보건학석사 학위논문

Comprehensive assessment of residential intake of EDCs, heavy metals, and house dust mite allergens in house dust

집 먼지 내 EDCs, 중금속 및 집 먼지 진드기 알레르겐의 종합평가

2022 년 2 월

서울대학교 보건대학원

환경보건학과 환경보건학 전공

김 동 현

Comprehensive assessment of residential intake of EDCs, heavy metals, and house dust mite allergens in house dust

집 먼지 내 EDCs, 중금속 및 집 먼지 진드기 알레르겐의 종합평가

지도 교수 이 기 영

이 논문을 보건학석사 학위논문으로 제출함
2021 년 11 월

서울대학교 보건대학원
환경보건학과 환경보건 전공
김 동 현

김동현의 보건학석사 학위논문을 인준함
2021 년 12 월

위 원 장 ______ 윤충식 ______ (인)

부위원장 ______ 박지영 ______ (인)

위 원 ______ 이기영 ______ (인)

Abstract

Comprehensive assessment of residential intake of EDCs, heavy metals, and house dust mite allergens in house dust

Donghyun Kim

Department of Environmental Health Sciences

Graduate School of Public Health

Seoul National University

Advisor Kiyoung Lee, Sc.D, CIH

Abstract

House dust is a reservoir for EDCs, heavy metals, and house dust mite allergens. Long term exposure to house dust contaminants could pose adverse health effects, but few studies to date have simultaneously evaluated various chemicals and biological contaminants in house dust. The objectives of this study were to comprehensively assess the characteristics of contaminants in house dust and investigate infant's residential intake.

A total of 107 settled house dust (SHD) and 120 air cleaner captured dust (ACCD) samples were collected from 107 and 120 houses, respectively, in Seoul and Gyeonggi Province in 2021. Among the 107 houses selected for SHD collection, 30 houses were recruited for collecting bedding dust samples. All participants completed a questionnaire comprised of housing and lifestyle related factors. Sample extracts of 18 organophosphorus flame retardants (OPFRs), 16 phthalate esters (PHTHs), and 5 non-phthalate plasticizers (NPPs) were analyzed by gas chromatography-mass spectrometry (GC-MS). Sample extracts of 7 heavy metal elements were analyzed using an inductively coupled plasma optical emission spectrometer and mass spectrometer (ICP-OES and ICP-MS), and those of two house dust mite allergens (Dermatophagoides farinae type 1 (Der f 1) and Dermatophagoides pterynossynus type 1 (Der p 1)) were analyzed with VersaMax™ ELISA. A Pearson correlation analysis was conducted to assess the relationship between contaminants and multiple regression analysis (MLR) was conducted to identify the determinants in association with contaminants. To estimate infant's residential intake of contaminants in house dust, ingestion and inhalation intakes were calculated using the concentrations of contaminants in SHD and ACCD.

For SHD, the most frequently detected compounds with the highest concentrations were NPPs, whereas those of PHTHs were the highest for ACCD. High concentrations of 7 heavy metal elements were detected in all SHD samples, whereas those in ACCD were lower with significantly low detection rates. Der f 1 was detected in all bedding dust samples with significantly higher levels than Der p 1. Among the contaminants, TPhP and EHDPP, and DiBP and DEHP showed strong correlations. The levels of EDCs were largely associated with the type and number of housing appliances and the use of air fresheners or incenses, whereas those of heavy metals in SHD were mainly associated with the type and number of housing appliances and fuel used for cooking. Der f 1 showed strong associations with the number of occupants and water penetration. In contrast, ventilation, vacuum cleaning, and wet cleaning or dry mopping the floor significantly reduced the levels of contaminants in dust. Residential intake of most chemicals in house dust were significantly higher via ingestion than inhalation. In addition, inhalation intake of chemicals was significantly higher for ACCD than for SHD.

This study comprehensively assessed various chemicals and biological contaminants in SHD and ACCD. The results indicated that numerous contaminants including EDCs, heavy metals, and house dust mite allergens were prevalent in residential environments. In particular, the number and type of electronic appliances, use of air fresheners or diffusers, and combustion activities were in significant association with the elevated levels of contaminants in house dust. In addition, infant's residential intake of contaminants in house dust was greater via ingestion than inhalation. As infants could be exposed to a wide array of pollutants in house dust via ingestion, adequate measures are required to prevent potential exposures.

Keywords: Settled house dust; air cleaner captured dust; EDCs; heavy metals; house dust mite allergens; determinants; residential intake; infants

Student Number: 2020-21089

Table of Contents

List of Tables

List of Figures

List of Supplementary Materials

I. Introduction

House dust can settle onto surfaces as settled house dust (SHD) or suspend in air as airborne dust. Dusts are typically solid particles below 1 μm and up to 100 μm (ISO, 1995; IUPAC, 1990). The gravitational force upon particles above 1 μm may exceed other forces, inducing sedimentation of particles (Lu et al., 2008; Uma et al., 2011). With increasing size and mass, particles settle onto objects, surfaces, floors, and carpets to form SHD, which get entrenched in crevices within walls or floors. SHD can be resuspended as airborne dust via walking, floor type, and cleaning activities (Lai et al., 2017). Resuspension rate typically increased for coarse and fine particles in the range between 0.7 to 10 μm (Qian et al., 2014).

SHD is a reservoir for endocrine disrupting chemicals (EDCs), heavy metals, and biological contaminants. EDCs are chemical compounds that mimic or block the endogenous hormonal activity, which can induce developmental and reproductive disorders with chronic exposure (Tabb and Blumberg, 2006). Many EDCs used in consumer products, plastic items, electrical products, and furniture are semi-volatile organic compounds (SVOCs) that partition into both gas and condensed phases (Weschler, 2009). Owing to mass transfer to gas and particle phases, SVOCs can redistribute from their original source to house dust over time (Rudel et al., 2010). Among various SVOCs detected indoors, organophosphorus flame retardants (OPFRs), phthalate (PHTH) esters, and non-phthalate plasticizers (NPPs) were the major compounds (D'Hollander et al., 2010). High concentrations of 18 OPFRs were detected in all 111 dust samples collected in Korea, whereas high levels of 8 PHTHs in SHD were observed in 30 French houses (Blanchard et al., 2014; Lee et al., 2020). N,N-diethylhydroxylamine (DEHA) and tris (2-ethylhexyl) trimellitate (TOTM) were detected in 24 SHD samples (Hammel et al., 2019). Consumption of OPFRs as alternatives to brominated flame retardants (BFRs) have increased due to restrictions on legacy FRs. For the last decade, the annual global consumption for OPFRs increased by 2.7% and reached 2.39 million tons in 2019 (Flame retardants-online, 2013). PHTHs were the most ubiquitously used plasticizers, but the restriction of few esters including di (2-ethylhexyl) phthalate (DEHP), benzyl butyl phthalate (BBzP), and diisobutyl phthalate (DiBP) have increased the demand for NPPs as alternatives (RoHS, 2015). Consumption of NPPs accounted for more than 70% of the alternative plasticizer market in 2012 and the market size is projected to reach 3.9 billion US dollars by 2025 (https://www.marketsandmarkets.com/).

Significant amount of heavy metals could be in SHD. Heavy metals are of particular concern for high toxicity, as their accumulation in the body could destroy the nervous system, kidney, and circulatory systems, inducing carcinogenesis (Needleman, 2009; Nriagu, 1988; Shi and Wang, 2021). Along with arsenic (As), manganese (Mn), and cadmium (Cd), that may originate from natural sources, anthropogenic activities produce chromium (Cr), nickel (Ni), lead (Pb), and mercury (Hg) (Chen et al., 2005). Heavy metal elements are absorbed to atmospheric particulate matter (PM) and enter into houses via air exchange (Li et al., 2013). Particles mix with existing indoor pollutants, accumulating on floors and surfaces due to high densities (Duffus, 2002). In all 90 SHD samples, high concentrations of Cr, Cd, Pb, and Ni were detected and their concentrations were 2-13 times higher than the atmospheric background concentrations (Cheng et al., 2018; Yadav et al., 2019).

House dust mites are detected in bedding dust. House dust mites are Arachnids included in the Pyroglyphidae family with typical length of 0.2-0.3 mm (Platts-Mills, 1992). House dust mites are of particular concern as they can cause allergic and asthmatic responses (Seuri et al., 2000). Cuticle fragments and fecal pellets of house dust mites contain tropomyosin, which can stimulate the immune system to produce immunoglobulin E (IgE) antibodies (WHO, 2009). Among the 27 house dust mite species discovered to date, Dermatophagoides farinae (Der f) and Dermatophagoides pterynossinus (Der p) are the most common types detected in homes (Lind, 1985). Because they feed on skin flakes of humans in dust, house dust mites are usually found in beddings and sofas (Verhoeff, 1994). Der f 1 and Der p 1 were detected in all bedding dust samples collected from 54 houses in Korea (Kim et al., 2012).

Airborne dust could contain significant amount of EDCs and heavy metals. SVOCs with high molecular weight (MW) could partition from gas phase to particle phase, adhering to airborne particles (Weschler and Nazaroff, 2010). Particle phase fraction of SVOCs with MW higher than 250 g/mol exceeded 75% as compared to that of the gas phase (Xie et al., 2013). Concentrations of FRs in indoor air were similar to those in SHD, whereas highest concentrations for diisobutyl phthalate (DiBP), diethyl phthalate (DEP), di(2-ethylhexyl) phthalate (DEHP), and diisononyl phthalate (DINP) were measured in gas phase and airborne particles (Blanchard et al., 2014; Cequier et al., 2014). Heavy metals adhered to PM below 1 µm could float irregularly via Brownian motion (Uma et al., 2011). Heavy metals originating from industries and personal products were detected in fine and coarse particles collected from indoor sampling locations (Conner et al., 1998). In addition, EDCs and heavy metals on floors and surfaces may resuspend into air due to human activities. SHD resuspended as airborne dust via walking and cleaning activities of residents, which allowed contaminants to re-entrain into the air (Lai et al., 2017; Qian and Ferro, 2008).

To fully comprehend the potential exposure to contaminants in house dust, measurement of their concentrations in airborne dust was required in addition to SHD sampling. Various studies have used SHD as an indicator for residential contamination, but studies on airborne dust are lacking (Lioy et al., 2002; Roberts et al., 2009). The age of SHD is usually unknown and sampling is localized typically to represent a narrow collection area (Bi et al., 2018). If the residence time of SHD is too short, concentrations of SVOCs can be underestimated due to difference in non-equilibrium state by chemical type (Weschler and Nazaroff, 2010). In addition, respirable and inhalable particles take up small proportions in SHD. SHD particles that may resuspend into air are in the range between 0.7 to

10 μm, which are respirable (aerodynamic diameter <2.5 μm) and inhalable (aerodynamic diameter <10 μm) particles (Miller et al., 1979; Qian et al., 2014). Among 5.9 kg of SHD samples collected from 32 houses, the yield for respirable fractions obtained was 0.6% (Gustafsson et al., 2018).

Conventional methods for collecting airborne dust had limitations. Most studies used passive air samplers and collected $PM_{2.5}$ or PM_{10} for 24-48 h (Cheng et al., 2018; Wang et al., 2014). Such short time sampling cannot reflect the general residential air quality and collection of large particles are limited (WHO, 2014). An alternative method used in few studies was heating, ventilation, and air conditioning (HVAC) filters (Bi et al., 2018; He et al., 2016). However, HVACs are typically installed close to or on ceilings to provide enough space for ductwork and piping, which cannot accurately contemplate residential conditions affecting airborne dust (Seyam, 2018). Therefore, air cleaners were selected in this study. Air cleaners are commonly used in households. The global market value of air cleaners was predicted to reach 13.6 billion US dollars by 2025, increasing 1.5 times annually (https://www.innopolis.or.kr/mps). Air cleaners are used for long time range in households. The daily average time for usage of air cleaners in Korea was approximately 7.2 h (https://www.kca.go.kr/). In addition, most air cleaners are equipped with high efficiency particulate air (HEPA) filters with removal efficiency of 99.97% for particles 0.3 μm or larger (https://www.epa.gov/).

Comprehensive assessment of various chemicals and biological contaminants in house dust was needed. In most studies, one to two chemical classes or biological contaminants were investigated. However, as numerous chemicals are used simultaneously, multiple contaminants, which could be affected by various housing and lifestyle factors coexist in houses. FRs, PHTHs, and NPPs are used in crib mattresses and foams as plasticizers (Boor et al., 2015). Heavy metals and FRs were found in most electronic appliances and house dust mites were identified in all 424 houses sampled across the United States (Needhidasan et al., 2014; Lintner and Brame, 1993). Concentrations of OPFRs in dust were associated with the use of electrical applicants, electronic textiles, and flooring or furniture type, whereas those of PHTHs and NPPs were related to the use of plasticizers, incenses, and wall type (Kolarik et al., 2008; Lee et al., 2020). Heavy metals in dust were related to house age, floor levels, and cleaning or cooking behaviors, whereas those of biological agents were associated with human occupancy and dampness (Fujimura et al., 2010; Rintala et al., 2012; Tong and Lam, 2000).

Since infants may be susceptible to various chemicals in house dust, assessment of infant's residential intake of contaminants in house dust was necessary for establishing protection measures. Exposure pathways for contaminants in house dust include ingestion, inhalation, and dermal absorption. However, the major exposure pathway could be different by contaminants. Due to relatively high vapor pressure, SVOCs could partition between the indoor surfaces and the gas phase, adhering to particles (Liu et al., 2017). Contribution of inhalation intake was higher than ingestion for FRs and PHTHs (Bi et al., 2018; Tay et al., 2017). Typically, exposure through dermal contact was negligible for FRs and PHTHs (Zheng et al., 2017).

This study aimed to comprehensively assess EDCs, heavy metals, and house dust mite allergens in SHD and airborne dust, and estimate residential intake of infants. SHD from 107 houses and airborne dust from 120 houses were collected for analyzing contaminants in residential environment. Questionnaire survey was conducted for identifying the determinants associated with the levels of contaminants in dust. Ingestion and inhalation intake of EDCs in SHD and airborne dust were estimated for evaluating the residential intake of infants.

II. Materials and Methods

2.1. Sample Collection

A total of 107 SHD samples and 120 air cleaner captured dust (ACCD) samples were collected from 107 and 120 houses, respectively, in Seoul and Gyeonggi Province of Korea (Figure 1). Of the 107 houses selected for SHD collection, 30 houses that applied were additionally recruited for collecting bedding dust. SHD and bedding dust samples were collected for two weeks during April and May of 2021, and air cleaner filters used for at least one year were collected during May and June of 2021. Additional 9 pairs of SHD and ACCD samples were collected from 9 houses during June of 2021 for analyzing the correlation of EDCs between SHD and ACCD. This study was reviewed and approved by the Seoul National University Institutional Review Board (IRB# SNU 21-02-004).

Researchers contacted all participants prior to SHD sample collection and sent two polyethylene zipper bags to each home. Participants collected SHD samples for two weeks using vacuum cleaners. After two weeks, trained researchers were sent to each home to retrieve SHD samples. Dust was transported from the vacuum cleaner into one zipper bag and the other zipper bag was used to seal the sample for preventing contamination. For bedding dust sample collection, trained researchers were sent to each home. Dust samples were collected from mattress covers by vacuuming for 5 min. Before sampling dust samples, all researchers were informed to clean their hands and use poly gloves. All dust samples were delivered to the laboratory and sieved through a 150 μm mesh for removing non-dust materials. Sieved dust samples were collected into three separate 10 ml screw top vials. Each vial included dust samples of 0.6 g for EDCs, 0.5 g for heavy metals, and 0.1 g for house dust mite allergens analyses. One SHD sample that weighed less than 1.2 g in total was omitted from the analysis.

ACCD samples were collected from air cleaner in each home. Protocols for sample collection were provided to all participants. All participants were requested to transport used filters into poly bags and completely seal the entrance with wires provided by the research team. To prevent inflow of air, two poly bags and two wires were used for each sample. All filters were delivered to the laboratory and pretreated with a paper cutter. Before pretreatment, fixing pins attached backwards of the filter plate were removed for unfurling the folded filters. For both EDCs and heavy metals analyses, filters were cut into 25 cm^2 samples. Pretreated samples were collected into three separate 10 ml screw top vials and transferred for chemical analysis.

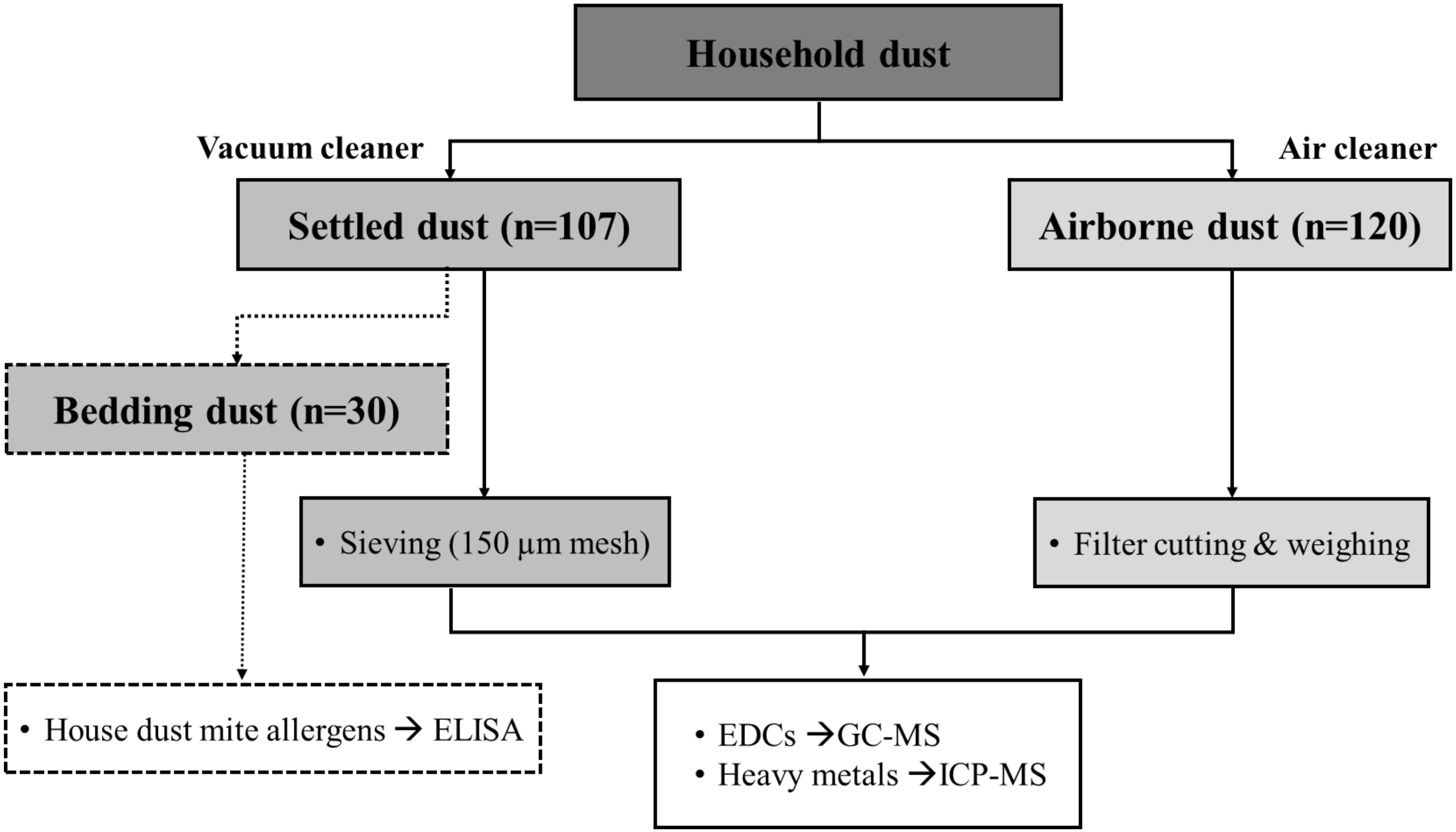

Figure 1. Schematic diagram of the sample collection and treatment process. Among the 107 houses recruited for SHD collection, 30 houses were additionally selected for bedding dust collection.

2.2. Questionnaire

The questionnaire information used for surveying indoor air quality of the houses are shown in Table 1. All participants who provided the dust samples completed the questionnaire. A total of 24 questions were classified into 4 categories: resident related factors, housing related factors, resident behavior related factors, and indoor air quality management factors.

Table 1. The questionnaire information used for surveying indoor air quality of the houses recruited for dust collection.

Category	No.	Questionnaire content
Resident related factors	4	Number of residents (children, teenagers, and elderly) Residents with allergies and the type Presence of smokers and indoor smoking within 1month
Housing related factors	11	Type, size, and age of housing, and number of floors Move in date and residence months Whether the house was repaired in the last 6 months Whether new furniture was bought in the last 6 months Type and number of electronic appliances Dew condensation in winter Water leakage Mold occurrence Carpet or rug used
Resident behavior related factors	4	Type and number of pets and plants Type and frequency of air freshener used Cooking frequency and fuel used Ventilation during cooking
Factors for Indoor air quality management	5	Frequency of vacuum cleaning How floors are cleaned Ventilation (frequency, time per event, method) Use of air cleaners and the frequencies by season Type and frequency of bedding and mattress care

2.3. Sample Preparation and Instrumental Analysis

2.3.1. Standard Solutions and Reagents

The physicochemical information of EDCs investigated are shown in Table 2. A total of 18 OPFR and 16 PHTH compounds were purchased from AccuStandard (New Haven, CT, USA). Among the NPPs, ATBC, DEHA, DEHTP, and TOTM were purchased from Sigma-Aldrich (St. Louis, MO, USA) and DINCH was purchased from BOC Sciences (Shirley, NY, USA). D_{15}-TEP, D_{21}-TPrP, D_{27}-TBP, D_{12}-TCEP, D_{18}-TCPP, D_{15}-TDCPP, and D_{15}-TPhP used as internal standards for OPFRs and DMP-D_4, DEP-D_4, DnPrP-D_4, DiBP-D_4, DnBP-D_4, DnBeP-D_4, DnHxP-D_4, DCHP-D_4, DEHP-D_4, and DnOP-D_4 used as internal standards for PHTHs were from Wellington Laboratories (Guelph, ON, Canada).

Standard reagents for Pb, Ni, Mn, and Cr were purchased from AccuStandard and those for Cd, Hg, and As were purchased from Inogranic Ventures (Christiansburg, VA, USA). Yttrium (Y) and tibidium (Tb) purchased from Inorganic Ventures and PerkinElmer (Waltham, MA, USA) were used for internal standard methods.

Two ELISA kits, including EPC-DF1 for Der f 1 standard and EPC-DP1 for Der p 1 standard were purchased from INDOOR Biotechnologies (Charlottesville, VA, USA). Biotinylated monoclonal antibody 4C1, streptavidin-peroxidas, assay buffer solution (1% BSA PBS-T), wash buffer solution (PBS-T), developing substrate solution (TMB), and stop solution (0.5 N sulfuric acid) were purchased from INDOOR Biotechnologies.

Table 2. Physicochemical properties of EDCs investigated in this study†.

Chemical group	Chemicals	Abbreviations	Formula	CAS	MW (g/mol)	Log (K_{oa})‡, §
OPFRs	trimethyl phosphate	TMP	$(CH_3)_3PO_4$	512-56-1	140.07	-
	triethyl phosphate	TEP	$(C_2H_5)_3PO_4$	78-40-0	182.15	-
	triisopropyl phosphate	TiPP	$C_9H_{21}O_4P$	513-02-0	224.23	-
	tripropyl phosphate	TPrP	$C_9H_{21}O_4P$	513-08-6	224.23	-
	tributyl phosphate	TBP	$(C_4H_9)_3PO_4$	126-73-8	266.31	8.20
	tris (2- chloroethyl) phosphate	TCEP	$(ClCH_2CH_2O)_3PO$	115-96-8	285.5	7.85
	tris (1-chloro-2-propanyl) phosphate	TCPP	$C_9H_{18}Cl_3O_4P$	13674-84-5	327.6	8.04
	tripentyl phosphate	TPeP	$C_{15}H_{33}O_4P$	2528-38-3	308.39	-
	tris (1,3-dichloro-2propyl) phosphate	TDCPP	$C_9H_{15}Cl_6O_4P$	13674-87-8	430.9	9.92
	tris (2-butoxyethyl) phosphate	TBOEP	$C_{18}H_{39}O_7P$	78-51-3	398.5	10.7
	triphenyl phosphate	TPhP	$(C_6H_5)_3PO_4$	115-86-6	326.3	10.1
	2-ethylhexyl diphenyl phosphate	EHDPP	$C_{20}H_{27}O_4P$	1241-94-7	362.4	10.7
	tris (2-ethylhexyl) phosphate	TEHP	$C_{24}H_{51}O_4P$	78-42-2	434.6	10.9
	cresyl diphenyl phosphate	CDP	$C_{19}H_{17}O_4P$	5254-12-6	340.3	-
	tri-o-cresyl phos- phate	ToCP	$C_{21}H_{21}O_4P$	78-30-8	368.4	10.7
	tri-m-cresyl phosphate	TmCP	$C_{21}H_{21}O_4P$	563-04-2	368.4	11.1
	tri-p-cresyl phosphate	TpCP	$C_{21}H_{21}O_4P$	78-32-0	368.4	11.3
	tri (2-isopropylphenyl) phosphate	TiPPP	$C_{27}H_{33}O_4P$	64532-95-2	452.5	-
PHTHs	dimethyl phthalate	DMP	$C_6H_4(COOCH_3)_2$	131-11-3	194.2	6.69
	diethyl phthalate	DEP	$C_6H_4(COOC_2H_5)_2$	84-66-2	222.2	7.02
	diisopropyl phthalate	DiPrP	$C_{14}H_{18}O_4$	605-45-8	250.29	-
	di-n-butyl phthalate	DnBP	$C_6H_4(COOC_4H_9)_2$	84-74-2	278.4	8.63
	di-n-pentyl phthalate	DnPeP	$C_{18}H_{26}O_4$	131-18-0	306.4	-
	di-n-hexyl phthalate	DnHxP	$C_{20}H_{30}O_4$	84-75-3	334.4	9.8
	butylbenzyl phthalate	BBzP	$C_{19}H_{20}O_4$	85-68-7	312.4	9.02
	dicyclohexyl phthalate	DCHP	$C_6H_4(CO_2C_6H_{11})_2$	84-61-7	330.4	
	di (2-ethylhexyl) phthalate	DEHP	$C_6H_4(COOC_8H_{17})_2$	117-81-7	390.6	12.56
	diisoheptyl phthalate	DiHpP	$C_{22}H_{34}O_4$	41451-28-9	362.5	-
	di-n-octyl phthalate	DnOP	$C_{24}H_{38}O_4$	117-84-0	390.6	12.08
	di-n-propyl phthalate	DnPrP	$C_{14}H_{18}O_4$	131-16-8	250.29	-

	diallyl-m-phthalate	DAIP	$C_{14}H_{14}O_4$	131-17-9	246.26	-
	diisobutyl phthalate	DiBP	$C_{16}H_{22}O_4$	84-69-5	278.4	8.41
	diisononyl phthalate	DiNP	$C_{26}H_{42}O_4$	28553-12-0	418.6	13.59
	diisodecyl phthalate	DiDP	$C_{28}H_{46}O_4$	26761-40-0	446.7	14.7
NPPs	acetyl tributyl citrate	ATBC	$C_{20}H_{34}O_8$	77-90-7	402.5	12.1
	diethyl hydroxylamine	DEHA	$C_4H_{11}NO$	3710-84-7	89.14	-
	di (2-ethylhexyl) terephthalate	DEHTP	$C_{24}H_{38}O_4$	6422-86-2	390.6	-
	trioctyl trimellitate	TOTM	$C_{33}H_{54}O_6$	89-04-3	546.8	16.24
	1,2-cyclohexane dicarboxylic acid diisononyl ester	DINCH	$C_{26}H_{48}O_4$	166412-78-8	424.7	12.14

[†]**:** The information of chemical's abbreviations, formula, CAS number, and MW were obtained from the National Library of Medicine (NIH) (https://pubchem.ncbi.nlm.nih.gov/).

[‡]**:** Log (K_{oa}) values of TBP was obtained from Chupeau et al. (2020) and those of other compounds were obtained from Okeme et al. (2018).

[§]**:** Log (K_{oa}) values of PHTHs and NPPs were obtained from Schossler et al. (2011).

