Chemicals in European residences—Part II: a review of emissions, concentrations, and health effects of Semi-Volatile Organic Compounds (SVOCs)

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Review

Chemicals in European Residences—Part II: A Review of Emissions, Concentrations, and Health Effects of Semi-Volatile Organic Compounds (SVOCs)

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Abstract: This comprehensive review reports on concentrations, sources, emissions, and potential health effects from Semi-Volatile Organic Compounds (SVOCs) identified in the internal home environment in European residences. A total of 84 studies were identified, and concentrations were collated for inhalation exposure from dust, air and aerosol. A total of 298 individual SVOCs were identified and 67 compounds belonging to eight chemical classes: phthalates, flame retardants, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), per- and polyfluorinated alkyl substances (PFAS), biocides, bisphenols and musks were prioritised. Phthalates are the most abundant SVOCs with DEHP being the most abundant in both the dust and aerosol phases (WAGMs 426.4 μg g^{-1} and 52.2 ng m^{-3}, respectively) followed by DBP for dust (WAGMs are 95.9 μg g^{-1}). In the air, the most abundant SVOCs are DiBP (284.1 ng m^{-3}), DBP (179.5 ng m^{-3}), DEHP (106.2 ng m^{-3}) and DMP (27.79 ng m^{-3}). Chemicals from all SVOC categories are emitted from building and construction materials, furnishings and consumer products, especially phthalates. Both legacy chemicals and their alternatives were detected. Complexities of reporting on SVOCs included differing sampling methodologies, multiple standards in their definition, lack of industry data, and toxicological data focused primarily on ingestion not inhalation exposures. Further research is recommended to develop the evidence base for potential health effects including via inhalation, reporting of emission rates and undertaking future monitoring studies.

Keywords: SVOCs; indoor; European residences; emissions; health effects

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1. Introduction

In developing and developed countries, people spend a large part of their lives in indoor environments and there are several factors that can impact the indoor air quality. Following on from a literature review on Volatile Organic Compounds (VOCs) in European residences [1], in this second part, we review literature on emissions, concentrations and health effects from Semi-Volatile Organic Compounds (SVOCs) in European homes.

SVOCs have been defined in various ways, including the WHO definition of organic compounds with boiling points within the range from (240 °C to 260 °C) to (380 °C to 400 °C) [2], or according to Weschler and Nazaroff [3] as organic compounds with vapour pressures between 10^{-14} and 10^{-4} Standard Atmospheric Pressure (atm) (10^{-9} to 10 Pa), which corresponds to saturated mixing ratios of 0.001 ppt to 100 ppm, assuming 1 atm of total air pressure. Since we commenced this review, the International Organization for Standardization (ISO) [4] has defined an SVOC as an organic compound eluting after n-hexadecane on a 5% phenyl 95% methyl polysiloxane phase capillary gas chromatography column. Boiling point is a poor measure of volatility because many of these chemicals decompose at temperatures below their boiling point yet can still be found intact in the air/gas phase. In this review, we follow the methodologies used in Part 1 (Halios et al. [1]) and by (WHO [2]) and have not used the ISO 16000-6 definition as it was published once the review had been undertaken; however, its implications are discussed in a later part of this work (ISO [4]).

SVOCs are found in both settled dust and indoor air (gas and particulate phase) (WHO, [2]). Lucattini et al. [5], describe house dust as a complex mixture of biological matter from indoor aerosols and soil particles.

Given the differences between indoor and outdoor concentrations, coupled with humans spending more time indoors than outdoors, total exposure to a given SVOC may be strongly influenced by indoor hygrothermal conditions (temperature and relative humidity) and processes (e.g., various sources including building materials, furniture, heating sources and occupant behaviour and materials [3]. Increasing airtightness of homes to improve energy efficiency will affect ventilation rates and impact all three phases of SVOCs in the indoor environment [6].

Overall, exposures to SVOCs can occur via inhalation, ingestion, and dermal pathways. Food consumption is another exposure pathway for SVOCs, since many are food contaminants, are present in food contact materials or have been identified when exposed to fumes when cooking typical Chinese dishes, dependent on the cooking style and product being used in the cooking process [7]; however, this is outside the scope of this review. Inhalation exposures depend on the airborne concentrations of SVOCs, both gaseous and sorbed to suspended particles [3], and this is the focus of the current review.

The SVOC compounds that are observed in indoor environments were identified by Weschler and Nazaroff [3] and can be summarised into eight chemical classes: phthalates, flame retardants (FR), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), per- and poly-fluorinated alkyl substances (PFAS), biocides (pesticides/herbicides/fungicides), bisphenols and musks. The SVOC main uses are reported in Table 1.

Table 1. Uses of SVOCs.

SVOC	Uses
Phthalates	Used mainly as plasticizers which, when added to plastic, make it stronger and more flexible; they are also used as film-forming agents, solvents and denaturants in body care products, soft polyvinylchloride (PVC) products and food grade products.
Brominated Flame Retardants (BFRs)	Since the 1930s, flame retardants (FRs) have been used in various products (e.g., plastics, textiles, electrical equipment) to make them less flammable. One of the most widely used FR classes since the 1970s are BFRs that are consistently present in large quantities in consumer products such as plastics, textiles, furniture, television sets, synthetic building materials, cars, and computers to prevent formation of flames. They are described as either reactive or additive dependent on whether they form chemical bonds with the materials they are incorporated into or not. Additive FRs, including polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCDD), are added to foams in furniture.

	Besis and Samara [8] report that PBDEs have been massively produced and extensively used in numerous household products, providing longer escape times in case of fire, as well as reducing damage to property. Additive FRs are much more likely to leach out of goods and products than reactive FRs.
Polyaromatic Hydrocarbons (PAHs)	PAHs emanate from combustible products including vehicles, smoking, heating, and consumer products. PAHs can be present in the gas and airborne particulate phase [3].
Polychlorinated biphenyls (PCBs)	PCBs have been used mainly as dielectric fluids in electronic applications, and in building materials (e.g., elastic sealants, glue for double-glazed windows and paints to enhance elasticity and durability) since the late 1920s [9].
Per-and Polyfluorinated Alkyl Substances (PFAS)	PFAS are synthetic chemicals that contain strong thermally and chemically stable C–F bonds which are highly hydrophobic, lipophobic, and resistant to oxidation; they are used in commercial products and industrial applications for their water-resistant, stain-resistant, flame-resistant, and anti-stick properties [9]. According to Simonetti et al. [10], they are pollutants of increasing interest. They have been produced since the 1920s, with perfluoro-octanoic acid (PFOA) and perfluoro-octane sulfonic acid (PFOS) being the most extensively used and studied [11].
Biocides	Biocides are inherently toxic chemicals used to kill or control pests, including fungi, weed plants, insects and rodents, and include both banned “legacy” (e.g., DDT and hexachlorocyclohexanes) and currently used pesticides (e.g., chlorpyrifos and permethrin, Cao [12]).
Bisphenols	Bisphenols including bisphenol A (BPA) are a class of chemicals that are used as additives and/or reactive raw materials in polycarbonate plastics, plastic linings for food containers, dental sealants and thermo-sensitive coatings for paper products [13]. Human exposure to BPA is of concern, and prohibition has been implemented in the European Union for BPA-based bottles and packaging since 2011 [14]. This prohibition has led to replacement, including by related bisphenols, e.g., bisphenols S, F, M, B, AP, AF and Bisphenol A diglycidyl ether (BADGE) [15].
Musks	Originally, natural musk fragrances were mostly extracted from exocrine gland secretions of the musk ox (*Ovibos moschatus*) and musk deer (*Moschus moschiferus*). These days, synthetic substances, aromatic nitro-musks (e.g., musk ketone and musk xylene) and polycyclic musks, are industrially and commercially produced in large quantities. Due to their musk-like odour and their binding ability, they are widely employed for cosmetics and perfumes, cleaning products, polishing and washing agents, household products, and aromatic oils.

For some chemical classes such as flame retardants, pesticides and plasticizers, concentrations are available for indoor air and dust but are scarce for consumer products such as computers, televisions, furniture, and carpets, and often only the presence of chemicals is reported [5].

Due to their physicochemical properties, SVOCs partition strongly between indoor air, surfaces, particles, and dust [16]; therefore, sampling each will be reported separately for the air and dust phase. The most common chromatographic techniques applied for separation, detection, and quantitation of SVOCs are Gas Chromatography (GC) and High-Performance Liquid Chromatography (HPLC), usually coupled with Mass Spectrometry (MS) [17].

SVOCs are associated with various health effects; in this review, we focused on the same health endpoints as Part 1 [1] for VOCs (Respiratory, Cardiovascular, Neurological, Carcinogenic, and irritant), and we also considered adverse endocrine effects. This review will report on evidence from identified human or animal inhalation studies and will also use the toxicological profiles from recognised agencies including World Health Organization (WHO), Agency for Toxic Substances and Disease Registry (ATSDR), US Environmental Protection Agency (US-EPA) and European Chemicals Agency (ECHA), to assess health effects from the identified SVOCs.

The aim of the current scoping review is to report on concentrations, emissions, and potential health effects from SVOCs identified in European residences. The results from this review will be used both to parameterise and validate a modelling tool to assess exposure to SVOCs, which is currently under development.

Legislative Restrictions: "Legacy" and "Novel" Chemicals

Due to their potential adverse environmental and health effects, the manufacture and use of several of these chemicals have been banned or restricted in many countries and they are being replaced by other products. For example, the use of PCBs was banned in most countries during the late 1970s due to their persistence in the environment and documented adverse environmental and health effects [18]. The use of the most potentially harmful phthalates is restricted in toys and products intended for infants and toddlers (EFSA [19]). PFOA (Perfluoro-octanoic acid) and PFHxS (Perfluorohexane sulfonic acid), their salts and related compounds are listed for elimination, and PFOS and its salts and related compounds are restricted under the Stockholm Convention on persistent organic pollutants (POP), based on their persistence in the environment and in vivo and in vitro evidence for adverse effects on human health, such as hepatotoxicity, neurotoxicity, reproductive toxicity, immunotoxicity, thyroid disruption, cardiovascular toxicity, pulmonary toxicity and renal toxicity [20].

The Stockholm Convention [21] on POPs is an environmental treaty that was signed in 2001 and came into force in 2004, and its objective is to protect human health and the environment. This Convention requires countries to eliminate (Annex A), restrict (Annex B) or reduce (Annex C) certain chemical and their by-products. Several biocides, flame retardants (PBDEs and HBCDD), PCBs and PFAS and their related chemicals are included in these annexes. The Stockholm convention reports on these restrictions, and for chemicals whose use has been discontinued or restricted ("legacy" chemicals) alternatives ('novel' or 'emerging' chemicals) are proposed for use. A summary of these legacy and alternative chemicals can be found in Supplementary Materials (S1).

