9 Determination of the emission of volatile organic compounds from building products and furnishing – Emission test chamber method (ISO EN)	A 1901, 1911, 1912
ISO-16000-10 Determination of the emission of volatile organic compounds from building products and furnishing – Emission test cell method (ISO EN)	
ISO-16000-11 Determination of the emission of volatile organic compounds from building products and furnishing – Sampling, storage of samples and preparation of test specimens (ISO EN)	A 1902-1,2,3,4
ISO-16000-12 Sampling strategy for polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzo-furans (PCDFs) and polycyclic aromatic hydrocarbons (PAHs) (ISO EN)	
ISO-16000-13 Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDDs/PCDFs) – Collection on sorbent-backed filters	
ISO-16000-14 Determination of total (gas and particle-phase) polychlorinated dioxin-like biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDDs/PCDFs) – Extraction, clean-up and analysis by high-resolution gas chromatography and mass spectrometry	
ISO-16000-15 Sampling strategy for nitrogen dioxide (NO ₂) (ISO EN)	
ISO-16000-16 Detection and enumeration of moulds -Sampling by filtration-	
ISO-16000-17 Detection and enumeration of moulds -Culture based method-	
ISO-16000-18 Detection and enumeration of moulds -Sampling by impaction- (2011-07-01)	

ISO-16000-19 Sampling strategy for moulds (2012-06-01)	
ISO-16000-20 Detection and enumeration of moulds -Determination of total spore count- (DIS)	
ISO-16000-21 Detection and enumeration of moulds -Sampling from materials-	
ISO-16000-23 Performance test for evaluating the reduction of formaldehyde concentrations by sorptive building materials	A 1905-1 (2015)
ISO-16000-24 Performance test for evaluating the reduction of volatile organic compounds (except formaldehyde) concentrations by sorptive building materials	A 1906 (2015)
ISO-16000-25 Determination of the emission of semi-volatile organic compounds by building products - Micro chamber method (2011-07-01)	A1904 (2015)
ISO-16000-26 Sampling strategy for carbon dioxide (CO2) (ISO EN) (2012-08-01)	
ISO-16000-27 Determination of settled fibrous dust on surfaces by SEM (scanning electron microscopy) (direct method)	
ISO-16000-28 Sensory evaluation of emissions from building materials and products (2012-03-15)	
ISO-16000-29 Test method for VOC detectors	
ISO-16000-30 Sensory test of indoor air	
ISO-16000-31 Measurement of flame retardants and plasticizers based on organophosphorus compounds – Phosphoric acid ester	
ISO-16000-32 Investigation of buildings for occurrence of pollutants (ISO EN)	
ISO-16000-33 Determination of phthalates with GC/MS(CD)	
ISO-16000-34 Strategies for the measurement of airborne particles(AWI)	
ISO-16000-35 Measurement of polybrominated diphenylether, hexabromocyclododecane and hexabromobenzene(AWI)	
ISO-16000-36 Test method for the reduction rate of airborne bacteria by air purifiers using a test chamber(AWI)	
ISO-16000-37 Strategies for the measurement of PM2,5(AWI)	
ISO-16017-1 Indoor, ambient air and workplace air – Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography – part 1 : Pumped sampling (ISO EN)	A 1966 (2015)
ISO-16017-2 Indoor, ambient air and workplace air – Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography – part 2 : Diffusive sampling (ISO EN)	A 1967 (2015)