2.3.2. Sample Preparation

For EDCs sample preparation, approximately 50 mg of dust was weighted in a pre-cleaned 15 mL glass tube, spiked with internal standards of OPFRs and phthalates. The spiked samples were extracted two times by sonication with 5 mL of DCM and hexane (1:1) for 30 min. The extracted solutions were left 1 h for layer separation and transferred to a 15 mL glass vial. The extraction procedure was repeated twice and the supernatants were combined. The extracts were concentrated to 0.5 mL under gentle stream of nitrogen, filtered through nylon filter (0.2 μm; Thermo Fisher Scientific, San Jose, USA) and transferred for instrumental analysis.

For heavy metals sample preparation, approximately 100 mg of dust samples were transferred to a TFM container. The dust samples were reacted with 3.5 mL of nitric acid (HNO_3), 0.5 mL of hydrogen peroxide (H_2O_2), 0.5 mL of hydrogen fluoride (HF), and 0.1 mL of gold (Au: 100 mg/L) solvent in a fume hood and left with the cover open. The container cover was shut after the reaction was completed and attached to the microwave sample acid digestion system (MARS 6; CEM Corp., Charlotte, NC, USA) for the microwave ingestion. The ingested samples were cooled down and transferred to a volumetric flask. Remnants from the decomposition vessel and container cover were cleansed with distilled water and added to the flask to adjust the total volume to 10 mL.

For house dust mite allergens sample preparation, approximately 100 mg of dust samples were transferred to a conical tube and mixed with 2 mL of PBS-T (15 mL/ 150 mL). The sample solution was shaken for 2 h and mixed thoroughly at room temperature. The solution was centrifuged at 3300 rpm for 45 min using a multi-purpose high speed centrifuge (Centrifuge 1580R; Labogene Inc., Daejeon, Korea). The supernatants were filtered and washed twice with buffer solution (15 mL/ 150 mL) on a 96 well plate. Allergen standards (EPC-DF1 and EPC-DP1) were diluted with assay buffer solution (3 mL/ 30 mL) to reach concentration between of 0.098 ng/mL to 50 ng/mL. Diluted allergen standards were injected into the 96 well plates with supernatants and cultivated at room temperature for 1 h.

2.3.3. Instrumental Analysis

Quantitative analyses of 18 OPFRs, 16 PHTHs, and 5 NPPs were performed by a gas chromatograph (GC; Agilent 7890, Agilent Technologies, Santa Clara, CA, USA) coupled with a mass spectrometer (MS; Agilent 5975C, Agilent Technologies, Santa Clara, CA, USA) in the electron capture negative ionization mode. A DB5-UI-MS capillary column (J&W GC column; Agilent Technologies, Santa Clara, CA, USA) with 30 m length, 0.25 mm inner diameter, and 0.25 μm film thickness was used to separate the OPFRs. All analyses using the GC-MS were replicated three times.

Quantitative analyses of Pb, Ni, Mn, and Cr were performed using an inductively coupled plasma optical emission spectrometer (ICP-OES; AVIO 500, Perkin Elmer Inc., Houston, TX, USA). Quantitative analyses of Cd, Hg, and As were performed using an inductively coupled plasma mass spectrometer (ICP-MS; NexION 350D, Perkin Elmer Inc., Houston, TX, USA). The argon (Ar) flow rate were 12 L/min, 0.2 L/min, and 0.65 L/min for the plasma, auxiliary, and nebulizer in the ICP-OES, respectively. The flow rate of the sample was set at 1.5 mL/min and the wavelengths of Pb, Ni, Mn, Cr, and Y were 220.353 nm, 231.604 nm, 257.610 nm, 267.716 nm, and 317.029 nm, respectively, and the plasma view for ICP-OES was set as axial. For the ICP-MS, the sweep/reading was 30 and the reading/replicate was one. The scan mode for ICP-MS was set as peak hopping and the analyses were conducted using the standard oxygen DRC (AsO). The integration time of ICP-MS was 1500 ms and the mass of Cd, Hg, As, AsO, and Tb were 111 amu, 202 amu, 75 amu, 91 amu, and 159 amu, respectively. All analyses using the ICP-OES and ICP-MS were replicated three times.

Quantitative analyses of Der f 1 and Der p 1 were performed by microplate reader (VersaMax™ ELISA, Molecular Devices LLC., San Jose, CA, USA) with SoftMax software (SoftMax® Pro Software, Molecular Devices LLC., San Jose, CA, USA). The VersaMax™ ELISA was set at 36.9-37 ℃ and the program was set as house dust mite protocol mode. The 96 wells were washed three times with a wash buffer and dyed with blue fluorescent. Stop solutions of 50 μL were aliquoted onto wells and the plate was placed inside of VersaMax™ ELISA. The cover was shut and the reads were performed at optical density (OD) of 450 nm. The OD reads were set between 1.2-3.5 for the highest concentrations. All analyses using the VersaMax™ ELISA were replicated two times.

2.4. Quality Assurance and Quality Control

The information of limits of quantification (LOQ) and recovery rates for EDCs and heavy metals are shown in Table 3. To check background contamination of target contaminants during EDCs analyses, procedural blanks (n=10) were processed every 10 samples as real samples during the experimental procedure. The concentrations in procedural blanks were subtracted from the concentrations of target contaminants in dust samples. As the standard reference material (SRM), 2585 house dust (NIST, Gaithersburg, MD, USA) was analyzed with real dust samples to assess the accuracy of measurement for target contaminants. For OPFRs and PHTHs, recoveries of internal standards ranged from 72 ± 12% to 109 ± 19%. For heavy metals analyses, the standard experiment methods from National Institute of Environmental Research of Korea (NIER) methods 2021-12 was followed. The precision was calculated as the standard deviation of 4 replicated results divided by the average and multiplied by 100 (%). The recovery rates for internal standards ranged from 95.2 ± 1.1% to 99.3 ± 1.3%.

For house dust mite allergens analyses, the calibration curve coefficient R^2 was ensured to be above 0.98. Any test results below 0.98 were omitted and the analyses were re-tested. For precision, coefficient of variation (CV) of all test results were scrutinized. The CVs were calculated as the difference of concentrations between the two replicated experiment results. Analyses with differences above 20% were re-tested.

Table 3. The LOQ values and recovery rates of EDCs and heavy metals.

Chemicals	LOQ (ng/g)	Internal Standards	Recovery Rate ± RSD (%)
TMP	7.4	D_{15}-TEP	72 ± 12
TEP	5.0		
TiPP	1.9		
TPrP	2.0	D_{21}-TPrP	84 ± 16
TBP	3.7	D_{27}-TBP	89 ± 11
TCEP	1.5	D_{12}-TCEP	91 ± 13
TCPP	4.7	D_{18}-TCPP	104 ± 11
TPeP	0.9		
TDCPP	0.8	D_{15}-TDCPP	104 ± 11
TBOEP	1.9		
TPhP	1.5	D_{15}-TPhP	97 ± 13
EHDPP	1.8		
TEHP	1.1		
CDP	7.9		
ToCP	1.8		
TmCP	2.7		
TpCP	1.5		
TiPPP	4.4		
OPFRs			
DMP	0.6	DMP-D_4	77 ± 19
DEP	0.5	DEP-D_4	87 ± 13
DiPrP	0.4		
DnBP	0.2	DnBP-D_4	109 ± 19
DnPeP	0.4	DnPeP-D_4	106 ± 18
DnHxP	0.9	DnHxP-D_4	91 ± 13
BBzP	0.5		
DCHP	1.3	DCHP-D_4	94 ± 13
DEHP	0.5	DEHP-D_4	98 ± 19
DiHpP	0.5		
DnOP	7.5	DnOP-D_4	98 ± 15
DnPrP	0.3	DnPrP-D_4	93 ± 17
DAIP	1.8		
DiBP	0.2	DiBP-D_4	83 ± 12
DiNP	351		
DiDP	131		
PHTHs			
ATBC	0.2		
DEHA	1.1		
DEHTP	34.4		
TOTM	58.1		
DINCH	42.9		
NPPs			
Cd	10.0	Cd	99.3 ± 1.3
Mn	3040.0	Mn	96.3 ± 4.7
Cr	3040.0	Cr	97.4 ± 5.4
Pb	4340.0	Pb	97.0 ± 4.4
As	20.0	As	95.2 ± 1.1
Ni	3130.0	Ni	96.3 ± 5.3
Hg	40.0	Hg	97.6 ± 2.6
ΣHeavy metals			

2.5. Estimation of Residential Intake

The residential intake of infants (0 to <2) to OPFRs, PHTHs, and NPPs in SHD and ACCD via ingestion and inhalation were calculated. For estimating ingestion intake, the 50th, 75th, and 95th percentile concentrations of EDCs in SHD were used. The dust ingestion rate of 95th percentile was used for the high ingestion exposure scenario and 100% absorption was assumed. The equation for the estimation of ingestion intake was derived from Jones-Otazo et al. (2005) as shown in Equation (1).

$$Ingestion_{exp} = \frac{IR_{ing} \times \mathrm{ABS} \times Dust_{concn} \times Fr_{day}}{\mathrm{BW}} \qquad \text{Equation (1)}$$

where $Ingestion_{exp}$ is the contaminant exposure estimates through ingestion (ng/kg/day), IR_{ing} is the ingestion rate of dust (100 mg/day), ABS is the dimensionless absorption rate assumed as 100%, $Dust_{concn}$ is the contaminant's concentration in SHD (μg/g), Fr_{day} is the time fraction exposed to the contaminant in residence (79.3%), and BW is the body weight of infants (12.2 kg).

For estimating inhalation intake, the 50th, 75th, and 95th percentile concentrations of EDCs in ACCD and SHD were used, derived from Bi et al. (2018) and Weiss et al (2018). To estimate inhalation rate of dust, the 95th percentile concentration of particles in the respirable (< 2.5 μm) fraction was used in account for high inhalation exposure scenario and 100% absorption was assumed. The concentration of $PM_{2.5}$ (18.00 μg/m^3) was taken from the Korea National Health and Nutrition Examination Survey (KHANES 2019-ER3417-00, Development of the indoor air quality monitoring model and pilot survey) measured from December 2019 to March 2020 in 60 houses in Korea. To estimate inhalation intake using SHD, the resuspendable fraction of respirable dust was assumed to be 0.6% as derived from Gustafsson et al. (2018) and multiplied to the estimated inhalation rate of dust. The equation for the estimation of inhalation intake was derived from Jones-Otazo et al. (2005) as shown in Equation (2).

$$Inhalation_{exp} = \frac{IR_{inh} \times \mathrm{ABS} \times Dust_{concn} \times Fr_{day}}{\mathrm{BW}}$$ Equation (2)

where $\mathrm{Inhalation_{exp}}$ is the contaminant exposure estimates through inhalation (ng/kg/day), $\mathrm{IR_{inh}}$ is the inhalation rate of air (9.49 m^3/day), ABS is the dimensionless absorption rate assumed as 100%, $\mathrm{Dust_{concn}}$ is the contaminant's concentration in ACCD and SHD (μg/m^3), $\mathrm{Fr_{day}}$ is the time fraction exposed to the contaminant in residence (79.3%), and BW is the body weight of infants (12.2 kg).

The information of infant's dust ingestion rate, inhalation rate, fraction of time spent indoors (19.02 hr/day), and body weight were obtained from the child specific exposure factors handbook provided by the National Institute of Environmental Research of Korea (NIER, 2019).

2.6. Statistical Analysis

The weight fraction concentration (μg/g) of contaminants in dust was calculated by dividing the weight of contaminants by the weight of dust analyzed. For ACCD, because the dust was undetachable from the filter, the weight of dust was measured by subtracting the weight of blank filter from the weight of filter and dust. In addition, for ACCD, weight per surface area ($\mu g/cm^2$) of filter was estimated by dividing the weight of chemicals by the surface area of the filter analyzed.

Since the concentration profiles of contaminants in SHD and ACCD followed a log-normal distribution, geometric means (GM) and geometric standard deviations (GSD) were used in this study. The GSD for most contaminants were <3.0 and values <LOQ were replaced by $1/\sqrt{2}$ LOQ. Contaminants detected in <90% of dust samples and the total concentrations of OPFRs (ΣOPFRs; sum of 18 OPFR compounds), PHTHs (ΣPHTHs; sum of 16 PHTH compounds), and NPPs (ΣNPPs; sum of 5 NPP compounds) were omitted from statistical analyses.

A Pearson correlation analysis was conducted to evaluate the relationship within a group of contaminants and between different groups of contaminants. Multiple linear regression (MLR) analysis was conducted to identify the determinants in association with contaminants. Univariate linear regression analysis was conducted for every explanatory variable. Explanatory variables identified with marginally significant relationship ($p<0.1$) were sorted for MLR analysis. Insignificant variables or those that did not reflect a plausible relationship between the independent and the dependent variables were excluded from the MLR models. A stepwise method was conducted and the models with the lowest Akaike information criterion (AIC) values were selected. All Pearson correlation and MLR analyses were conducted after logarithmically transforming concentrations of contaminants. A Kruskal-Wallis test was conducted to evaluate the difference between the total concentrations of contaminants and estimated intakes by different routes.

A p-value of less than 0.05 was considered statistically significant. All statistical analyses were conducted using Rex-software version 3.3.1.1 (Rexsoft, Co. Ltd., Seoul, KR) and SigmaPlot 12.0 (Systat Software, Inc.; San Jose, CA, USA) was used to visualize the results.

3. Results

3.1. Survey Responses

The participant's responses to survey questionnaires are shown in Table 4. Most households comprised of 2-3 residents, where more than 50% of the residents in houses recruited for SHD and ACCD carried allergic diseases. Most participants lived in apartments that aged typically between 3-4 years old with 94.62 ± 48.45 m^2 to 110.16 ± 40.65 m^2 in size and 2-3 rooms. Majority of the participants owned 9-11 housing appliances and more than 25% of the participants used candles, air fresheners, and diffusers indoors. The cooking frequency per day were 1-2 times per day and more than 50% of the participants used both gas or electricity for cooking. Most residents naturally ventilated 10 min to 1.5 h per day, vacuum cleaned the house 4-7 times per week, and cleaned the mattresses 1-2 times per month. In addition, majority of the participants routinely cleaned the floors via wet cleaning, using disposable wet tissues, and dry mopping.

Table 4. The information of participant's questionnaire responses.

Category	Questionnaire content	SHD (n=106)		ACCD (n=120)		Bedding dust (n=30)	
		Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Resident related factors	Total household residents (n)	2.95 ± 1.25	1-8	3.24 ± 0.87	1-6	2.90 ± 1.54	1-8
	Below 10 years old (n)	0.53 ± 0.76	0-2	0.78 ± 0.77	0-2	0.45 ± 0.69	0-2
	Between 11-20 years old (n)	0.24 ± 0.56	0-3	0.30 ± 0.56	0-2	0.34 ± 0.72	0-3
	Above 70 years old (n)	0.08 ± 0.31	0-2	0.08 ± 0.35	0-2	0.03 ± 0.19	0-1
	Presence of allergic diseases	Yes (51.8%)		Yes (50.8%)		Yes (41.4%)	
	Presence of smokers	Yes (15.1%)		Yes (28.3%)		Yes (24.1%)	
Housing related factors	Age of building (yrs.)	3.64 ± 1.35	1-6	3.34 ± 1.23	1-6	3.34 ± 1.32	1-5
	Residence duration (MThs)	50.25 ± 70.28	0-438	49.12 ± 45.88	0-208	31.45 ± 40.04	1-163
	House size (m^2)	101.05 ± 49.15	19.80-270.60	110.16 ± 40.65	36.30-399.30	94.62 ± 48.45	19.80-238.00
	Rooms (n)	2.98 ± 0.96	0-6	3.14 ± 0.60	2-6	2.97 ± 1.05	1-6
	Housing appliances (n)	9.94 ± 3.20	0-19	11.83 ± 2.78	7-22	10.31 ± 3.14	5-18
	House type†	A (69.8%), D (10.4%), R (19.8%)		A (87.5%), D (3.3%), R (9.2%)		A (72.4%), D (13.8%), R (13.8%)	
	Home repair in 6 months	Yes (13.2%)		Yes (11.7%)		Yes (13.8%)	
	Presence of water penetration	Yes (26.4%)		Yes (55%)		Yes (24.1%)	
	Presence of mold	Yes (47.2%)		Yes (9.2%)		Yes (48.3%)	
	Use of carpets or rugs	Yes (38.3%)		Yes (42.5%)		Yes (44.8%)	
Resident behavior related factors	Number of cooking (per day)	1.69 ± 0.50	0-2	1.51 ± 0.79	0-3	1.47 ± 0.99	0.29-3
	Communal animals (n)	0.43 ± 0.98	0-7	0.18 ± 0.55	0-4	0.52 ± 1.35	0-7
	Plants (n)	2.08 ± 1.02	1-5	2.06 ± 0.93	1-5	2.31 ± 1.11	1-5
	Gas fuel for cooking	Yes (59.4%)		Yes (59.2%)		Yes (62.1%),	
	Electricity for cooking	Yes (58.5%)		Yes (66.7%)		Yes (65.5%)	
	Ventilation during cooking	Yes (99.2%)		Yes (100%)		Yes (100%)	
	Candles used	Yes (25.8%)		Yes (34.2%)		Yes (27.6%)	
	Air fresheners used	Yes (25.8%)		Yes (34.2%)		Yes (37.9%)	
	Diffusers used	Yes (43.3%)		Yes (44.2%)		Yes (37.9%)	
Indoor air quality management factors	Vacuum cleaning (hrs. per day)	0.99 ± 0.74	0.14-3	0.97 ± 0.77	0-5	1.14 ± 0.97	0.14-4
	Natural ventilation (hrs. per day)	1.18 ± 0.81	0-3	1.51 ± 0.99	0-5	1.15 ± 0.74	0.14-3
	Mechanical ventilation (hrs. per day)	0.24 ± 0.48	0-3	0.26 ± 0.99	0-1.43	0.39 ± 0.67	0-3
	Number of mattresses cleaned (per MTh)	0.89 ± 1.05	0-5.38	1.02 ± 0.72	0-3.31	0.70 ± 0.56	0-2
	Wet cleaning	Yes (67%)		Yes (71.7%)		Yes (56.7%)	
	Air cleaners used‡	Sp (83.0%), Su (84.9%), Au (80.2%), Wi (80.2%)		Sp (97.5%), Su (94.2%), Au (97.5%), Wi (92.5%)		Sp (58.6%), Su (48.3%), Au (51.7%), Wi (51.7%)	

†: A is apartment, D is detached house, and R is row house.
‡: Sp is Spring, Su is Summer, Au is Autumn, Wi is Winter.

3.2. Contaminants in SHD

The detection rates and concentrations of OPFRs, PHTHs, NPPs, and heavy metals in SHD are shown in Table 5. The detection rates and concentrations of house dust mite allergens in bedding dust are shown in Table 6. Among the 48 contaminants investigated, 25 contaminants were >90% detection whereas 15 compounds were <30%. For OPFRs, 5 compounds were >90% detection rate, whereas 7 PHTHs and all 5 NPPs were >90%. Among the three EDC groups, the average concentration of ΣNPPs (GM (GSD): 1.45×10^3 (1.55) μg/g) was significantly the highest, followed by ΣPHTHs (GM (GSD): 6.76×10^2 (1.40) μg/g) and ΣOPFRs (GM (GSD): 1.00×10^1 (1.39) μg/g). The average concentrations of DEHTP, DINCH, and TOTM were the highest for NPPs, whereas DEHP, DiNP, and DiDP were the highest for phthalates, and EHDPP, TCPP, and TPhP were the highest for OPFRs.

The detection rates were 100% for all 7 heavy metal elements in SHD samples and the average concentrations of Mn, Cr, and Ni were the highest. For house dust mite allergens, the detection rate of Der f1 was 100% whereas that of Der p1 was 37%. The average concentration of Der f1 (GM (GSD): 9.22×10^{-2} (1.78) μg/g) was more than 66 times higher than that of Der p1 (GM (GSD): 1.39×10^{-3} (2.31) μg/g).

Table 5. Descriptive statistics of EDCs and heavy metals in SHD.

Chemicals	Detection rate (%)	Settled house dust (n=106) (µg/g)					
		GM (GSD)	Min	25^{th}	50^{th}	75^{th}	Max
TMP	0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
TEP	99	1.41 x 10^{-1} (1.55)	1.39 x 10^{-2}	7.35 x 10^{-2}	1.26 x 10^{-1}	2.29 x 10^{-1}	3.55
TiPP	19	2.39 x 10^{-3} (1.70)	<LOQ	<LOQ	<LOQ	<LOQ	6.66 x 10^{-1}
TPrP	9	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	5.93 x 10^{-1}
TBP	93	1.35 x 10^{-1} (1.71)	<LOQ	1.16 x 10^{-1}	1.56 x 10^{-1}	2.15 x 10^{-1}	5.17
TCEP	100	6.20 x 10^{-1} (1.52)	3.42 x 10^{-2}	3.45 x 10^{-1}	5.68 x 10^{-1}	1.12	1.39 x 10^{1}
TCPP	90	1.42 (2.70)	<LOQ	1.26	2.36	4.42	7.15 x 10^{1}
TPeP	7	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	5.65 x 10^{-1}
TDCPP	57	3.17 x 10^{-2} (4.75)	<LOQ	<LOQ	1.76 x 10^{-1}	6.46 x 10^{-1}	7.03
TBOEP	81	1.13 x 10^{-1} (2.66)	<LOQ	1.14 x 10^{-1}	2.39 x 10^{-1}	4.37 x 10^{-1}	2.37
TPhP	99	1.05 (1.52)	<LOQ	6.93 x 10^{-1}	1.01	1.62	6.58
EHDPP	99	1.38 (1.77)	<LOQ	7.94 x 10^{-1}	1.18	2.44	9.65 x 10^{1}
TEHP	82	1.53 x 10^{-1} (3.00)	<LOQ	2.09 x 10^{-1}	3.78 x 10^{-1}	6.40 x 10^{-1}	2.65
CDP	75	1.40 x 10^{-1} (2.34)	5.59 x 10^{-3}	4.14 x 10^{-2}	2.64 x 10^{-1}	5.48 x 10^{-1}	3.26
TmCP	8	2.74 x 10^{-3} (1.75)	<LOQ	<LOQ	<LOQ	<LOQ	7.83 x 10^{-1}
ToCP	52	1.25 x 10^{-1} (2.74)	<LOQ	<LOQ	2.48 x 10^{-2}	1.00 x 10^{-1}	2.31
TpCP	3	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	6.16 x 10^{-1}
TiPPP	29	9.43 x 10^{-3} (2.14)	<LOQ	<LOQ	<LOQ	8.57 x 10^{-2}	5.01 x 10^{-1}
ΣOPFRs		**1.00 x 10^{1} (1.39)**					
DMP	62	1.97 x 10^{-2} (3.85)	<LOQ	<LOQ	7.92 x 10^{-2}	2.71 x 10^{-1}	2.09
DEP	100	5.41 x 10^{-1} (1.59)	9.45 x 10^{-2}	3.05 x 10^{-1}	4.73 x 10^{-1}	7.47 x 10^{-1}	4.15 x 10^{1}
DiPrP	14	5.23 x 10^{-4} (2.06)	<LOQ	<LOQ	<LOQ	<LOQ	6.14 x 10^{-1}
DnPrP	0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
DAIP	3	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	1.05
DnBP	100	1.60 x 10^{1} (1.57)	1.71	8.4	1.37 x 10^{1}	2.97 x 10^{1}	1.15 x 10^{3}
DiBP	100	3.20 (1.55)	2.41 x 10^{-1}	1.62	2.9	5.62	1.03 x 10^{2}
DnPeP	0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
DnHxP	24	2.28 x 10^{-3} (2.39)	<LOQ	<LOQ	<LOQ	3.32 x 10^{-2}	1.31 x 10^{-1}
BBzP	99	1.23 (2.18)	<LOQ	3.85 x 10^{-1}	8.92 x 10^{-1}	2.65	4.10 x 10^{2}
DCHP	12	1.94 x 10^{-3} (2.56)	<LOQ	<LOQ	<LOQ	<LOQ	8.51
DEHP	100	4.42 x 10^{2} (1.48)	6.94 x 10^{1}	2.41 x 10^{2}	4.35 x 10^{2}	6.96 x 10^{2}	5.22 x 10^{3}

DiHpP	0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
DnOP	5	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
DiNP	100	1.10 x 10^{2} (1.41)	2.30 x 10^{1}	6.49 x 10^{1}	1.02 x 10^{2}	1.78 x 10^{2}	3.68 x 10^{3}
DiDP	100	1.83 x 10^{1} (1.36)	4.38	1.14 x 10^{1}	1.65 x 10^{1}	2.84E x 10^{1}	2.11 x 10^{2}
ΣPHTHs		**6.76 x 10^{2} (1.40)**					
ATBC	100	1.82 x 10^{-1} (1.93)	4.68 x 10^{-1}	7.45	1.43 x 10^{1}	3.22 x 10^{1}	4.61 x 10^{3}
DEHA	96	6.73 (2.45)	<LOQ	4.37	9.3	1.65 x 10^{1}	5.63 x 10^{2}
DEHTP	100	1.17 x 10^{3} (1.56)	6.95 x 10^{1}	6.07 x 10^{2}	1.29 x 10^{3}	2.34 x 10^{3}	1.40 x 10^{4}
DINCH	100	7.24 x 10^{1} (1.72)	4.49	3.27 x 10^{1}	5.05 x 10^{1}	1.44 x 10^{2}	4.69 x 10^{3}
TOTM	100	1.07 x 10^{1} (1.55)	2.14	5.76	8.49	1.41 x 10^{1}	7.24 x 10^{2}
ΣNPPs		**1.45 x 10^{3} (1.55)**					
Cd	100	6.06 x 10^{-1} (1.35)	1.54 x 10^{-1}	3.80 x 10^{-1}	5.66 x 10^{-1}	8.28 x 10^{-1}	5.84
Mn	100	1.05 x 10^{2} (1.27)	2.58 x 10^{1}	6.55 x 10^{1}	1.03 x 10^{2}	1.55 x 10^{2}	4.78 x 10^{2}
Cr	100	4.81 x 10^{1} (1.28)	5.94	3.53 x 10^{1}	4.56 x 10^{1}	6.18 x 10^{1}	2.67 x 10^{2}
Pb	100	2.94 x 10^{1} (1.40)	6.41	1.67 x 10^{1}	2.61 x 10^{1}	4.01 x 10^{1}	3.98 x 10^{2}
As	100	2.22 (1.20)	1.16 x 10^{-1}	1.88	2.25	2.64	8.93
Ni	100	4.41 x 10^{1} (1.29)	<LOQ	3.23 x 10^{1}	4.14 x 10^{1}	6.07 x 10^{1}	4.00 x 10^{2}
Hg	100	1.08 (1.67)	2.09 x 10^{-1}	5.55 x 10^{-1}	7.63 x 10^{-1}	1.28	2.52 x 10^{2}
Heavy metals							

Table 6. Descriptive statistics of house dust mite allergens in bedding dust.

Allergens	**Detection rate (%)**	**Bedding dust (n=30) (μg/g)**					
		GM (GSD)	Min	25th	50th	75th	Max
Der f 1	100	9.22 x 10^{-2} (1.78)	2.16 x 10^{-3}	3.47 x 10^{-2}	8.52 x 10^{-2}	2.67 x 10^{-1}	2.37
Der p 1	37	1.39 x 10^{-3} (2.31)	<LOQ	<LOQ	<LOQ	1.65 x 10^{-3}	3.05 x 10^{-2}

3.3. Correlation Analyses of Contaminants in SHD

For EDCs, a strong positive correlation ($r=0.80$) was observed between TPhP and EHDPP, whereas most compounds showed insignificant or weak positive correlations ($0<r<0.3$ or $-0.3<r<0$) (Table S1, S2, and S3). Intercorrelations between most of the OPFRs, PHTHs, and NPPs were insignificant or weak (Table S4, S5, and S6).

3.4. Determinants in Association with Contaminants in SHD

MLR models of housing/lifestyle factors affecting the concentrations of OPFRs, PHTHs, and NPPs are shown in Table 7, 8, and 9, respectively. In general, OPFRs, PHTHs, and NPPs showed significant associations with the type and number of home appliances. In particular, for OPFRs, residences with >3-4 kitchen appliances and >3-4 digital appliances significantly elevated the levels of TEP, TBP, TCPP, TPhP, and EHDPP. On the other hand, for PHTHs and NPPs, home appliances bought after 2019 were in significant associations. The levels of DEP, DEHP, and DiDP significantly decreased in residences that bought refrigerators, microwaves, televisions, and printers after 2019, whereas that of DEHA increased for airfryer bought after 2019. In addition, usage of candles, diffusers, and air fresheners significantly elevated the levels of DEP, DnBP, DiBP, DEHP, DiNP, BBzP, and ATBC in SHD. However, the levels of most EDCs significantly decreased for ventilating >1.5 h/day, vacuum cleaning >4-7 times/week, and either wet cleaning or dry mopping the floors.