Some legacy phthalates are currently included in REACH, 2018 Annex XVII list of restricted substances [22]: DEHP, DNBP, BzBP, DINP and DIDP in PVC products, toys and childcare articles must not exceed 0.1% weight per weight (*w*/*w*) of the plasticized material [22]. In addition, DEHP has been listed in category 1B of substances known, or presumed, to have carcinogenic effects in animals, based on the Globally Harmonized System of classification and labelling of chemicals (GHS). Toxicological information concerning phthalates is largely available, but this is lacking for their alternatives [22].

PFAS, PBDE, PCBs, Dichlorvos (pesticide), DEHA (phthalate substitute) and tetrabromobisphenol A (TBBPA, novel flame retardant) are also being evaluated by The Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT), an independent UK scientific committee that provides advice to Government Departments and Agencies, with a focus on the potential risk of ingestion especially in the infant diet. However, the HBCDD statement [23] notes that infants and young children can be exposed to HBCDDs through their presence in breast milk and other foods. In older infants and young children, swallowed domestic dust is also a source of exposure to

HBCDDs. Given that uses of HBCDDs are being phased out because of inclusion in the Stockholm convention on POPs, and that the main source of exposure to residual environmental HBCDDs is ingested domestic dust, the priority is for continued monitoring of levels of HBCDDs in dust to ensure that they are declining as expected [24].

Alternatives to BFRs include organophosphate flame retardants (OPFRs) classified in three groups based on their composition: alkyl OPFRs, aryl-OPFRs and chlorinated OPFRs [25]. Adverse properties of these are less studied than those of PBDEs, but there is evidence for neurotoxicity, developmental toxicity, damage to the reproductive function, endocrine disruption, and carcinogenicity.

Some flame retardants, including Dechlorane Plus (DP or DDC-CO), HBB, PBT, and DBE-DBCH, have been manufactured for several decades; however, Newton et al. [26] reported that there may be renewed concern due to PBDE restrictions, and that limited data is available on emerging flame retardants (EFRs) especially on production volumes, usages, toxicity, and physical–chemical properties.

2. Methods

The methodology followed was as previously detailed in Part 1 [1] and is according to the PRISMA guidelines [27]. Online databases including Global Health, Scopus and Environment Complete were searched using key terms to identify the literature for SVOC sources, concentrations, and emissions from inside residential properties in European countries. The review required the publications to be written in English and published between 2000 and 2020. The PRISMA diagram is presented in Figure 1. The exact search strings used are detailed in Appendix A.

An inclusion criterion was also applied that required the study to contain monitoring or modelling of SVOCs in a residential environment, laboratory, or chamber. Residential was defined as a house or flat, and other types of residences (care homes and student housing) were excluded. The study was required to have been undertaken within the UK, a European country, or an EU member country to capture the impact of chemical strategies/policies in Europe. Finally, papers presenting only sum and not individual SVOCs were excluded; the focus was on exposure via inhalation in indoor air to SVOCs in resuspended dust, air and aerosols, so ingestion and dermal contact were deemed outside of the scope of this current study.

The search string reported on all studies but was not geographically constrained and therefore articles had to be manually reviewed to determine if they met the inclusion strategy. This provides an explanation for the large number of studies not proceeding in this review.

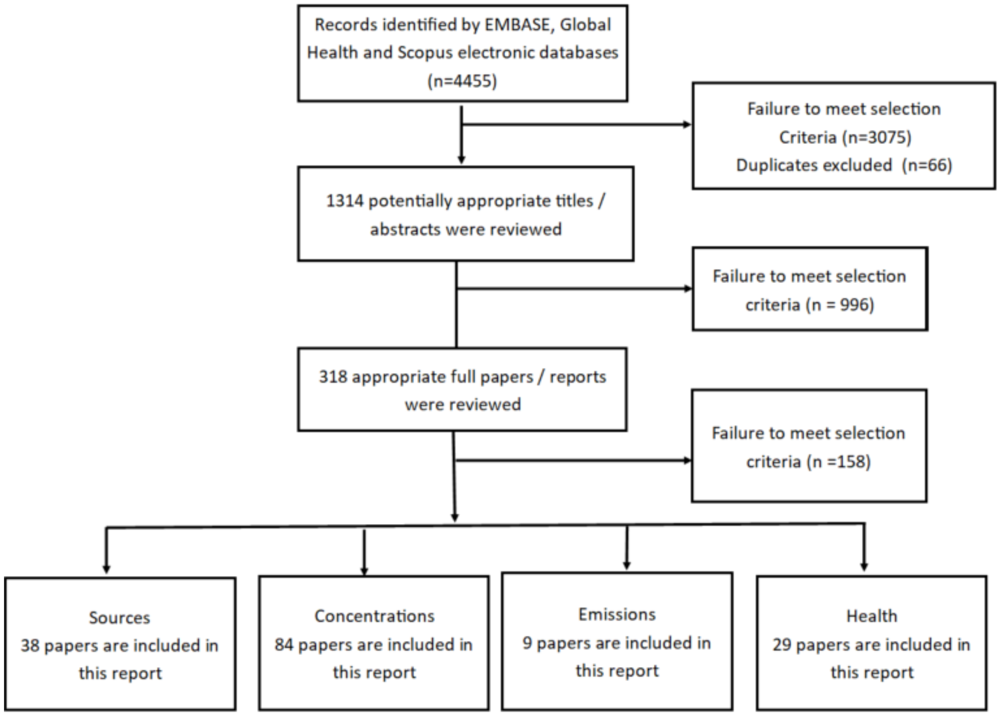

Figure 1. PRISMA diagram.

3. Results and Discussion

The identified SVOCs were selected based on their boiling points (BP) in accordance with part 1 [1] and World Health Organization (WHO) [2]; those chemicals described in the literature as SVOCs but with BP >400 °C in the extracted manuscripts. This shows that temperature is a poor delineator for volatility, and there are limitations related to the available definitions. These compounds need to be assessed, to identify if vapour pressure is a better indicator of whether a substance is likely to be detected in air. In addition, many SVOCs are reported as decomposing on heating but this is unlikely to be achieved in the home environment unless the product was heated or burned; such instances have not been reported. Intact SVOCs are reported in the vapour phase or attached to dust. Lucattini et al. [5] also report that a specific indoor air quality index for SVOCs does not exist.

3.1. Overview and Concentrations

Monitoring Techniques

- SVOCs sampling in Air

Passive air sampling, over periods of weeks or months, has been widely used to capture SVOCs in both gas and aerosol phases by sorbents via diffusion mechanisms [2]. The substance most widely used in passive samplers (PASs) is polyurethane foam (PUF) due to its retention capacity, but semipermeable membrane devices (SPMD), poly-dimethylsiloxane (PDMS) and XAD-2 resin-based passive air samplers (XAD-PASs) are also used [15]. Active air sampling, over days to hours, involves a pump that generates flow, a sampling medium onto which the flow is driven, and a flow calibrator that determines the flow rate [16].

- SVOCs sampling in Dust

The most common sampling method for dust-phase SVOC is vacuuming: a cellulose thimble inserted between the cleaner tube and the crevice tool is used to capture dust samples and avoid contamination from the plastic parts of the vacuum cleaner [16]. Other common sampling strategies for indoor dust analysis from surfaces involve surface wiping using surgical gauze pads soaked with a solvent [28] or cotton sponges and PUF foam rollers [29]. Passive settled dust accumulation has also been used [30].

After collection, the samples undergo extraction, concentration, and clean-up to prepare them for the subsequent chemical analyses [16]. Solvent extraction includes techniques such as Soxhlet extraction (extraction into a solvent under reflux, De Castro and Priego-Capote [31]), accelerated solvent extraction (samples are extracted into solvent under increased temperature and pressure—e.g., Richter et al. [32]), ultrasonication extraction (solvent extraction enhanced using high frequency sound to disrupt sample matrix—e.g., Bi et al. [33]), or microwave-assisted extraction (where microwaves are used to break down sample matrix—e.g., Bouras et al. [34]). Impurities and interferences are removed from the extracted solutions by centrifugation and/or filtration, to protect analytical instruments and improve sensitivity, and sample volume is reduced by evaporation to enable detection [16].

Emissions from products or materials used in indoor environments using test chambers and test cells are described in the revised ISO 16000-6:2021, which uses sorbent sampling tubes with subsequent thermal desorption (TD) GC-MS analysis with or without an additional flame ionisation detector (FID) [35].

The sampling strategies for PCBs, polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and PAHs are described in ISO 16000-12:2008; for dioxin-like PCBs, PCDDs and PCDFs, details are in ISO 16000-13:2008 (AQEG [35]). Specific protocols for some SVOCs (phthalates, musks, FRs and OPFRs) are outlined in World Health Organization (WHO) [2].

3.2. Monitoring Results

We identified 298 individual SVOCs within 84 studies that reported concentrations in the home environment (summary in Supplementary Material S2 and S3). A total of 14 studies reported only air concentrations, 50 studies only dust concentrations and 20 studies reported both dust and air concentrations. A glossary can be found in Appendix B which provides the full chemical name, abbreviation, group and Chemical Abstract Service (CAS) number.

41 studies reported only on flame retardants (FRs), six only on phthalates, and five studies measured several SVOCs from different classes at the same time. The remaining studies either reported on individual SVOCs (e.g., three for pesticides, four for PFAS) or two chemical families (e.g., four on FRs and phthalates). The largest number of studies were conducted in Germany (13), Sweden (12) and the UK (9), and 7 studies reported concentrations from multiple countries.

According to Malliari and Kalantzi [36], large geographical variations were observed for all brominated flame retardants (PBDE, HBCDD, TBBPA), with the highest concentrations of PBDEs being measured in North America (BDE-47) and Europe (BDE-209), where higher concentrations of PBDEs are present in dust from houses, day-care centres, and primary schools. Interestingly, in Asia, most studies did not find elevated levels of BDE-47 except where houses were near e-waste recycling plants (reported maximum concentration is 3440 ng/g). Fewer studies have focused on novel and emerging FRs (NFRs or EFRs), of which decabromodiphenylethane (DBDPE) has the highest concentration in indoor environments, especially in China [36].

The same author reports a smaller number of studies for BDE-47 and BDE-209 indoor air concentrations, presumably due to the ease of sampling dust. In the home environment, the maximum concentration for BDE-209 was 4150 pgm^{-3} in Norway.

The reported concentrations were used for the calculation of the Weighted Average Geometric Mean (WAGM), as previously outlined in Halios et al.[1].

Given the large number of individual SVOCs, only the 67 SVOCs with reported health effects via inhalation in European residential microenvironments will be discussed in Table 2, based on their adverse health effect endpoints (i.e., irritation of the upper airway system and eyes, carcinogenic, cardiovascular, endocrine, respiratory, and neurological). Among these, the most widely studied category is flame retardants (36 studies) followed by phthalates (15 studies), pesticide/biocide (nine studies), PCBs and PFASs (seven studies each) and PAHs (five studies). Five studies focused on bisphenol, alkylphenols and plasticizers. Reflecting the studies included here, flame retardants and pesticides are the most well-represented groups (each accounting for 25% of the 67 chemicals), whilst PCBs and PAHs are the least represented (5% and 7%, respectively). PCB congeners 18, 28, 101, 118, 138, 153 and 180 are among the most commonly occurring PCBs in indoor air.