JISとISOの関係

その1－建材等からの放散<13規格:経産省所管>

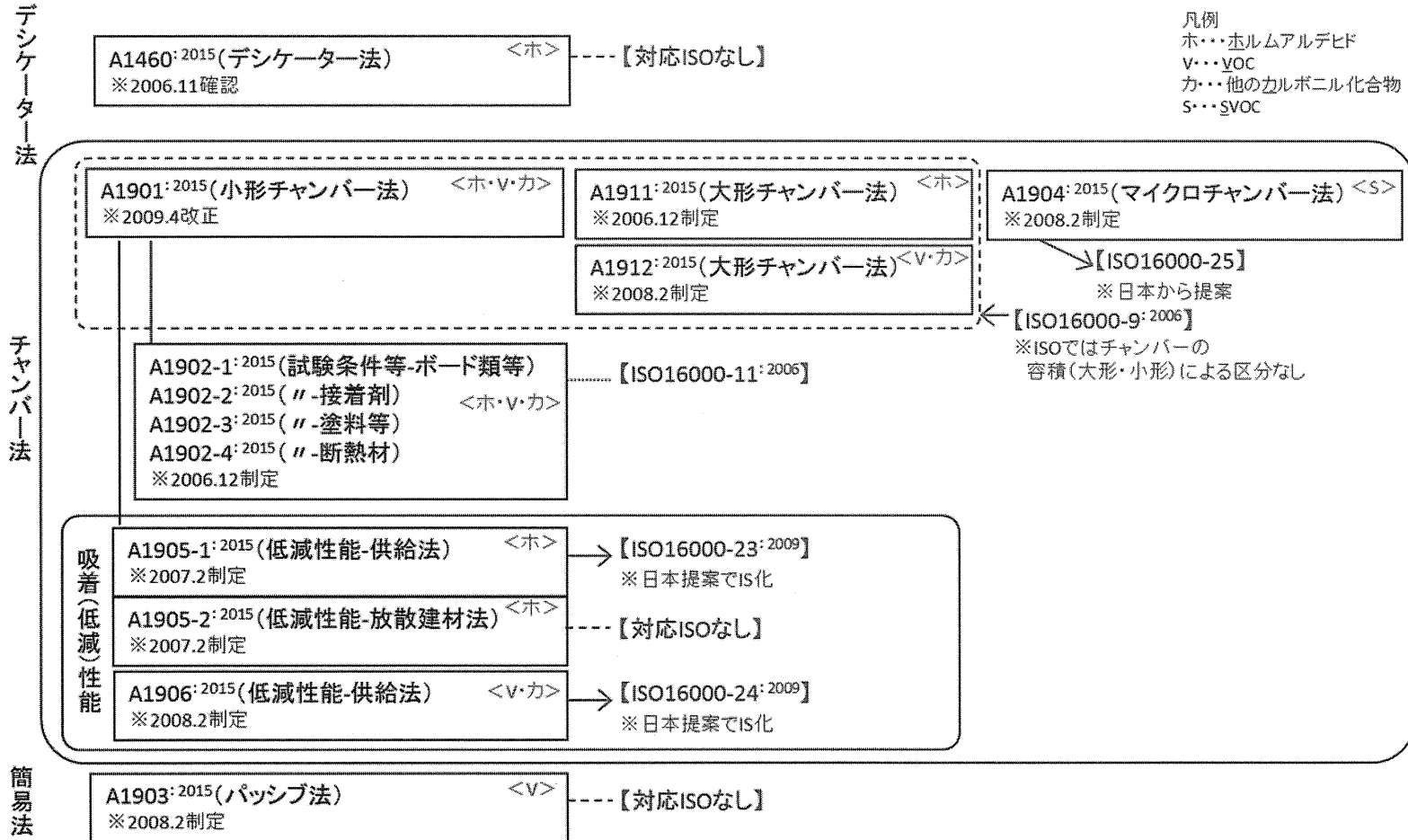


図1 JISとISOの関係(その1－建材などからの放散<13規格:経産省所管>)