MLR models of housing/lifestyle factors associated with the concentrations of heavy metals in SHD and Der f 1 in bedding dust are shown in Table 7 and 8, respectively. For heavy metals, most elements showed significant associations with the type and number of home appliances. In particular, in residences that bought refrigerator and printer after 2019, the levels of As, Cd, Pb, and As significantly decreased. On the other hand, use of gas fuel or electricity for cooking significantly elevated the levels of Cd, Mn, and As. Der f 1 showed significantly positive associations with the number of residents and the presence of water penetration. The levels of most heavy metals significantly decreased for ventilating >1.5 h/day, vacuum cleaning >4-7 times/week, and wet cleaning, whereas that of Der f 1 significantly decreased for wet cleaning. However, while mechanically ventilating lowered the levels of Cd (-22%), Pb (-25%), As (-13%), and Ni (-36%), naturally ventilating >1.5 h/day elevated the level of Ni (54%).

Table 7. MLR models of housing/lifestyle factors associated with OPFRs in SHD.

Variables		TEP			TBP			TCEP		
Reference	**Subcategory**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**
	(Intercept)	-1.19 (0.17)	<0.001	0.30	-1.70 (0.41)	<0.001	0.84	-0.77 (0.31)	0.01	0.46
1 laundry appliance†	vs.									
	2 laundry appliances	0.10 (0.08)	0.31	1.11	0.25 (0.12)	0.04*	1.28	0.12 (0.09)	0.19	1.13
	>3 laundry appliances	0.26 (0.12)	0.03*	1.30	0.05 (0.15)	0.71	1.05	0.26 (0.12)	0.03*	1.30
1-2 kitchen appliances‡	vs.									
	3-4 kitchen appliances	0.28 (0.13)	0.04*	1.32						
	>4 kitchen appliances	0.39 (0.15)	0.009**	1.48						
1-2 digital appliances§	vs.									
	3-4 digital appliances				0.30 (0.15)	0.04*	1.35			
	>4 digital appliances				0.25 (0.16)	0.12	1.28			
Ventilation <1.5 h/day¶	vs.									
	1.5-8 h/day				-0.85 (0.42)	0.06	0.43	-0.48 (0.26)	0.05	0.62
	>8 h/day				-1.07 (0.39)	0.009**	0.36	-0.64 (0.31)	0.09	0.53
Wet cleaning# (no)	vs. yes	-0.17 (0.09)	0.05	0.84						
Dry mopping♠ (no)	vs. yes	-0.23 (0.10)	0.02*	0.80						
Adj. R^2		0.21			0.13			0.15		

†: Laundry appliances are the total number of washing machines, dryers, and stylers in residence.
‡: Kitchen appliances are the total number of refrigerators, kimchi refrigerators, airfryers, microwaves, and ovens in residence.
§: Digital appliances are the total number of televisions, desktops, laptops, and printers in residence.
¶: Ventilation is the sum of natural ventilation frequency and mechanical ventilation frequency.
#: Wet cleaning includes cleaning using wet mop cleaners and wet woolen rags.
♠: Dry mopping includes cleaning using microfiber clothes and dry mops.
*: Factors with statistical significance (p<0.05).
**: Factors with statistical significance (p<0.01).

Table 7. continued.

Variables		TCPP			TPhP			EHDPP		
Reference	**Subcategory**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**
	(Intercept)	0.33 (0.16)	0.01	1.39	-0.52 (0.32)	<0.001	0.59	-0.32	0.02	0.73
1-2 kitchen appliances†	vs.									
	3-4 kitchen appliances	0.14 (0.07)	0.06	1.15						
	>4 kitchen appliances	0.32 (0.19)	0.03*	1.38						
1-2 digital appliances‡	vs.									
	3-4 digital appliances				0.33 (0.11)	0.004**	1.39	0.34 (0.16)	0.03*	1.40
	>4 digital appliances				0.39 (0.12)	0.002**	1.48	0.30 (0.17)	0.07	1.35
Carpets used (no)	vs. yes				0.16 (0.09)	0.06	1.17			
Ventilation <1.5 h/day§	vs.									
	1.5-8 h/day				-0.31 (0.16)	0.17	0.73	-0.29 (0.15)	0.04*	0.75
	>8 h/day				-0.62 (0.29)	0.03*	0.53	-0.11 (0.19)	0.64	0.90
Vacuum cleaning <4 times/week	vs.									
	4-7 times/week				-0.09 (0.07)	0.33	0.91	-0.11 (0.13)	0.41	0.90
	>7 times/week				-0.31 (0.12)	0.009**	0.73	-0.49 (0.16)	0.003**	0.61
Adj. R^2		0.11			0.26			0.13		

†: Kitchen appliances are the total number of refrigerators, kimchi refrigerators, airfryers, microwaves, and ovens in residence.
‡: Digital appliances are the total number of televisions, desktops, laptops, and printers in residence.
§: Ventilation is the sum of natural ventilation frequency and mechanical ventilation frequency.
*: Factors with statistical significance (p<0.05).
**: Factors with statistical significance (p<0.01).

Table 8. MLR models of housing/lifestyle factors associated with phthalates in SHD.

Variables		DEP			DnBP			DiBP			BBzP		
Reference	Subcategory	β (SE)	p-value	Exp (β)	β (SE)	p-value	Exp (β)	β (SE)	p-value	Exp (β)	β (SE)	p-value	Exp (β)
	(Intercept)	-0.10 (0.03)	0.14	0.90	1.92 (0.32)	<0.001	6.82	0.14 (0.05)	0.06	1.15	-0.24 (0.20)	0.23	0.79
<8 electronic appliances†	vs.												
	9-13 electronic appliances				0.09 (0.12)	0.43	1.09						
	>13 electronic appliances				0.28 (0.14)	0.05	1.32						
Refrigerator bought before 2019	vs. bought after 2019				-0.36 (0.18)	0.06	0.70						
Printers bought before 2019	vs. bought after 2019	-0.25 (0.12)	0.04*	0.78									
Electricity used for cooking (no)	vs. yes	0.23 (0.12)	0.06	1.26									
Candles used (no)	vs. yes	0.23 (0.10)	0.03*	1.26									
Diffusers used (no)	vs. yes				0.16 (0.09)	0.05	1.12	0.23 (0.08)	0.006**	1.26	0.24 (0.15)	0.01*	1.27
Ventilation <1.5 h/day‡	vs.												
	1.5-8 h/day							0.11 (0.09)	0.20	1.12	-0.23 (0.11)	0.34	0.79
	>8 h/day							-0.24 (0.12)	0.05	0.79	-0.29 (0.13)	0.05	0.75
Vacuum cleaning <4 times/week	vs.												
	4-7 times/week										-0.52 (0.24)	0.02*	0.59
	>7 times/week										-0.41 (0.16)	0.004**	0.66
Wet cleaning§ (no)	vs. yes	-0.19 (0.09)	0.05	0.83									
Dry mopping¶ (no)	vs. yes										-0.37 (0.17)	0.04*	0.69
Adj. R^2			0.18			0.33			0.18			0.12	

†: Electronic appliances are the total number of laundry appliances, kitchen appliances, and digital appliances in residence.
‡: Ventilation is the sum of natural ventilation frequency and mechanical ventilation frequency.
§: Wet cleaning includes cleaning using wet mop cleaners and wet woolen rags.
¶: Dry mopping includes cleaning using microfiber clothes and dry mops.
*: Factors with statistical significance (p<0.05).
**: Factors with statistical significance (p<0.01).

Table 8. continued.

Variables		DEHP			DiNP			DiDP		
Reference	**Subcategory**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**
	(Intercept)	1.29 (0.09)	<0.001	3.63	2.21 (0.10)	<0.001	9.12	2.76 (0.08)	<0.001	15.8
1 laundry appliance†	vs.									
	2 laundry appliances	0.05 (0.06)	0.45	1.05						
	>3 laundry appliances	0.18 (0.08)	0.03*	1.20						
1-2 kitchen appliances‡	vs.									
	3-4 kitchen appliances	0.05 (0.06)	0.43	1.05						
	>4 kitchen appliances	0.14 (0.08)	0.07	1.15						
Refrigerator bought before 2019	vs. bought after 2019	-0.81 (0.28)	0.01*	0.44				-0.26 (0.15)	0.03*	0.77
Microwave bought before 2019	vs. bought after 2019	-0.65 (0.27)	0.03*	0.52						
Televisions bought before 2019	vs. bought after 2019							-0.23 (0.11)	0.04*	0.79
Electricity used for cooking (no)	vs. yes				0.13 (0.07)	0.06	1.14			
Candles used (no)	vs. yes				0.15 (0.07)	0.04*	1.16			
Air fresheners used (no)	vs. yes	0.15 (0.07)	0.03*	1.16						
Carpets used (no)	vs. yes				0.15 (0.07)	0.03*	1.16			
Wet cleaning§ (no)	vs. yes	-0.12 (0.06)	0.06	0.89	-0.14 (0.07)	0.05	0.87			
Dry mopping¶ (no)	vs. yes				-0.17 (0.08)	0.04*	0.84	-0.16 (0.08)	0.06	0.85
Adj. R^2		0.14			0.18			0.09		

†: Laundry appliances are the total number of washing machines, dryers, and stylers in residence.
‡: Kitchen appliances are the total number of refrigerators, kimchi refrigerators, airfryers, microwaves, and ovens in residence.
§: Wet cleaning includes cleaning using wet mop cleaners and wet woolen rags.
¶: Dry mopping includes cleaning using microfiber clothes and dry mops.
*: Factors with statistical significance (p<0.05).

Table 9. MLR models of housing/lifestyle factors associated with NPPs in SHD.

Variables		ATBC			DEHA			DEHTP		
Reference	**Subcategory**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**
	(Intercept)	1.11 (0.21)	<0.001	3.03	-1.93 (0.65)	0.004	0.15	2.80 (0.09)	<0.001	16.44
1 laundry appliance†	vs.									
	2 laundry appliances							0.20 (0.09)	0.03*	1.22
	>3 laundry appliances							0.12 (0.07)	0.19	1.13
Airfryer bought before 2019	vs. bought after 2019				0.36 (0.15)	0.06	1.43			
Gas fuel used for cooking (no)	vs. yes				0.46 (0.22)	0.05	1.58			
Electricity used for cooking (no)	vs. yes	0.18 (0.13)	0.03*	1.20	0.41 (0.26)	0.03*	1.51	0.17 (0.09)	0.04*	1.19
Candles used (no)	vs. yes	0.23 (0.14)	0.01*	1.26						
Air fresheners used (no)	vs. yes	0.23 (0.13)	0.07	1.26						
Ventilation <1.5 h/day‡	vs.									
	1.5-8 h/day	-0.13 (0.15)	0.31	0.88	-0.39 (0.19)	0.04*	0.68			
	>8 h/day	-0.24 (0.19)	0.02*	0.79	-0.57 (0.27)	0.03*	0.57			
Vacuum cleaning <4 times/week	vs.									
	4-7 times/week	-0.11 (0.09)	0.16	0.90						
	>7 times/week	-0.42 (0.18)	0.02*	0.66						
Cleaning dust on electronic appliances (no)	vs. yes							-0.23 (0.08)	0.008**	0.79
Wet cleaning§ (no)	vs. yes				-0.36 (0.18)	0.05	0.70			
Adj. R^2		0.14			0.26			0.14		

†: Laundry appliances are the total number of washing machines, dryers, and stylers in residence.
‡: Ventilation is the sum of natural ventilation frequency and mechanical ventilation frequency.
§: Wet cleaning includes cleaning using wet mop cleaners and wet woolen rags.
*: Factors with statistical significance ($p<0.05$).
**: Factors with statistical significance ($p<0.01$).

Table 9. continued.

Variables		DINCH			TOTM		
Reference	Subcategory	β (SE)	p-value	Exp (β)	β (SE)	p-value	Exp (β)
	(Intercept)	2.03 (0.23)	<0.001	7.61	1.26 (0.14)	<0.001	3.53
<8 electronic appliances[†]	vs.						
	9-13 electronic appliances	0.32 (0.16)	0.17	1.38			
	>13 electronic appliances	0.33 (0.23)	0.05	1.39			
1-2 kitchen appliances[‡]	vs.						
	3-4 kitchen appliances	0.36 (0.20)	0.08	1.43	0.22 (0.13)	0.03*	1.25
	>4 kitchen appliances	0.38 (0.17)	0.03*	1.46	0.15 (0.06)	0.11	1.16
1-2 digital appliances[§]	vs.						
	3-4 digital appliances	0.07 (0.12)	0.69	1.07			
	>4 digital appliances	0.44 (0.21)	0.03*	1.55			
New furniture bought in 6 months (no)	vs. yes				0.21 (0.09)	0.02*	1.23
Cooking <1 time/day	vs.						
	2 times/day				0.14 (0.12)	0.24	1.15
	>3 times/day				0.18 (0.10)	0.05	1.20
Dry mopping[¶] (no)	vs. yes	-0.26 (0.13)	0.05	0.77			
Adj. R^2		0.20			0.13		

[†]: Electronic appliances are the total number of laundry appliances, kitchen appliances, and digital appliances in residence.
[‡]: Kitchen appliances are the total number of refrigerators, kimchi refrigerators, airfryers, microwaves, and ovens in residence.
[§]: Digital appliances are the total number of televisions, desktops, laptops, and printers in residence.
[¶]: Dry mopping includes cleaning using microfiber clothes and dry mops.
*: Factors with statistical significance ($p<0.05$).

Table 10. MLR models of housing/lifestyle factors associated with heavy metals in SHD.

Variables		Cd			Mn			Cr			Pb		
Reference	Subcategory	β (SE)	p-value	Exp (β)	β (SE)	p-value	Exp (β)	β (SE)	p-value	Exp (β)	β (SE)	p-value	Exp (β)
	(Intercept)	0.95 (0.14)	0.009	2.56	0.57 (0.23)	0.15		1.64 (0.07)	<0.001	5.16	1.57 (0.06)	<0.001	4.81
1 laundry appliance[†]	vs.												
	2 laundry appliances	0.12 (0.07)	0.08	1.13				0.10 (0.07)	0.14	1.11	0.13 (0.10)	0.16	1.14
	>3 laundry appliances	0.16 (0.09)	0.05	1.17				0.12 (0.05)	0.02^{*}	1.13	0.16 (0.07)	0.04^{*}	1.17
1-2 digital appliances[‡]	vs.												
	3-4 digital appliances	0.03 (0.08)	0.10	1.03									
	>4 digital appliances	0.15 (0.09)	0.02^{*}	1.16									
Printers bought before 2019	vs. bought after 2019	-0.42 (0.12)	0.003^{**}	0.66							-0.34 (0.16)	0.05	0.71
New furniture bought in 6 months (no)	vs. yes							0.10 (0.05)	0.03^{*}	1.11			
Gas fuel used for cooking (no)	vs. yes	0.16 (0.06)	0.01^{*}	1.17	0.10 (0.05)	0.03^{*}	1.11						
Carpets used (no)	vs. yes	0.12 (0.06)	0.05	1.13									
Mechanical ventilation (no)	vs. yes	-0.25 (0.12)	0.04^{*}	0.78							-0.29 (0.13)	0.03^{*}	0.75
Vacuum cleaning <4 times/week	vs.												
	4-7 times/week	-0.04 (0.06)	0.14	0.96									
	>7 times/week	-0.13 (0.08)	0.01^{*}	0.88									
Cleaning dust on electronic appliances (no)	vs. yes				-0.09 (0.05)	0.06	0.91						
Adj. R^2			0.26			0.11			0.11			0.18	

[†]: Laundry appliances are the total number of washing machines, dryers, and stylers in residence.
[‡]: Digital appliances are the total number of televisions, desktops, laptops, and printers in residence.
*: Factors with statistical significance ($p<0.05$).
**: Factors with statistical significance ($p<0.01$).

Table 10. continued.

Variables		As			Ni			Hg		
Reference	**Subcategory**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**
	(Intercept)	0.45 (0.08)	<0.001	1.57	1.60 (0.08)	<0.001	4.95	0.15 (0.13)	<0.001	1.16
<8 electronic appliances[†]	vs.									
	9-13 electronic appliances							0.40 (0.12)	0.002**	1.49
	>13 electronic appliances							0.43 (0.15)	0.007**	1.54
Refrigerator bought before 2019	vs. bought after 2019	-0.07 (0.03)	0.04*	0.93	-0.17 (0.08)	0.05	0.84			
Printers bought before 2019	vs. bought after 2019	-0.14 (0.06)	0.02*	0.87						
New furniture bought in 6 months (no)	vs. yes				0.13 (0.05)	0.01*	1.14	0.20 (0.10)	0.05	1.22
Gas fuel used for cooking (no)	vs. yes	0.18 (0.05)	0.06	1.20						
Electricity used for cooking (no)	vs. yes	0.09 (0.05)	0.05	1.09						
Natural ventilation <1.5 h/day	vs.									
	1.5-8 h/day				0.08 (0.10)	0.42	1.08			
	>8 h/day				0.43 (0.22)	0.05	1.54			
Mechanical ventilation (no)	vs. yes	-0.12 (0.04)	0.004**	0.87	-0.45 (0.21)	0.03*	0.64			
Vacuum cleaning <4 times/week	vs.									
	4-7 times/week	-0.05 (0.05)	0.32	0.95						
	>7 times/week	-0.09 (0.04)	0.05	0.91						
Wet cleaning[‡] (no)	vs. yes				-0.19 (0.06)	0.002**	0.83	-0.22 (0.10)	0.04*	0.80
Adj. R^2		0.19			0.13			0.15		

[†]: Electronic appliances are the total number of laundry appliances, kitchen appliances, and digital appliances in residence.
[‡]: Wet cleaning includes cleaning using wet mop cleaners and wet woolen rags.
[*]: Factors with statistical significance ($p<0.05$).
[**]: Factors with statistical significance ($p<0.01$).

Table 11. MLR model of housing/lifestyle factors associated with Der f 1 in bedding dust.

Variables		**Der f 1**		
Reference	**Subcategory**	**β (SE)**	**p-value**	**Exp (β)**
	(Intercept)	0.78 (0.49)	<0.001	2.18
Single person household	vs.			
	2 person	0.26 (0.33)	0.44	1.30
	3 person	1.15 (0.34)	0.003**	3.16
	>4 person	1.35 (0.33)	<0.001***	3.86
Water penetration (no)	vs. yes	0.31 (0.21)	0.02*	1.36
Carpets used (no)	vs. yes	0.37 (0.20)	0.06	1.45
Vacuum cleaning <4 times/week	vs.			
	4-7 times/week	-0.41 (0.31)	0.20	0.66
	>7 times/week	-0.85 (0.25)	0.003**	0.43
Wet cleaning† (no)	vs. yes	-1.18 (0.43)	0.01*	0.31
Adj. R^2			0.75	

†: Wet cleaning includes cleaning using wet mop cleaners and wet woolen rags.
*: Factors with statistical significance (p<0.05).
**: Factors with statistical significance (p<0.01).
***: Factors with statistical significance (p<0.001).

3.5. Chemicals in ACCD

The detection rates and concentrations of OPFRs, PHTHs, NPPs, and heavy metals in ACCD samples are shown in Table 12. Among the 46 chemicals investigated, 10 chemicals were >90% detection rate. For OPFRs, three compounds were >90% detection rate, whereas 4 PHTHs and 3 NPPs were >90%. Among the three EDC groups, ΣPHTHs (GM (GSD): 5.77 x 10^2 (1.57) μg/g) showed the highest average concentration, followed by ΣNPPs (GM (GSD): 3.89 x 10^2 (1.64) μg/g) and ΣOPFRs (GM (GSD): 2.90 x 10^2 (1.79) μg/g). The average concentrations of DEHP, DiDP, and DnBP were the highest for PHTHs, whereas DEHTP, ATBC, and DEHA were the highest for NPPs, and TPhP, EHDPP, and TCEP were the highest for OPFRs. For heavy metal elements in ACCD samples, the detection rates of all elements were <90%.

Table 12. Descriptive statistics of EDCs and heavy metals in ACCD.

Chemicals	Detection rate (%)	Air cleaner captured dust (n=120)					
		Mass of contaminants per mass of dust (µg/g)			Mass of contaminants per surface area (µg/cm^2)		
		GM (GSD)	Range	Median	GM (GSD)	Range	Median
TMP	0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
TEP	5	4.36 x 10^{-3} (1.60)	<LOQ-1.94 x 10^{1}	<LOQ	1.88 x 10^{-5} (2.73)	<LOQ-8.44	<LOQ
TiPP	3	2.83 x 10^{-3} (1.68)	<LOQ-3.10 x 10^{2}	<LOQ	1.06 x 10^{-5} (2.45)	<LOQ-1.28 x 10^{2}	<LOQ
TPrP	1	1.98 x 10^{-3} (2.69)	<LOQ-9.13 x 10^{1}	<LOQ	6.87 x 10^{-6} (4.59)	<LOQ-1.05 x 10^{2}	<LOQ
TBP	8	7.21 x 10^{-3} (2.48)	<LOQ-1.38 x 10^{4}	<LOQ	3.54 x 10^{-5} (3.68)	<LOQ-6.90 x 10^{1}	<LOQ
TCEP	95	1.19 x 10^{1} (2.44)	<LOQ-2.53 x 10^{3}	1.87 x 10^{1}	3.39 (3.21)	<LOQ-5.70 x 10^{1}	6.78
TCPP	12	2.21 x 10^{-2} (4.04)	<LOQ-2.69 x 10^{4}	<LOQ	1.28 x 10^{-4} (5.54)	<LOQ-2.26 x 10^{3}	<LOQ
TPeP	0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
TDCPP	43	2.11 x 10^{-1} (4.34)	<LOQ-1.78 x 10^{4}	<LOQ	5.29 x 10^{-3} (8.66)	<LOQ-2.00 x 10^{3}	<LOQ
TBOEP	38	1.01 x 10^{-1} (4.88)	<LOQ-4.06 x 10^{3}	<LOQ	2.02 x 10^{-3} (7.10)	<LOQ-1.55 x 10^{2}	<LOQ
TPhP	96	2.52 x 10^{1} (2.40)	<LOQ-2.39 x 10^{3}	3.10 x 10^{1}	7.65 (3.10)	<LOQ-2.70 x 10^{2}	<LOQ
EHDPP	98	1.58 x 10^{1} (1.99)	<LOQ-1.40 x 10^{3}	2.05 x 10^{1}	5.13 (2.42)	<LOQ-6.83 x 10^{1}	7.79
TEHP	18	8.11 x 10^{-3} (3.93)	<LOQ-2.13 x 10^{3}	<LOQ	6.34 x 10^{-5} (5.70)	<LOQ-4.26 x 10^{1}	<LOQ
CDP	63	6.86 x 10^{-1} (3.60)	<LOQ-2.40 x 10^{2}	3.78	3.98 x 10^{-2} (5.74)	<LOQ-4.19 x 10^{1}	1.67
TmCP	2	3.27 x 10^{-3} (1.28)	<LOQ-1.92 x 10^{2}	<LOQ	1.17 x 10^{-5} (1.86)	<LOQ-1.82 x 10^{1}	<LOQ
ToCP	65	6.00 x 10^{-1} (1.40)	<LOQ-4.61 x 10^{3}	5.81	4.24 x 10^{-2} (6.50)	<LOQ-3.00 x 10^{1}	2.47
TpCP	1	1.87 x 10^{-3} (2.11)	<LOQ-6.21	<LOQ	6.46 x 10^{-6} (7.10)	<LOQ-7.17	<LOQ
TiPPP	4	8.41 x 10^{-3} (1.44)	<LOQ-5.64 x 10^{1}	<LOQ	3.45 x 10^{-5} (2.48)	<LOQ-3.84 x 10^{1}	<LOQ
ΣOPFRs		**2.90 x 10^{2} (1.79)**			**1.00 x 10^{2} (1.77)**		
DMP	83	4.11 x 10^{-1} (3.18)	<LOQ-1.28 x 10^{2}	1.13	6.72 x 10^{-2} (4.75)	<LOQ-3.12	4.83 x 10^{-1}
DEP	79	6.16 x 10^{-1} (4.13)	<LOQ-2.72 x 10^{2}	1.71	8.56 x 10^{-2} (5.80)	<LOQ-7.20 x 10^{1}	9.52 x 10^{-1}
DiPrP	4	5.20 x 10^{-4} (1.43)	<LOQ	<LOQ	2.11 x 10^{-6} (2.42)	<LOQ-5.23 x 10^{-1}	<LOQ
DnPrP	85	6.52 x 10^{-1} (2.85)	<LOQ-3.91 x 10^{2}	1.55	1.77 x 10^{-6} (2.36)	<LOQ-3.37	<LOQ
DAIP	3	4.60 x 10^{-4} (1.59)	<LOQ-1.93 x 10^{1}	<LOQ	3.97 x 10^{-6} (3.67)	<LOQ-1.71	<LOQ

DnBP	99	1.24 x 10^{1} (1.87)	<LOQ-1.41 x 10^{3}	1.08 x 10^{1}	3.49 (1.91)	<LOQ-1.82 x 10^{2}	3.04
DiBP	99	1.00 x 10^{1} (1.94)	<LOQ-9.81 x 10^{2}	9.02	1.09 x 10^{-1} (4.23)	<LOQ-8.82	5.42 x 10^{-1}
DnPeP	8	8.02 x 10^{-4} (2.34)	<LOQ-7.32	<LOQ	4.31 (1.81)	<LOQ-1.12 x 10^{2}	4.49
DnHxP	0	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
BBzP	91	1.85 (2.63)	<LOQ-3.84 x 10^{2}	2.88	4.53 x 10^{-1} (3.59)	<LOQ-4.96 x 10^{1}	1.07
DCHP	1	1.14 x 10^{-3} (1.89)	<LOQ-1.17	<LOQ	<LOQ	<LOQ	<LOQ
DEHP	99	4.43 x 10^{2} (1.97)	<LOQ-3.54 x 10^{4}	4.09 x 10^{2}	1.54 x 10^{2} (2.01)	<LOQ-2.94 x 10^{3}	1.65 x 10^{2}
DiHpP	3	7.39 x 10^{-4} (2.11)	<LOQ-3.25 x 10^{3}	<LOQ	<LOQ	<LOQ	<LOQ
DnOP	4	1.02 x 10^{-2} (1.46)	<LOQ-1.05 x 10^{2}	<LOQ	4.25 x 10^{-5} (2.31)	<LOQ-4.56 x 10^{1}	<LOQ
DiNP	80	1.39 (3.34)	<LOQ-3.68 x 10^{2}	4.3	2.16 x 10^{-1} (5.11)	1.17 x 10^{-5}-6.89 x 10^{1}	1.85
DiDP	17	4.39 x 10^{-3} (2.78)	<LOQ-1.80 x 10^{2}	<LOQ	3.50 x 10^{-5} (4.70)	<LOQ-1.62 x 10^{1}	<LOQ
ΣPHTHs		**5.77 x 10^{2} (1.57)**			**1.89 x 10^{2} (1.69)**		
ATBC	98	2.08 x 10^{1} (2.25)	<LOQ-3.54 x 10^{3}	2.30 x 10^{1}	6.95 (2.46)	<LOQ-1.72 x 10^{3}	8.64
DEHA	98	3.68 (2.83)	<LOQ-9.13 x 10^{2}	5.21	8.83 x 10^{-1} (3.88)	<LOQ-1.03 x 10^{2}	1.98
DEHTP	92	2.52 x 10^{2} (2.33)	<LOQ-1.26 x 10^{5}	3.48 x 10^{2}	8.33 x 10^{1} (2.79)	<LOQ-2.98 x 10^{3}	1.32 x 10^{2}
DINCH	9	4.80 x 10^{-2} (2.46)	<LOQ-9.59 x 10^{3}	<LOQ	2.65 x 10^{-4} (4.04)	<LOQ-1.26 x 10^{3}	<LOQ
TOTM	40	2.37 x 10^{-1} (2.26)	<LOQ-6.19 x 10^{1}	<LOQ	5.61 x 10^{-3} (4.53)	<LOQ-5.57	<LOQ
ΣNPPs		**3.89 x 10^{2} (1.64)**			**1.35 x 10^{2} (1.75)**		
Cd	19	1.50 x 10^{-1} (1.97)	<LOQ-8.47 x 10^{2}	<LOQ	3.94 x 10^{-3} (2.37)	<LOQ -8.92 x 10^{-3}	2.91 x 10^{-3}
Mn	58	2.42 x 10^{1} (2.59)	<LOQ-1.73 x 10^{4}	6.60 x 10^{1}	3.19 x 10^{-2} (2.18)	<LOQ -2.13 x 10^{-1}	3.09 x 10^{-2}
Cr	8	3.94 (2.66)	<LOQ-1.33 x 10^{3}	3.54	1.50 x 10^{-2} (1.25)	<LOQ -4.96 x 10^{-2}	1.45 x 10^{-2}
Pb	61	2.48 x 10^{1} (2.09)	<LOQ-1.54 x 10^{4}	7.25 x 10^{1}	3.29 x 10^{-2} (2.25)	<LOQ-3.77 x 10^{-1}	3.07 x 10^{-2}
As	57	2.90 (2.90)	<LOQ-3.94 x 10^{3}	2.48	2.77 x 10^{-3} (5.71)	2.91 x 10^{-4}-4.03 x 10^{-2}	1.24 x 10^{-3}
Ni	8	4.61 (2.29)	<LOQ-4.70 x 10^{2}	3.54 x 10^{1}	1.55 x 10^{-2} (1.29)	<LOQ-5.82 x 10^{-2}	1.45 x 10^{-2}
Hg	31	1.19 x 10^{-1} (1.65)	<LOQ-8.98 x 10^{1}	<LOQ	3.51 x 10^{-4} (1.73)	<LOQ-5.84 x 10^{-3}	2.91 x 10^{-4}
Heavy metals							

3.6. Correlation Analyses of Contaminants in ACCD

In general, most EDCs showed moderate positive correlations within the same chemical group (Table S7, S8, S9, and S10). TPhP and EHDPP (r=0.77), and DiBP and DEHP (r=0.74) showed strong positive correlations, whereas PHTHs and NPPs showed moderate positive correlations.