Table 2. Most health-relevant and commonly measured 67 individual SVOCs identified through measurements in European residences: their calculated Weighted Average Geometric Mean (WAGM) and health effects. X indicates a reported health endpoint.

		WAGM			**Health End-points**					
Chemical	**Uses**	**Dust (μgg⁻¹)**	**Air (ngm⁻³)**	**Aerosol (ngm⁻³)**	**Irritant**	**Carcinogen**	**Cardiovascular**	**Endocrine**	**Respiratory**	**Neurological**
Phthalates										
Benzyl-Butyl Phthalate (BBP/BBzP/BzBP)	Plasticizer mainly used in PVC for vinyl floor tiles, vinyl foams, and carpet backing, sealants, foams, adhesives, coating and inks, and cosmetics	26.79	5.95	1.95				x		
Dibutyl phthalate (DBP)	Materials for floor coverings (PVC, linoleum, rubber, poly-olefine, vinyl), carpet, wallpaper, vinyl wallcoverings	95.9	179.5	1.439	x			x		x
Di(2-ethylhexyl) phthalate (DEHP)	Stick incense, vinyl flooring, low density polyethylene, wallpapers, refrigerator strip, electrical wire, wax, vinyl wallcoverings	426.44	106.21	52.18	x	x		x	x	x
Di-isobutyl phthalate (DiBP)	Artists' acrylic paint, stick incense, low density polyethylene, wallpapers, and vinyl wallcoverings	25.64	284.07	1.55				x		
Dimethyl phthalate (DMP)	Plasticizer	15.53	27.79	0.015	x			x		
Flame retardants										
Benzene, 1,2,3,4-tetrabromo-5-(2,3,4,6-tetrabromophenoxy) (BDE 196)	Housings of electrical and electronic equipment	0.0016				x				
DecaBDE(BDE 209)	Electronic devices (game console, TV, radio, DVD/CD player, laptop)	0.45	0.017		x	x		x		x
2,4-Dibromo-1-(4-bromophenoxy)benzene (BDE 28)	TV set (old)	0.00038	0.0023	0.0000002	x					
Hexabromobenzene (HBBz)	Polymers, additives in textiles, electronics, and plastics	0.0089			x				x	x

beta-Hexabromo-cyclododecane (β-HBCD/β-HBCDD)	TV, thermal insulation and electronic equipment	0.063	0.0003		x		x		
Meta, meta, para-tricresyl phosphate (mmp-TMPP)	Electronic devices (game console, TV, radio, DVD/CD player, laptop)	0.23			x		x		x
Nonabromodiphe-nyl ether (BDE 206)	Plastics used in consumer products	0.023	0.0086			x			x
2,2′,3,3′,4,4′,5,6,6′-nonabromodiphe-nyl ether (BDE 207)	Plastics used in consumer products	0.017	0.0021			x			
2,2′,3,4,4′,5,5′,6-Oc-tabromodiphenyl ether (BDE 203)	Housings of electrical and electronic equipment	0.0016				x	x		
2,2′,3,3′,4,4′,6,6′-Octabromodiphe-nyl ether (BDE 197)	Housings of electrical and electronic equipment	0.0018	0.0006				x		
2,2′,4,4′,5-Pen-tabromodiphenyl ether (BDE 99)	TV set (old)	0.028	0.0040	0.0057			x		x
Polybrominated biphenyls (PBB)	Plastics in computer monitors, televisions, textiles, and plastic foams	0.00019	0.0056			x		x	x
2,2′,4,4′-Tetrabro-modiphenyl ether (BDE 47)	TV set (old)	0.015	0.012	0.0076			x		
1,2,4,5-tetrabromo-3,6-dimethylben-zene (pTBX)	Flame retardant		0.00029		x				
1,2-Bis(2,4,6-tribro-mophe-noxy)ethane (TBE)	Solvents, flame retardant in synthetic fibres, polysty-rene, polyurethanes, and polyolefins	0.0053						x	x
2,2′,4-tribromodi-phenyl ether(BDE 17)	Plastics in consumer products	0.000086	0.012		x				
tri-n-bu-tylphosphate (TBP)	Paints, colorants, and pigments, multi-component crafting kits, pottery making, ink, medical and dental supplies and equipment (e.g., wheelchairs, colostomy bag)			0.014	x	x			x
Trixylenyl phos-phate (TXP)	Flame retardant	0.015			x		x		
Polyaromatic hydrocarbons									
Benz[a]anthracene	Primer, wallpaper paste, latex and dispersion paint, plaster, vinyl and ingrained wallpaper, candles, in-cense sticks	0.017		0.030	x	x		x	

Benzo[a]pyrene	Primer, wallpaper paste, latex and dispersion paint, plaster, vinyl and ingrain wallpaper, candles, incense sticks, coal tar-based glue in parquet flooring	0.0092		0.069	x	x		x	x	x
Benzo[b]fluoranthene	Candles	0.014		0.18	x	x			x	
Chrysene	Candles	0.039		0.053	x	x			x	
dibenz[a,h]anthracene	Primer, wallpaper paste, latex and dispersion paint, plaster, vinyl and ingrained wallpaper, candles			0.012	x	x			x	
Biocides										
Aldrin	Used as an insecticide; banned under annex A of the Stockholm convention			0.0010	x	x	x	x	x	x
Atrazine	Biocide, pesticide, herbicide			0.0021	x			x	x	x
Clofenotane (p,p′-DDT (4,4′-DDT))	Insecticide, pesticide	0.11	0.042		x	x	x	x		x
cypermethrin	Pesticide, insecticide, used mainly in households	0.18			x	x		x	x	x
Diazinon	Biocide, insecticide			0.022	x	x			x	x
Dieldrin	Biocide, insecticide			0.0029	x	x	x	x	x	x
α-endosulfan	Insecticide			0.0066					x	x
Endrin	Biocide, insecticide			0.0053				x		x
Alpha-hexachlorocyclohexane (α-HCH)	Insecticide, herbicide and used in personal care products	0.002	0.067	0.0011		x				
beta-hexachlorocyclohexane (β-HCH)	Insecticide, herbicide and used in personal care products	0.0037	0.013			x	x	x	x	
γ-HCH/lindane	Moisturisers and shampoos, biocide, insecticide	0.30	0.90	0.0029	x	x	x			x
Metolachlor	Biocide, insecticide			0.00053	x	x	x			x
Pentachlorophenol (PCP)	Biocide, insecticide	0.41	2.4		x	x		x	x	x
permethrin	Construction materials—flooring, tiles, sinks, bathtubs, mirrors, wall materials/drywall, wall-to-wall carpets, insulation, shampoos, make-up and cosmetic products, general pesticide products, insect repellents, biocide	0.21		0.059	x				x	x
Permethrin (fine dust)		9.65			x				x	x
Permethrin (coarse dust)		7.85			x				x	x
Piperonyl butoxide (PBO)	Beauty products and insecticide	0.22			x					
Polychlorinated biphenyl										
2,2′,3,3′,4,4′-Hexachlorobiphenyl, aroclor 1260 (PCB 128)	Coolants and lubricants in transformers, capacitors, and other electrical devices (such as fluorescent lights and refrigerators) produced before 1977		0.0008		x	x		x	x	x
2,2′,4,4′,5,5′-Hexachlorobiphenyl (PCB 153)	Coolants and lubricants in transformers, capacitors, and other electrical devices (such as fluorescent lights and refrigerators) produced before 1977	0.00025	0.021	0.0024	x	x		x	x	x
2,2′,4,5,5′-Pentachlorobiphenyl (PCB 101)	Coolants and lubricants in transformers, capacitors, and other electrical devices (such as fluorescent lights and refrigerators) produced before 1977	0.000088	1.22	0.0018		x		x		x
2,3′,4,4′,5-Pentachlorobiphenyl (PCB 118)	Coolants and lubricants in transformers, capacitors, and other electrical devices (such as fluorescent lights and refrigerators) produced before 1977	0.000046	0.26	0.0018		x		x		x
Perfluoroalkyl and polyfluoroalkyl substances										

10:2 Fluorotelomer acrylate (10:2 FTAC)	Surfactants, lubricants, repellents, consumer products		0.12		x					
6:2 Fluorotelomer methacrylate (6:2 FTMAC)	Construction materials—flooring, tiles, sinks, bathtubs, mirrors, wall materials/drywall, wall-to-wall carpets, insulation, taps and light fixtures	0.020	0.020		x					
6:2 Fluorotelomer alcohol (6:2 FTOH)	Surfactants, lubricants, repellents, consumer products	0.040	1.011		x					
8:2 Fluorotelomer acrylate (8:2 FTAC)	Surfactants, lubricants, repellents, consumer products		0.27		x					
Fosamine (FOSA)	In protective coatings for fabrics and carpet, paper coatings, insecticide formulations, and surfactants	0.0044			x	x	x			
N-Methylperfluorooctanesulfonamidoethanol (MeFOSE)	Surfactants, lubricants, repellents, consumer products	0.033	0.090		x					
Perfluorodecanoic acid (PFDA)	Surfactants, lubricants, repellents, consumer products	0.0012			x	x		x		
Perfluorododecanoic acid (PFDoA)	Surfactants, lubricants, repellents, consumer products	0.0016			x					
Perfluorohexanesulfonic acid (PFHxS)	Previously used in firefighting foam, carpet treatment solutions and as a stain and water repellent	0.0034				x		x		x
Perfluorononanoic acid (PFNA)	Used as a surfactant, lubricant, textile finishing agent, and in liquid crystal display panels	0.00063			x	x		x		x
Perfluorooctanoic acid (PFOA)	Used to produce fire-fighting applications, cosmetics, greases, lubricants, paints, polishes, and adhesives	0.0061			x	x	x	x	x	x
Perfluorooctanesulfonic acid (PFOS)	Surfactant in fire-fighting foams, alkaline cleaners, floor polishes, active ingredient for ant bait traps, protective surface coatings (i.e., carpets, fabrics, and food packaging), and consumer products	0.0037			x	x	x	x	x	x
Perfluoropentanoate (PFPA)	Surfactants, lubricants, repellents, consumer products	0.006			x					
Bisphenol										
Bisphenol-A (BPA)	Vinyl flooring, thermal paper, toys, medical devices, printer paper, coating in food storage containers	0.31		0.54	x			x		
Bisphenol F (BPF)	Epoxy resins, lacquers, varnishes, liners, adhesives, plastics, water pipes, dental sealants, and food packaging	0.052			x					
4-n-nonylphenol (4-NP)	Children's art supplies and toys, blankets, games, baby bottles and pacifiers, dolls, electronics, dishwasher detergents	0.018		0.0029				x		
4-n-octylphenol (OP)	Non-ionic surfactants, resins, fungicides, bactericides, dyestuffs, adhesives, rubber chemicals, plasticizers and antioxidants	0.068			x				x	
4-tert-butylphenol	Dishwasher detergents and stain-related products			0.0062	x				x	
4-tert-octylphenol	Used as an intermediate for surfactants, resins, rubber additives, antioxidants, adhesives, dyestuffs, fungicides, and bactericides			0.0069				x		
Musk										
Triclosan	cosmetics and toilet soaps	0.22		0.082				x		

The categorization of health endpoints for the 67 identified health relevant SVOCs in European residences are presented in Figure 2. Two PFAS (PFOA and PFOS) and four PCBs (PCB-101, PCB-118, PCB-128 and PCB-153) were reported to be associated with all six health endpoints. In total, 44 individual SVOCs were associated with irritation of the upper airway, 28 with carcinogenic effects, 27 with endocrine effects, 20 with neurological effects, 17 with respiratory effects, and six with cardiovascular effects. However, for the endocrine endpoint, the highest association was found with flame retardants and phthalates (six and five individual SVOCs, respectively). It is interesting to note that even though there was only a small number of health studies for PCBs and PAHs in the 67 selected individual SVOCs (5% and 7%, respectively), they are disproportionally highly associated with the carcinogenic health endpoint (18% and 17% of the total chemicals associated with the carcinogenic health endpoint, respectively).