JISとISOの関係

その2－室内空気<10規格：国交省所管>

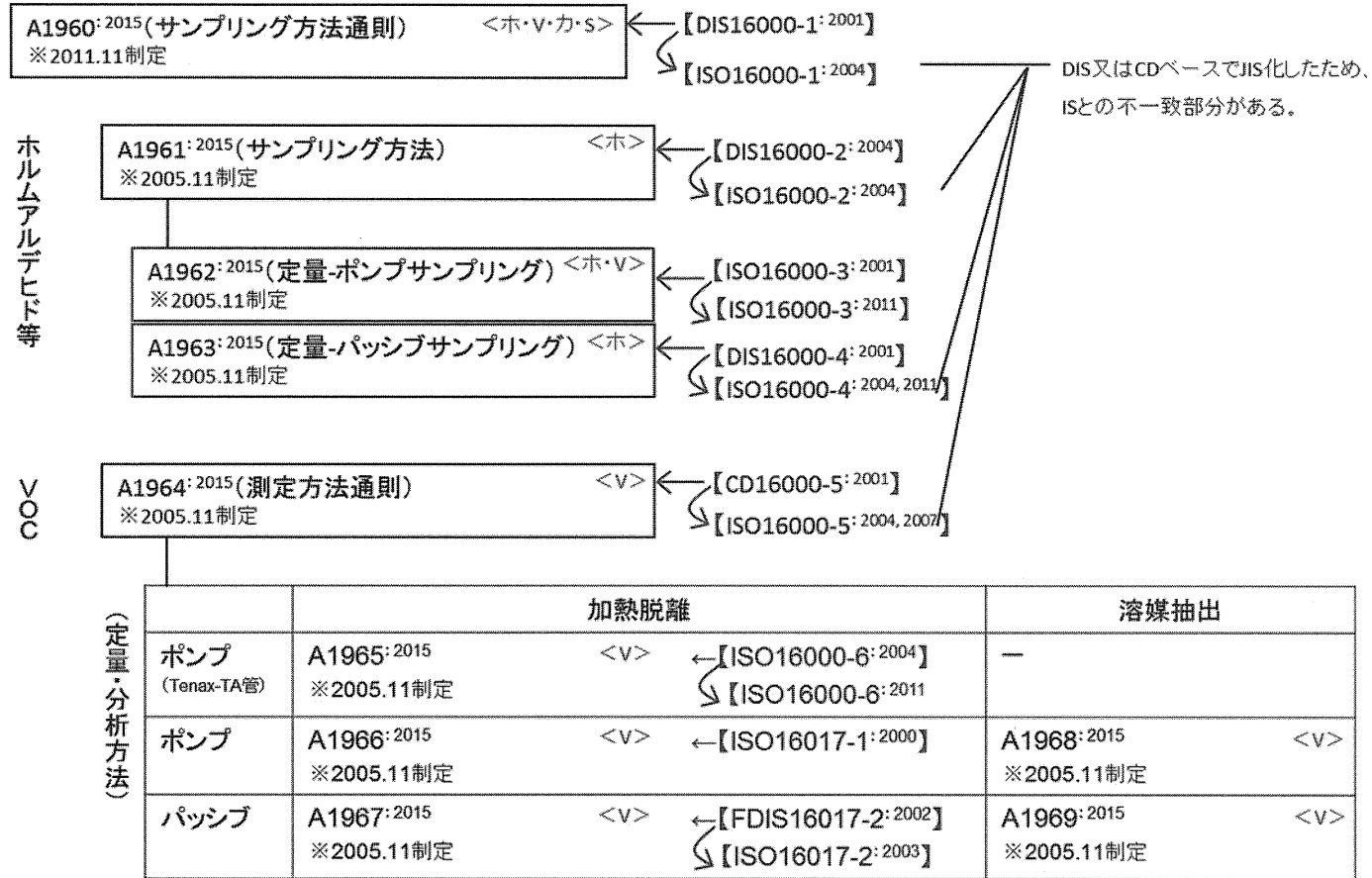


図2 JISとISOの関係（その2－室内空気<10規格：国交省所管>）

Ⅲ. 研究成果の刊行に関する一覧表

研究成果の刊行に関する一覧表

雑誌

発表者氏名	論文タイトル名	発表誌名	巻号	ページ	出版年
Takeuchi S., Tanaka-Kagawa T., Saito I., Kojima H., Jin K., Sato M., Kobayashi S., Jinno H.	Differential determination of plasticizers and organophosphorus flame retardants in residential indoor air in Japan.	Environ Sci. Pollut. Res.		DOI 10.1007/ s11356- 015-4858-z	2015
斎藤育江, 大貫 文, 鈴木俊也, 栗田雅行	シロアリ駆除剤由来のネオニコチノイド系殺虫剤による室内環境汚染	東京都健康安全研究センター年報	66	225-233	37-47
斎藤育江, 大貫 文, 鈴木俊也, 栗田雅行	ネオニコチノイド系殺虫剤の大気中への拡散に及ぼす水分、温湿度及び粒子状物質の影響	臨床環境医学	24 (1)	37-47	2015
大貫 文, 菱木麻佑, 斎藤育江, 保坂三継, 中江 大	線香等から放出される揮発性有機化合物類, アルデヒド類及び有機酸の調査	室内環境	18 (1)	15-25	2015

IV. 研究成果の刊行物・別刷

Differential determination of plasticizers and organophosphorus flame retardants in residential indoor air in Japan

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Abstract A variety of chemicals have been used in a wide range of indoor materials, such as wallpaper and furniture, and some of them are released into the indoor air. The level of consumption as well as the diversity of these chemicals has been increasing. The particle size of the materials in the air is known to affect the depth of human exposure, e.g., particles >10 µm can only reach the nasal cavity, whereas particles 2.5–10 µm can reach the respiratory tract and particles <2.5 µm can reach the bottom of the lungs. However, information on the concentrations and form of these chemicals in indoor air is very limited. In this study, we measured 54 compounds, including plasticizers (phthalates, adipates, and others) and organophosphorus flame retardants, in indoor air samples from the living rooms of 21 dwellings in 11 prefectures across Japan. For sampling, we used a four-stage air sampler (multi-nozzle cascade impactor) equipped with three quartz fiber filters to capture chemical particulates in three size ranges (<2.5, 2.5–10, and >10 µm) and a C₁₈ solid-phase extraction disk to capture chemicals that exist in a gas phase in indoor air. Each of the chemicals in the three particulate phases and single gas phase was extracted by acetone and measured separately using GC/MS. Of the 54 compounds tested, 37 were detected in the indoor air samples. The highest concentration

observed was that of 2-ethyl-1-hexanol (5.1 µg/m³), which was detected in samples from all 21 houses. The 37 compounds were captured in the four fractions at different rates roughly based on their molecular sizes. Compounds with a smaller molecular size were commonly detected as a gas phase, whereas compounds with a larger molecular size were detected as one or more of the three particulate phases in the indoor air samples. Among the three particulate phases, many of the compounds were detected from the filter capturing the smallest (<2.5 µm) particles. Therefore, these results suggest that the chemicals measured in this study might penetrate deeply into the lungs as many of them tend to exist as a gas and/or as particles smaller than 2.5 µm.

Keywords Indoor air · Plasticizer · Flame retardant · Semi-volatile organic compounds · Gas-particle partitioning · Multi-nozzle cascade impactor

Introduction

The variety of chemicals present in indoor environments has been increasing over the last few decades due to improvements in building materials, furnishings, and consumer products (Abe et al. 2012; Alaei et al. 2003; Rudel and Spengler 2001; Schossler et al. 2011). In the 1990s, health problems suspected of being induced by volatile organic chemicals (VOCs) in indoor air began to be observed in Japan (Seki et al. 2007). These problems have generally improved as a result of the Japanese Ministry of Health, Labor and Welfare setting guideline values for 13 compounds between 1997 and 2002. However, “non-regulated” chemicals have since been used in place of the 13 regulated compounds, resulting in sporadic health problems (Kamijima et al. 2002; Kobayashi et al. 2010). In order to clarify the causes of these problems,

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we investigated indoor air chemicals in several buildings in Sapporo, including the houses of patients with sick-building syndrome and/or chemical sensitivity (Takeuchi et al. 2004, 2005a, 2007).

Semi-volatile organic compounds (SVOCs) are a group of chemicals that have boiling points higher than those of VOCs. Concentrations of SVOCs in indoor air are generally much lower than those of VOCs (Kanazawa et al. 2010); however, a number of SVOCs have been detected in indoor dust (Bornehag et al. 2005; Meeker and Stapleton 2010; Hoffman et al. 2015). In addition, SVOCs, such as plasticizers and flame retardants, have been suggested as causing adverse health effects, including ocular and nasal symptoms and endocrine-disrupting effects (Kojima et al. 2009, 2013; Rudel and Perovich 2009; Takeuchi et al. 2005b; Wieslander and Norbäck 2010).