3.6.1 Between EDCs in SHD and ACCD

The Pearson correlation analysis of DEHTP in SHD and ACCD is shown in Figure 2. Of the 39 EDCs, concentrations of DEHTP in SHD and ACCD showed strong positive correlation (r=0.71), whereas all other compounds were insignificantly correlated.

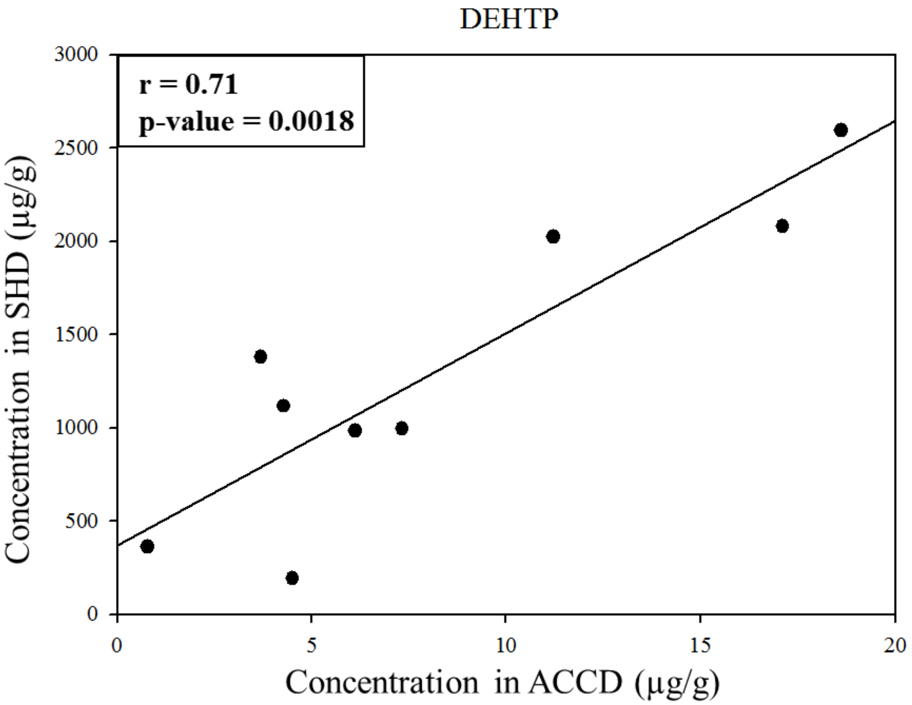

Figure 2. Result of Pearson correlation analysis between concentrations of DEHTP in SHD and ACCD.

3.7. Determinants in Association with Chemicals in ACCD

MLR models of housing/lifestyle factors affecting the concentrations of OPFRs, PHTHs, and NPPs are shown in Table 13, 14, and 15, respectively. In general, OPFRs, PHTHs, and NPPs showed significantly positive associations with the type and number of home appliances, and combustion activities. In particular, residences with >10 electronic appliances significantly elevated the levels of TCPP (57%) and BBzP (103%). For PHTHs and NPPs, home appliances bought after 2019 were in significant associations. The level of DiBP (-64%) significantly decreased in residences that bought dryers after 2019, whereas those of ATBC (169%) and DEHTP (286%) increased. In addition, usage of candles, diffusers, and air fresheners significantly elevated the levels of DnBP, DiBP, BBzP, BBzP and ATBC. However, the levels of most EDCs significantly decreased for ventilating >1.5 h/day, cleaning dust on electronic appliances, and either wet cleaning or dry mopping the floors.

Table 13. MLR models of housing/lifestyle factors associated with OPFRs in ACCD.

Variables		TCPP			TPhP			EHDPP		
Reference	**Subcategory**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**
	(Intercept)	1.01 (0.26)	<0.001	2.75	1.96 (0.27)	<0.001	7.10	1.83 (0.21)	<0.001	6.23
<10 electronic appliances[†]	vs.									
	10-13 electronic appliances	0.04 (0.25)	0.89	1.04						
	>13 electronic appliances	0.45 (0.26)	0.03[*]	1.57						
Cooking <1 time/day	vs.									
	2 times/day				0.44 (0.24)	0.07	1.55	0.50 (0.22)	0.02[*]	1.65
	>3 times/day				0.75 (0.26)	0.005[**]	2.12	0.48 (0.20)	0.02[*]	1.62
Ventilation <1.5 h/day	vs.									
	1.5-8 h/day	-0.23 (0.22)	0.29	0.79	0.11 (0.21)	0.26	1.12	0.03 (0.18)	0.88	1.03
	>8 h/day	-1.16 (0.52)	0.03[*]	0.31	-1.13 (0.51)	0.03[*]	0.32	-1.07 (0.42)	0.01[*]	0.34
Wet cleaning[‡] (no)	vs. yes	-0.42 (0.21)	0.04[*]	0.66	-0.39 (0.23)	0.07	0.68			
Dry mopping[§] (no)	vs. yes				-0.50 (0.25)	0.04[*]	0.61	-0.29 (0.18)	0.01[*]	0.75
Adj. R^2		0.12			0.14			0.13		

[†]: Electronic appliances are the total number of laundry appliances, kitchen appliances, and digital appliances in residence.
[‡]: Wet cleaning includes cleaning using wet mop cleaners and wet woolen rags.
[§]: Dry mopping includes cleaning using microfiber clothes and dry mops.
[*]: Factors with statistical significance ($p<0.05$).
[**]: Factors with statistical significance ($p<0.01$).

Table 14. MLR model of housing/lifestyle factors associated with PHTHs in ACCD.

Variables		DnBP			DiBP			BBzP			DEHP		
Reference	**Subcategory**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**
	(Intercept)	-0.48 (0.30)	0.11	0.62	1.19 (0.17)	<0.001	3.29	0.68 (0.26)	0.01	1.97	2.62 (0.15)	<0.001	13.74
<8 electronic appliances†	vs.												
	9-13 electronic appliances							0.08 (0.27)	0.16	1.08			
	>13 electronic appliances							0.71 (0.33)	0.03*	2.03			
2-3 kitchen appliances‡	vs.												
	4-5 kitchen appliances							0.35 (0.25)	0.11	1.42			
	>5 kitchen appliances							0.96 (0.42)	0.02*	2.61			
Dryers bought before 2019	vs. bought after 2019				-1.02 (0.54)	0.05	0.36						
Presence of smokers (no)	vs. yes	0.52 (0.25)	0.04*	1.68									
Candles used (no)	vs. yes	0.50 (0.23)	0.03*	1.65	0.33 (0.16)	0.05	1.39				0.25 (0.17)	0.06	1.28
Diffusers used (no)	vs. yes				0.31 (0.15)	0.05	1.36	0.59 (0.20)	0.004**	1.80	0.29 (0.16)	0.03*	1.34
Air fresheners used (no)	vs. yes	0.44 (0.23)	0.06	1.55	0.35 (0.16)	0.03*	1.42						
Ventilation <1.5 h/day§	vs.												
	1.5-8 h/day	-0.30 (0.62)	0.63	0.74				-0.12 (0.23)	0.61	0.89			
	>8 h/day	-0.56 (0.26)	0.03*	0.57				-0.96 (0.42)	0.02*	0.38			
Adj. R^2		0.11			0.09			0.16			0.21		

†: Electronic appliances are the total number of laundry appliances, kitchen appliances, and digital appliances in residence.
‡: Kitchen appliances are the total number of refrigerators, kimchi refrigerators, airfryers, microwaves, and ovens in residence.
§: Ventilation is the sum of natural ventilation frequency and mechanical ventilation frequency.
*: Factors with statistical significance ($p<0.05$).
**: Factors with statistical significance ($p<0.01$).

Table 15. MLR model of housing/lifestyle factors associated with NPPs in ACCD.

Variables		ATBC			DEHA			DEHTP		
Reference	**Subcategory**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**	**β (SE)**	**p-value**	**Exp (β)**
	(Intercept)	2.01 (0.21)	<0.001	7.46	0.79 (0.17)	<0.001	2.20	2.08 (0.17)	<0.001	8.00
1-2 digital appliances†	vs.									
	3-4 digital appliances							0.29 (0.25)	0.24	1.37
	>4 digital appliances							0.52 (0.22)	0.02*	1.68
Refrigerator bought before 2019	vs. bought after 2019				1.43 (0.49)	0.007**	4.18			
Microwaves bought before 2019	vs. bought after 2019				1.63 (0.52)	0.004**	5.10			
Washing machine bought before 2019	vs. bought after 2019							1.29 (0.61)	0.04*	3.63
Dryers bought before 2019	vs. bought after 2019	0.99 (0.53)	0.06	2.69				1.35 (0.59)	0.03*	3.86
Presence of smokers (no)	vs. yes	0.30 (0.20)	0.01*	1.35						
Diffusers used (no)	vs. yes	0.32 (0.18)	0.04*	1.38						
Ventilation <1.5 h/day‡	vs.									
	1.5-8 h/day	-0.38 (0.49)	0.44	0.68						
	>8 h/day	-0.47 (0.20)	0.02*	0.63						
Cleaning dust on electronic appliances (no)	vs. yes				-0.74 (0.30)	0.01*	0.48			
Wet cleaning§ (no)	vs. yes				-0.52 (0.27)	0.04*	0.59			
Adj. R^2			0.12			0.08			0.16	

†: Digital appliances are the total number of televisions, desktops, laptops, and printers in residence.
‡: Ventilation is the sum of natural ventilation frequency and mechanical ventilation frequency.
§: Wet cleaning includes cleaning using wet mop cleaners and wet woolen rags.
*: Factors with statistical significance ($p<0.05$).
**: Factors with statistical significance ($p<0.01$).

3.8. Estimation of Residential Intake

The estimates for infant's residential intake of EDCs in house dust via ingestion and inhalation are shown in Table 16 and 17, respectively. The intake of NPPs was significantly the highest, followed by PHTHs and OPFRs. The intake of DEHTP was significantly the highest among NPPs, whereas DEHP and EHDPP were the highest for PHTHs and OPFRs, respectively.

For all chemicals, ingestion intake was significantly higher than that by inhalation. However, the inhalation intakes for all chemicals were significantly higher via ACCD than SHD. The residential intakes of most chemicals via both inhalation and ingestion were significantly lower than the RfDs. However, 75^{th} and 95^{th} percentile ingestion intakes for DEHP (4.53×10^3 and 1.85×10^4 ng/kg/day, respectively) were much higher than the RfD (3.8×10^3 ng/kg/day).

Table 16. Estimated ingestion intake of EDCs in SHD.

Chemicals	RfD (ng/kg/day)[†]	SHD (ng/kg/day)		
		Ingestion		
		50th	75th	95th
TCEP	7.00×10^{3}	3.69	7.30	2.12×10^{1}
TPhP		6.60	1.06×10^{1}	2.90×10^{1}
EHDPP		7.70	1.59×10^{1}	1.23×10^{2}
ΣOPFRs		2.30×10^{1}	3.06×10^{1}	1.17×10^{2}
DnBP	1.00×10^{5}	8.91×10^{1}	1.93×10^{2}	5.96×10^{2}
DiBP		1.88×10^{1}	3.65×10^{1}	1.06×10^{2}
BBzP	2.00×10^{5}	5.80	1.72×10^{1}	2.92×10^{2}
DEHP	3.80×10^{3}	2.83×10^{3}	4.53×10^{3}	1.85×10^{4}
ΣPHTHs		3.10×10^{3}	4.59×10^{3}	1.77×10^{4}
ATBC		9.32×10^{1}	2.09×10^{2}	2.56×10^{3}
DEHA	6.00×10^{5}	6.04×10^{1}	1.07×10^{2}	3.68×10^{2}
DEHTP		8.36×10^{3}	1.52×10^{4}	3.68×10^{4}
ΣNPPs		9.12×10^{3}	1.51×10^{4}	3.81×10^{4}

[†]**:** The RfD values of chemicals were obtained from the EPA CompTox Chemicals Dashboard (https://comptox.epa.gov/dashboard).

Table 17. Estimated inhalation intake of EDCs in ACCD and SHD.

Chemicals	RfD (ng/kg/day)†	Inhalation ($PM_{2.5}$)					
		ACCD (ng/kg/day)‡			SHD (ng/kg/day)§		
		50th	75th	95th	50th	75th	95th
TCEP	7.00×10^{3}	2.02×10^{-1}	3.54×10^{-1}	1.65	3.79×10^{-5}	7.48×10^{-5}	2.18×10^{-4}
TPhP		3.44×10^{-1}	1.00	4.50	6.76×10^{-5}	1.08×10^{-4}	2.97×10^{-4}
EHDPP		2.26×10^{-1}	4.90×10^{-1}	2.49	7.89×10^{-5}	1.63×10^{-4}	1.26×10^{-3}
ΣOPFRs		8.85×10^{-1}	1.86	7.94	2.35×10^{-4}	3.14×10^{-4}	1.20×10^{-3}
DnBP	1.00×10^{5}	1.09×10^{-1}	3.93×10^{-1}	2.33	9.14×10^{-4}	1.98×10^{-3}	6.11×10^{-3}
DiBP		1.00×10^{-1}	3.40×10^{-1}	2.70	1.93×10^{-4}	3.74×10^{-4}	1.08×10^{-3}
BBzP	2.00×10^{5}	2.93×10^{-2}	1.12×10^{-1}	7.21×10^{-1}	5.94×10^{-5}	1.77×10^{-4}	3.00×10^{-3}
DEHP	3.80×10^{3}	4.39	1.16×10^{1}	1.11×10^{2}	2.90×10^{-2}	4.64×10^{-2}	1.90×10^{-1}
ΣPHTHs		4.87	1.55×10^{1}	1.19×10^{2}	3.18×10^{-2}	4.71×10^{-2}	1.81×10^{-1}
ATBC		2.67×10^{-1}	6.31×10^{-1}	5.57	9.55×10^{-4}	2.14×10^{-3}	2.62×10^{-2}
DEHA	6.00×10^{5}	5.71×10^{-2}	1.72×10^{-1}	1.35	6.19×10^{-4}	1.10×10^{-3}	3.78×10^{-3}
DEHTP		3.99	7.84	3.79×10^{1}	8.56×10^{-2}	1.56×10^{-1}	3.77×10^{-1}
ΣNPPs		5.46	9.16	4.01×10^{1}	9.35×10^{-2}	1.55×10^{-1}	3.90×10^{-1}

†**:** The RfD values of chemicals were obtained from the EPA CompTox Chemicals Dashboard (https://comptox.epa.gov/dashboard).
‡**:** The concentrations of contaminants in ACCD were used for estimating the inhalation intake as derived from Bi et al. (2018).
§**:** The concentrations of contaminants in SHD were used for estimating the inhalation intake as derived from Weiss et al. (2018).

4. Discussion

4.1. Contaminants in SHD

More than half of the target contaminants were detected in >90% of the SHD samples, indicating widespread contamination of residential environments. The detection rates for OPFRs in this study were similar to other studies (Chupeau et al., 2020; Lee et al., 2020). It was suggested that TEP, TCEP, TCPP, TPhP, and EHDPP were the major compounds used for industrial and commercial applications in Korea (Lee et al., 2020). In particular, TCPP and TCEP were detected in a wide array of mediums due to use in various PVC materials (Cischem, 2009).

Detection rates of NPPs were significantly higher than those of PHTHs. This could be from the increase in demand for NPPs as alternatives to PHTHs. PHTHs were the most widely used plasticizers for polyvinyl chloride (PVC) production until 1999 (Jamarani et al., 2018). Due to concerns on reproductive toxicities, DnBP, DEHP, BBzP, DiBP, and DiDP have been subject to restrictions by the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) (EC, 2011). In Korea, following the Enforcement Decree of the Environmental Health Act (No. 2020-43) and Enforcement Decree of the Special Act on the Safety of Children's Products (Legislation Act-13859), DEHP, BBzP, DiNP, DiDP, and DnOP have been under regulations (KFDA, 2020; KMOE, 2017). Consequently, the market shares of PHTHs decreased from 42% in 1999 to 10% in 2014, whereas those of NPP consumption increased, accounting for 40% of the EU plasticizer market in 2019 (ECPI, 2018; ECPI, 2019). High concentrations of ATBC, DEHA, DEHTP, DINCH, and TOTM were detected in house dusts collected from Belgium, Ireland, and Netherlands (Christia et al., 2019).

For OPFRs, the average concentrations of TCPP, TPhP, and EHDPP were the highest, and the levels were comparable to those measured in Europe (1.30-

4.40 µg/g, 0.37-0.61 µg/g, and 0.43-0.99 µg/g, respectively) and China (0.99-2.05 µg/g, <LOD-0.34 µg/g, and 0.38-0.62 µg/g, respectively) (Table S11; de la Torre et al., 2020; He et al., 2015; Wu et al., 2016). High levels of OPFRs could be from the global increase in consumption as alternatives to legacy FRs. Most widely used BFRs and polychlorinated biphenyls (PCBs) have been proven to be persistent and bio-accumulative, officially being labeled as persistent organic pollutants (POPs) by the United Nations Environment Programme (UNEP) (UNEP, 2009). Onwards, the production of PCBs and BDE mixtures had been forbidden and OPFRs emerged in replacement. Consumption of OPFRs in Korea increased approximately 5 times from 1996 to 2008, whereas that of BFRs decreased to 75% (Cischem, 2009). Among the OPFRs, TCPP, TPhP, and EHDPP could be used more commonly than other substances. TCPP and TPhP were typically applied in polyurethane foam used in upholstered furniture (Bastiaensen et al., 2019). EHDPP was mostly used in flexible PVC, rubber, paints, textiles, and adhesives (Zhao et al., 2019).

For PHTHs, the average concentrations of DEHP, DiNP, and DiDP were the highest and the levels were comparable to those measured in Sweden (218-949 µg/g, 6.5-20 µg/g, and 0.1-0.6 µg/g, respectively) and Ireland (24-254 µg/g, 62-121 µg/g, and 16-67 µg/g, respectively) (Table S12; Christia et al., 2019; Weiss et al., 2018). High concentrations of PHTHs in SHD could be indicating inadequate management status of regulated PHTHs. The total content of DEHP, DiNP, and DiDP in consumer products had been restricted to be under 0.1% as of 2017 in Korea (KFDA, 2020; KMOE, 2017). However, specific management standards are lacking and high levels of restricted PHTHs are continuously detected in various products. PHTHs detected in baby products and PVC materials in 2020 were up to 579 times higher than the acceptance criteria (Lee et al., 2021).

Among the three EDCs in SHD, concentrations of NPPs were significantly the highest. The average concentrations of NPPs were up to 4.5 times higher than those in other countries (Table S13). In particular, the average concentration of DEHTP was up to 32 times higher than that measured in Belgium (36±27 μg/g) and DINCH was more than 7 times higher than that measured in Netherlands (10±6.1 μg/g) (Christia et al., 2019). This could be from the difference in the sampling year, as Christia et al. (2019) had investigated houses in Belgium and Netherlands in 2017. DEHTP has been increasingly used in PVC products as in replacement for DEHP and the use of DINCH has substantially increased in a wide range of applications including toys, food packaging, vinyl floorings, and medical devices ever since (BASF, 2014; Silva et al., 2015). With increasing demand high concentrations of DEHTP and DINCH indoors were reported (Silva et al., 2013).

High concentrations of heavy metal elements were detected in all SHD samples. The average concentrations of Mn, Cr, and Ni were the highest in this study, and the levels were within the range of those reported in other studies (0.07-8500 μg/g) (Table S14). Heavy metals from outdoor sources may translocate into indoors. Heavy metal bearing particles were found to transport from outdoors to dwellings via ventilation and infiltration (Tong and Lam, 2000). According to Hassan. (2012), contribution of footsteps to Cd, Cr, Pb, and Ni in dusts on stairs or entry ways was significantly high. Mn, Pb, As, and Hg found in indoor dust were correlated with vehicle emissions (Al-madanat et al., 2017; Wiśniewska et al., 2017). Other sources suggested for Mn, Cr, Ni, and As were soil parent materials from lithogenic origins (Ali et al., 2016). On the other hand, cleaning products, cooking emissions, cigarette smoking, paint, and furnace were suggested as indoor sources for Pb, Cd, and Ni (Khoder et al., 2010). Together, heavy metals from outdoors and indoors could accumulate as SHD. Cd, Mn, Cr, Pb, As, Ni, and Hg were found in all house dust samples collected in Canada and China (Dingle et al., 2021; Rasmussen et al., 2001; Wan et al., 2016).

For house dust mite allergens, the detection rate and average concentration of Der f 1 were significantly higher than those of Der p 1. This was consistent with a study in Europe, where the detection rate of Der f 1 was significantly higher than that of Der p 1 in Europe (Zock et al., 2006). However, it was the opposite for United Kingdom, Belgium, and Spain, which was from the high humidity in those regions. The average concentrations of Der f 1 (0.01-231 µg/g) in other studies were also significantly higher than those of Der p 1 (0.14-30 µg/g) (Table S15). This could be from the high viability of Der f 1 to external stressors. Der f 1 is known to well adapt to fluctuating humidity, whereas Der p 1 dominates in continuously humid conditions (Arlian et al., 1999). In addition, house dust mites are poikilothermic and cannot regulate the internal body temperature (Verhoeff, 1994). The fluctuation of temperature could impact the house dust mites, but Der f 1 could resist to some extent. According to Zock et al. (2006), Der f 1 had higher resistance to drought and variations in temperature than Der p 1.

The average concentrations of house dust mites in this study were significantly lower than those in other studies. The average concentration of Der f 1 in this study was up to 110 times lower than that measured in Korea (10.2 µg/g; Nam et al., 2008) and that of Der p 1 was more than 3500 times lower than that measured in Spain (4.9 µg/g; Zock et al., 2006). This could be from the fluctuation in weather conditions during sample collection. The weather patterns during April and May of 2021 in Korea were different from the previous years. The temperature during April ranged from 8 to 18 ℃, and the days of precipitation during May were 14.5 days, which was 1.7 times higher compared to common years (KMA, 2021).

4.2. Correlations Between Contaminants in SHD

Among the EDCs, TPhP and EHDPP showed strong correlation. This was similar to other study that suggested strong correlation between TPhP and EHDPP (Lee et al., 2020). This could be an indication of a common source. TPhP and EHDPP have been suggested as the major additives used in polyurethane foam in furniture, textile, electronics, and automobile products (Brommer and Harrad, 2015; Van der Veen and de Boer, 2012). TPhP and EHDPP were the largest contributors to ΣOPFR concentrations in house dust (Lee et al., 2020). However, most EDCs and heavy metals showed little to no statistically significant correlations, which could be from the variations in the concentration profiles derived from multiple sources (Figure S1, S2, S3, and S4).

Moderate correlation between Der f 1 and Der p 1 was observed. Other studies have reported that the two species showed moderate (r=0.35-0.47) to weak (r=0.08-0.21), but positive correlations (Barnes et al., 2015; Gross et al., 2000; Van Strien et al., 2004; Zock et al., 2006). According to those studies, presence of one species do not enhance nor reduce the presence of other species as the two house dust mites do not compete. In addition, Barnes et al. (2015) suggested that the positive correlations could be an indication of conditions conducive to the growth of two species. House dust mites are known to flourish in homes as humidity and temperature are optimal, and human skin can provide constant food supply (Arlian et al., 1999). Levels of house dust mite allergens were significantly higher in the mattresses and sofas than other places inside the home, which could be from the abundant remnants of human flakes (Luczynska et al., 1998; Moscato et al., 2000).

Most chemicals from different groups were weakly correlated. Similarly, weak correlations between different groups of SVOCs were reported in a previous study (Bi et al., 2018). This could be from the different physicochemical properties of contaminants. The octanol-air partition coefficients are different by EDC groups. The log (K_{oa}) of OPFRs ranged from 8.20-11.3, whereas those of PHTHs were from 6.69-14.7, and those of NPPs were above 12.1, reaching up to 16.24

(Schossler et al., 2011). SVOCs with log (K_{oa}) >10 were expected to have substantial association with dust particles, since dust with less organic content and smaller size fractions absorbed more compounds (Liu and Folk, 2021). On the other hand, heavy metals are group of metals and metalloids with relatively high densities (>5g/cm^3) that eventually deposit on floors (Koller and Saleh, 2018). Levels of Cd, Pb, and Hg in air were lower than those accumulated on floors and surfaces (WHO, 2007). In addition, multiple sources of various chemicals co-exist in sresidential environment. OPFRs, PHTHs and NPPs have been found in polyurethane or polyester foam, and PVC covers of crib mattresses (Table S16; Boor et al., 2015). PHTHs and NPPs were detected in PVC floorings and non-PVC products such as glues, paints and cosmetics (Larsson et al., 2017). Higher concentrations of OPFRs and PHTHs were associated with more numbers of electronics (He et al., 2016). Ni, Cd, Pb, DMP, DEP, DEHP, BBzP, DnOP, and DiBP were detected in food packaging of either metal or plastic forms, such as coffee capsules (de Toni et al., 2017). TEP, TCEP, TCIPP, TDCIPP, TPHP, EHDPP, and TEHP were detected in canned fishes and Pb, Cd, Hg, As, Fe, Cu, and Zn were found in tuna cans (Novakov et al., 2017; Poma et al., 2018).

4.3. Determinants in Association with Contaminants in SHD

Housing and behavior related factors could significantly influence the levels of contaminants in SHD. The greatest degree of change for EDC levels in dust was associated with the type and number of electronic appliances, use of air fresheners or incenses, and fuel used for cooking, which was in agreement with other studies (Brommer and Harrad, 2015; Yang et al., 2020). Studies that have directly sampled SVOCs reported that OPFRs are employed as additives applied in polyurethane and polymers for use in furniture, electronics, and textiles, whereas PHTHs and NPPs are used as plasticizers and lubricants in vinyl, detergents, spray products, and insulation wires (US FDA, 2013; WHO, 2000). However, housing appliances bought after 2019 were found to significantly reduce the levels of PHTHs whereas elevating those of NPPs. This could be from the restriction of PHTHs including DnBP, DiNP, BBzP, and DEHP for use in electronics, in contrast to increase in NPPs as alternatives.

The levels of heavy metals in SHD were mainly associated with the type and number of electronic appliances and fuel used for cooking. In particular, refrigerators and printers bought before 2019 significantly elevated the levels of heavy metals in dust. This was similar to Cheng et al. (2018), where aged coverings, paints on electronic gadgets, and the type of fuel used for cooking were in strong associations with the levels of Cr, Cd, Pb, and Ni concentrations in dust. This could be from the deterioration and peeling off of scraps and paints from surfaces with time (Rasmussen et al., 2001; Tan et al., 2016). However, use of natural gas (62.5%) contributed more than electricity (12.5%) in Cheng et al. (2018), while the effect of fuel type was negligible in this study. Such could be from the difference in air circulation within indoors. Rasmussen et al. (2001) reported that the Pb and Hg loadings in dust were greater during electrical heating than gas or oil heating. Although the method of heating the house could affect the levels of heavy metals in dust, air circulation and management could also have an influence (Rasmussen et al., 2001).