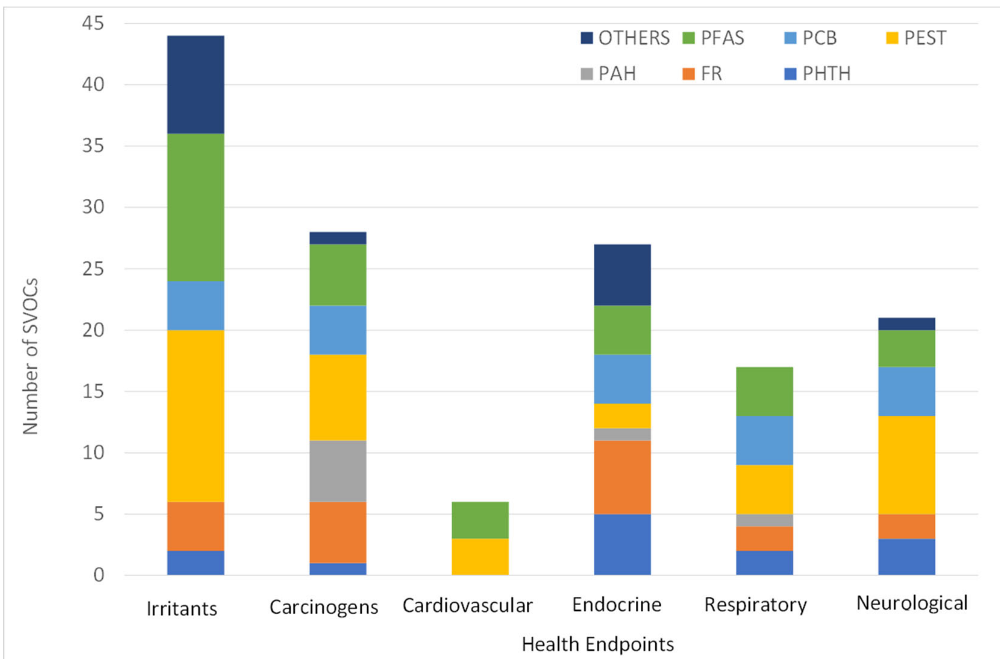

Figure 2. Categorization of health endpoints for the 67 identified health relevant SVOCs in European residences.

The concentrations of the prioritised SVOCs along with those that scored in three or more health endpoints are presented in Figure 3. In general, phthalates are the most abundant SVOCs: DEHP and DBP are the most abundant SVOC in the dust phase (WAGMs are 426.4 μg g^{-1} and 95.9 μg g^{-1}, respectively). In the air, the most abundant SVOCs are DiBP (284.1 ng m^{-3}), DBP (179.5 ng m^{-3}), DEHP (106.2 ng m^{-3}) and DMP (27.79 ng m^{-3}). The concentration range covers mostly seven orders of magnitude (Figure 3).

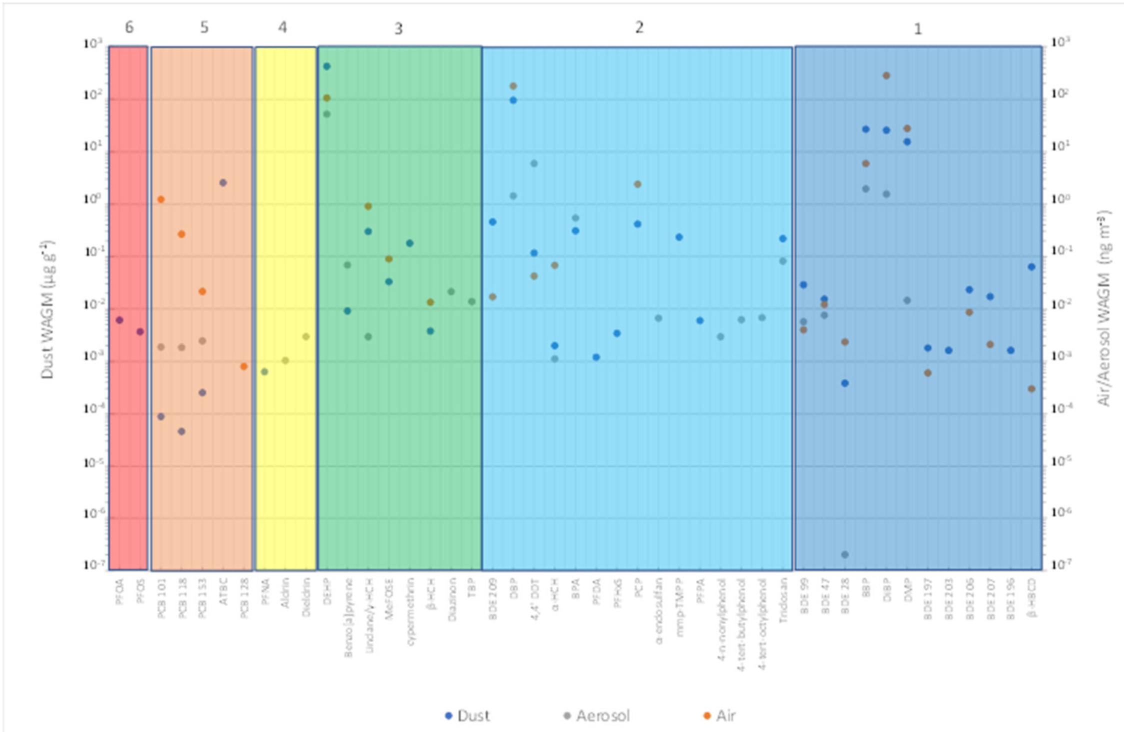

Figure 3. Concentrations of selected SVOCs in residences, with each point representing a weighted average geometric mean concentration. Note that vertical axis is presented on a logarithmic scale. Vertical coloured stripes correspond to number of health endpoints associated with each chemical (i.e., red (six), orange (five), yellow (four), green (three), light blue (two), dark blue (one)).

Based on the 67 chemicals discussed in Table 2, it can be seen in Figure 4 that chemicals from all SVOCs categories are emitted mostly from building and construction materials; in particular, the majority of phthalates are emitted from materials in this category. These findings agree with Lucattini et al. [5]. PAH sources also include incense sticks and candles, whilst PCBs were found only in electronics; Andersson, Ottesen and Volden [37], however, also reported PCBs in soil and plaster samples from buildings. Pesticides have been associated with all source categories.

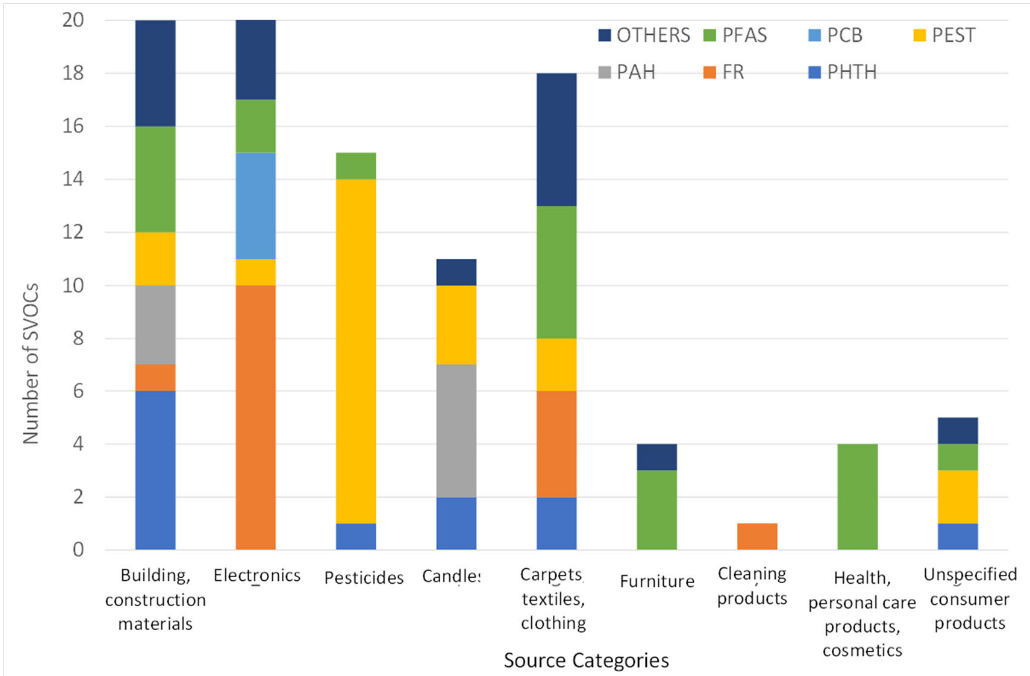

Figure 4. Categorization of sources for the 67 identified health relevant SVOCs in the European residences.

3.3. "Novel" Chemicals

Following concerns that led to inclusion of legacy FRs and phthalates into the Stockholm Convention (discussed above), alternatives have been developed and are already present in the indoor home environment and in humans. Emerging FRs, such as hexabromobenzene (HBB), Dechlorane Plus (DDC-CO), Dechlorane 602 (DDC-DBF) and Dechlorane 603 (DDC-Ant) have been detected in human serum from Norway [38] and there is an increased presence of OPFRs in a variety of materials. While the knowledge base on these alternatives continues to grow, the EU has already introduced restrictions on the use of OPFRs, including TDCIPP and TCPP, based on concerns related to their carcinogenic potency (European Chemicals Agency (ECHA) [39]); (ECHA [40]).

Concentrations of OPFRs from different microenvironments in Rhine/Main, Germany, including seven private homes, were reported in Zhou, Hiltscher and Püttmann [41]. The OPFRs identified included non-chlorinated OPFRs (TEP, TPP, TiBP, TnBP, TBEP, TEHP) and chlorinated OPFRs (TCEP, TCPP, TDCPP). It was noted that cleaning frequency and ventilation could have an influence on the indoor microenvironments' OPFR levels; identifying sources of these chemicals in the indoor environment is therefore important (e.g., TCPP was measured in a classroom where there were no known polyurethane foam-containing materials).