Large amounts of plasticizers and flame retardants are used in a wide range of building materials and furniture to increase strength, plasticity and safety. Although the level of consumption as well as the diversity of these chemicals has been increasing, information on the concentrations of these chemicals in indoor air is limited to only a small number of compounds. In a previous study, we measured 59 SVOCs in two separate phases (particle phase and gas phase) in indoor air samples from six houses in Sapporo, Japan, and found that SVOCs with a smaller molecular size preferentially exist as a gas phase whereas SVOCs with a larger molecular size exist in a particle phase (Takeuchi et al. 2014).

Particles with a diameter less than 10 μm and less than 2.5 μm are defined as PM_{10} and $\text{PM}_{2.5}$, respectively. The particle size of the materials in the air is known to affect the depth of human exposure, e.g., particles $>10 \mu\text{m}$ can only reach the nasal cavity, whereas particles 2.5–10 μm can reach the respiratory tract and particles $<2.5 \mu\text{m}$ can reach the bottom of the lungs. Exposure to PM_{10} or $\text{PM}_{2.5}$ is associated with the exacerbation of respiratory diseases, such as asthma, chronic obstructive pulmonary disease (COPD), and increased cardiopulmonary mortality (Pope and Kanner 1993; Schwartz and Dockery 1992).

In this study, we developed a method to separate indoor air chemicals into four fractions depending on their particle size ($>10 \mu\text{m}$, 2.5–10 μm , $<2.5 \mu\text{m}$, and gas) using an air sampler (multi-nozzle impactor cartridge) prior to measurement of the concentrations of all fractions by GC/MS. This method was applied to indoor air samples from 21 dwellings in 11 prefectures across Japan, and a total of 54 chemicals, consisting of 40 plasticizers and 14 organophosphorus flame retardants, were measured.

Materials and methods

Chemicals

The test chemicals used in this study were of the highest available purity and were purchased or provided as analytical

standards from the companies listed in Table 1. The chemical names and abbreviations for each category are also listed in Table 1. Anthracene- d_{10} was purchased from Wako Pure Chemical Industry (Osaka, Japan) and used as an internal control in the GC/MS analysis in this study.

Sampling and analysis of indoor air chemicals

Air samples were collected from 21 dwellings (ranging in age from three to 44 years, median 17.5 years) in 11 prefectures across Japan. The dwellings included 13 detached houses and six condominiums, with the eight of the 21 dwellings constructed of wood. Polyvinyl chloride (PVC) wallpaper, which is a known source of phthalate ester emissions, was used in seven dwellings. Interior renovations had been carried out in two dwellings 6 years prior to the air sampling in this study. The indoor air samples were collected from the living rooms in all cases. The air sampling rate was 10 L/min, and the sampling was performed for 24 h under everyday living conditions. The sampling was performed during October 2013 and January 2014. A multi-nozzle cascade impactor (air sampling cartridge) equipped with a four-stage filter (Tokyo Dylec Corp., Tokyo, Japan) was used for the separation of the indoor air chemicals. The air-sampling cartridge is designed to be able to capture indoor air chemicals based on their form (three sizes of particles and gas). A 47 mm quartz fiber filter (Tokyo Dylec Corp., Tokyo, Japan), which can catch particles larger than 10 nm, was used to catch particulate chemicals in three sizes ranges (larger than 10 μm , 2.5–10 μm , and smaller than 2.5 μm), and a solid-phase extraction disk (Empore 2215 FF C_{18} Disk; 3M Company, Saint Paul, MN, USA) was used as the last (fourth) stage to catch gaseous chemicals that were not captured by the three previous stages. The quartz fiber filters were baked at 400 $^{\circ}\text{C}$ for 3 h for cleaning. The solid-phase extraction disk, sampling cartridges, and all of the glassware tools were washed in ultra-purified acetone (acetone for pesticide residue and polychlorinated biphenyl analysis produced by Wako Pure Chemical Industries Ltd., Osaka, Japan) using an ultrasonic cleaner to remove pollutants, prior to use. After indoor air sampling, each stage of the filter was rolled up and placed in a 10-mL test tube along with 10 μL of 100 $\mu\text{g}/\text{mL}$ anthracene- d_{10} as an internal control. Compounds were extracted from the filters by ultra-sonication for 15 min with 10 mL of acetone and then concentrated to 1 mL using a rotary evaporator. The concentrated extracts were subjected to GC/MS as previously described (Takeuchi et al. 2005b, 2007).