House dust mite allergens were mainly associated with the number of residents and water penetration. This was in concordance with other studies that reported elevation of Der f 1 levels derived from human occupancy and humid conditions (Jarvis et al., 2007; Svennberg, 2005). The number of occupants and humidity can aid the growth of house dust mites as their food sources are skin scales, human dander, and appropriate humidity (Verhoeff, 1994). In addition, occupant's activities could influence the dynamics of dust, transporting house dust mite allergens throughout the indoors (Johansson et al., 2011). Perturbation of settled dust directly and indirectly relocated microbiota throughout the residential environment (Meadow et al., 2014). House dust mite pellets were found on airborne particles (6-20 μm) and were detected in air due to dust disturbing activities (Tovey et al., 1981).

Ventilating, vacuum cleaning, and wet cleaning or dry mopping the floors significantly decreased the levels of contaminants in dust. Cleaning is an effective way to reduce dust and indoor contaminants. Simply mopping the floors largely removed dust on floors and surfaces, and ventilating or vacuum cleaning effectively reduced the levels of dust (Roberts et al., 2009). However, for heavy metals in this study, natural ventilation significantly elevated the levels in dust, while the opposite was the case for mechanical ventilation. The major contributors to heavy metals in SHD are from external sources. Wind-blown dust from soil and roads were the main contributors of As, Cd, and Pb (Meyer et al., 1999). Homes with higher natural ventilation rates had higher levels of heavy metals in SHD (Tong and Lam, 2000). As house dust is a reservoir to various contaminants, reducing the levels in residential environments can be important for protecting the health of residents.

Although few housing and behavior related factors showed associations with contaminants in this study, identifying the precise source for contaminants in dust could be difficult due to the complexity of the indoor environment. Especially the complex dynamics of SVOCs could make it harder to trace direct sources. The transition from gas phase to particle phase was greater for SVOCs with MW higher than 250 g/mol (Xie et al., 2013). Except for few low MW compounds including TEP, DEP, and DMP, most compounds investigated in this study were > 250 g/mol (Blum et al., 2019; Kim et al., 2021; Wang et al., 2019). Mass transfer of SVOCs could redistribute the compounds from the original source to dust over time (Rudel et al., 2010). Therefore, further studies are required to verify the findings.

4.4. Chemicals in ACCD

In this study, mass per mass ratio was used to quantify the amount of chemicals in dust. Because ACCD samples were collected using thin HEPA filters in air cleaners, concentrations of chemicals were computed using μg/g and μg/cm^2 units. However, the time spent using air cleaners and air inflow settings in each home had not been investigated and uncertainty of mass per area unit remained. In Guo et al. (2020) that used HEPA filters for collecting airborne dust, the time spent using air purifiers and the flow rate settings were investigated. Other studies that used HVAC filters for sampling used μg/g units as the sampling duration was uncertain (Noris et al., 2009; Xu et al., 2015).

For ACCD, 10 chemicals were detected >90% of the samples, suggesting ubiquity of numerous EDCs in air. The high detection rates of EDCs could be from the increased consumption of plasticizers and FRs. Prohibition of halogenated flame retardants had increased the consumption of OPFRs (UNEP, 2009). Due to the regulations for DEHP, BBzP, DiNP, DiDP, and DnOP by the Korean Food and Drug Administration (KFDA) and the Korean Ministry of Environment (KMOE), use of NPPs as alternatives to PHTHs increased (KFDA, 2020; KMOE, 2017). However, regulated PHTHs were detected above the acceptance criteria in various consumer products in 2020, implying that numerous PHTHs are still in use (Lee et al., 2021).

The average concentrations of OPFRs and PHTHs were within the range of other studies that used HVAC filters for sampling (0.01-5190 μg/g and 5.49-6930 μg/g, respectively) (Bi et al., 2018; He et al., 2016; Xu et al., 2015). No studies to date sampled NPPs using filters and the levels were incomparable. The concentrations of OPFRs in ACCD in this study was up to 29 times higher than that in SHD. This was similar to Bi et al. (2018), where the average concentration of OPFRs in airborne dust (56.9 μg/g) was significantly higher than that in SHD (19.3 μg/g). This could be from the smaller size of particles captured in HEPA filters in air cleaners. Because the particle size distribution of ACCD was not determined in this study, the precise size fractions of the particles are unknown. However, airborne dust predominantly consists of fine particles with small portions of coarse particles entrained into air via resuspension of SHD, whereas SHD mainly consists of large particles between 86–685 μm (Gustafsson et al., 2018; Mukai et al., 2009). Considering that the SVOCs' mass transfer rates are higher in smaller particles due to larger surface areas and the fraction of organic matter increases with decrease in particle size, higher levels of SVOCs are expected in suspended particles (Liu et al., 2014). Concentrations of SVOCs in particles of respirable fractions (<5 μm) were significantly higher than those in larger particles (<75 μm) (Weiss et al., 2018).

All heavy metal elements were detected in <90% of the houses sampled. The average concentrations of heavy metals in this study were comparable to those (0.75-44.9 μg/g) in other study that used HVAC filters for sampling (Noris et al., 2009). Since Noris et al. (2009) sampled houses in proximity (<1.8 km) to highways, the results can be slightly higher than in this study. The average concentrations of most elements in ACCD were significantly lower than those measured in SHD, which could be from the high densities of heavy metals. Heavy metals have high densities >5 μg/cm^3 and substantial proportions of the suspended fractions could sink onto floors and accumulate (Lu et al., 2008). The opposite was the case in other study, where the levels of Cd, Mn, Cr, Pb, As, and Ni in suspended particles were significantly higher than those in SHD (Rasmussen et al., 2018). The dissimilarity could be from the sampling method as Rasmussen et al. (2018) used passive samplers with PTFE filters to collect $PM_{2.5}$ and PM_{10} samples for 5 consecutive days. In that study, the elevated elemental content in suspended fractions were explained by the resuspension of SHD alone. Significant correlations were found between elements in SHD and those in suspended particles (Rasmussen et al., 2018). However, HEPA filters in air cleaners were used to collect airborne dust for more than 1 year in this study.

4.5. Correlations Between Chemicals in ACCD

Strong positive correlations between TPhP and EHDPP, and DiBP and DEHP had been observed. This could be from the existence of a common source as chemicals are simultaneously used together. Co-use of chemicals from the same group have been reported in other studies. TPhP and EHDPP were detected in fats and oil products, grains and cheese products, food packaging, canned food, polyurethane foam in furniture, and electronic appliances (Poma et al., 2018; Lee et al., 2020). DiBP and DEHP are simultaneously used in polyurethane foams, plastic toys, PVC floorings, wall paintings, electronic devices, and food wraps (Boor et al., 2015; Larsson et al., 2017).

Moderate correlations were found between chemicals from different groups. Various chemicals are applied together for different purposes. OPFRs are widely used as flame retardants for prevention of fire, but are also utilized as plasticizers, anti-foams, and polishing agents (Pantelaki and Voutsa, 2019). PHTHs and NPPs are used as plasticizers to help dissolve other materials and as solvents in cosmetic products (Ventrice et al., 2013). OPFRs, PHTHs, and NPPs were found in mattress covers and polyurethane foams (Boor et al., 2015). Because multiple sources exist in residential environments, the correlations between chemicals could have been relatively weak.

In contrast to ACCD results, most EDCs in SHD showed weak or insignificant correlations. Similar disparities were observed in Bi et al. (2018). In that study the levels of OPFRs and PHTHs in SHD fluctuated by variation in temperature whereas those in airborne dust were uniform. Similarly, in this study, contaminants in SHD showed great variations in the concentration profiles (Figure S1, S2, S3, and S4), whereas the concentrations of chemicals in ACCD were skewed to the right and uniform throughout (Figure S5, S6, S7). The disparity between SHD and ACCD could be from the difference in sampling duration and particle size. In Bi et al. (2018), the sampling duration of airborne dust was longer (>1 month) and the particles were smaller than those of SHD. This allowed SVOCs to reach their equilibrium concentrations. In contrast, the duration of indoor residence for SHD may not have been sufficient for SVOCs to equilibrate between particle to gas phase (Bi et al., 2018). Therefore, sorption kinetics could have directly affected the SVOC concentrations in SHD (Edwards et al., 1998). Likewise, the sampling duration was longer (>1 year) in this study. The size fractions of the ACCD were not investigated in this study, but airborne dust predominantly consist of small particles, typically <15 μm (Gustafsson et al., 2018).

4.5.1. Between EDCs in SHD and ACCD

Significantly strong correlation between DEHTP in SHD and ACCD was observed, whereas all other compounds were not correlated. Similarly, other studies reported insignificant or weak correlations between SHD and airborne dust for OPFRs and PHTHs (Bergh et al., 2011; Bi et al., 2018). However, in Bergh et al. (2010), TBP, TCEP, and TCPP in SHD and airborne dust were moderately correlated, whereas TCPP in Bi et al. (2018) was moderately correlated. The difference with this study could be from the sampling duration, since air sampling in Bergh et al. (2011) (8 h) and Bi et al. (2018) (>1 month) were much shorter than in this study (>1 year). Cao et al. (2017) reported that the airborne particle's absorption of SVOCs in the boundary layer adjacent to the source surface increased with higher gas phase SVOCs concentrations. In this study, log (K_{oa}) and MW of OPFRs were the lowest among the three EDC groups, whereas those of NPPs were the highest. Therefore, OPFRs and few PHTHs including DMP, DEP, and DBP were expected to show correlations between SHD and ACCD, but not NPPs. However, because the sorption equilibrium between the gas and particle phase occurs at faster rates for compounds with low MW, DEHTP, but not OPFRs might be strongly correlated between SHD and ACCD in this study (Marklund et al., 2005). As the saturation vapor pressure decreases with increase in K_{oa} and MW, decreasing the desorption from particle phase, phase transition is slow for NPPs (Lutz et al., 2019). In realistic indoor environments, it could be difficult for SVOCs to attain equilibrium partition as the time required could be longer than the residence time of airborne particles. However, the sampling periods for ACCD was long in this study and DEHTP could have been in equilibrium state. On the other hand, OPFRs in airborne dust could have migrated from ACCD. Liu and Folk (2017) observed OPFRs in dust particles being re-emitted as gas phase. In that study, the test duration was more than 21 days and compounds were assumed to have reached equilibrium. However, OPFRs were re-emitted after removal of the source materials. Similarly, in this study, because of the frequent migrations from mediums to mediums, concentrations of OPFRs in SHD and ACCD could have fluctuated.

4.6. Determinants in Association with Chemicals in ACCD

The levels of chemicals in air could be significantly affected by housing and behavior related factors. The greatest degree of change for EDC levels in dust was associated with the type and number of electronic appliances, use of air fresheners or incenses, and indoor combustion activities. This was similar to other studies that reported strong relationship of OPFRs with the type and number of electronic appliances, and that of PHTHs and NPPs with polyurethane foams, electronic appliances, incenses, and cigarettes (Bi et al., 2018; Kolarik et al., 2008; Lee et al., 2020; Neamtiu et al., 2016). In particular, electronic appliances bought after 2019 significantly increased the levels of NPPs, whereas reducing those of PHTHs. This could be from the regulation of PHTHs in electronic appliances as of 2019, consequently increasing the use of NPPs as alternatives (KFDA, 2020). While the market shares of PHTHs decreased from by 32% in 15 years, NPP consumption increased, taking up to 40% of the EU plasticizer market in 2019 (ECPI, 2018; ECPI, 2019).

Ventilating, wet cleaning the floors, and cleaning electronic appliances significantly decreased the levels of contaminants in ACCD. Roberts et al. (2009) suggested that ventilating or mopping the floors could remove substantial amount of contaminants in air (Roberts et al., 2009). In addition, cleaning dust on electronic appliances could have reduced the levels of chemicals in ACCD as they are the direct sources of EDCs. Since residential environment is a mixture of various chemicals that can persistently influence residents, cleaning is essential to reduce the levels of chemicals.

Most factors in association with contaminants in ACCD and SHD were similar, but the presence of smokers did not show significant associations in SHD. This could be from the difference in the number of smokers who had smoked indoors within 1 month. For ACCD collected houses, 34 out of 120 participants were smokers, whereas it was 18 out of 106 participants for SHD collected houses. Among the smoking participants from ACCD collected houses, about 82% had smoked indoors within 1 month, whereas it was only 11% for SHD collected houses. Cigarette smoke contains more than 7,000 chemicals, in which more than 70 of them are known to be carcinogenic and can function as endocrine disruptors (US FDA, 2020). As smoking can induce toxic chemicals, residents should refrain from smoking indoors.

Associations of housing products and behavioral factors with numerous EDCs in both SHD and ACCD were observed in this study. Since people spend the majority of time indoors, chronic exposure to pollutants in house dust can occur. Therefore, adequate measures are required to reduce the levels of contaminants in residential indoors.

4.7. Residential Intake by Different Routes

Infant's residential intake of chemicals via ingestion was significantly higher than that by inhalation, suggesting that ingestion could be the major exposure route for contaminants in dust. This was similar to Bi et al. (2018), where intake of PHTHs and OPFRs by ingestion was significantly higher than that by inhalation. In Weiss et al. (2018), ingestion was the major contributor to daily intake of NPPs in dust. This could be attributable to the amount of dust entering the body by different exposure routes. The amount of dust ingested was greater than that inhaled in this study. It was estimated that infants would inhale 0.17 mg/day of respirable dust, which was significantly lower than the dust ingestion rate of 100 mg/day. According to Roberts et al. (2009), ingestion was the primary route of exposure for infants as they are in close contact with the floor and continuously exhibit mouthing of dust residues on hands. Luby et al. (2005) suggested that children could ingest significant amount of dust by sucking fingers and non-food items.

The estimated inhalation intake for most chemicals was significantly higher using ACCD than SHD. Gustafsson et al. (2018) and Miller et al. (1979) have underlined that airborne particles are typically <15 μm, where particles <5 μm accounted for 77% of the alveolar deposition. In consideration, the concentrations of chemicals in both ACCD and SHD were used for estimating inhalation intake in this study, as derived from Bi et al. (2018) and Weiss et al. (2018). In Bi et al. (2018), the size distribution of dust captured in HVAC filter was determined. In that study, concentrations of contaminants in HVAC captured dust were used for estimating the daily inhalation intake, assuming that airborne particles of small size would enter our body via inhalation. On the other hand, Weiss et al. (2018) assumed that settled dust below 5 μm could resuspend in air. Thus, the concentrations of chemicals in SHD were used in that study. In this study, the size fraction of SHD was not quantitatively assessed. Therefore, the amount of resuspendable SHD was estimated by multiplying 0.6% to inhalation rate of dust, assuming that small portions of SHD particles would be in the respirable particle fractions (Gustafsson et al., 2018). As a result, inhalation intakes for most chemicals in ACCD were significantly higher than those in SHD due to higher concentrations and inhalation rate of dust. However, the feasibility of such approaches contain few limitations. First, ACCD may not only contain airborne particles, but also resuspended SHD. Therefore, directly applying the concentrations of chemicals in ACCD may engender inaccuracies. Second, adsorption partitioning of chemicals could vary by particle size fractions. Higher concentrations of SVOCs were found in respirable (<5 μm) dust fractions than in larger (<75 μm) particles (Weiss et al., 2018). However, ACCD includes small portions of coarse to bulk sized particles (Mukai et al., 2009). Hence, assuming that ACCD consists mainly of respirable particles and estimating inhalation intake using $PM_{2.5}$ concentrations could lead to uncertainties. As means of assessments for estimating inhalation intake of chemicals in dust unto date contain uncertainties, more integrative studies on the quantification of exposure to contaminants in house dust are required in the future.

While intake of most chemicals were below the RfDs, the 95^{th} percentile ingestion intake of DEHP was much higher than the RfD value. This was similar to Bekö et al. (2013), where children's daily intake of DEHP by dust ingestion exceeded the RfD. However, because high exposure scenario was applied in this study, this level could have been overestimated. Despite the possibility for overestimation, DEHP could be toxic even at low levels of exposure, associated with reproductive and developmental toxicity in mammals (Yin et al., 2018). Therefore, precautions are needed to lower the levels of exposure.

Among the 10 EDCs investigated in this study, EPA CompTox Chemicals Dashboard provided RfD values for 5 chemicals based on single major exposure route. However, health effects from intake of chemicals may not only be related to the amount, but also to which substance enters through which route (Liu et al., 2017). Chemicals without RfDs are uncertain of their health effects. Therefore, consecutive researches are required to update hazard and toxicity information of various chemicals.

5. Conclusions

In this study, EDCs, heavy metals, and house dust mite allergens in SHD and ACCD in residential indoors were comprehensively assessed and infant's residential intake of contaminants in house dust was evaluated.

More than half of the contaminants in SHD and 10 EDCs in ACCD were detected in >90% of samples, indicating ubiquity of contaminants in residential environments. NPPs were the most frequently detected compounds with the highest concentrations in SHD, whereas those of PHTHs were the highest in ACCD, which could be from the different physicochemical properties of the SVOCs. High concentrations of Cd, Mn, Cr, Pb, As, Ni, and Hg elements were detected in all SHD samples, whereas those in ACCD were lower with significantly low detection rates. The detection rate and concentration of Der f 1 in bedding dust were significantly higher than those of Der p 1.

TPhP and EHDPP, and DiBP and DEHP showed strong correlations (r>0.7), suggesting occurrence from a common source. The concentrations of EDCs in both ACCD and SHD were largely affected by the type and number of electronics, air fresheners and incenses used, whereas heavy metals were in association with the type and number of electronics and fuel used for cooking. Der f 1 was related to the number of occupants and water penetration. However, ventilating >1.5 h/day, vacuum cleaning >4-7 times/week, and either wet cleaning or dry mopping the floors significantly lowered the levels of contaminants in dust. As various housing products and occupant's activities can induce numerous contaminants indoors, residents should choose items acquainted with awareness.

Infant's residential intake of most chemicals were significantly higher via ingestion of dust than inhalation, indicating that ingestion could be the major exposure route for infants. In addition, inhalation intake using ACCD was significantly higher than that by SHD. However, as adsorption of chemicals can differ by particle size, more integrative studies on the quantification of residential intake are needed in the future. Although residential intake of most chemicals were below RfDs in this study, many contaminants in house dust are unknown of their health effects with chronic exposure. Thus, adequate measures are necessary to reduce the levels of contaminants in house dust.

6. References

Ali MH, Mustafa ARA, El-Sheikh AA. Geochemistry and spatial distribution of selected heavy metals in surface soil of Sohag, Egypt: a multivariate statistical and GIS approach. Environ Earth Sci. 2016;75(18):1-17. https://doi.org/10.1007/s12665-016-6047-x

Al-madanat O, Jiries A, Batarseh M, Al-nasir F. Indoor and outdoor pollution with heavy metals in Al-Karak city, Jordan. J Int Environ Appl Sci. 2017;12(2):131-139. https://dergipark.org.tr/tr/pub/jieas/issue/40262/480192

Arlian LG, Neal JS, Vyszenski-Moher DAL. Reducing relative humidity to control the house dust mite Dermatophagoides farinae. J Allergy Clin Immunol. 1999;104(4 I):852-856. https://doi.org/10.1016/S0091-6749(99)70298-8

Barnes CS, Pacheco F, Portnoy JM. Relationship of Der f1 and Der p1 levels in house dust in the midwestern US. J Allergy Clin Immunol. 2016;137(2):AB28. https://doi.org/10.1016/j.jaci.2015.12.092

Badische Anilin und Soda Fabrik (BASF). BASF doubles production capacity of Hexamoll DINCH to 200,000 metric tons 2014. https://www.basf.com/ru/ru/media/news-releases/2014/05/p-14-231.html. Accessed November 02, 2021

Bastiaensen M, Ait Bamai Y, Araki A, et al. Biomonitoring of organophosphate flame retardants and plasticizers in children: Associations with house dust and housing characteristics in Japan. Environ Res. 2019;172:543-551. https://doi.org/10.1016/j.envres.2019.02.045

Bekö G, Weschler CJ, Langer S, Callesen M, Toftum J, Clausen G. Children's phthalate intakes and resultant cumulative exposures estimated from urine compared with estimates from dust ingestion, inhalation and dermal absorption in their homes and daycare centers. PLoS One. 2013;8(4). https://doi.org/10.1371/journal.pone.0062442

Bergh C, Torgrip R, Emenius G, Östman C. Organophosphate and phthalate esters in air and settled dust - a multi-location indoor study. Indoor Air. 2011;21(1):67-76. https://doi.org/10.1111/j.1600-0668.2010.00684.x

Bi C, Maestre JP, Li H, et al. Phthalates and organophosphates in settled dust and HVAC filter dust of US low-income homes: Association with season, building characteristics, and childhood asthma. Environ Int. 2018;121:916-930. https://doi.org/10.1016/j.envint.2018.09.013

Blanchard O, Glorennec P, Mercier F, et al. Semivolatile organic compounds in indoor air and settled dust in 30 French dwellings. Environ Sci Technol. 2014;48:3959–3969. https://doi.org/10.1021/es405269q

Blum A, Behl M, Birnbaum LS, et al. Organophosphate ester flame retardants: Are they a regrettable substitution for polybrominated diphenyl ethers? Environ Sci Technol Lett. 2019;6(11):638-649. https://doi.org/10.1021/acs.estlett.9b00582

Boor BE, Liang Y, Crain NE, Järnström H, Novoselac A, Xu Y. Identification of phthalate and alternative plasticizers, flame retardants, and unreacted isocyanates in infant crib mattress covers and foam. Environ Sci Technol Lett. 2015;2(4):89-94. https://doi.org/10.1021/acs.estlett.5b00039

Brommer S, Harrad S. Sources and human exposure implications of concentrations of organophosphate flame retardants in dust from UK cars, classrooms, living rooms, and offices. Environ Int. 2015;83:202-207. https://doi.org/10.1016/j.envint.2015.07.002

Cao J, Liu C, Zhang Y. Influence of airborne particles on convective mass transfer of SVOCs on flat surfaces: Novel insight and estimation formula. Int J Heat Mass Transf. 2017;115:127-136. https://doi.org/10.1016/j.ijheatmasstransfer.2017.07.024

Cequier E, Ionas AC, Covaci A, Marcé RM, Becher G, Thomsen C. Occurrence of a broad range of legacy and emerging flame retardants in indoor environments in Norway. Environ Sci Technol. 2014;48:6827–6835. https://doi.org/10.1021/es500516u

Chen TB, Zheng YM, Lei M, et al. Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China. Chemosphere. 2005;60:542–551. https://doi.org/10.1016/j.chemosphere.2004.12.072

Cheng Z, Chen LJ, Li HH, et al. Characteristics and health risk assessment of heavy metals exposure via household dust from urban area in Chengdu, China. Sci Total Environ. 2018;619–620:621–629.

https://doi.org/10.1016/j.scitotenv.2017.11.144

Christia C, Poma G, Harrad S, et al. Occurrence of legacy and alternative plasticizers in indoor dust from various EU countries and implications for human exposure via dust ingestion and dermal absorption. Environ Res. 2019;171:204-212. https://doi.org/10.1016/j.envres.2018.11.034

Chupeau Z, Bonvallot N, Mercier F, Bot BL, Chevrier C, Glorennec P. Organophosphorus flame retardants: A global review of indoor contamination and human exposure in Europe and epidemiological evidence. Int J Environ Res Public Heal. 2020;17(18):1-24. https://doi.org/10.3390/ijerph17186713

Cischem Ltd. Korea. Report on the recent domestic and foreign market and environmental regulation of flame retardants 2009. https://pdf4pro.com/view/183-flame-retardants-3544b4.html Accessed November 15, 2021

Conner TL, Norris GA, Landis MS, Williams RW. Individual particle analysis of indoor, outdoor, and community samples from the 1998 Baltimore particulate matter study. Atmos Environ. 2001;35:3935–3946. https://doi.org/10.1016/S1352-2310(01)00191-1

de la Torre A, Navarro I, Sanz P, de los Ángeles Martínez M. Organophosphate compounds, polybrominated diphenyl ethers and novel brominated flame retardants in European indoor house dust: Use, evidence for replacements and assessment of human exposure. J Hazard Mater. 2020;382:121009. https://doi.org/10.1016/j.jhazmat.2019.121009

de Toni L, Tisato F, Seraglia R, et al. Phthalates and heavy metals as endocrine disruptors in food: A study on pre-packed coffee products. Toxicol Reports. 2017;4:234-239. https://doi.org/10.1016/j.toxrep.2017.05.004

Dingle JH, Kohl L, Khan N, et al. Sources and composition of metals in indoor house dust in a mid-size Canadian city. Environ Pollut. 2021;289:117867. https://doi.org/10.1016/j.envpol.2021.117867

D'Hollander W, Roosens L, Covaci A, et al. Brominated flame retardants and perfluorinated compounds in indoor dust from homes and offices in Flanders, Belgium. Chemosphere. 2010;81:478–487. https://doi.org/10.1016/j.chemosphere.2010.07.043

Duffus JH. Heavy metals, a meaningless term? (IUPAC Technical Report). Pure and Applied Chemistry. 2002;74: 793-807. https://doi.org/10.1351/pac200274050793

European Commission (EC). Commission regulation (EU) No 143/2011 of 17 February 2011. Amending annex XIV to regulation (EC) No 1907/2006 of the European parliament and of the council on registration, evaluation, authorisation and restriction of chemicals (REACH) 2011. https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:044:0002:0006:en:PDF Accessed November 15, 2021

European Council for Plasticisers and Intermediates (ECPI). Plasticisers and flexible PVC 2018. https://www.plasticisers.org/wp-content/uploads/2018/10/ECPI_proposal_V19b_15022016.pdf Accessed November 15, 2021

European Council for Plasticisers and Intermediates (ECPI). Focus on plasticisers 2019. https://www.plasticisers.org/wp-content/uploads/2019/01/PLASTICISERS_LEAFLET_UPDATE_15012019_for_REPRINT_2019.pdf Accessed November 15, 2021

Edwards RD, Yurkow EJ, Lioy PJ. Seasonal deposition of house dusts onto household surfaces. Sci Total Environ. 1998;224:69-80. https://doi.org/10.1016/S0048-9697(98)00348-9

Flame retardants-online. Global flame retardants market by chemistry 2013. https://www.flameretardants-online.com/flame-retardants/market Accessed November 15, 2021

Fujimura KE, Johnson CC, Ownby DR, et al. Man’s best friend? The effect of pet ownership on house dust microbial communities. J Allergy Clin Immunol. 2010;126(2):8-13. https://doi.org/10.1016/j.jaci.2010.05.042

Genchi G, Carocci A, Lauria G, Sinicropi MS, Catalano A. Nickel: Human health and environmental toxicology. Int J Environ Res Public Heal. 2020;17(3). https://doi.org/10.3390/ijerph17030679

Gross I, Heinrich J, Fahlbusch B, Jäger L, Bischof W, Wichmann HE. Indoor determinants of Der p 1 and Der f 1 concentrations in house dust are different. Clin Exp Allergy. 2000;30(3):376-382. https://doi.org/10.1046/j.1365-2222.2000.00780.x

Guo J, Xiong Y, Kang T, Xiang Z, Qin C. Bacterial community analysis of floor dust and HEPA filters in air purifiers used in office rooms in ILAS, Beijing. Sci Rep. 2020;10(1):1-11. https://doi.org/10.1038/s41598-020-63543-1

Gustafsson Å, Krais AM, Gorzsás A, Lundh T, Gerde P. Isolation and characterization of a respirable particle fraction from residential house dust. Environ Res. 2018;161:284-290. https://doi.org/10.1016/j.envres.2017.10.049

Hammel SC, Levasseur JL, Hoffman K, et al. Children's exposure to phthalates and non-phthalate plasticizers in the home: The TESIE study. Environ Int. 2019;132:105061. https://doi.org/10.1016/j.envint.2019.105061

Hassan SKM. Metal concentrations and distribution in the household, stairs and entryway dust of some Egyptian homes. Atmos Environ. 2012;54:207-215. https://doi.org/10.1016/j.atmosenv.2012.02.013

He R, Li Y, Xiang P, et al. Organophosphorus flame retardants and phthalate esters in indoor dust from different microenvironments: Bioaccessibility and risk assessment. Chemosphere. 2016;150:528-535. https://doi.org/10.1016/j.chemosphere.2015.10.087