Firemaster 550 was created as a replacement for pentaBDE and is a commercially available chemical mixture of OPFR and FR including EHTBB and BEH-TEBP. Evidence is building for the adverse effects of Firemaster 550, including as an endocrine disruptor in rats and DNA damage in fathead minnows [26].

Tao, Abdallah and Harrad [42] identified EFRs in indoor dust in European residences, but data on concentrations in indoor air is scarce. The same authors report that some EFRs are potentially persistent and bioaccumulative, intensifying human health concerns; animal studies suggest adverse health effects including endocrine disruption, neurodevelopmental and behavioural effects, and possibly cancer.

Demirtepe et al. [43] undertook indoor samples for legacy, current and 'novel' SVOCs. A classification framework was proposed using ingested toxicity reference values (TRVs) which prioritised several PCB congeners (CB-11, 28, 52), Hexachlorobenzene (HCB), BaP and γ-HCH for indoor monitoring. The SVOCs in question are legacy compounds; however, a predominance of the non-legacy PCB congener (CB-11) was observed in indoor dust and air, suggesting modern indoor sources of PCBs. Therefore, attention should be given to a broader set of PCB congeners beyond the standard seven indicator PCBs (18, 28, 101, 118, 138, 153 and 180) which represent legacy PCB uses.

The only EFR identified in Table 2 was HBBz, but concentrations were reported to be low for both dust and indoor air samples (0.04 to 8.9 ng/g in house dust and 4.03 to 4.11 pgm^{-3} in indoor air). The highest concentrations were noted in houses near e-waste recycling areas and other environmental settings including educational establishments and vehicles [36].

Lucattini et al. [5] note that comparison between studies can be hampered due to the lack of harmonized protocols for dust (different units, sample preparation/analytical method, sampling method not standardized). The lack of data on concentrations of SVOCs in consumer goods still represents the biggest obstacle in linking the sources of chemicals to their concentrations in air and dust unless chemicals have very specific uses, e.g., tetrabromo bisphenol A (TBBPA) is only used in circuit boards whereas a pesticide may originate from indoor/outdoor air or be carried in on food.

3.4. Health Studies

In a report on SVOCs health effects in a school environment [44], respiratory health effects were identified from BBP, and also a negative association was found between air flow in the lungs and formaldehyde in the air. PAH was related to both asthma development and exacerbation. In the same study, neurological health effects were also reported including subclinical changes on the caudate nucleus from exposure to PAHs, particularly BaP. Early life exposures to phthalates, bisphenol A, PCBs, PBDE and PAHs were reported to potentially cause neurodevelopmental deficits. In the International Agency for Research on Cancer (IARC) [45] report, PAHs were found to be related to carcinogenicity: BaP was reported as a probable, and chrysene, benzo[a]anthracene, benzo[k]fluoranthene and benzo[b]fluoranthene were reported as possible human carcinogens.

It was also noted by COT that dibenzo[a,l]pyrene should be considered as a highly potent genotoxic carcinogen in experimental animals. In conclusion, there is a need for further consideration of the potential importance of exposure to dibenzo[a,l]pyrene and other highly potent carcinogenic PAHs in air pollution (COT, [23]).

3.4.1. Human Studies

Studies that were identified through the search string and either included human biomonitoring or a health endpoint have been outlined in Table 2 and further details are contained in the Supplementary Material S4 and S5. Studies that included a health questionnaire or medical diagnosis are included in the supplementary health table S6. Several papers referenced potential health effects based on animal studies; however, there were no specific animal studies identified from the papers in this review. Studies on exposure assessment were not considered.

In total, there were 20 human studies identified in this review: seven had investigated phthalates and respiratory effects (Shu et al. [46]; Bornehag et al. [47]; Kolarik et al. [48]; Jaakkola et al. [49,50]; Larsson et al. [51]; Bornehag and Nanberg [52]); ten FR studies were identified: one for respiratory effects (Canbaz et al.[53]), three for neurological effects (Chevrier et al. [54], Roze et al. [55], Herbstman et al. [56]), and six for endocrine effects (Chevrier et al. [54], Johnson et al. [57], Johnson et al. [58], Meeker and Stapleton [59], Stapleton et al.[60], Meeker et al. [61]); Bergh et al. [62] investigated respiratory health effects from FR and phthalates while Heudorf et al. [63] examined respiratory effects from exposure to PAH (BaP) and Deen et al. [64] recently investigated carcinogenicity from exposure to PCBs.

Respiratory

From the ten studies on respiratory effects, eight focused on children and two on adult populations and their exposure to phthalates, FRs, phthalates and FRs combined, and PAHs. From these, five studies undertook either dust or air sampling (two for phthalates, and one each for FRs, phthalates and FRs, and PAH) whilst five phthalate studies did not include any monitoring but used questionnaires to estimate exposure. Six of the ten studies reported an association between exposure to phthalates and respiratory effects.

Seven of the studies focused on association between exposure to phthalates, PVC flooring or wall material and respiratory effects: an association was established in six out of the seven studies. Within the studies that found associations between exposure and respiratory effects, four studies did not undertake any environmental monitoring; further research is required for increasing the evidence base in this area, especially as there is no emission data to report on this source (3.5 emissions).

Based on epidemiological data, Bornehag and Nanberg [52] indicated a possible correlation between phthalate exposure and asthma in children. An association between PVC surface material in the home and airway diseases in children was further reported in the first epidemiological study in Oslo, Norway, and it was also found that the presence of PVC materials increased the risk for bronchial obstruction in small children (Jaakkola et al. [65]; Nafstad et al. [66]). Three subsequent studies from Sweden, Russia and Finland supported these findings, and cross-sectional questionnaire investigations showed that PVC flooring and/or PVC wall covering materials were associated with airway symptoms in children (Jaakkola et al. [49]; Jaakkola et al. [67]; Bornehag et al [68]).

More recently, Jaakkola et al. [50] focused on interior surface material and recent renovations in relation to diagnostic criteria for asthma. The risk of asthma was slightly increased among subjects with plastic flooring, where plastic was present on less than half of the flooring or on half or more of the surface area. Renovations that had taken place at home during the past 12 months were not related to an increased risk of asthma, except in cases of floor-levelling plaster use, where a risk for asthma was observed.

In phthalate toxicology studies reviewed by Jaakkola and Knight [69], two mouse inhalation experiments indicated that mono-2-ethylhexyl phthalate (MEHP, a marker of exposure to DEHP) can modulate the immune response to exposure to a co-allergen. The data suggested a no-observed effect level of 300 μgm^{-3} for DEHP; in this review, the DEHP air-WAGM was found to be 106 ngm^{-3}. Cases of asthma that the authors considered were likely caused by emissions from PVC film. Five epidemiological studies in children showed an association between PVC surface material in the home and the risk of asthma and allergies.

Jaakkola and Knight [69] report that damp can enhance degradation of PVC flooring and result in elevated indoor concentrations of DEHP. Therefore, measurement of dampness should be considered during monitoring studies.

An association was also reported between the concentrations of phthalates in indoor dust and asthma/wheezing in children, particularly for homes with flooring (PVC, linoleum) in bedrooms (Shu et al. [46]; Bornehag et al. [47]; Kolarik at al. [48]; Larsson et al. [51];). Shu et al. [46] concluded that PVC flooring exposure during pregnancy could be a critical period for the later development of asthma in children; therefore, prenatal exposure measurements of phthalate metabolites should be included in future studies.

Polishing products were also found to be a strong source of phthalates, and a dose–response relationship between DEHP in dust and symptoms were observed both in buildings with high and low polish use [49].

Bergh et al [62] concluded that there were no significant relationships between OPFR and phthalate levels and any of the reported symptoms (self-reported asthma and allergy or Sick Building Syndrome—SBS). A limitation of this study was that symptoms were reported as a single frequency for all occupants of the building and not to the level of an individual apartment.

The work of Canbaz et al. [53] was the only respiratory study identified on FR, and there were no positive associations between the exposures to PBDEs and OPFRs and the development of childhood asthma.

Heudorf et al. [63] investigated whether BaP in parquet flooring and glue contributed to reported health effects in children living in these homes. Significant correlations between passive smoking in the household and the reported dermal/bronchial symptoms, nausea, and lack of concentration demonstrated the impact of personal behaviour and lifestyle on the indoor air environments.

The Wilcoxon rank sum test (located in the Supplementary Material S7) indicated that irritation of the upper airway and eyes was associated with higher concentrations in the dust phase. This association might reflect the capacity of large dust particles to deposit on skin and the upper airway.

Neurological

For the neurological endpoints, two studies of FR were identified that found associations with flooring material and with indoor dust, respectively. Chevrier et al. [54] reported that verbal comprehension and working memory scores were lower in children from homes with higher concentrations of BDE-99 and of BDE-209 in dust. It must be noted that even though BDE-99 has been banned, it is still present in the home environment in belongings that predate the ban. Therefore, advice should be provided on how to further reduce exposure to these chemicals in indoor environments including increasing awareness, ventilation, replacement of old furniture and furnishings that may predate FR bans, and dust removal.

Roze et al. [55] reported that FR exposure correlated with worse fine manipulative abilities and attention but better coordination, visual perception, and behaviour. Chlorinated Organohalogen compounds (OHCs) correlated with less involuntary movement and hydroxylated PCBs correlated with worse fine manipulative abilities and better attention and visual perception.

Endocrine

No endocrine studies were located within Europe. Six American studies in adults each found an association between endocrine effects and FRs (PBDE and OPFR).

Carcinogenic

From the PAHs measured in European residences (Table 2), the only well-established carcinogen is BaP (skin and lung carcinogen [70]), which was classified by IARC in Group 2A as probably carcinogenic to humans (IARC [71]). Chrysene, benzo[a]anthracene, benzo[k]fluoranthene and benzo[b]fluoranthene are classified in Group 2B, possible carcinogens [45].

Only one study was identified that investigated cancer risk following residential exposure to airborne PCBs; Deen et al. [64] undertook the first known population-based cohort for residential exposure to airborne PCBs and no association was found between concentrations inside the home and overall cancer risk.

Hermant et al. [72] reported that toxicological studies show acute exposure to permethrin results in minor reversible adverse health effects and chronic exposure is associated with cancers and/or endocrine disorders.

The Wilcoxon rank sum test (located in the Supplementary Material S7) indicated that carcinogenicity was associated with higher aerosol concentrations. The association between aerosol phase concentrations and carcinogens may be related to the penetration of the smaller aerosol particles to the lower respiratory system.

Irritant and cardiovascular

Chronic inhalation exposure to PAH mixtures can be associated with ischemic heart disease and chest and throat irritation, but these associations are based on occupational exposure studies [71]. No studies reported here found either cardiovascular or irritant adverse health endpoints associated with exposure to SVOCs.

3.4.2. Biomonitoring

On reviewing the results of our literature search, 12 studies with biomonitoring data related to indoor exposure to SVOCs were identified.