Sampling and analysis of indoor dust

Indoor dust samples were collected from 19 of the 21 dwellings using a compact vacuum cleaner equipped with a Teflon

Table 1 Chemical names and abbreviations of the 54 compounds measured in this study

No.	Chemical name	Abbreviation	Supplier
21 Phthalates			
1	Dimethyl phthalate	DMP	Wako ^a
2	Diethyl phthalate	DEP	Wako
3	Diisopropyl phthalate	DiPP	TCI ^b
4	Diallyl phthalate	DAP	Wako
5	Dipropyl phthalate	DPP	Wako
6	Diisobutyl phthalate	DiBP	Wako
7	Dibutyl phthalate	DBP	Wako
8	Dipentyl phthalate	DPeP	Kanto ^c
9	Diisohexyl phthalate	DiHP	Kanto
10	Butyl phthalyl butyl glycolate	BPBG	Wako
11	Dihexyl phthalate	DHP	Wako
12	Butyl benzyl phthalate	BBzP	Kanto
13	Diisoheptyl phthalate	DiHpP	S-A ^d
14	Di(2-ethyl-1-hexyl)phthalate	DEHP	Wako
15	Diheptyl phthalate	DHpP	Wako
16	Dicyclohexyl phthalate	DcHP	Wako
17	Diphenyl phthalate	DPhP	Wako
18	Diocetyl phthalate	DOP	Wako
19	Dibenzyl phthalate	DBzP	Wako
20	Diisononyl phthalate	DiNP	Wako
21	Diisodecyl phthalate	DiDP	Wako
19 Non-phthalate plasticizers			
1	2-Ethyl-1-hexanol	2EH	Wako
2	1-Methyl-2-pyrrolidinone	1M2Pd	Wako
3	Dimethyl adipate	DMA	Wako
4	Diethyl adipate	DEA	Wako
5	2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	Txol	S-A
6	Diisopropyl adipate	DiPA	Wako
7	Diopropyl adipate	DPA	Junsei
8	Diisobutyl adipate	DiBA	Wako
9	Dibutyl adipate	DBA	Wako
10	Isopropyl myristate	iPMs	Wako
11	Dibutyl sebacate	DBSb	Wako
12	AcetylTributyl citrate	AcTBCT	Wako
13	Di(2-ethyl-1-hexyl)adipate	DEHA	Kanto
14	Di(2-ethyl-1-hexyl)terephthalate	DEHT	Wako
15	Di(2-ethyl-1-hexyl)azelate	BEHAz	Wako
16	1,2-Cyclohexane dicarboxylic acid diisononyl ester	DINCH	Wako
17	Bis(2-ethyl-1-hexyl)sebacate	BEHSb	Wako
18	Diocetyl azelate	DOAz	Wako
19	Tris(2-ethyl-1-hexyl)trimellitate	TEHTm	Wako
14 Phosphorous flame retardants			
1	Trimethyl phosphate	TMP	Wako
2	Triethyl phosphate	TEP	Wako
3	Tripropyl phosphate	TPrP	S-A
4	Tributyl phosphate	TBP	Wako
5	Tris(2-chloroethyl)phosphate	TCEP	Wako
6	Tris(2-chloro-1-methylethyl)phosphate	TCMEP	Wako
7	Tris(1,3-dichloro-2-propyl)phosphate	TDCPP	Wako
8	Tris(2-butoxyethyl)phosphate	TBEP	Wako
9	Triphenyl phosphate	TPhP	Wako
10	Tri(2-ethyl-1-hexyl)phosphate	TEHP	Wako

Table 1 (continued)

No.	Chemical name	Abbreviation	Supplier
11	2-Ethyl-1-hexyl diphenyl phosphate	EHDPhP	TCI
12	Cresyl diphenyl phosphate	CsDPhP	TCI
13	Tricresyl phosphate	TCsP	Wako
14	Trixylenyl phosphate	TXP	DH ^e

^aWako: Wako Pure Chemical Industry (Osaka, Japan)

^bTCI: Tokyo Chemical Industry (Tokyo, Japan)

^cKanto: Kanto Chemical Co. Inc. (Tokyo, Japan)

^dS-A: Sigma-Aldrich Co. (St. Louis, MO, USA)

^eJunsei: Junsei Chemical Co. Ltd. (Tokyo, Japan)

^fDH: Daihachi Chemical Industry (Osaka, Japan)

fiber bag (sufficient dust samples could not be collected in two of the 21 dwellings). After removing contaminants such as pieces of food and hair from dust samples, 25 mg of the dust was placed in a precleaned 10-mL centrifuge test tube. Two milliliters of acetone and 10 μ L of 100 μ g/mL anthracene- d_{10} were added, and chemicals were extracted by ultra-sonication for 15 min. The extracts were then centrifuged at 1000 rpm for 5 min, and the supernatants were subjected to GC/MS at an injection volume of 1 μ L.

Instruments and analytical conditions

Analysis of the test compounds was performed using a Shimadzu QP-2010 GC/MS system equipped with a DB-5MS column (30 m \times 0.25 mm i.d. \times 0.25 μ m) as previously reported (Takeuchi et al. 2014). The following conditions were used for quantitative detection in this study: injection volume, 2 μ L (1 μ L for dust samples); carrier gas, helium; and column head pressure, 72 kPa. The GC oven was initially maintained at 40 $^{\circ}$ C for 2 min, then increased by 25 $^{\circ}$ C/min to 200 $^{\circ}$ C and 40 $^{\circ}$ C/min to 280 $^{\circ}$ C, at which temperature it was maintained for 6 min, and finally increased by 10 $^{\circ}$ C/min to 320 $^{\circ}$ C, at which temperature it was maintained for 7 min.