Innopolis Korea. Global market of household air purifiers 2021. file:///C:/Users/user/Google%20Drive/62.%20%EA%B0%80%EC%A0%95%EC%9A%A9%20%EA%B3%B5%EA%B8%B0%EC%B2%AD%EC%A0%95%EA%B8%B0%20%EC%8B%9C%EC%9E%A5%20(1).pdf. Accessed November 15, 2021

International Organization for Standardization (ISO). Air quality - particle size fraction definitions for health-related sampling 1995. ISO Standard 7708. ISO, Geneva. https://www.iso.org/standard/14534.html Accessed November 15, 2021

International Union of Pure and Applied Chemistry (IUPAC). Glossary of atmospheric chemistry terms. Pure and Applied Chemistry. 1990;62(11):2167-2219. http://publications.iupac.org/pac/1990/pdf/6211x2167.pdf

Jamarani R, Erythropel HC, Nicell JA, Leask RL, Marić M. How green is your plasticizer? Polymers (Basel). 2018;10(8):1-17. https://doi.org/10.3390/polym10080834

Jarvis D, Zock JP, Heinrich J, et al. Cat and dust mite allergen levels, specific IgG and IgG4, and respiratory symptoms in adults. J Allergy Clin Immunol. 2007;119(3):697-704. https://doi.org/10.1016/j.jaci.2006.10.042

Johansson E, Vesper S, Levin L, Lemasters G, Grinshpun S, Reponen T. Streptomycetes in house dust: Associations with housing characteristics and endotoxin. Indoor Air. 2011;21(4):300-310. https://doi.org/10.1111/j.1600-0668.2010.00702.x

Khoder MI, Hassan SK, El-Abssawy AA. An evaluation of loading rate of dust, Pb, Cd, and Ni and metals mass concentration in the settled surface dust in domestic houses and factors affecting them. Indoor Built Environ. 2010;19(3):391-399. https://doi.org/10.1177/1420326X10367284

Kim KH, Kabir E, Jahan SA. A review on the distribution of Hg in the environment and its human health impacts. J Hazard Mater. 2016;306:376-385. https://doi.org/10.1016/j.jhazmat.2015.11.031

Kim SH, Park DJ, Byun HJ, et al. House dust mites and associated environmental factors in homes of atopic children: A case-control study. Korean J Environ Heal Sci. 2012;38(3):204-212. https://doi.org/10.5668/JEHS.2012.38.3.204

Kim Y, Kim S, Liao C, Moon HB. Severe contamination and time trend of legacy and alternative plasticizers in a highly industrialized lake associated with regulations and coastal development. Mar Pollut Bull. 2021;171:112787. https://doi.org/10.1016/j.marpolbul.2021.112787

Kolarik B, Bornehag CG, Naydenov K, Sundell J, Stavova P, Nielsen OF. The concentrations of phthalates in settled dust in Bulgarian homes in relation to building characteristic and cleaning habits in the family. Atmos Environ. 2008;42:8553–8559. https://doi.org/10.1016/j.atmosenv.2008.08.028

Koller M, Saleh MH. Introductory chapter: Introducing heavy metals. IntechOpen. 2018;(6). https://www.intechopen.com/chapters/59857

Korea Consumer Agency (KCA). Comparison of energy cost by home appliance efficiency 2021. file:///C:/Users/user/Google%20Drive/%EA%B0%80%EC%A0%84%EC%A0%9C%ED%92%88+%ED%9A%A8%EC%9C%A8%EB%93%B1%EA%B8%89%EC%97%90+%EB%94%B0%EB%A5%B8+%EC%97%90%EB%84%88%EC%A7%80%EB%B9%84%EC%9A%A9+%EB%B9%84%EA%

B5%90%EC%A1%B0%EC%82%AC+%EA%B2%B0%EA%B3%BC.pdf. Accessed November 15, 2021

Korea Meteorological Administration (KMA). Past observations-daily climate data 2021. https://www.weather.go.kr/w/obs-climate/land/past-obs/obs-by-day.do. Accessed November 15, 2021

Korean Ministry of Environment (KMOE). Regulations on restrictions on the use of environmentally harmful factors for children's products 2017. http://www.law.go.kr/admRulInfoP.do?admRulSeq=2100000061809#J1835732 Accessed November 15, 2021

Korean Ministry of Food and Drug Safety (KFDA). Ministry of Food and Drug Safety Notice No. 2020-43. Food Utensils, Containers, and Packaging Regulations 2020. https://www.mfds.go.kr/brd/m_207/view.do?seq=14529 Accessed November 15, 2021

Lai ACK, Tian Y, Tsoi JYL, Ferro AR. Experimental study of the effect of shoes on particle resuspension from indoor flooring materials. Build. Environ. 2017;118:251–258. https://doi.org/10.1016/j.buildenv.2017.02.024

Larsson K, Lindh CH, Jönsson BA, et al. Phthalates, non-phthalate plasticizers and bisphenols in Swedish preschool dust in relation to children's exposure. Environ Int. 2017;102:114-124. https://doi.org/10.1016/j.envint.2017.02.006

Lee HK, Kang H, Lee S, Kim S, Choi K, Moon HB. Human exposure to legacy and emerging flame retardants in indoor dust: A multiple-exposure assessment of PBDEs. Sci Total Environ. 2020;719:137386. https://doi.org/10.1016/j.scitotenv.2020.137386

Lee I, Ra J, Ji K. Regulation of phthalates and their alternatives in children's products and their toxicity data. J Environ Heal Sci. 2021;47:1-19. https://doi.org/10.5668/JEHS.2021.47.1.1

Li H, Qian X, Wang Q. Heavy metals in atmospheric particulate matter: A comprehensive understanding is needed for monitoring and risk mitigation. Environ Sci Technol. 2013;47:13210–13211. https://doi.org/10.1021/es404751a

Lind P. Purification and partial characterization of two major allergens from the house dust mite Dermatophagoides pteronyssinus. J Allergy Clin Immunol. 1985;76(5):753-761. https://doi.org/10.1016/0091-6749(85)90682-7

Lioy PJ, Freeman NCG, Millette JR. Dust: A metric for use in residential and building exposure assessment and source characterization. Environ Heal Perspect. 2002;110(10):969-983. https://doi.org/10.1289/ehp.02110969

Lintner TJ, Brame KA. The effects of season, climate, and air-conditioning on the prevalence of Dermatophagoides mite allergens in household dust. J Allergy Clin Immunol. 1993;91(4):862-867. https://doi.org/10.1016/0091-6749(93)90343-E

Liu C, Zhang Y, Weschler CJ. The impact of mass transfer limitations on size distributions of particle associated SVOCs in outdoor and indoor environments. Sci Total Environ. 2014;497-498:401-411. https://doi.org/10.1016/j.scitotenv.2014.07.095

Liu C, Zhang Y, Weschler CJ. Exposure to SVOCs from inhaled particles: Impact of desorption. Environ Sci Technol. 2017;51:6220–6228. https://doi.org/10.1021/acs.est.6b05864

Liu X, Folk E. Sorption and migration of organophosphate flame retardants between sources and settled dust. Chemosphere. 2021;278:130415. https://doi.org/10.1016/j.chemosphere.2021.130415

Lu WM, Tung KL, Pan CH, Hwang KJ. The effect of particle sedimentation on gravity filtration. Sep Sci Technol. 1998;33:1723–1746. https://doi.org/10.1080/01496399808545902

Luby SP, Agboatwalla M, Feikin DR, et al. Effect of handwashing on child health: A randomised controlled trial. Lancet. 2005;366(9481):225-233. https://doi.org/10.1016/S0140-6736(05)66912-7

Luczynska C, Sterne J, Bond J, Azima H, Burney P. Indoor factors associated with concentrations of house dust mite allergen, Der p 1, in a random sample of houses in Norwich, UK. Clin Exp Allergy. 1998;28(10):1201-1209. https://doi.org/10.1046/j.1365-2222.1998.00410.x

Lutz A, Mohr C, Le Breton M, et al. Gas to particle partitioning of organic acids in the boreal atmosphere. ACS Earth Sp Chem. 2019;3(7):1279-1287. https://doi.org/10.1021/acsearthspacechem.9b00041

Markets and market. Non-phthalate plasticizers market by type (adipates, trimellitates, benzoates, epoxies, and others), application (flooring & wall coverings, wires & cables, films & sheets, coated fabrics, consumer goods), and region - global forecast to 2025, 2021. https://www.marketsandmarkets.com/Market-Reports/non-phthalate-plasticizer-market-255784623.html?gclid=CjwKCAjwy7CKBhBMEiwA0Eb7akr8aMTo3-VWeJMiJT0Uk7TQ6xxPVyrPLVL-A8xr-W4iY5D_WYrNJxoCVtUQAvD_BwE. Accessed November 15, 2021

Marklund A, Andersson B, Haglund P. Organophosphorus flame retardants and plasticizers in air from various indoor environments. J Environ Monit. 2005;7(8):814-819. https://doi.org/10.1039/b505587c

Meadow JF, Altrichter AE, Kembel SW, et al. Indoor airborne bacterial communities are influenced by ventilation, occupancy, and outdoor air source. Indoor Air. 2014;24(1):41-48. https://doi.org/10.1111/ina.12047

Meyer I, Heinrich J, Lippold U. Factors affecting lead, cadmium, and arsenic levels in house dust in a smelter town in eastern Germany. Environ Res. 1999;81(1):32-44. https://doi.org/10.1006/enrs.1998.3950

Miller FJ, Gardner DE, Graham JA, Lee RE, Wilson WE, Bachmann JD. Size considerations for establishing a standard for inhalable particles. J Air Pollut Control Assoc. 1979;29(6):610-615. doi:10.1080/00022470.1979.10470831

Moscato G, Perfetti L, Galdi E, Pozzi V, Minoia C. Levels of house-dust-mite allergen in homes of non-allergic people in Pavia, Italy. Allergy Eur J Allergy Clin Immunol. 2000;55(9):873-878. https://doi.org/10.1034/j.1398-9995.2000.00584.x

Mukai C, Siegel JA, Novoselac A. Impact of airflow characteristics on particle resuspension from indoor surfaces. Aerosol Sci Technol. 2009;43(10):1022-1032. https://doi.org/10.1080/02786820903131073

Nam HS, Siebers R, Lee SH, et al. House dust mite allergens in domestic homes in Cheonan, Korea. Korean J Parasitol. 2008;46(3):187-189. https://doi.org/10.3347/kjp.2008.46.3.187

Neamtiu IA, Bloom MS, Dumitrascu I, et al. Impact of exposure to tobacco smoke, arsenic, and phthalates on locally advanced cervical cancer treatment-preliminary results. PeerJ. 2016;2016(9):1-15. https://doi.org/10.7717/peerj.2448

Needhidasan S, Samuel M, Chidambaram R. Electronic waste - An emerging threat to the environment of urban India. J Environ Heal Sci Eng. 2014;12:1–9. https://doi.org/10.1186/2052-336X-12-36

Needleman H. Low level lead exposure: History and discovery. Ann Epidemiol. 2009;19(4):235-238. https://doi.org/10.1016/j.annepidem.2009.01.022

Noris F, Siegel JA, Kinney KA. Biological and metal contaminants in HVAC filter dust. ASHRAE Trans. 2009;115(2):484-491. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.611.3687&rep=rep1&type=pdf

Novakov NJ, Mihaljev ŽA, Kartalović BD, et al. Heavy metals and PAHs in canned fish supplies on the Serbian market. Food Addit Contam Part B Surveill. 2017;10(3):208-215. https://doi.org/10.1080/19393210.2017.1322150

Nriagu JO. A silent epidemic of environmental metal poisoning? Water Res. 1988;50:139-161. https://doi.org/10.1016/0269-7491(88)90189-3

Okeme JO, Rodgers TFM, Jantunen LM, Diamond ML. Examining the gas-particle partitioning of organophosphate esters: How reliable are air measurements? Environ Sci Technol. 2018;52(23):13834-13844. doi:10.1021/acs.est.8b04588

Platts-Mills TAE. Dust mite allergens and asthma: Report of a second international workshop. J Allergy Clin Immunol. 1992;89(5):1046-1060. https://doi.org/10.1016/0091-6749(92)90228-T

Poma G, Sales C, Bruyland B, et al. Occurrence of organophosphorus flame retardants and plasticizers (PFRs) in Belgian foodstuffs and estimation of the dietary exposure of the adult population. Environ Sci Technol. 2018;52(4):2331-2338. https://doi.org/10.1021/acs.est.7b06395

Qian J, Peccia J, Ferro AR. Walking-induced particle resuspension in indoor environments. Atmos Environ. 2014;89:464–481. https://doi.org/10.1016/j.atmosenv.2014.02.035

Rasmussen PE, Subramanian KS, Jessiman BJ. A multi-element profile of house dust in relation to exterior dust and soils in the city of Ottawa, Canada. Sci Total Environ. 2001;267:125–140. https://doi.org/10.1016/S0048-

9697(00)00775-0

Rasmussen PE, Levesque C, Chénier M, Gardner HD. Contribution of metals in resuspended dust to indoor and personal inhalation exposures: Relationships between PM_{10} and settled dust. Build Environ. 2018;143:513-522. https://doi.org/10.1016/j.buildenv.2018.07.044

Restriction of Hazardous Substances Directive (RoHS). COMMISSION DELEGATED DIRECTIVE (EU) 2015/863 of 31 March 2015 amending annex II to directive 2011/65/EU of the European parliament and of the council as regards the list of restricted substances 2015. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L0863&from=EN Accessed November 15, 2021

Rintala H, Pitkäranta M, Täubel M. Microbial communities associated with house dust. Advances in Applied Microbiology. 2012;78:75-120. https://doi.org/10.1016/B978-0-12-394805-2.00004-X

Roberts JW, Wallace LA, Camann DE, et al. Monitoring and reducing exposure of infants to pollutants in house dust. 2009;201:1-39. doi:10.1007/978-1-4419-0032-6_1

Rudel RA, Dodson RE, Perovich LJ, et al. Semivolatile endocrine-disrupting compounds in paired indoor and outdoor air in two Northern California communities. Environ Sci Technol. 2010;44(17):6583-6590. https://doi.org/10.1021/es100159c

Schossler P, Schripp T, Salthammer T, Bahadir M. Beyond phthalates: Gas phase concentrations and modeled gas/particle distribution of modern plasticizers. Sci Total Environ. 2011;409(19):4031-4038. https://doi.org/10.1016/j.scitotenv.2011.06.012

Seuri M, Husman K, Kinnunen H, et al. An outbreak of respiratory diseases among workers at a water-damaged building - A case report. Indoor Air. 2000;10:138–145. https://doi.org/10.1034/j.1600-0668.2000.010003138.x

Seyam S. Types of HVAC systems. IntechOpen. 2018;13:49-66. http://dx.doi.org/10.5772/intechopen.78942

Shi T, Wang Y. Heavy metals in indoor dust: Spatial distribution, influencing factors, and potential health risks. Sci Total Environ. 2021;755:142367.

https://doi.org/10.1016/j.scitotenv.2020.142367

Silva MJ, Jia T, Samandar E, Preau JL, Calafat AM. Environmental exposure to the plasticizer 1,2-cyclohexane dicarboxylic acid, diisononyl ester (DINCH) in US adults (2000-2012). Environ Res. 2013;126:159-163. https://doi.org/10.1016/j.envres.2013.05.007

Silva MJ, Samandar E, Calafat AM, Ye X. Identification of di-2-ethylhexyl terephthalate (DEHTP) metabolites using human liver microsomes for biomonitoring applications. Toxicol Vitr. 2015;29(4):716-721. https://doi.org/10.1016/j.tiv.2015.02.002

Svennberg K. House dust mites in beds and bedrooms. Physics B, Materials B. 2005:1-24. https://bwk.kuleuven.be/bwf/projects/annex41/protected/data/LTH%20Apr%202006%20Paper%20A41-T4-S-06-2.pdf Accessed November 15, 2021

Tabb MM, Blumberg B. New modes of action for endocrine-disrupting chemicals. Mol Endocrinol. 2006;20(3):475-482. (2018) 25:34623–34635. https://doi.org/10.1210/me.2004-0513

Tan SY, Praveena SM, Abidin EZ, Cheema MS. Heavy metal quantification of classroom dust in school environment and its impacts on children health from Rawang (Malaysia). Environ Sci Pollut Res. 2018;25(34):34623-34635. https://doi.org/10.1007/s11356-018-3396-x

Tapio S, Grosche B. Arsenic in the aetiology of cancer. Mutat Res - Rev Mutat Res. 2006;612(3):215-246. https://doi.org/10.1016/j.mrrev.2006.02.001

Tay JH, Sellström U, Papadopoulou E, Padilla-Sánchez JA, Haug LS, De Wit CA. Human exposure to legacy and emerging halogenated flame retardants via inhalation and dust ingestion in a Norwegian cohort. Environ Sci Technol. 2017;51:8176–8184. https://doi.org/10.1021/acs.est.7b02114

Tong STY, Lam KC. Home sweet home? A case study of household dust contamination in Hong Kong. Sci Total Environ. 2000;256:115–123. https://doi.org/10.1016/S0048-9697(00)00471-X

Tovey ER, Chapman MD. Mite faeces are a major source of house dust allergens Active antitoxic immunization by a diphtheria toxin synthetic oligopeptide. 1981;289:592-593. https://doi.org/10.1038/289592a0

Uma B, Swaminathan TN, Radhakrishnan R, Eckmann DM, Ayyaswamy PS.

Nanoparticle Brownian motion and hydrodynamic interactions in the presence of flow fields. Phys Fluids. 2011;23:073602. https://doi.org/10.1063/1.3611026

United Nations Environment Programme (UNEP). Outcome of the fourth meeting of the conference of the parties relevant to the work of the persistent organic pollutants review committee 2009. Stockholm Convention on Persistent Organic Pollutants. UNEP/POPS/POPRC.5/INF/3.

United States Environmental Protection Agency (US EPA). Air pollution control technology fact sheet 1997. https://www3.epa.gov/ttncatc1/dir1/ff-hepa.pdf Accessed November 15, 2021

United States Food and Drug Administration (USFDA). Phthalates 2013. https://www.fda.gov/cosmetics/cosmetic-ingredients/phthalates Accessed November 15, 2021.

United States Food and Drug Administration (US FDA). Chemicals in cigarettes: From plant to product to puff 2020. https://www.fda.gov/tobacco-products/products-ingredients-components/chemicals-cigarettes-plant-product-puff Accessed November 15, 2021

Van der Veen I, de Boer J. Phosphorus flame retardants: Properties, production, environmental occurrence, toxicity and analysis. Chemosphere. 2012;88(10):1119-1153. https://doi.org/10.1016/j.chemosphere.2012.03.067

Van Strien RT, Gehring U, Belanger K, et al. The influence of air conditioning, humidity, temperature and other household characteristics on mite allergen concentrations in the northeastern United States. Allergy Eur J Allergy Clin Immunol. 2004;59(6):645-652. https://doi.org/10.1111/j.1398-9995.2004.00470.x

Verhoeff AP. Home dampness, fungi and house dust mites and respiratory symptoms in children 1994. file:///C:/Users/user/Google%20Drive/940601%20VERHOEFF,%20Arnoud%20Paul.pdf Accessed November 15, 2021

Wan D, Han Z, Liu D, Yang J. Risk assessments of heavy metals in house dust from a typical industrial area in Central China. Hum Ecol Risk Assess. 2016;22(2):489-501. https://doi.org/10.1080/10807039.2015.1080593

Wang Y, Zhu H, Kannan K. A review of biomonitoring of phthalate exposures. Toxics. 2019;7(2):1-28. https://doi.org/10.3390/toxics7020021

Wang X, Tao W, Xu Y, Feng J, Wang F. Indoor phthalate concentration and exposure in residential and office buildings in Xi'an, China. Atmos Environ. 2014;87:146-152. https://doi.org/10.1016/j.atmosenv.2014.01.018

Weiss JM, Gustafsson Å, Gerde P, Bergman Å, Lindh CH, Krais AM. Daily intake of phthalates, MEHP, and DINCH by ingestion and inhalation. Chemosphere. 2018;208:40-49. https://doi.org/10.1016/j.chemosphere.2018.05.094

Weschler CJ, Nazaroff WW. Semivolatile organic compounds in indoor environments. Atmos Environ. 2008;42(40):9018-9040. https://doi.org/10.1016/j.atmosenv.2008.09.052

Weschler CJ. Changes in indoor pollutants since the 1950s. Atmos Environ. 2009;43:153–169. https://doi.org/10.1016/j.atmosenv.2008.09.044

Weschler CJ, Nazaroff WW. SVOC partitioning between the gas phase and settled dust indoors. Atmos Environ. 2010;44:3609–3620. https://doi.org/10.1016/j.atmosenv.2010.06.029

Weschler CJ, Nazaroff WW. SVOC exposure indoors: Fresh look at dermal pathways. Indoor Air. 2012;22:356–377. https://doi.org/10.1111/j.1600-0668.2012.00772.x

Wiśniewska K, Lewandowska AU, Witkowska A. Factors determining dry deposition of total mercury and organic carbon in house dust of residents of the tri-city and the surrounding area (Baltic Sea coast). Air Qual Atmos Heal. 2017;(10):821–832. https://doi.org/10.1007/s11869-017-0471-2

World Health Organization (WHO). Flame retardants: Tris(2-butoxyethyl) phosphate, tris(2-ethylhexyl) phosphate and tetrakis(hydroxymethyl) phosphonium salts, World Health Organization, Geneva 2000. http://apps.who.int/iris/bitstream/handle/10665/42248/WHO_EHC_218.pdf?sequence=1 Accessed November 15, 2021

World Health Organization (WHO) Europe. Health risks of heavy metals from long-range transboundary air pollution, Copenhagen 2007. https://www.euro.who.int/__data/assets/pdf_file/0007/78649/E91044.pdf Accessed November 15, 2021

World Health Organization (WHO) Europe. WHO guidelines for indoor air quality:

Dampness and mould, Copenhagen, 2009. https://www.euro.who.int/__data/assets/pdf_file/0017/43325/E92645.pdf Accessed November 15, 2021

World Health Organization (WHO). Hazard prevention and control in the work environment: Airborne dust 2014. https://www.who.int/occupational_health/publications/en/oehairbornedust3.pdf Accessed November 15, 2021

Wu M, Yu G, Cao Z, et al. Characterization and human exposure assessment of organophosphate flame retardants in indoor dust from several microenvironments of Beijing, China. Chemosphere. 2016;150:465-471. https://doi.org/10.1016/j.chemosphere.2015.12.111

Xie M, Barsanti KC, Hannigan MP, Dutton SJ, Vedal S. Positive matrix factorization of $PM_{2.5}$-eliminating the effects of gas/particle partitioning of semivolatile organic compounds. Atmos Chem Phys. 2013;13(15):7381-7393. https://doi.org/10.5194/acp-13-7381-2013

Xu Y, Liang Y, Urquidi JR, Siegel JA. Semi-volatile organic compounds in heating, ventilation, and air-conditioning filter dust in retail stores. Indoor Air. 2015;25(1):79-92. https://doi.org/10.1111/ina.12123

Yadav IC, Devi NL, Singh VK, Li J, Zhang G. Spatial distribution, source analysis, and health risk assessment of heavy metals contamination in house dust and surface soil from four major cities of Nepal. Chemosphere. 2019;218:1100–1113. https://doi.org/10.1016/j.chemosphere.2018.11.202

Yang C, Harris SA, Jantunen LM, Kvasnicka J, Nguyen LV, Diamond ML. Phthalates: Relationships between air, dust, electronic devices, and hands with implications for exposure. Environ Sci Technol. 2020;54(13):8186-8197. https://doi.org/10.1021/acs.est.0c00229

Yin J, Liu R, Jian Z, et al. Di (2-ethylhexyl) phthalate-induced reproductive toxicity involved in DNA damage-dependent oocyte apoptosis and oxidative stress in Caenorhabditis elegans. Ecotoxicol Environ Saf. 2018;163:298-306. https://doi.org/10.1016/j.ecoenv.2018.07.066

Zhao F, Kang Q, Zhang X, Liu J, Hu J. Urinary biomarkers for assessment of human exposure to monomeric aryl phosphate flame retardants. Environ Int. 2019;124:259-264. https://doi.org/10.1016/j.envint.2019.01.022

Zheng X, Qiao L, Covaci A, et al. Brominated and phosphate flame retardants (FRs) in indoor dust from different microenvironments: Implications for human exposure via dust ingestion and dermal contact. Chemosphere. 2017;184:185–191. https://doi.org/10.1016/j.chemosphere.2017.05.167

Zock JP, Heinrich J, Jarvis D, et al. Distribution and determinants of house dust mite allergens in Europe: The European community respiratory health survey II. J Allergy Clin Immunol. 2006;118(3):682-690. https://doi.org/10.1016/j.jaci.2006.04.060

[Supplementary Materials]

Table S1. Correlation coefficients within OPFRs in SHD.

	TEP	**TBP**	**TCEP**	**TCPP**	**TPhP**	**EHDPP**
TEP						
TBP	-0.03					
TCEP	0.04	0.11				
TCPP	**0.35**	0.05	0.24			
TPhP	-0.15	-0.05	0.03	0.13		
EHDPP	-0.22	0.01	0.01	0.04	**0.80**	

Table S2. Correlation coefficients within PHTHs in SHD.

	DEP	**DnBP**	**DiBP**	**BBzP**	**DEHP**	**DiNP**	**DiDP**
DEP							
DnBP	-0.06						
DnBP	0.17	-0.16					
BBzP	-0.06	-0.01	0.19				
DEHP	0.01	0.01	0.32	**0.43**			
DiNP	0.08	-0.03	0.04	0.14	**0.32**		
DiDP	0.11	0.16	0.08	0.07	0.11	0.17	

Table S3. Correlation coefficients within NPPs in SHD.

	ATBC	**DEHA**	**DEHTP**	**DINCH**	**TOTM**
ATBC					
DEHA	-0.01				
DEHTP	0.19	0.19			
DINCH	0.25	0.16	**0.34**		
TOTM	0.20	0.04	0.09	0.15	

Table S4. Correlation coefficients within heavy metals in SHD.

	Cd	**Mn**	**Cr**	**Pb**	**As**	**Ni**	**Hg**
Cd							
Mn	0.22						
Cr	**0.37**	**0.34**					
Pb	**0.45**	**0.36**	**0.45**				
As	0.19	**0.30**	-0.06	0.04			
Ni	**0.37**	**0.32**	**0.47**	**0.45**	0.02		
Hg	0.17	0.08	0.25	0.26	0.02	0.22	

Table S5. Correlation coefficients between EDCs and heavy metals in SHD.

	Cd	**Mn**	**Cr**	**Pb**	**As**	**Ni**
TEP	0.24	**0.41**	0.28	**0.32**	-0.16	0.23
TCEP	0.28	0.08	0.23	0.29	0.03	0.17
TCPP	0.21	0.23	**0.30**	0.27	-0.03	**0.30**
TPhP	**0.32**	0.15	0.04	-0.01	**0.61**	0.04
EHDPP	0.19	-0.06	-0.01	-0.04	**0.43**	-0.08
DEP	0.18	0.15	0.11	0.02	0.21	0.07
DiBP	0.13	0.13	0.22	0.23	0.01	0.12
BBzP	**0.51**	-0.01	0.09	0.28	-0.06	0.16
DEHP	**0.41**	-0.08	0.15	0.15	0.02	0.19
DiNP	0.26	-0.01	0.07	0.05	0.05	0.07

Table S6. Correlation coefficients between PHTHs and NPPs in SHD.

	DEP	**DnBP**	**DiBP**	**BBzP**	**DEHP**	**DiNP**	**DiDP**
ATBC	0.17	0.02	0.04	-0.14	-0.02	0.04	-0.02
DEHA	-0.07	0.01	0.02	**0.31**	0.09	**0.31**	0.10
DEHTP	-0.11	0.05	-0.01	-0.23	-0.06	0.28	0.04
DINCH	0.02	-0.06	0.12	-0.07	-0.01	**0.33**	0.24
TOTM	**0.32**	-0.02	0.17	0.02	-0.03	0.16	0.07

Table S7. Correlation coefficients within OPFRs in ACCD.

	TCEP	**TPhP**	**EHDPP**
TCEP			
TPhP	**0.60**		
EHDPP	**0.39**	**0.77**	

Table S8. Correlation coefficients within PHTHs in ACCD.