An association was found between air levels of PCBs and plasma concentrations in adults [73]; FR in dust (BDE-99 and BDE-100) and placenta [74] (TBOEP, TDCIPP and DPHP) and hair/urine [75].

Shu et al. [76] reported an association in pregnant women between urinary phthalates and PVC flooring, and Carlstedt, Jönsson and Bornehag [77] found an association between PVC flooring and phthalate exposure in children.

Four studies report some association of dust and air levels of FR and phthalates with plasma levels in adults and children (Sahlström et al. [78], Tay et al. [79]; Bornehag, Sundell and Sigsgaard [80]; Bertelsen et al [81]).

The three remaining studies (Heudorf et al. [63]; Heudorf and Angerer [82]; Chevrier et al. [54]) report no associations between exposures to BaP in dust and levels in the urine or between levels of FR in dust and in the blood.

Gilles et al. [83] note that a Human Biomonitoring for Europe (HBM4EU) initiative has been conducted in 21 countries and has prioritised the following SVOCs: phthalates and substitute Hexamoll® DINCH, FR and OPFR, PFAS, bisphenols and PAHs, with an aim to establish reference ranges.

Exposure to PBDEs and HBCD show the highest intake during infancy; furthermore, exposure of the general population varies considerably in different parts of the world and even within countries [84]. Total BDE-209 and HBCD intake was reported to be the highest in the UK. For HBCD and all PBDEs except BDE-209, diet accounts for a large proportion of the total intake during infancy in all countries. Fromme et al.'s [84] study concludes that more exposure and toxicological data are urgently needed for an appropriate risk assessment of exposure.

Several factors affect the population's exposure to FRs, including half-life of the individual congeners within the human body, duration and location of the source relative to the individual, and the status of the product (legacy or alternative/emerging) [85]. Penta-BDEs were found to correlate strongly with dust concentrations, apart from BDE-153 which is persistent in humans. Despite BDE-209 having a short half-life and low bio-availability, its abundance in dust strongly correlates with body burden. Therefore, a simple recommendation, such as more frequent hand washing and vacuuming, would remove dust and reduce PBDE body burden [85].

In Malliari and Kalantzi's [36] FR review, it was reported that few studies focused on children's tissues such as serum, and only two studies reported exposures via mouthing behaviours. They proposed that alternative, non-invasive sampling matrices and faecal sampling warrant further research. While many studies have associated different indoor environment characteristics, there is a knowledge gap concerning the association between children's behaviour, activity patterns and products and their exposure to FRs. Results from these studies showed that dust ingestion was the dominant exposure pathway for most FRs compared to indoor air inhalation and dermal contact, especially for infants and toddlers, who have higher exposures than older children.

OPFRs are increasingly being utilised in building materials, textiles and electronic equipment that can be used in the home environment and are an alternative to brominated flame retardants. Saillenfait et al. [86] undertook an updated review that showed that urinary levels of metabolites can be used to increase the knowledge base in evaluating human exposure to OPFRs from multiple sources and other intake pathways. These metabolites have been used as a biomarker of exposure in both adults and children and could be used to refine the assessment of human exposure to other SVOCs. Exposure continues to be dependent on a range of factors including individual (age, location) and environmental (source, emission, concentration, SVOC compound, legislation).

Due to the uncertainty of SVOC concentrations and their impact on health, this research is an important next step of the work, and we will be considering how we can support it in future workstreams.

3.5. Emissions

We report emission factors defined as weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant [87]. Only emissions that were quantified in the relevant papers are presented. Approximate values presented in figures in papers were not included; also, emissions in terms of concentrations are not reported.

Emission factors presented in the same paper and obtained with the same methodology (e.g., test chamber) have been merged and their statistical values (median, min and max) are reported. This method was deemed sufficient for the needs of this study, as the results of each study were processed separately and not combined with data from other studies. In cases where two or more different methods are used in the same paper, results are presented separately; an exception to this is Manoukian et al. [88], where only minimum and maximum emission factors are reported for experiments with three varying parameters (temperature, relative humidity, and air exchange rate) and these are reported together as they are in the paper.

It was found that studies which investigate emissions are limited to a rather narrow spectrum of conditions, chemicals, and environmental conditions; however, as there is considerable diversity of available materials, processes, and environmental and real-life conditions, a large variability in reported emission levels is expected to be observed. Here, we separate sources into three categories: candles/incense burning, consumer products (including electronics and furniture) and building materials. Emission factors/rates for individual prioritised SVOCs in these three categories are reported in Tables 3–5, and non-prioritised SVOCs are located in the Supplementary Materials S8 and S9.

Table 3. Most health-relevant and commonly measured SVOCs identified in European residences: emissions from combustion.

Chemical	Group	Study or Reference	Category	Matrix	Emission Factor	Emission Rate *	Unit
Benzo[a]anthracene	PAH	Manoukian et al. [88] **TC**	Incense (reports min and max)	Particles	Nd, 938 [3]		µg/g
Benzo[a]anthracene	PAH	Petry et al. [89] TC	Scented candles	Particles and gas phase		<0.21[1]	µg/h
			Unscented candles	Particles and gas phase		<0.21[1]	µg/h
Benzo[a]anthracene	PAH	Derudi et al. [90] TC	Scented candles	Particles and gas phase	0.03 [1]		ng/g
Benzo[a]anthracene	PAH	Derudi et al. [91] TC	Unscented Candles		<0.01 [1]		ng/g
Benzo[a]pyrene	PAH	Manoukian et al. [88] TC	Incense	Particles	Nd, 766 [3]		µg/g
Benzo[a]pyrene	PAH	Petry et al. [89] TC	Scented candles	Particles and gas phase		<0.21[1]	µg/h
			Unscented candles	Particles and gas phase		<0.21[1]	µg/h
Benzo[a]pyrene	PAH	Derudi et al. [90] TC	Scented candles	Particles and gas phase	0.33 [1]		ng/g
Benzo[a]pyrene	PAH	Derudi et al. [91] TC	Unscented Candles	Particles and gas phase	1.41 ± 1.00 (<0.01, 3.44 ± 3.40) [2]		ng/g
Benzo[b]fluoranthene	PAH	Derudi et al. [91] TC	Unscented Candles	Particles and gas phase	<0.01 (<0.01, 3.46 ± 3.45) [2]		ng/g
Chrysene	PAH	Manoukian et al. [88] TC	Unscented candles	Particles		<0.21 [1]	µg/h
Chrysene Chrysene Chrysene	PAH PAH PAH	Derudi et al, [90] TC Manoukian et al. [88] TC Derudi et al. [91] TC	Scented candles	Particles and gas phase	0.75 [1]		ng/g
			Unscented Candles	Particles and gas phase Particles	0.10 ± 0.08 (<0.01, 0.53 ± 0.51) [2]		ng/g
Chrysene	PAH	Derudi et al. [90] TC	Incense	Particles and gas phase	Nd, 718 [3]		µg/g
DEHP	Phthalates	Manoukian et al. [88] TC	Incense	Particles	1206, 31080 [3]		µg/g
Dibenzo[a,h]anthracene	PAH	Petry et al [88] TC	Scented candles	Particles and gas phase		<0.21 [1]	µg/h
Dibenzo[a,h]anthracene	PAH	Derudi et al. [91] TC	Unscented Candles	Particles and gas phase	<0.01 [1]		ng/g
DIBP	Phthalates	Manoukian et al. [88] TC	Incense	Particles	354, 4274 [3]		µg/g

* Emission rate: emitted mass per unit time EH: experimental house; TC: test chamber or cell; MEC: Miniature Emissions Chamber; [1]: sample value [2]: medium (minimum, maximum) [3]: minimum, maximum.

Table 4. Most health-relevant and commonly measured SVOCs identified in European residences: emissions from consumer products.

Chemical	Group	Author	Category/Item	Matrix Measured	Area Specific Emission Rates (SERa)	Unit Specific Emission Rates (SERu)	Unit
BDE17	Flame retardant (brominated)	Kemmlein, Hahn and Jann [92] GD	Printed circuit board	gas phase		0.6 [1]	$ng\,unit^{-1}h^{-1}$
BDE28	Flame retardant (brominated)	Kemmlein, Hahn and Jann [92] GD	Television set housing	gas phase	0.2 [1]		ng/m^2h
			Printed circuit board	gas phase		1.9 [1]	$ng\,unit^{-1}h^{-1}$
BDE47	Flame retardant (brominated)	Kemmlein, Hahn and Jann [92] GD	Television set housing	gas phase	6.6 [1]		ng/m^2h
			Printed circuit board	gas phase		14.2 [1]	$ng\,unit^{-1}h^{-1}$
BDE99	Flame retardant (brominated)	Kemmlein, Hahn and Jann [92] GD	Television set housing	gas phase	1.7 [1]		ng/m^2h
			Printed circuit board	gas phase		2.6 [1]	$ng\,unit^{-1}h^{-1}$
DecaBDE (BDE209)	Flame retardant (brominated)	Kemmlein, Hahn and Jann [92] GD	Television set housing	gas phase	0.3 [1]		ng/m^2h
NonaBDE (BDE-206, BDE-207)	Flame retardant (brominated)	Kemmlein, Hahn and Jann [92] GD	Television set housing	gas phase	0.8 [1]		ng/m^2h
OctaBDE (BDE-196, BDE-197, BDE-203)	Flame retardant (brominated)	Kemmlein, Hahn and Jann [92] GD	Television set housing	gas phase	1.5 [1]		ng/m^2h

TC: test chamber or cell; GC: glass cell; GD: glass desiccator; [1]: sample value.

Table 5. Most health-relevant and commonly measured SVOCs identified in European residences: emissions from building materials.