The limit of detection (LOD) was defined as the amount of each test compound that yielded S/N=3 in the analysis. The limits of quantification (LOQs) of the indoor chemicals were calculated from their LODs (except for DEP, DBP, DEHP, Txol, and TBP, which were calculated based on the “travel blank” values described below), the area of the peaks in the analysis of the test compounds extracted from the filters, and the air sampling volume (14.4 m³). To check for contamination by chemicals during the transport of the sampling materials and air sampling, we used a travel blank, which was an additional cartridge equipped with the same types of filters used for the air sampling that was transported together with the sampling materials. The five compounds (DEP, DBP, DEHP, Txol, and TBP) were detected at low concentrations even in the extracts from the cleaned filters, including those of the travel blanks. Therefore, the LOQs of those compounds

were set at a value 3-fold that of the highest concentration among the travel blanks in this study. The indoor air concentrations of these compounds were calculated by subtracting the travel blank values from the indoor air sample values.

Recovery tests were performed, revealing that the recovery rates were within the range of 50–150 % (data not shown). Laboratory blanks and travel blanks were also checked regularly. Breakthrough test using two stages of the solid-phase extraction disk revealed a breakthrough rate of 33 % for 2EH under 10 L/min air flow for 24 h whereas the breakthrough rates for the other test compounds were within 10 %.

Results and discussion

Table 2 shows the concentration ranges for 37 of the 54 tested compounds detected in the indoor air from the 21 dwellings in this study. The compounds are listed by their molecular weight. The compound detected at the highest concentration was 2EH (5.1 μ g/m³) (Table 2), with Txol and iPM also found at concentrations higher than 1 μ g/m³ (Table 2). Txol is used as a plasticizer, solvent and surface stabilizer for water-based paints (Wilke et al. 2004), and we previously found Txol and 1M2Pd at much higher concentrations (maximum concentrations were over 510 and 1000 μ g/m³, respectively) in the indoor air of a newly built primary school in Hokkaido in which teachers and students had suffered from sick-building syndrome (Kobayashi et al. 2010). Bönisch et al. (2012) reported that exposure to Txol (32 \pm 6 μ g/m³) and 1M2Pd (51 \pm 11 μ g/m³) for 5 h/day for 19 days increased the allergic immune response in ovalbumin-sensitized mice, reduced IL-12 production in maturing dendritic cells, and enhanced airway inflammation after adoptive dendritic cell transfer into Balb/c mice.

Among the 54 compounds measured in this study, only DBP and DEHP (220 and 120 μ g/m³, respectively) have had guideline values set by the Japanese Ministry of Health, Labor and Welfare (Committee on Sick House Syndrome: Indoor Air Pollution 2002). These compounds were detected

Table 2 Concentrations of the 37 compounds detected in the indoor air samples from the 21 dwellings

No.	Chemical	MW	Med ($\mu\text{g}/\text{m}^3$)	Max ($\mu\text{g}/\text{m}^3$)	DF (%)	LOQ ($\mu\text{g}/\text{m}^3$)
1	1M2Pd	99	0.11	0.34	48	0.05
2	2EH	130	1.1	5.1	100	0.04
3	DMA	174	0.028	0.20	71	0.01
4	TEP	182	0.0040	0.015	100	0.00007
5	DMP	194	0.019	0.12	90	0.002
6	Txol	216	0.50	2.1	100	0.02
7	DEP	222	0.033	0.20	95	0.004
8	DiPA	230	0.0077	0.74	81	0.001
9	DBA	258	0.0041	0.24	38	0.001
10	DiBA	258	0.027	0.056	62	0.01
11	TBP	266	0.010	0.029	67	0.006
12	iPMs	270	0.0052	2.0	90	0.01
13	DiBP	278	0.15	0.46	100	0.01
14	DBP	278	0.067	0.48	100	0.003
15	TCEP	285	0.0067	0.034	90	0.00007
16	BBzP	312	0.022	0.022	5	0.003
17	DBSb	314	0.0059	0.018	48	0.002
18	TPhP	326	0.0027	0.0089	67	0.0007
19	TCMEP	327	0.010	0.018	67	0.003
20	DHP	334	0.0013	0.0013	5	0.00007
21	CsDPhP	340	0.0019	0.0019	10	0.00007
22	DHpP	362	0.0029	0.0029	5	0.00007
23	DiHpP	362	0.059	0.059	5	0.00007
24	EHDPhP	362	0.0041	0.0044	76	0.00007
25	TCsP	368	0.0021	0.013	48	0.003
26	DEHA	370	0.0044	0.013	38	0.02
27	DEHP	390	0.086	0.27	76	0.02
28	DEHT	390	0.0069	0.029	10	0.004
29	DOP	390	0.0055	0.012	38	0.00007
30	TBEP	397	0.013	0.029	52	0.0002
31	AcTBCt	402	0.017	0.11	48	0.002
32	DiNP	418	0.016	0.016	5	0.01
33	BEHSb	426	0.0022	0.0063	48	0.0002
34	DINCH	427	0.0040	0.0043	14	0.0001
35	TDCPP	430	0.0036	0.0052	24	0.0002
36	TEHP	434	0.0031	0.0031	5	0.00007
37	TEHT	546	0.018	0.022	10	0.002

MW molecular weight, Med median, Max maximum, DF detection frequency, LOQ limit of quantitation

in the indoor air samples at concentrations less than 440-fold smaller than the guideline values (Table 2). However, these compounds and their metabolites have been frequently detected in human urine samples (Carlstedt et al. 2013; Bertelsen et al. 2013), which suggests the continuous exposure of humans to DBP and DEHP. Moreover, Carlstedt et al. (2013) reported that polyvinyl chloride flooring, which is

known to contain phthalates, is related to phthalate uptake in humans.