	DnBP	**DiBP**	**BBzP**	**DEHP**
DnBP				
DiBP	**0.45**			
BBzP	0.29	**0.41**		
DEHP	**0.46**	**0.74**	**0.52**	

Table S9. Correlation coefficients within NPPs in ACCD.

	ATBC	**DEHA**	**DEHTP**
ATBC			
DEHA	**0.38**		
DEHTP	**0.47**	**0.52**	

Table S10. Correlation coefficients between PHTHs and NPPs in ACCD.

	DnBP	**DiBP**	**BBzP**	**DEHP**
ATBC	**0.35**	**0.69**	**0.43**	**0.58**
DEHA	0.23	**0.55**	0.28	**0.48**
DEHTP	0.12	**0.50**	0.10	**0.44**

Table S11. The range of OPFR concentrations in SHD of other countries.

OPFRs	Country (concentration in µg/g)											
	Belgium	China	China	China	Germany	Korea	Spain	Nepal	Nepal	Philippines	United States	United States	United States
TMP	-	-	-	-	-		-	-	-	-	-	-	-
TEP	<LOD	<0.006–0.26	0.02–0.24	0.02–1.4	<LOD-2.3	<LOQ–8.3	-	-	-	-	-	0.015-2.70	-
TiPP	-		-	-	-		-	-	-	-	-	-	-
TPrP	-	ND	-	-	-		-	-	-	-	-	-	-
TBP	-	0.02–1.17	-	0.07–9.6	-		-	-	-	-	-	0.012-0.39	-
TCEP	0.08–2.65	0.05–3.13	1.55–9.70	0.2–38.0	<LOD-5.0	0.0065–20.0	0.12-13.20	0.00011-0.0069	0.0006-5.29	<LOD-1.20	-	<LOQ-2.13	<LOD-160
TCPP	0.19–73.7	0.11–4.59	0.16–2.93	0.6–18.2	1.7-10.0	<LOQ–22.0	0.78-64.42	0.024-0.81	0.016-0.14	-	-	-	<LOD-166
TPeP	-	-	-	-	-		-	-	-	<LOD-0.00078	-	-	-
TDCPP	0.08–6.64	0.42–10.19	-	0.2–1.7	<LOD-4.3		0.13-10.52	0.0010-1.42	0.0001-0.020	-	-	-	<LOD-228
TBOEP	-	-	-	-	2.1-99.0	<LOQ–36.0	-	-	-	-	<MDL-121	8.59-196	-
TPhP	-	0.1–3.55	0.01–0.80	-	0.48-23.0	0.0068–13.0	0.018-14.1	0.0098-3.67	0.0008-0.22	-	-	<LOQ-3.50	<LOD-62.1
EHDPP	-	0.25–6.53	0.03–3.47	0.3–1.4	-	<LOQ–39.0	0.37-4.03	0.026-0.53	0.019-0.032	0.00080-0.77	-	<LOQ-0.456	-
TEHP	-	0.14–1.22	0.03–1.37	-	<LOD-2.1	<LOQ–0.650	0.057-3.49	0.026-0.75	-	0.00041-0.97	-	0.077-1.44	-
CDP	-	-	-	-	-		-	-	-	-	-	-	-
TmCP	-	-	-	-	-		-	-	-	-	-	-	-
ToCP	-	-	-	-	-		-	-	-	-	-	-	-
TpCP	-	-	-	-	-		-	-	-	-	-	-	-
TiPPP	-	<0.01–0.22	-	-	-		-	-	-	-	-	-	-
Total	1.92–94.7	2.06–19.95	4.45–27.5	3.8-44.0	5.9-110	0.0049–59.0	-	0.15-12.1	0.20-240	0.021-4.3	8.24-1220	16.2-224	-

Sampling year	-	-	2013-2014	-	2015	2015	-	2014	2015	2008	2014-2015	2018	2003-2006
Reference	Van et al., 2011	Tan et al., 2017	He et al., 2015	Peng et al., 2017	Zhou et al., 2017	Lee et al., 2020	Cristale et al., 2016	Yadav et al., 2017	Yadav et al., 2018	Kim et al., 2013	Bi et al., 2018	Kim et al., 2019	Percy et al., 2020

Table S12. The range of PHTH concentrations in SHD of other countries.

PHTHs	Country (concentration in µg/g)									
	Belgium	China	China	China	Korea	Ireland	Netherlands	Vietnam	United States	United States
DMP	-	0.035–26.6	LOD-68.84	<LOD–24.0		-	< LOQ-0.31	<LOD–0.69	<MDL-111	<LOD-0.96
DEP	0.16-1.5	0.013–4.01	-	<LOD–33.9		0.39-6.6	0.19-3.82	0.0009–0.36	<MDL-6.93	<LOD-15
DiPrP	-	-	-	-		-	-		-	-
DnPrP	-	-	-	-		-	-		-	-
DAIP	-	-	-	-		-	-		-	-
DiBP	1.2-51	0.452–262	LOD-7228.34	-	< LOD-21.1	4.6-150	< LOQ-26	0.018 – 0.97	-	3.3-43
DnBP	0.67-109	-	3.64-4357.32	-	< LOD-190.7	5.7-187	1.2-146	-	<MDL-950	5.4-204
DnPeP	-	-		-		-	-	-	-	-
DnHxP	-	-	-	-		-	-	-	-	0.21-1.9
BBzP	0.20-16	<LOD-0.648	-	<LOD–38.7	< LOD-444.4	2.0-6.4	0.70-18	0.028–4.60	<MDL-2380	8.0-619
DCHP	-	<LOD-0.166	-	-		-	-	<LOD–0.30	-	-
DEHP	9.0-497	0.503–1550	67.06-3475.73	0.3–9950	114-4321	24-254	32-307	2.08–76.50	<MDL-2120	253-803
DiHpP	-	-	-			-	-		-	<LOD-17
DnOP	-	<LOD-6.81	-	<LOD–39.5	< LOD-15.4	-	-	0.018–1.45	<MDL-355	-
DiNP	5.2-296	-	-	-		62-121	< LOQ-152	-	-	2.6-13
DiDP	4.4-59	-	-	-		16-67	< LOQ-62	-	-	<LOD-19
Total	-	2.31–1590	122.88-9504.38	0.9–10900	175-4491	-	-	3.44–79.30	26.4-5420	261-1570

Sampling year	2017	2017-2018	2012-2013	2011	2011	2017	2017	2014	2014-2015	2014-2015
Reference	Christia et al., 2019	Zhu et al., 2019	Wang et al., 2014	Zhange et al., 2013	Kweon et al., 2018	Christia et al., 2019	Christia et al., 2019	Tran et al., 2016	Bi et al., 2018	Bi et al., 2015

Table S13. The range of NPP concentrations in SHD of other countries.

NPPs	Country (concentration in µg/g)						
	Belgium	Germany	Ireland	Netherlands	China	United States	United States
ATBC	0.22-101	<LOQ–3314	4.8-17	0.20-21	1.34–37.27		24.7-2180
DEHA	0.27-272	1.0–724	1.6-4.7	0.20-17	<LOD−1.52	<LOD–17.16	21.8-225
DEHTP	5.1-101	-	32-247	6.9-764	-	-	-
DINCH	1.2-1051	32–2732	1.7-111	< LOQ-19	1.06–11.55	-	-
TOTM	0.46-130	<LOQ–107	1.2-3.2	< LOQ-46	0.40–101.25	<LOD-36.19	-
Total	-	-	-	-	61.2–1118.35	-	-
Sampling year	2017	2011-2012	2017	2017	2017	2014 and 2016	2016
Reference	Christia et al., 2019	Fromme et al., 2016	Christia et al., 2019	Christia et al., 2019	Tang et al., 2020	Hammel et al., 2019	Subedi et al., 2017

Table S14. The range of heavy metal element concentrations in SHD of other countries.

Heavy metals	Country (concentration in µg/g)										
	China	China	China	Hong Kong	Canada	Canada	Egypt	Iran	Korea	Korea	Russia	United States
Cd	-	8.55-84.6	-	0.2-2340.6	-	0.068-170	1.3 – 8.8	8.02-17.72			-	-
Mn	392.1-549.2	-	-	44.7-2463.8	-	5.5-3500	138 – 237	-			-	-
Cr	74.1-152.6	0.60-3.08	-	-	-	3.0-1200	-	3.49-22.55			28-71	-
Pb	92.9-266.0	0.62-10.7	-	0.1-1415.2	-	0.99-8500	85.3 – 120	10.28-101.65	52–2350	19–491	27-520	-
As	-	-	-	-	-	0.13-150	-	-			3.9-15.9	-
Ni	29.6-1367.1	0.40-10.9	-	-	-	1.9-550	-	25.00-89.47			21.0-57.0	-
Hg	-	-	-	-	-	-	-	-			-	-
Total	-	-	-	-	-	-	-	-			-	-
Sampling year	-	2014-2015	2018	-	2012-2013	2017-2018	-	2017	1996	1996	2017	-
Reference	Wan et al., 2016	Cheng et al., 2018	Zhou et al., 2019	Tong and Lam, 2000	Hejami et al., 2020	Dingle et al., 2021	Rashed, 2008	Sabzevari and Sobhanardakani, 2018	Kim et al., 1998	Kim et al., 1998	Krupnova et al., 2019	Tong, 1998

Table S15. The range of house dust mite allergen concentrations in bedding dust of other countries.

Country	Allergens (concentration in μg/g)		Sampling year	Reference
	Der f 1	Der p 1		
China	0.03-1.77	0.03-4.34	2013-2014	Liu et al., 2020
China	0.03-1.77	0.03-4.34	2011-2012	Huang et al., 2019
Korea	0.01-230.9	0.14-30.0	2006	Nam et al., 2008
Estonia*	0.24	0.05	2000-2002	Zock et al., 2006
Germany*	1.945	0.54	2000-2002	Zock et al., 2006
United Kingdom*	0.26	0.05	2000-2002	Zock et al., 2006
Belgium*	0.25	0.735	2000-2002	Zock et al., 2006
France*	0.515	0.08	2000-2002	Zock et al., 2006
Switzerland*	0.35	-	2000-2002	Zock et al., 2006
Italy*	3.01	0.04	2000-2002	Zock et al., 2006
Spain*	1.03	4.88	2000-2002	Zock et al., 2006
United States*	-	2.78	1998	Mansour et al., 2001
United States	0.05-24.9	0.05-17.6	-	Barnes et al., 2001

*****: Mean concentrations are listed for studies that have not reported the range.

References used for Table S11-S15

Barnes CS, Pacheco F, Portnoy JM. Relationship of Der f1 and Der p1 levels in house dust in the midwestern US. J Allergy Clin Immunol. 2016;137(2):AB28. https://doi.org/10.1016/j.jaci.2015.12.092

Bi C, Maestre JP, Li H, et al. Phthalates and organophosphates in settled dust and HVAC filter dust of US low-income homes: Association with season, building characteristics, and childhood asthma. Environ Int. 2018;121:916-930. https://doi.org/10.1016/j.envint.2018.09.013

Bi X, Yuan S, Pan X, Winstead C, Wang C. Comparison, association, and risk assessment of phthalates in floor dust at different indoor environs in Delaware, USA. J Environ Sci Health, Part A. 2015;50(14):1093-4529. https://doi.org/10.1080/10934529.2015.1074482

Cheng Z, Chen LJ, Li HH, et al. Characteristics and health risk assessment of heavy metals exposure via household dust from urban area in Chengdu, China. Sci Total Environ. 2018;619–620:621–629. https://doi.org/10.1016/j.scitotenv.2017.11.144

Christia C, Poma G, Harrad S, et al. Occurrence of legacy and alternative plasticizers in indoor dust from various EU countries and implications for human exposure via dust ingestion and dermal absorption. Environ Res. 2019;171:204-212. https://doi.org/10.1016/j.envres.2018.11.034

Cristale J, Hurtado A, Gómez-Canela C, Lacorte S. Occurrence and sources of brominated and organophosphorus flame retardants in dust from different indoor environments in Barcelona, Spain. Environ Res. 2016;149:66-76. https://doi.org/10.1016/j.envint.2020.105619

Dingle JH, Kohl L, Khan N, et al. Sources and composition of metals in indoor house dust in a mid-size Canadian city. Environ Pollut. 2021;289:117867. https://doi.org/10.1016/j.envpol.2021.117867

Fromme H, Schütze A, Lahrz T, et al. Non-phthalate plasticizers in German daycare centers and human biomonitoring of DINCH metabolites in children attending the centers (LUPE 3). Int J Hyg Environ Health. 2016;219(1):33-39. https://doi.org/10.1016/j.ijheh.2015.08.002

Hammel SC, Levasseur JL, Hoffman K, et al. Children’s exposure to phthalates and non-phthalate plasticizers in the home: The TESIE study. Environ Int. 2019;132:105061. https://doi.org/10.1016/j.envint.2019.105061

He CT, Zheng J, Qiao L, et al. Occurrence of organophosphorus flame retardants in indoor dust in multiple microenvironments of southern China and implications for human exposure. Chemosphere. 2015;133:47-52. https://doi.org/10.1016/j.chemosphere.2015.03.043

Hejami AAl, Davis M, Prete D, Lu J, Wang S. Heavy metals in indoor settled dusts in Toronto, Canada. Sci Total Environ. 2020;703:134895. https://doi.org/10.1016/j.scitotenv.2019.134895

Huang C, Cai J, Liu W, et al. Associations of household dust mites (Der p 1 and Der f 1) with childhood health outcomes masked by avoidance behaviors. Build Environ. 2019;151(January):198-206. https://doi.org/10.1016/j.buildenv.2019.01.040

Kim JW, Isobe T, Sudaryanto A, et al. Organophosphorus flame retardants in house dust from the Philippines: Occurrence and assessment of human exposure. Environ Sci Pollut Res. 2013;20(2):812-822. doi:10.1007/s11356-012-1237-x

Kim KW, Myung JH, Ahn JS, Chon HT. Heavy metal contamination in dusts and stream sediments in the Taejon area, Korea. J Geochemical Explor. 1998;64(1-3-3 pt 1):409-419. https://doi.org/10.1016/j.envpol.2020.115028

Kim UJ, Wang Y, Li W, Kannan K. Occurrence of and human exposure to organophosphate flame retardants/plasticizers in indoor air and dust from various microenvironments in the United States. Environ Int. 2019;125:342-349. doi:10.1016/j.envint.2019.01.065

Krupnova TG, Rakova OV, Mashkova IV, Artyukov EV, Vlasov NE. Health risk assessment of metal(loid)s exposure via indoor dust from urban area in Chelyabinsk, Russia. Int J GEOMATE. 2019;16(55):1-7. doi:10.21660/2019.55.16501

Lee HK, Kang H, Lee S, Kim S, Choi K, Moon HB. Human exposure to legacy and emerging flame retardants in indoor dust: A multiple-exposure assessment of PBDEs. Sci Total Environ. 2020;719:137386. https://doi.org/10.1016/j.scitotenv.2020.137386

Liu W, Cai J, Huang C, Zou Z, Sun C, Li B. Family and building characteristics in relation to levels of bed dust mites in 453 beddings of Shanghai children. Sustain Cities Soc. 2020;54:102007. https://doi.org/10.1016/j.scs.2019.102007

Mansour M, Lanphear BP, Hornung R, et al. A side-by-side comparison of sampling methods for settled, indoor allergens. Environ Res. 2001;87(1):37-46. https://doi.org/10.1006/enrs.2001.4284

Nam HS, Siebers R, Lee SH, et al. House dust mite allergens in domestic homes in Cheonan, Korea. Korean J Parasitol. 2008;46(3):187-189. https://doi.org/10.3347/kjp.2008.46.3.187

Peng X, Fu H, Hu J, Luo F. Investigation on mercury migration discipline in different paper-plastic food packaging containers. J Food Sci. 2020;85(4):1186-1192. https://doi.org/10.1111/1750-3841.15060

Percy Z, La Guardia MJ, Xu Y, et al. Concentrations and loadings of organophosphate and replacement brominated flame retardants in house dust from the home study during the PBDE phase-out. Chemosphere. 2020;239:124701. https://doi.org/10.1016/j.chemosphere.2019.124701

Rashed MN. Total and extractable heavy metals in indoor, outdoor and street dust from Aswan city, Egypt. Clean - Soil, Air, Water. 2008;36(10-11):850-857. https://doi.org/10.1002/clen.200800062

Sabzevari E, Sobhanardakani S. Analysis of Selected Heavy Metals in Indoor Dust in Khorramabad City, Iran: A Case Study. Jundishapur J Heal Sci. 2018;10(3); e6738. doi:10.5812/jjhs.67382

Subedi B, Sullivan KD, Dhungana B. Phthalate and non-phthalate plasticizers in indoor dust from childcare facilities, salons, and homes across the USA. Environ Pollut. 2017;230:701-708. https://doi.org/10.1016/j.envpol.2017.07.028

Tan H, Peng C, Guo Y, Wang X, Wu Y, Chen D. Organophosphate Flame Retardants in House Dust from South China and Related Human Exposure Risks. Bull Environ Contam Toxicol. 2017;99(3):344-349. doi:10.1007/s00128-017-2120-8

Tang B, Christia C, Malarvannan G, et al. Legacy and emerging organophosphorus flame retardants and plasticizers in indoor microenvironments from Guangzhou, South China. Environ Int. 2020;143:105972. https://doi.org/10.1016/j.envint.2020.105972

Tong STY, Lam KC. Home sweet home? A case study of household dust contamination in Hong Kong. Sci Total Environ. 2000;256:115–123. https://doi.org/10.1016/S0048-9697(00)00471-X

Tong STY. Indoor and outdoor household dust contamination in Cincinnati, Ohio, USA. Environ Geochem Health. 1998;20(3):123-133. doi:10.1023/A:1006561832381

Tran TM, Minh TB, Kumosani TA, Kannan K. Occurrence of phthalate diesters (phthalates), p-hydroxybenzoic acid esters (parabens), bisphenol A diglycidyl ether (BADGE) and their derivatives in indoor dust from Vietnam: Implications for exposure. Chemosphere. 2016;144:1553-1559. https://doi.org/10.1021/es303516u

Van den Eede N, Dirtu AC, Neels H, Covaci A. Analytical developments and preliminary assessment of human exposure to organophosphate flame retardants from indoor dust. Environ Int. 2011;37(2):454-461. https://doi.org/10.1016/j.envint.2010.11.010

Wan D, Han Z, Liu D, Yang J. Risk assessments of heavy metals in house dust from a typical industrial area in Central China. Hum Ecol Risk Assess. 2016;22(2):489-501. https://doi.org/10.1080/10807039.2015.1080593

Wang X, Tao W, Xu Y, Feng J, Wang F. Indoor phthalate concentration and exposure in residential and office buildings in Xi’an, China. Atmos Environ. 2014;87:146-152. https://doi.org/10.1016/j.atmosenv.2014.01.018

Yadav IC, Devi NL, Singh VK, Li J, Zhang, G. Spatial distribution, source analysis, and health risk assessment of heavy metals contamination in house dust and surface soil from four major cities of Nepal. Chemosphere. 2019;218:1100–1113. https://doi.org/10.1016/j.chemosphere.2018.11.202

Yadav IC, Devi NL, Zhong G, Li J, Zhang G, Covaci A. Occurrence and fate of organophosphate ester flame retardants and plasticizers in indoor air and dust of Nepal: Implication for human exposure. Environ Pollut. 2017;229:668-678. https://doi.org/10.1016/j.envpol.2017.06.089

Zhang Q, Lu XM, Zhang XL, et al. Levels of phthalate esters in settled house dust from urban dwellings with young children in Nanjing, China. Atmos Environ. 2013;69:258-264. doi:10.1016/j.atmosenv.2012.12.029

Zhou L, Hiltscher M, Püttmann W. Occurrence and human exposure assessment of organophosphate flame retardants in indoor dust from various microenvironments of the Rhine/Main region, Germany. Indoor Air. 2017;27(6):1113-1127. https://doi.org/10.1111/ina.12397

Zhou L, Liu G, Shen M, Hu R, Sun M, Liu Y. Characteristics and health risk assessment of heavy metals in indoor dust from different functional areas in Hefei, China. Environ Pollut. 2019;251:839-849. https://doi.org/10.1016/j.envpol.2019.05.058

Zhu Q, Jia J, Zhang K, Zhang H, Liao C, Jiang G. Phthalate esters in indoor dust from several regions, China and their implications for human exposure. Sci Total Environ. 2019;652:1187-1194. https://doi.org/10.1016/j.scitotenv.2018.10.326

Zock JP, Heinrich J, Jarvis D, et al. Distribution and determinants of house dust mite allergens in Europe: The European community respiratory health survey II. J Allergy Clin Immunol. 2006;118(3):682-690. https://doi.org/10.1016/j.jaci.2006.04.060

Table S16. Usage/applications of chemicals and sampling methods.

Chemicals	Sampling	Usage/Applications	Reference
DEHP, DiNP, DINCH, TPP	Fractions of crib mattress covers and foam surfaces sampled	Crib mattresses and polyurethane foam	Boor et al., 2015
DnBP, DEHP, DiNP, DEHTP, DINCH	113 urine samples of children and dust samples from 30 preschools collected	Building year, foam mattresses, plastic toys, PVC flooring, room size, wall paintings, and electronic devices	Larsson et al., 2017
Cd, Hg, Pb, Ni, Cr	NA	Rechargeable computer batteries, liquid crystal displays (LCDs), mobile phones, computer monitors, television monitors, and electric toys	ECHA, 2021
Ni, Cd, Pb, DEP, DBP, DEHP, BBzP, DnOP, DiBP, DMP	Coffee surrogates from metal biodegradable and plastic coffee capsules collected	Metal biodegradable and plastics coffee capsules	De Toni et al., 2017
TEP, TNBP, TCEP, TCIPP, TDCIPP, TPHP, EHDPP, TEHP	165 food products including eggs, crutaceans, vegetables, fish, milk, potatoes, mussels, desserts, baby foods, stocks, cheeses, grains, and fats collected from supermarket	Fats and oil products, grains and cheese products, food packagings, canned food, and mechanical drying of food	Poma et al., 2018
ATBC, TOTM, DINCH, DEHTP	Urinary samples collected	Plastic and resin food packagings, and canned foods	Rudel et al., 2011
Hg, Cd, Pb	4 different paper-plastic food packagings and food 4 food simulants selected	Paper-plastic food packagings, water, acid food, milk products, oil-in-water food	Peng et al., 2020
Pb, Cu, Ni, Zn, Mn, Cr	30 different plastic food packagings collected	Plastic food packagings	Khan and Rahman, 2015

References used for Table S16

Boor BE, Liang Y, Crain NE, Järnström H, Novoselac A, Xu Y. Identification of phthalate and alternative plasticizers, flame retardants, and unreacted isocyanates in infant crib mattress covers and foam. Environ Sci Technol Lett. 2015;2(4):89-94. https://doi.org/10.1021/acs.estlett.5b00039

de Toni L, Tisato F, Seraglia R, et al. Phthalates and heavy metals as endocrine disruptors in food: A study on pre-packed coffee products. Toxicol Reports. 2017;4:234-239. https://doi.org/10.1016/j.toxrep.2017.05.004

Khan S, Rahman A. Contamination of toxic heavy metal contamination in locally made plastic food container. Int J Sci Eng Res. 2015;6(6):45-47. http://www.ijser.org

Larsson K, Lindh CH, Jönsson BA, et al. Phthalates, non-phthalate plasticizers and bisphenols in Swedish preschool dust in relation to children's exposure. Environ Int. 2017;102:114-124. https://doi.org/10.1016/j.envint.2017.02.006

Peng X, Fu H, Hu J, Luo F. Investigation on mercury migration discipline in different paper-plastic food packaging containers. J Food Sci. 2020;85(4):1186-1192. https://doi.org/10.1111/1750-3841.15060

P Poma G, Sales C, Bruyland B, et al. Occurrence of organophosphorus flame retardants and plasticizers (PFRs) in Belgian foodstuffs and estimation of the dietary exposure of the adult population. Environ Sci Technol. 2018;52(4):2331-2338. https://doi.org/10.1021/acs.est.7b06395

Rudel RA, Dodson RE, Perovich LJ, et al. Semivolatile endocrine-disrupting compounds in paired indoor and outdoor air in two Northern California communities. Environ Sci Technol. 2010;44(17):6583-6590. https://doi.org/10.1021/es100159c

US consumer product safety commission, Exposure and risk assessment division. Review of exposure and toxicity data for phthalate substitutes 2010. https://www.cpsc.gov/s3fs-public/phthalsub.pdf . Accessed November 15, 2021

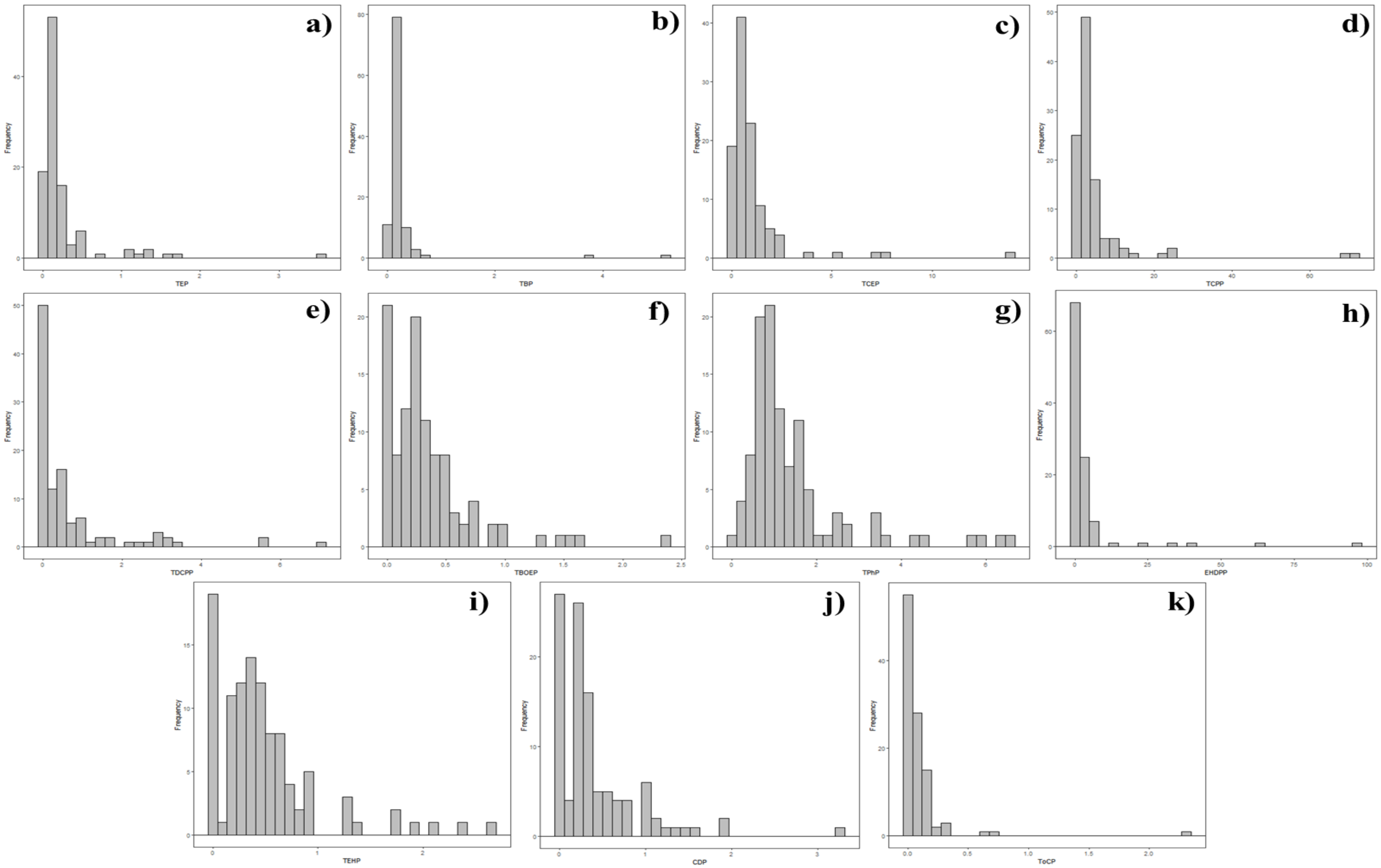

Figure S1. The concentration profiles of OPFRs in SHD. a) is TEP, b) is TBP, c) is TCEP, d) is TCPP, e) is TDCPP, f) is TBOEP, g) is TPhP, h) is EHDPP, i) is TEHP, j) is CDP, and k) is ToCP.