Chemical	Group	Author	Building Materials	Matrix Measured	Emission Rate	Area Specific Emission Rates (SERa) *	Duration	Unit
DnBP	phthalate	Schripp et al. [93] TC/EC	Paint —latex F2 (doped)	Gas phase	238 [6]		5 days	$\mu g/m^2h$
			Paint —latex F1 (doped)	Gas phase	303 [6]		5 days	$\mu g/m^2h$
			Paint —latex F1 LC (doped)	Gas phase	186 [6]		1 week	$\mu g/m^2h$
			Paint —latex F1 LC (doped)	Gas phase	384 [6]		1 week	$\mu g/m^2h$
			Paint —latex F1 LC (doped)	Gas phase	448 [6]		Not stated	$\mu g/m^2h$
HBCD			EPS [1] (0.02 m^3)	Gas phase		4 [6]		$\mu g/m^2h$

	Flame retardant (organophosphate)	Kemmlein, Hahn and Jann [92] GC/GD	EPS [1] (0.001 m^3)	Gas phase		1 [6]		$\mu g/m^2h$
			XPS [2] (0.02 m^3)	Gas phase		29 [6]		$\mu g/m^2h$
			XPS [2] (0.001 m^3)	Gas phase		0.1 [6]		$\mu g/m^2h$
Permethrin	insecticide	Yu, Crump and Brown [94]) MC	Scots pine pre-treated with solvent-based wood preservative	Particles and gas phase	18 [6]		3–10 days	ng/m^2h
			Scots pine pre-treated with solvent-based wood preservative	Particles and gas phase	18 [6]		28–34 days	ng/m^2h
			Scots pine pre-treated with solvent-based wood preservative	Particles and gas phase	27 [6]		56–61 days	ng/m^2h
			Scots pine pre-treated with solvent-based wood preservative	Particles and gas phase	27 [6]		79–90 days	ng/m^2h
			Scots pine pre-treated with water-based wood preservative	Particles and gas phase	20 [6]		3–10 days	ng/m^2h
			Scots pine pre-treated with water-based wood preservative	Particles and gas phase	27 [6]		28–34 days	ng/m^2h
			Scots pine pre-treated with water-based wood preservative	Particles and gas phase	33 [6]		56–61 days	ng/m^2h
			Scots pine pre-treated with water-based wood preservative	Particles and gas phase	27 [6]		79–90 days	ng/m^2h
			Spruce pre-treated with solvent-based wood preservative	Particles and gas phase	27 [6]		3–10 days	ng/m^2h

	Spruce pre-treated with solvent-based wood preservative	Particles and gas phase	32 [6]		28–34 days	ng/m²h
	Spruce pre-treated with solvent-based wood preservative	Particles and gas phase	27 [6]		56–61 days	ng/m²h
	Spruce pre-treated with solvent-based wood preservative	Particles and gas phase	27 [6]		79–90 days	ng/m²h
	Spruce pre-treated with water-based wood preservative	Particles and gas phase	<18 [6]		3–10 days	ng/m²h
	Spruce pre-treated with water-based wood preservative	Particles and gas phase	18 [6]		28–34 days	ng/m²h
	Spruce pre-treated with water-based wood preservative	Particles and gas phase	20 [6]		56–61 days	ng/m²h
	Spruce pre-treated with water-based wood preservative	Particles and gas phase	<18 [6]		79–90 days	ng/m²h
	Untreated Scots pine	Particles and gas phase	<18 [6]		3–10 days	ng/m²h
	Untreated Scots pine	Particles and gas phase	<15 [6]		28–34 days	ng/m²h
	Untreated Scots pine	Particles and gas phase	<18 [6]		56–61 days	ng/m²h
	Untreated Scots pine	Particles and gas phase	<18 [6]		79–90 days	ng/m²h
	Untreated spruce	Particles and gas phase	<17 [6]		3–10 days	ng/m²h

			Untreated spruce	Particles and gas phase	<15 [6]		28–34 days	ng/m²h
			Untreated spruce	Particles and gas phase	<18 [6]		56–61 days	ng/m²h
			Untreated spruce	Particles and gas phase	<18 [6]		79–90 days	ng/m²h
			Pine coated with acypetacs zinc and permethrin	Particles and gas phase	<18 [6]		3–10 days	ng/m²h
			Pine coated with acypetacs zinc and permethrin	Particles and gas phase	<18 [6]		28–34 days	ng/m²h
			Pine coated with acypetacs zinc and permethrin	Particles and gas phase	<18 [6]		56–61 days	ng/m²h
			Pine coated with acypetacs zinc and permethrin	Particles and gas phase	<18 [6]		79–90 days	ng/m²h
Permethrin		Horn, Jann and Wilke [95]	Wood preservative	Particles and gas phase		0.003 [C,6]		µg/m²h
			Fibre, leather, rubber, and polyermisd material preservatives (carpet)	Particles and gas phase		0.006 [C,6]		µg/m²h

[1] Expandable polystyrene (EPS) insulating board; [2] Extruded polystyrene (XPS) insulating board; [3] Polyisocyanurate insulating boards (PIR); [4] One-component PU foam (1_C assembly foam) in cartridges, rough surface; [5] One-component PU foam (1_C assembly foam) in cartridges, smooth surface; [6] sample value; MC: microchamber; EC: exposure chamber; TC: test chamber or cell; GC: glass cell; GD: glass desiccator * Area specific emission rates (SERaa) vs. Area specific emissions rates (SERab): a Calculated from: mtot/(ttot x A); mtot(µg): integrated emission concentration + total mass on chamber walls; ttot(h): total test period; A(m²): sample surface area. b Calculated from: ceq x q; ceq(µgm^{-3}): estimated equilibrium concentration; q (m^3 m^{-2}h^{-1}): area-specific air flow rate. C: SERa = Cq (c = concentration, q = area specific flow rate).

We discuss key elements of experiments reported in the current literature: facilities where the measurements took place (emission chambers, etc.), and sensitivity of results due to quantification methods and conditions.

One study was identified to report emission rate for FRs [92], two for phthalates (Petry et al. [89]; Schripp et al. [93]), four for PAHs (Manoukian et al. [88]; Petry et al. [89]), Derudi et al. [90]; Derudi et al [91]; and two for pesticides (Yu, Crump and Brown [94]; Horn, Jann and Wilke [95]); furthermore, four review papers were identified and crossreferenced (Marć, Zabiegała and Namieśnik [96]; Rauert et al. [97]; Wensing, Uhde and Salthammer [98] and Naldzhiev, Mumovic and Strlic [99]).

3.5.1. Candles/Incense Burning

SVOC emission factors from combustible products were reported in four studies (Manoukian et al, [88]; Petry et al. [89]; Derudi et al [90]; Derudi et al [91]). Heating sources were not included in this review. These products included scented and unscented candles, and incense sticks. A total of 22 individual SVOCs were shown to be emitted from these products and the results are presented in Table 3 and Supplementary Material S8 and S9.

The experiments performed by Manoukian et al. [88] Derudi et al. [90], Derudi et al. [91] and were undertaken in laboratory test chambers. In Derudi et al. [90], large differences were found in emission factors resulting from similar candles, and in Derudi et al [91] the wax quality and composition were found to strongly influence air pollutant emissions. Furthermore, it was evidenced that the PAHs emitted depended on the wax quality rather than wax additives. Manoukian et al. [88] investigated the influence of temperature, relative humidity, and air exchange rate on the emission of VOCs and SVOCs during incense burning, and it was found that the emission factor is proportional to ventilation. Air exchange rate (AER) and temperature were the most influential parameters for DIBP emissions (minimum emissions were observed for lowest AER), and for chrysene emissions (maximum emissions for lowest temperature), respectively. BaP (a known carcinogen–see Section 3.4.1) was emitted during incense burning, and instantaneous concentration values reached close to or higher than air quality standards defined for specific time of exposure.

Petry et al. [89] used a large emissions chamber (approximately 26 m^3) to test emission rates of PAHs and polychlorinated dibenzodioxins/furans from fragranced and unfragranced candles. The SVOC emissions rates were below the limits of detection.

Manoukian et al. [100] focussed on VOC emissions but did try to measure acenaphthene emissions from incense sticks using an experimental house (the "Mechanised House for Advanced Research on Indoor Air" (MARIA), Ribéron and O'Kelly [101]). As no chromatographic separation was conducted before the high-sensitivity proton transfer reaction mass spectrometer (HS-PTR-MS), several isobaric ions/fragments could have contributed to the acenaphthene signal. Acenaphthalene was detected by Automatic Thermal Desorption (ATD) capillary gas chromatography (GC) coupled to a Flame Ionization Detector (FID) (ATD-GC-FID), but levels were below the limit of quantification. The *m*/*z* 155 ion (emission rate of 92 ± 4 μgh^{-1}) detected was likely due to linalool and not acenaphthalene as reported in part I/VOC paper [1].

It should be noted that different experimental approaches were followed in these studies: Petry et al [89], Derudi et al. [90] and Derudi et al. [91] used different methods for burning and sampling.

3.5.2. Consumer Products

SVOC emission factors from consumer products were reported in one study [92]. This study focused on OPFRs and FRs and included electronic devices (printed circuit boards, television set housing and computer systems) and upholstery/mattress. Sampling was undertaken using glass cells with volumes of 0.001 and 0.02 m^3 and 1 m^3 standard VOC emission test chambers with calculation of area-specific flow rate and corresponding sample size based on a model room prescribed by European pre-standard and industry instruction. Eleven individual SVOCs were emitted from these products (Table 4 and Supplementary Material S8 and S9).

Most of the experiments were carried out at 23 °C; where circuit boards were heated to 60 °C to simulate operating conditions, the emissions increased significantly—for example, BDE-47 emissions increased 500-fold. Furthermore, it is reported that for compounds with relatively low vapour pressures, applicability of the emissions test chambers used in the work of Kemmlein et al. [92] was limited. For FRs with more than six bromine atoms in the compound, the emissions were affected by sink effects, and non-volatile FRs such as deca-BDE (BDE-209) tended to bond to particles and consequently would be concentrated in house dust. It should be noted that the computer housing tested was manufactured in 1995, the TV housing tested was from earlier than 1979, the computers were from 2000 and 2001, and the circuit board from 2000. To the best of our knowledge, no data exist for more recently manufactured products.

Afshari et al. [102] aimed to determine the emission rates of phthalates from different materials: consumer products including a refrigerator, two electric cables and floor wax, as well as building materials including PVC flooring, polyolefin flooring, and PVC skirting. Each material tested in the Climpaq test chamber had high emissions of DEHP and very low emissions of DBP, except for wax, which was vice versa. However, sufficient data to calculate emissions rates were not obtained, due to adsorption onto chamber surfaces.

3.5.2. Building Materials

SVOC emission factors from building materials were reported in four studies (Kemmlein et al. [92]; Schripp et al. [93]; Yu et al. [94]; Horn et al. [95]). Building materials included wood, carpet, ceramic tile, latex paint (doped with a known quantity of phthalates), assembly foam and several insulation boards, but none of the studies identified provided emission rates from PVC. There are indications of PVC being a source of interest regarding respiratory diseases; unfortunately, we did not identify any emissions papers, and this should be an area for future research. Thirteen individual SVOCs were found in emissions from these products and the results are presented in Table 5 and the Supplementary Material S8 and S9.

Different test chambers were used including glass cells with volumes of 0.001 and 0.02 m^3 and 1 m^3 in standard VOC emission test chambers (Kemmlein et al. [92]), 20 L and 23 L glass desiccators (Horn et al. [95]), a small (0.25 m^3) and a large (55 m^3) test chamber (Schripp et al. [93]), and 2-litre microchambers and a test cabin of 27 m^3 (Yu et al. [94]).

In an experiment conducted over several years, Horn et al. [95] tested the emissions from two commercial products (plastic foil and wool carpet), along with seven types of biocidal formulations which were applied to either wood or clay tiles. They found that unlike VOCs, SVOC emissions slowly increase until reaching a constant value, and for permethrin a maximum emission rate of 6 ngm^2h^{-1} was found. After a period of almost nine years, the area specific emission rates (SERas) of permethrin, tebuconazole, and dichlofluanid still remained detectable. As permethrin is also readily bound to house dust and the many sinks for biocides in the indoor environment (e.g., walls, furniture, house dust, etc.), the extent of the utility of the obtained results in the indoor air was uncertain.