Five compounds (2EH, TEP, Txol, DiBP, DBP) were detected at 100 % in this study, and three compounds (DEP, iPM, TCEP) were also detected at over 90 % (Table 2). The measurement of these 12 compounds in the indoor air in 10 Swedish houses was also reported by Bergh et al. (2011). Although seven (TEP, DMP, TBP, DiBP, TCEP, BBzP, DEHA) of the compounds were detected at values similar to those in our study, DEP, DBP, and TDCPP concentrations were reported at approximately 10-fold higher levels, whereas TPhP and TBEP concentrations were reported at approximately 10-fold lower levels (Bergh et al. 2011). These differences may be related to differences in building materials used in houses, interior materials, and furniture between Sweden and Japan. Bergh et al. (2011) measured six phthalate and 11 organophosphates in 30 indoor locations, including 10 houses in Stockholm, and reported that phthalate esters were more abundant than organophosphates and typically showed 10-fold higher total concentrations. Among the 14 organophosphorus flame retardants tested in this study, 11 compounds were detected in the indoor air samples from the 21 dwellings (Table 2). EHDPhP was detected at the highest concentration ($0.044 \mu\text{g}/\text{m}^3$) among the 14 organophosphorus flame retardants measured in this study, although it was only detected in two dwellings. These results suggest that the concentrations of organophosphorus flame retardants in indoor air tend to be lower than the concentrations of certain plasticizers, such as 2EH, DBP, and DEHP. This trend was also observed in our previous study of indoor air chemicals from houses in Sapporo, Japan (Takeuchi et al. 2014).

The gas and particle phases of the 37 compounds were measured separately using a multi-nozzle cascade impactor equipped with three quartz fiber filters and a solid-phase extraction disk in the cartridge. These indoor air chemicals were caught by the four stages at different rates. The values for each chemical captured by each stage was divided by those of the total amount detected from each dwelling and abundance ratios were calculated for the chemicals captured in each phase in each dwelling. We then calculated the 50th and 95th percentiles for the abundance ratios as listed in Table 3. The compounds in Table 3 are listed by molecular weight as shown in Table 2. The compounds with a smaller molecular weight, tended to be captured in the C₁₈ solid-phase extraction disk used for capturing compounds existing in the gas phase. These results supported those of our previous study which suggested that compounds with higher volatility preferentially exist in a gas phase in indoor air, whereas compounds with lower volatility preferentially exist in a particulate phase (Takeuchi et al. 2014). Moreover, we newly found that particulate compounds in indoor air mainly exist as particles smaller than 2.5 μm . These results suggest that most of the chemicals in the indoor can reach the deepest part of the lungs through inhalation. Brown et al. (2004) reported that

Table 3 Distributions of detection ratios of the 37 compounds detected in each stage from indoor air in the 21 dwellings

No.	Chemical	>10 μm			2.5–10 μm			<2.5 μm			Gas		
		50th ^a (%)	95th ^b (%)	<i>n</i> ^c	50th (%)	95th (%)	<i>n</i>	50th (%)	95th (%)	<i>n</i>	50th (%)	95th (%)	<i>n</i>
1	1M2Pd			0			0			0	100	100	10
2	2EH			0			0			0	100	100	21
3	DMA	8	11	3	12	13	3			0	100	100	16
4	TEP	30	34	16	35	45	18	38	100	21	44	61	2
5	DMP	7	8	4	8	10	4	14	14	1	100	100	19
6	Txol	7	10	17	9	14	18	11	57	17	77	92	21
7	DEP	8	9	7	10	13	10	23	62	9	91	100	20
8	DiPA	13	20	10	20	38	13	54	100	17	36	74	7
9	DBA	20	89	4	29	47	5	67	100	7			0
10	DiBA			0			0	100	100	13			0
11	TBP			0			0	71	97	2	100	100	14
12	iPMs	8	9	6	13	14	7	44	66	11	72	100	19
13	DBP	10	11	14	16	20	18	73	100	21	8	20	9
14	DiBP	9	11	15	14	18	16	68	100	21	13	34	16
15	TCEP	29	39	13	30	39	13	41	100	17	40	88	6
16	BBzP	16	16	1	20	20	1	64	64	1			0
17	DBSb			0			0	71	100	7	45	100	7
18	TPhP	20	29	3	34	87	6	100	100	13	14	14	1
19	TCMEP	30	32	4	27	33	8	77	100	14			0
20	DHP			0			0	100	100	1			0
21	CsDPhP			0			0	75	97	2	50	50	1
22	DHpP			0			0	100	100	1			0
23	DiHpP	11	11	1	18	18	1	66	66	1	5	5	1
24	EHDPhP	33	45	6	33	49	8	52	100	15	7	7	1
25	TCsP	24	25	2	24	25	2	100	100	10	24	25	2
26	DEHA	27	29	2	28	30	2	100	100	7	62	96	2
27	DEHP	7	7	1	13	19	3	100	100	16	7	7	1
28	DEHT			0	37	37	1	82	98	2			0
29	DOP	25	33	5	28	33	5	36	100	8	22	25	3
30	TBEP	33	50	6	48	50	7	51	100	9	29	29	1
31	AcTBCt	21	45	6	15	33	5	71	100	10	18	18	2
32	DiNP			0			0	100	100	1			0
33	BEHSb			0	49	90	5	100	100	9	32	32	1
34	DINCH			0			0	100	100	3			0
35	TDCPP			0			0	100	100	5			0
36	TEHP			0			0	100	100	1			0
37	TEHT	34	34	1	41	49	2	42	49	2			0