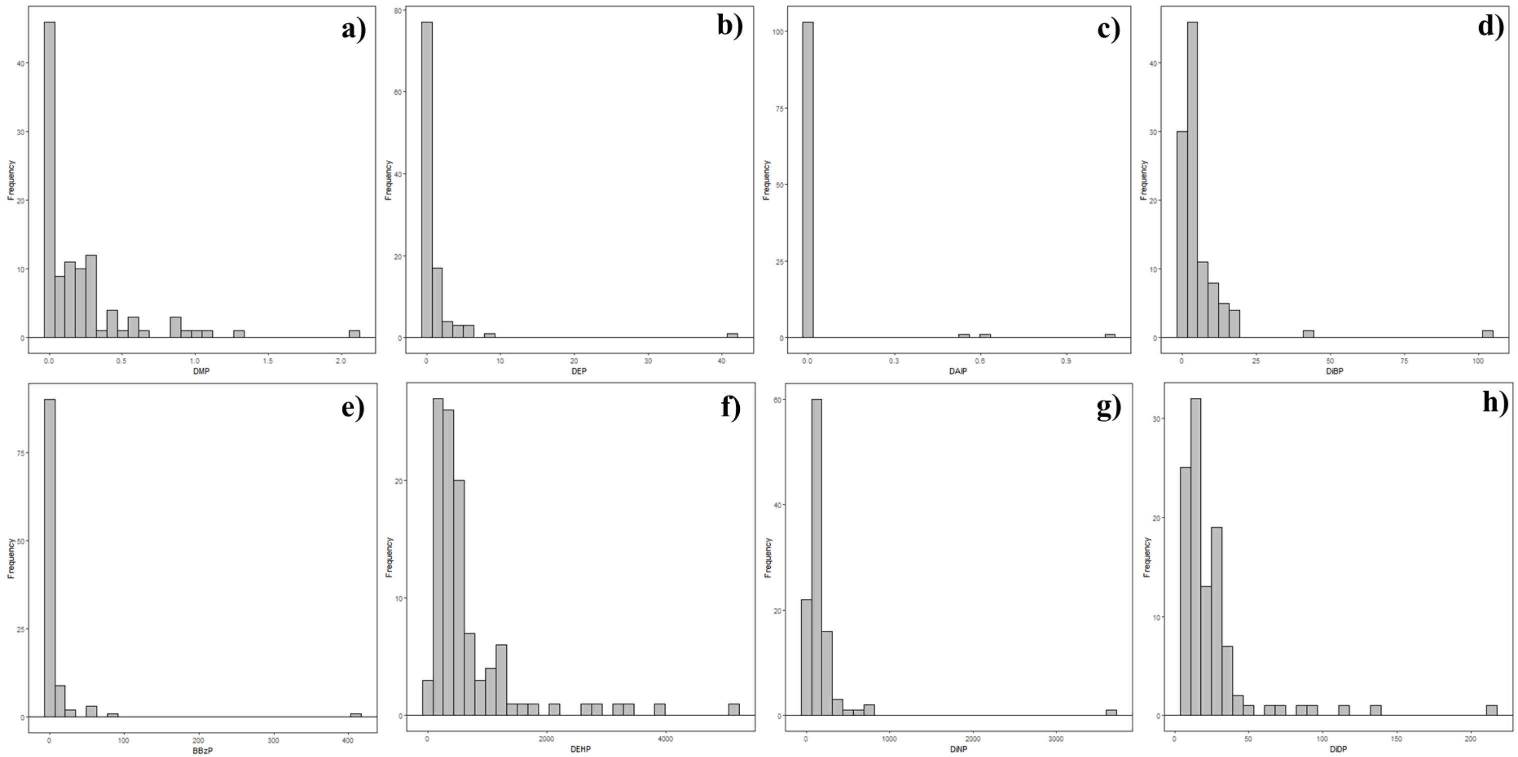

Figure S2. The concentration profiles of PHTHs in SHD. a) is DMP, b) is DEP, c) is DAIP, d) is DiBP, e) is BBzP, f) is DEHP, g) is DiNP, and h) is DiDP.

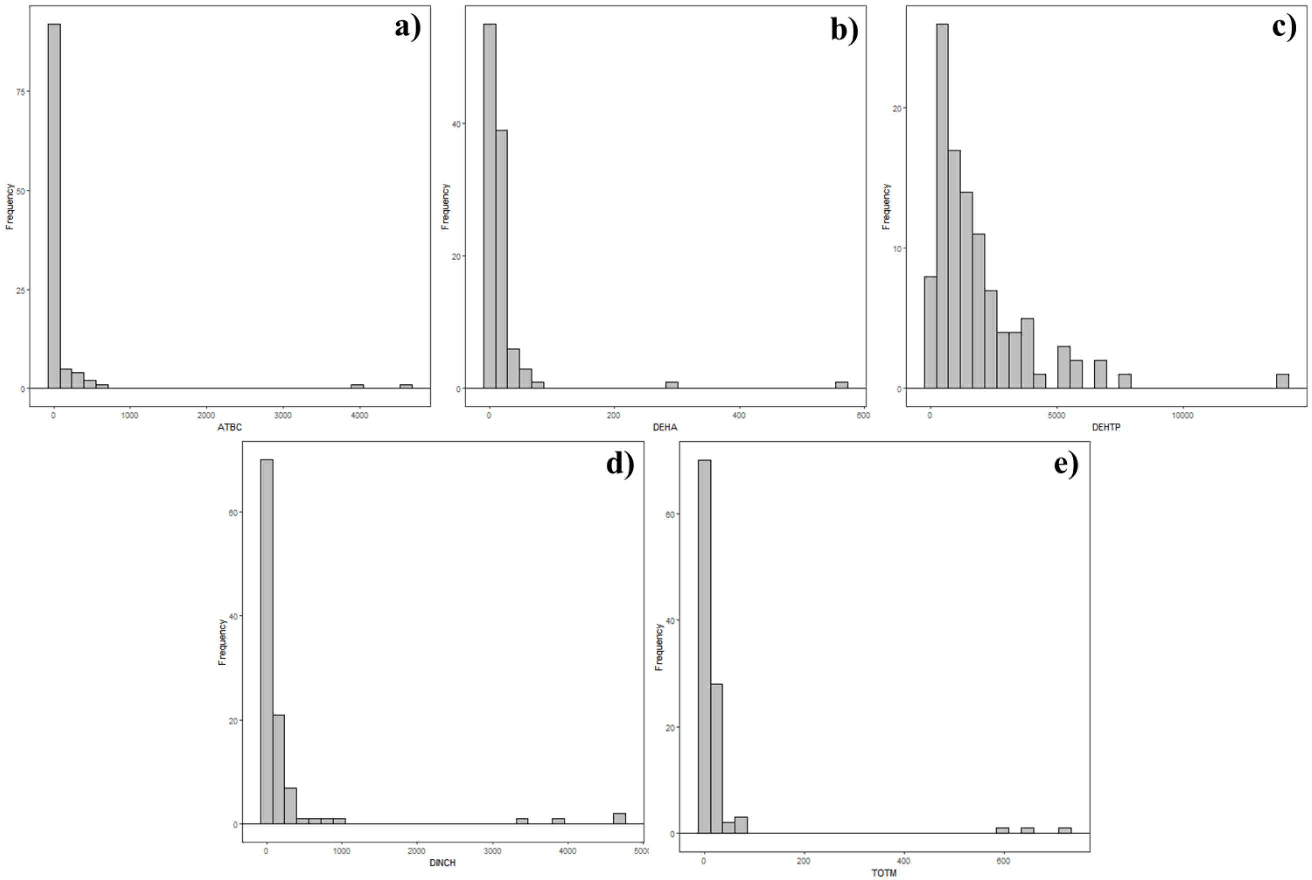

Figure S3. The concentration profiles of NPPs in SHD. a) is ATBC, b) is DEHA, c) is DEHTP, d) is DINCH, and e) is TOTM.

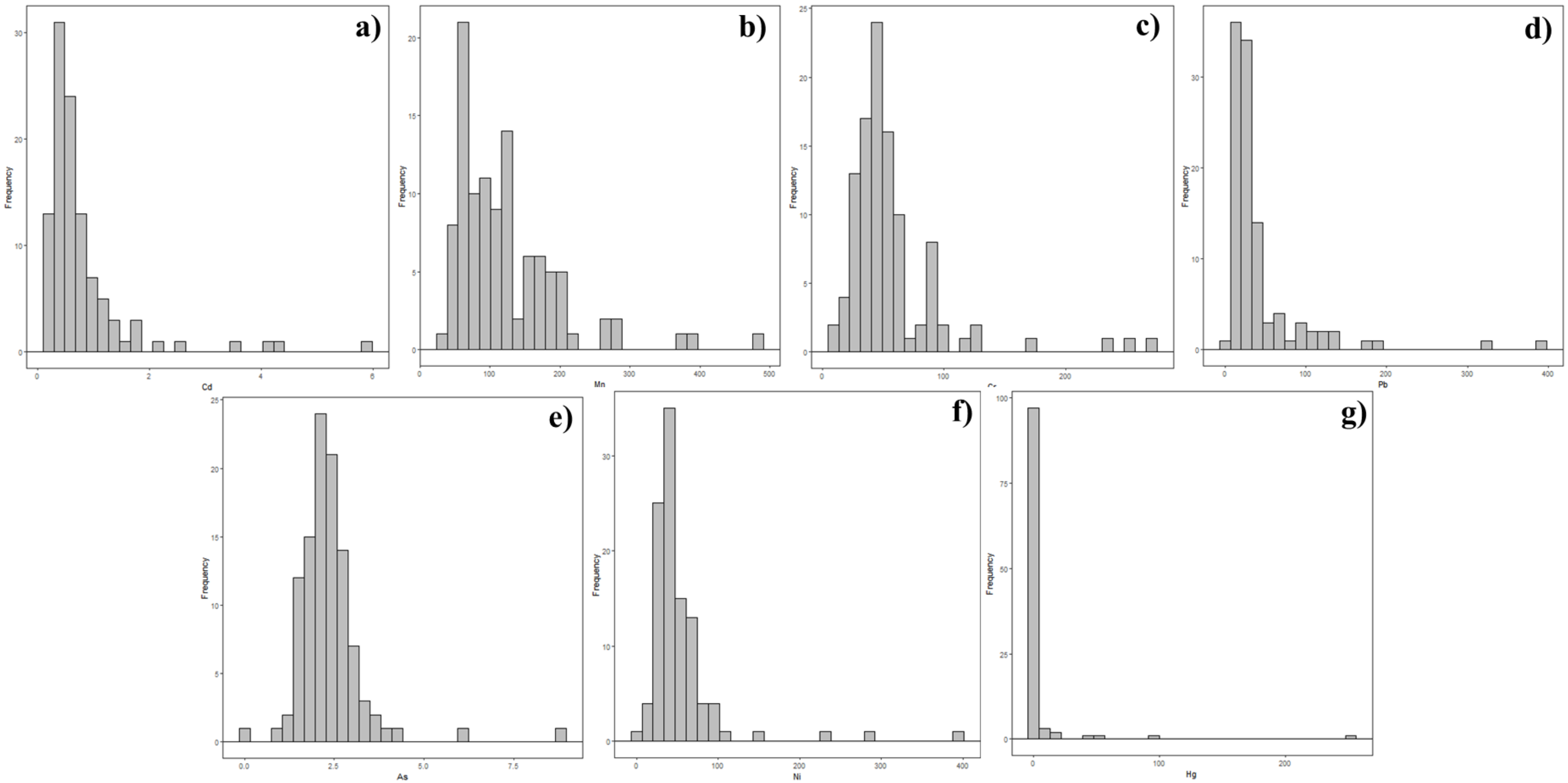

Figure S4. The concentration profiles of heavy metals in SHD. a) is Cd, b) is Mn, c) is Cr, d) is Pb, e) is As, f) is Ni, and g) is Hg.

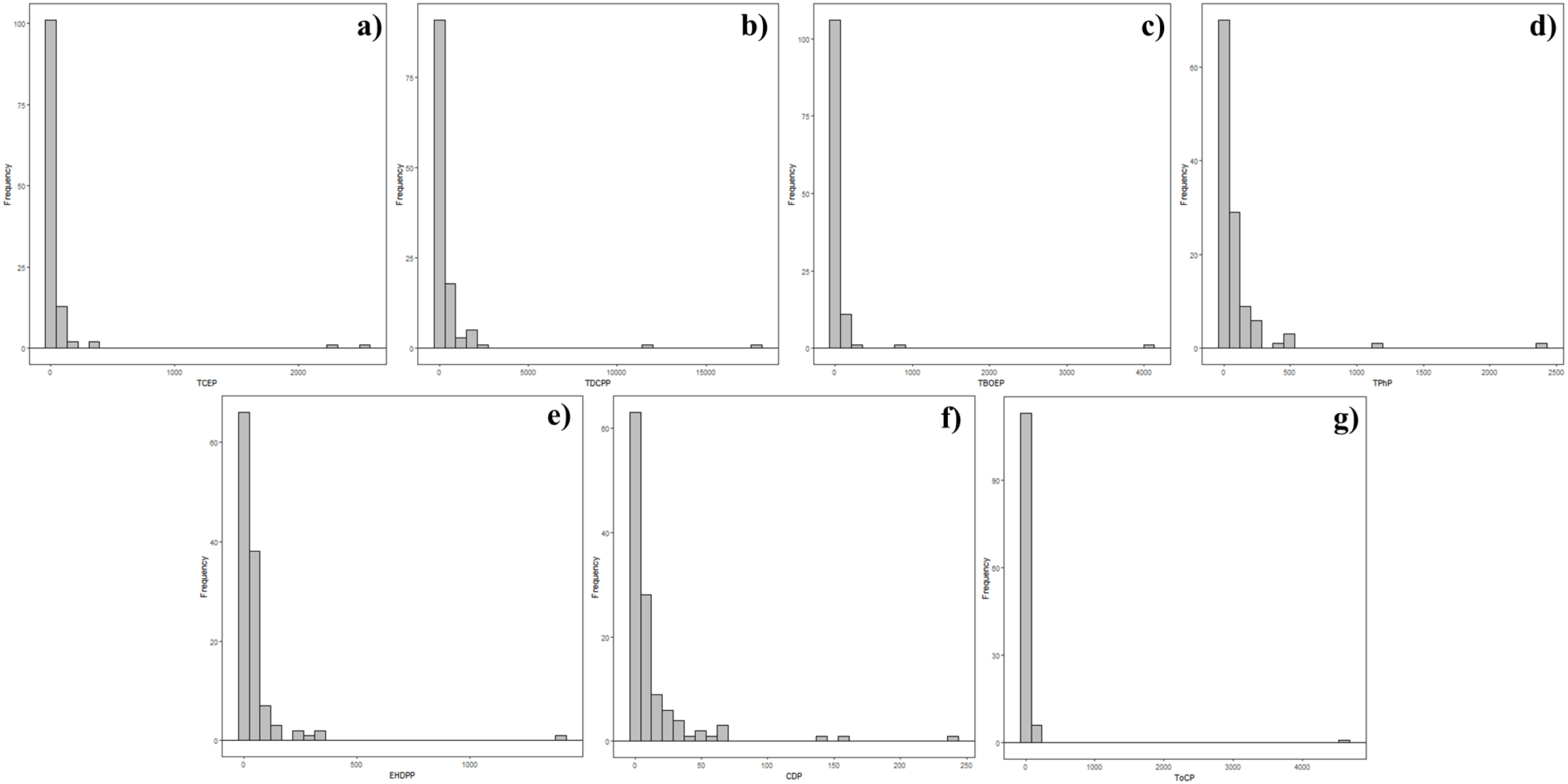

Figure S5. The concentration profiles of OPFRs in ACCD. a) is TCEP, b) is TDCPP, c) is TBOEP, d) is TPhP, e) is EHDPP, f) is CDP, and g) is ToCP.

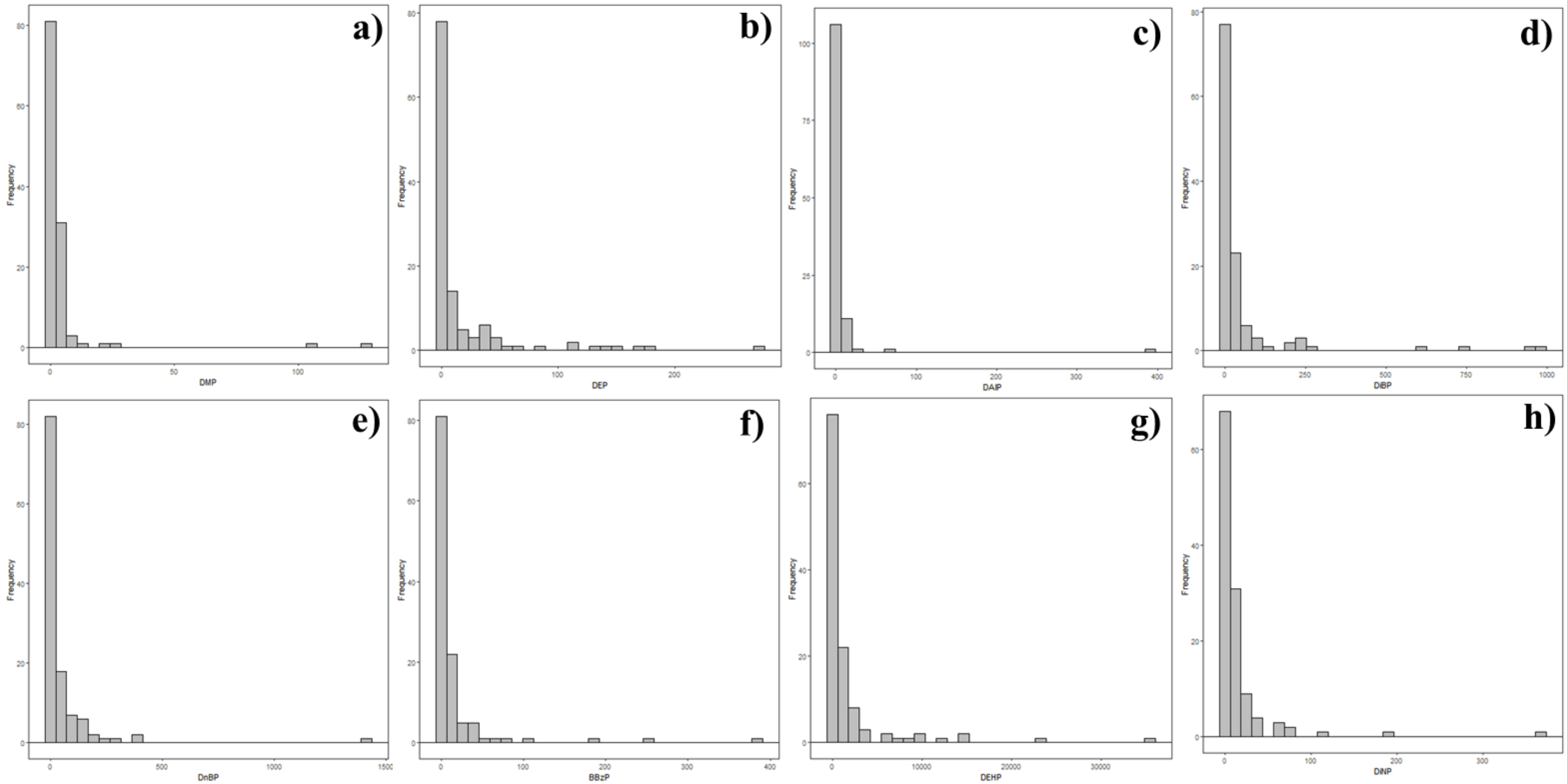

Figure S6. The concentration profiles of PHTHs in ACCD. a) is DMP, b) is DEP, c) is DAIP, d) is DiBP, e) is DnBP, f) is BBzP, g) is DEHP, and h) is DiNP.

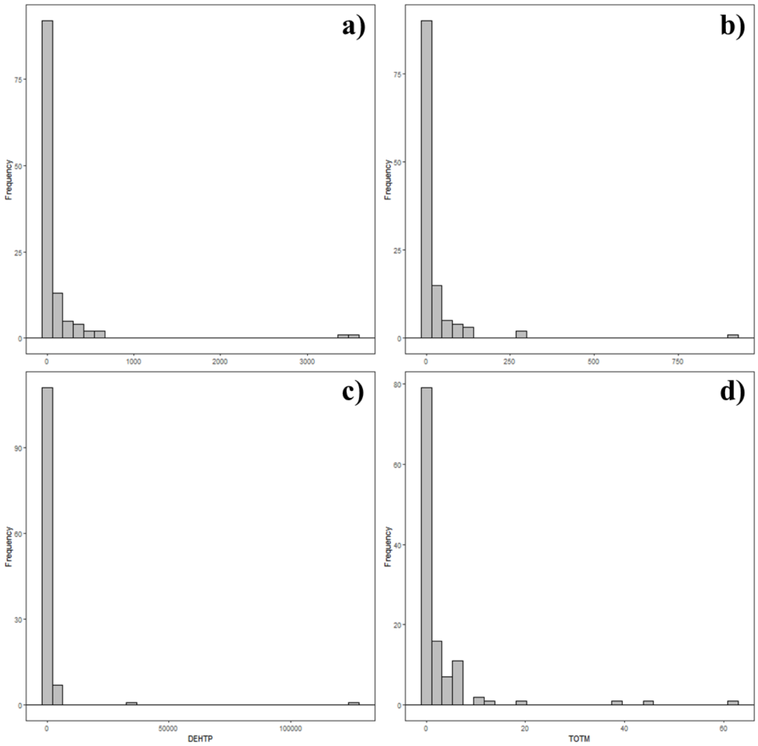

Figure S7. The concentration profiles of NPPs in ACCD. a) is ATBC, b) is DEHA, c) is DEHTP, and d) is TOTM.

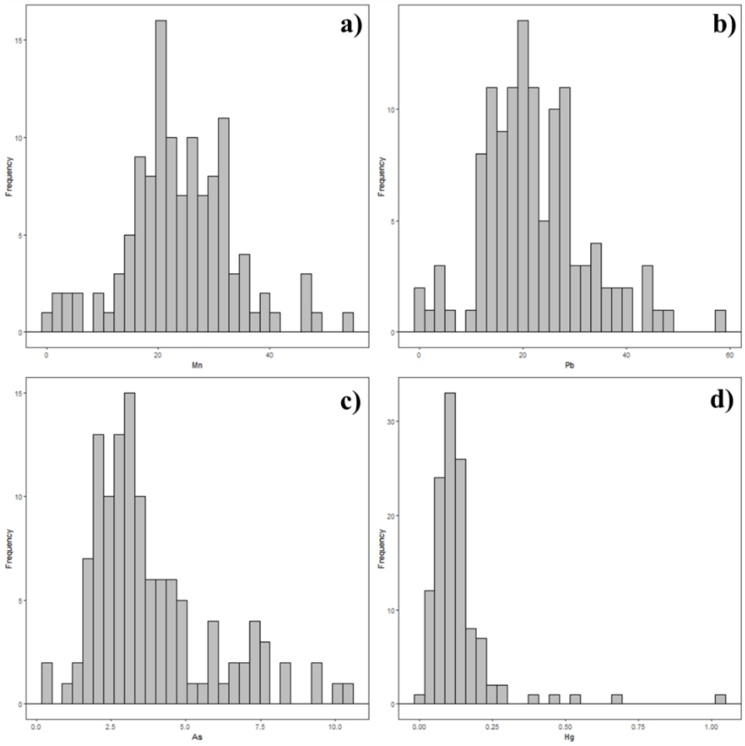

Figure S8. The concentration profiles of heavy metals in ACCD. a) is Mn, b) is Pb, c) is As, and d) is Hg.

국문초록

집 먼지 내 EDCs, 중금속 및 집 먼지 진드기 알레르겐의 종합평가

김 동 현

서울대학교 보건대학원

환경보건학과 환경보건학 전공

지도교수 이 기 영

집 먼지는 내분비교란물질 (Endocrine Disrupting Chemicals, EDCs), 중금속 및 집 먼지 진드기 알레르겐을 포함한 다양한 오염물질의 저장소이다. 집 먼지 내 유해물질에 장기간 노출되면 건강상 악영향을 야기할 수 있지만, 집 먼지에 포함된 다양한 화학물질과 생물학적 유해물질을 종합적으로 평가한 연구는 없다. 본 연구의 목적은 집 먼지에 포함된 다양한 유해 인자의 특성을 종합적으로 평가하고, 농도에 영향을 끼치는 실내 주거환경 요인 및 영유아의 경로별 노출량을 평가하는 것이다.

집 먼지 내 EDCs와 중금속 분석을 위해 2021년 4월과 5월 서울과 경기도의 107가구와 120가구에서 각각 107개의 침강먼지 (Settled House Dust, SHD)와 120개의 공기청정기포집먼지 (Air Cleaner Captured Dust, ACCD) 샘플을 수집하였다. 집 먼지 내 진드기 알레르겐 분석을 위해 SHD를 수집한 107가구 중 30개 가구를 모집하여 30개의 침구 먼지 (bedding dust) 샘플을 수집하였다. 모든

참가자는 주택 및 생활 관련 요인으로 구성된 설문지를 작성하였다. 집먼지 내 유해물질은 유기인계 난연제 (Organophosphorus Flame Retardants, OPFR) 18종, 프탈레이트계 가소제 (Phthalate Esters, PHTH) 16종, 비프탈산계 가소제 (Non-Phthalate Plasticizers, NPP) 5종, 중금속 7종, 집먼지 진드기 알레르겐 2종 (Dermatophagoides farinae type 1, Der f 1; Dermatophagoides pterynossynus type 1, Der p 1)이 정량 분석되었다. 물질 간 관계를 평가하기 위해 Pearson 상관 분석이 수행되었으며 연관 요인을 식별하기 위해 다중회귀분석 (MLR)이 진행되었다. 영유아의 경로별 노출량을 비교하기 위해 SHD 및 ACCD 내 유해물질 농도와 국립환경과학원 (National Institute of Environmental Research, NIER)에서 차용한 노출 계수로 섭취량과 흡입량을 추정하였다.

SHD에서 가장 높은 농도로 검출된 화합물은 NPPs이었으며 PHTHs 및 OPFRs이 그 뒤를 이었다. 반면 ACCD는 반대의 순서였다. 모든 SHD 샘플에서 높은 농도의 Cd, Mn, Cr, Pb, As, Ni 및 Hg가 검출된 반면, ACCD에서의 검출률은 유의하게 낮았다. 집 먼지 진드기 알레르겐은 Der f 1의 수준이 Der p 1에 비해 현저히 높았다. SHD 내 오염 물질은 대부분의 물질이 상관성이 낮았던 반면 ACCD 내 대부분의 화학물질은 유의한 양의 상관 관계가 관찰되었다. ACCD와 SHD 모두 EDCs 농도는 전자제품과 향초 사용과 유의한 연관성을 보였던 한편 SHD 내 중금속은 연소 활동과 높은 연관성을 보였다. 집 먼지 진드기 알레르겐은 거주자의 수 및 반려동물의 유무와 유의한 연관성을 보였다. 그러나 대부분의 유해물질은 환기, 진공청소 빈도, 그리고 바닥 청소 유무에 따라 감소하는 경향을 보였다. 대부분의 화학 물질은 흡입에 비해 섭취를 통한 노출량이 훨씬 높았다. 화학물질의 흡입 노출은 SHD의 농도를 이용한 평가방법에 비해 ACCD의 농도를 이용한 방법이

유의하게 높았다.

본 연구는 SHD와 ACCD 내 EDCs, 중금속 및 집 먼지 진드기 알레르겐을 종합적으로 평가하였다. 조사 결과 다양한 발생원에서 비롯된 여러가지 오염물질이 실내환경 내에 존재했다. 특히, 가전제품과 거주자의 생활패턴이 집 먼지 내 오염물질 수준에 영향을 미치는 것으로 나타났다. 또한 영유아의 집 먼지 내 오염물질 섭취량은 흡입에 비해 섭취가 높았으나 집 먼지 내 오염물질의 흡입 노출에 대한 정량적인 평가방법이 없기 때문에 후속 연구가 필요한 것으로 사료된다. 대부분의 사람이 실내에서 오랜 시간을 보내기 때문에 집 먼지로 인한 다양한 유해물질의 노출 가능성이 있다. 따라서 집 먼지 내 유해물질 수준을 줄이기 위한 적절한 조치가 필요하다.

주요어 : 침강먼지; 공기청정기포집먼지; 내분비교란물질; 중금속; 집 먼지 진드기; 주거환경 요인; 노출량; 영유아

학번 : 2020-21089