50th fiftieth percentile of detection ratio of the compound at the particle size among the detected samples, 95th ninety-fifth percentile of detection ratio of the compound at the particle size among the detected samples, *n* number of the indoor air samples which the chemical was detected at the particle size

ultrafine particles may exert their pro-inflammatory effects through the modulation of intracellular calcium concentrations, and the activation of transcription factors and cytokine production via a reactive oxygen species-mediated mechanism. Exposure to the chemicals at the deepest part of the lungs might, therefore, result in adverse effects on human health.

The 54 compounds were also measured in house dust samples taken from 19 of the 21 dwellings, with the 28 compounds detected listed by their molecular weight in Table 4. The compound detected at the highest concentration was DEHP (7400 μg/g), with DiDP (3100 μg/g) and DiNP (2300 μg/g) also detected at relatively high concentrations. These results

Table 4 Concentrations of the 28 compounds detected in house dust samples from 19 dwellings

No.	Chemical	Med ($\mu\text{g/g}$)	Max ($\mu\text{g/g}$)	DF (%)	R^2 (%)
1	2EH	3.0	25	100	
2	DMP	<0.1	2.7	42	0.9
3	Txol	0.5	6.3	63	15
4	DEP	0.2	0.7	100	17
5	DiPA	<0.1	1.5	5	
6	DiBA	<0.1	76	21	
7	TBP	<0.1	4.3	21	
8	iPMs	<0.1	99	16	0.7
9	DiBP	6.1	53	100	27
10	DBP	30	120	100	9
11	TCEP	13	20	95	13
12	BBzP	4.7	290	89	
13	DBSb	<0.1	32	11	
14	TPhP	4.3	17	63	0.7
15	TCMEP	5.8	18	79	0.2
16	CsDPhP	<0.1	7.4	5	
17	EHDPhP	<0.1	140	21	
18	DEHA	11	440	74	0.4
19	DEHP	1,700	7,400	100	1
20	DEHT	20	140	100	0.5
21	DOP	4.6	40	58	
22	TBEP	45	810	84	44
23	AcTBCt	13	160	95	12
24	DiNP	140	2,300	100	
25	BEHSb	<0.1	150	5	
26	TDCPP	<0.1	43	47	9
27	DiDP	<0.1	3,100	5	
28	TEHT	25	240	100	

Med median, *Max* maximum, *DF* detection frequency of the compound in the dust samples from 19 dwellings, R^2 square of the correlation coefficient between air samples and dust samples

suggest that compounds with larger molecular weights tend to exist at relatively higher concentrations in house dust than in indoor air. The detection frequencies of eight compounds (2EH, DEP, DiBP, DBP, DEHP, DEHT, DiNP, TEHT) were found to be 100 %. No significant correlations were observed in concentrations between the indoor air and house dust samples. Kanazawa et al. (2010) reported that TBEP, TCEP, and TCMEP were detected at high concentrations (5890, 308, and 291 $\mu\text{g/g}$, respectively) in the floor dust samples from 41 dwellings in Sapporo. Saito et al. (2007) reported that the use of floor polish agents containing TBEP could affect the concentration of TBEP in indoor air. Interestingly, the correlation between the TBEP concentration in the indoor air and house dust samples was the highest for all compounds tested in this study (Table 4). Nagorka et al. (2011) reported that the concentrations of DINCH and DEHT in house dust have been increasing recently in

Germany. Although DINCH was not detected in the house dust samples in this study, DEHT was detected in all the house dust samples. Contaminants in dust can vary depending on particle size. Further, dust may coagulate differently depending on moisture and oil content. Life-style factors, such as whether shoes are worn indoors or not, may also influence particle size and constituent distributions in house dust. Therefore, we measured whole house dust without sieving in this study in the same manner as that in a number of other studies performed in Japan (Kanazawa et al. 2010; Saito et al. 2007). However, standardized sampling method adequate for house dust in Japanese residences needs to be established in the future.

Conclusions

In this study, we measured 54 SVOCs in indoor air samples from 21 dwellings in 11 prefectures across Japan, and were able to detect 37 of the 54 compounds tested. The concentration of 2EH (5.1 $\mu\text{g}/\text{m}^3$) was the highest among the 37 chemicals detected in this study, with Txol and iPM also found at concentrations higher than 1 $\mu\text{g}/\text{m}^3$. House dust samples from 19 dwellings were also investigated, with the concentration of DEHP (7400 $\mu\text{g/g}$) being the highest among the 28 chemicals detected, although no significant correlations in concentrations between indoor air and dust samples were found. These results suggest that various plasticizers and flame retardants are present in indoor environments. Moreover, we newly found that particulate compounds in indoor air mainly exist as particles smaller than 2.5 μm . These results suggest that most of the indoor air chemicals can reach the deepest part of the lungs through inhalation. There are several reports that exposure to ultrafine particles may exert biological effects, especially on the immune system, in a particle size-dependent manner. Exposure to such chemicals at the deepest part of the lungs might result in adverse effects to human health. Further studies are required to elucidate the relations between the biological effects and particle size of chemicals in indoor air.

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