In Yu et al. [94], emissions within the microchambers and test cabin, which was built to simulate the living room of a newly built house, were sampled once a month over a two-year period in three phases: first without the plasterboard cladding of the wall panel, window or door (phase 1); with the window and door being added (phase two); and with the cladding (phase three). They found low SVOC (including permethrin) emission rates from the treated timber, most of which were close to the level of quantitation in both the test chamber experiments and monitoring results in the test cabin.

In Schripp et al. [93], measurements aimed to determine the feasibility of scaling emissions rates from the small (0.25 m^3 at 23 °C) or large (55 m^3, at 23 °C and 30 °C) chamber, and emissions from a latex paint with known amounts of DEP and DnBP into chamber air were found to be well-defined and relatively constant for periods as long as five days; they found that materials with known emission characteristics for phthalates could be prepared.

Naldzhiev et al. [99] conducted a review of polyurethane insulation and household products and their impact on indoor environmental quality. Emissions were mostly given as concentrations, except for one study carried out in the USA which is not included in this review; they found that "OPFRs are not typically bound to polyurethane matrix and emit indefinitely". This review also states that "the use of standard protocols…would be beneficial to determine repeatable and comparable emission rates". Naldzhiev et al [99] conclude that an appropriate database of emission rates for modelling purposes would be beneficial.

None of the emissions studies looked at dust, which is one of the many sinks for SVOCs (e.g., permethrin is readily bound to house dust [95]. Schripp et al. [93]) looked at emissions of DEHP and DNP into dust but only reported the emissions as concentrations. Yu et al. [94]) acknowledged a need for the assessment of the possible intake of active substances via particulates and dusts and Naldzhiev et al. [99]) stated that indoor dust seemed to be the best proxy for internal exposure for OPFRs.

4. Conclusions

4.1. Summary

The definitions of SVOCs in standards and studies are inconsistent, with many studies including chemicals which are described as SVOC but do not meet the definition. Boiling temperature may be a poor delineator for volatility, and there are limitations related to the available definitions; in the future, these compounds need to be assessed to identify if vapour pressure is a better indicator of whether they are likely to be detected in air.

There is also not much research on SVOC emission rates and what we have identified used inconsistent methods making inter-study comparisons an almost impossible task. Emissions data from important sources including furniture, flooring materials, plastics, and from modern electronic devices are largely missing. Technology has advanced significantly in the last 20 years and there is more of it present in the home (laptops, mobile phones, tablets, printers, flat screen TVs, gaming consoles, speakers, health and wellbeing gadgets, hair straighteners/hair dryers, Wi-Fi routers, etc.). There is also no known emission data repository from industry that can be used.

There was a lot of missing toxicological data for PCBs, PFAS, musks, bisphenols and emerging/alternative FRs and phthalates. The methodologies used in epidemiological studies are not consistent (questionnaire design, assessment of home environment for other contributors or confounders, e.g., metals and damp, sampling techniques) and should be harmonised to further develop the evidence base. Legacy chemicals have presented alternatives due to the concern about health and environmental effects; however, many of these alternatives are not currently being assessed to determine whether they pose risks. The toxicological data on SVOC chemicals is dominated by ingestion studies, whilst exposures by inhalation or dermal routes are not being considered.

Concentrations of both legacy and emerging/alternative chemicals in the home environment in dust, air and aerosol demonstrates the continued presence of legacy pollutants, and further research is required on emerging/alternative chemicals to be able to determine attributable health effects from being exposed to these chemicals and to propose future indoor air quality guideline values. These chemicals have only been considered individually and there is a requirement for non-target sampling in the home environment, and exposure assessment is required for multiple chemicals and all pathways. Chemicals in the same class may have effects through the same mechanism, and therefore may act additively or even synergistically.

A balance in the advice provided to the public to inform on the hazards of indoor SVOCs and the actions they can take to reduce or remove exposures is needed. Although health studies have noted positive associations with flooring material, these studies had no emission data. This indoor source should be reviewed as a priority.

4.2. Recommendations

- Toxicological and mechanistic studies on short term and long-term exposures are required to set health-based indoor air quality guidelines, similar to those that were developed for VOCs, and to provide advice to the public on how to minimise their exposure.
- Large-scale epidemiological studies (population-based cohort and incident case- control studies) and human biomonitoring studies are needed, together with monitoring studies, to examine the population-level adverse effects of exposure to SVOCs on adults and children, including the effects on at-risk populations and housing conditions. These are especially important as legacy chemicals will continue to reduce, while their replacements and emerging SVOCs are likely to increase. This exposure data, together with better understanding of any adverse health effects from emerging or alternative chemicals, will inform regulators and any necessary restrictions.
- A standardised health questionnaire and repository for epidemiological data from various studies is required, as there are several cohorts that have been identified in this review which are using different questionnaires. Deen et al.'s [64] study was possible due to all residents having a unique personal identification number, as required by legislation introduced in 1968. This contains historical records on each individual's residential addresses and relocation details. A repository of this nature would be useful for future long-term epidemiological studies but would need to be transparent and meet all necessary data storage requirements.
- Monitoring studies are needed to determine the presence of SVOCs in house dust and their resuspension. Lifestyle, behaviour, temperature, seasonality, and ventilation could impact on indoor concentrations, and these should be assessed. This information can assist in identifying strategies to reduce exposure and provide public advice (hand washing after handling dust and vacuuming).
- Assessment of emission rates and migration from different types of surface materials would allow the removal of products with high emission rates.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/article/10.3390/environments12020040/s1, Table S1: Legacy and alternative SVOCs; Table S2: Concentration Studies; Table S3: Concentrations sorted by WAGM for air, aerosol and dust; Table S4: Health effects not determined for 224 SVOCs; Table S5: Prioritized SVOCs and health endpoints; Table S6: Health studies—epidemiological; Table S7: Wilcoxon rank-sum; Table S8: Emission studies; Table S9: Emission tables—non-prioritized SVOCs. References [103–255] are cited in the supplementary materials.

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Data Availability Statement: Research data can be found in the Supplementary Materials.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix

Appendix A. Search string for PRISMA diagram.

Embase search strategy
1 exp volatile organic compound/ (18094)
2 "volatile organic compound*".tw. (13103)
3 VOC.tw. (7711)
4 VOCs.tw. (8322)
5 "semi volatile organic compound*".tw. (452)
6 "semi volatile compound*".tw. (201)
7 SVOC.tw. (230)
8 SVOCs.tw. (400)
9 exp dust/ (32383)
10 dust.tw. (51330)
11 exp benzene/ (20487)
12 benzene.tw. (32874)
13 exp formaldehyde/ (52127)
14 formaldehyde.tw. (24148)
15 exp toluene/ (20526)
16 toluene.tw. (23764)
17 exp styrene/ (6823)
18 styrene.tw. (11964)
19 exp acetaldehyde/ (9604)
20 acetaldehyde.tw. (10691)
21 exp pinene/ (6202)
22 a-pinene.tw. (178)

23 exp limonene/ (7504)
24 D-Limonene.tw. (989)
25 exp naphthalene/ (8809)
26 naphthalene.tw. (13488)
27 exp tetrachloroethylene/ (3352)
28 tetrachloroethylene.tw. (1342)
29 exp trichloroethylene/ (10791)
30 trichloroethylene.tw. (4340)
31 m-xylene.tw. (930)
32 p-xylene.tw. (1501)
33 o-xylene.tw. (1189)
34 exp ethylbenzene/ (3758)
35 ethylbenzene.tw. (2865)
36 exp "benzo[a]pyrene"/ (16794)
37 benzopyrene.tw. (427)
38 exp carbon monoxide/ (36477)
39 carbon monoxide.tw. (31459)
40 exp nitrogen dioxide/ (12837)
41 nitrogen dioxide.tw. (6589)
42 exp ozone/ (28082)
43 ozone.tw. (28382)
44 exp phthalic acid diethyl ester/ (1400)
45 Diethyl phthalate.tw. (933)
46 Diisobutyl phthalate.tw. (217)
47 di-n-butyl phthalate.tw. (976)
48 exp galaxolide/ (444)
49 galaxolide.tw. (331)
50 tonalide.tw. (239)
51 exp acenaphthene/ (807)
52 acenaphthene.tw. (682)
53 exp acenaphthylene/ (1222)
54 acenaphthylene.tw. (476)
55 exp phenanthrene/ (6371)
56 phenanthrene.tw. (6344)
57 exp anthracene/ (4917)
58 anthracene.tw. (12647)
59 exp "benz[a]anthracene"/ (2927)
60 exp "benzo[b]fluoranthene"/ (1638)
61 exp "benzo[k]fluoranthene"/ (1665)
62 exp "benzo[e]pyrene"/ (640)
63 exp "benzo[ghi]perylene"/ (1502)
64 benzo.tw. (27099)
65 exp chrysene/ (2762)
66 chrysene.tw. (1612)
67 exp "dibenz[a,h]anthracene"/ (1646)
68 exp "dibenzo[a,l]pyrene"/ (266)
69 dibenz*.tw. (18662)
70 exp fluoranthene/ (3605)
71 fluoranthene.tw. (2928)
72 exp fluorene/ (2780)
73 fluorene.tw. (2865)

74 indenol.tw. (27)
75 exp pyrene/ (7711)
76 pyrene.tw. (25167)
77 exp phenol/ (26475)
78 phenol*.tw. (113770)
79 exp plasticizer/ (15969)
80 plastici?er*.tw. (6491)
81 or/1-80 (530745)
82 exp fragrance/ (22341)
83 air freshener*.tw. (186)
84 exp antiinfective agent/ (3479324)
85 antimicrobial.tw. (201609)
86 exp antioxidant/ (220297)
87 antioxidant*.tw. (257737)
88 exp biocide/ (2507)
89 biocide.tw. (2328)
90 exp building material/ (5693)
91 building material*.tw. (2776)
92 cable*.tw. (9264)
93 candle*.tw. (1451)
94 carpet*.tw. (3328)
95 exp domestic chemical/ (17080)
96 cleaning agent*.tw. (933)
97 coalescing agent*.tw. (7)
98 combustion byproduct*.tw. (73)
99 decoration*.tw. (3300)
100 exp deodorant agent/ (841)
101 deodorant*.tw. (680)
102 deod?ri?er.tw. (87)
103 diffuser*.tw. (1505)
104 exp disinfectant agent/ (463296)
105 disinfectant*.tw. (11349)
106 exp electronics/ (67201)
107 electronic component*.tw. (794)
108 exp emulsifying agent/ (45452)
109 emulsifying agent*.tw. (503)
110 exp essential oil/ (25078)
111 essential oil*.tw. (24260)
112 fixture*.tw. (3001)
113 exp flame retardant/ (10748)
114 flame retardant*.tw. (5146)
115 floor covering*.tw. (205)
116 exp fungicide/ (33568)
117 fungicide*.tw. (11108)
118 furnish*.tw. (14287)
119 exp furniture/ (28093)
120 furniture.tw. (2616)
121 heat transfer fluid*.tw. (99)
122 exp herbicide/ (52986)
123 herbicide*.tw. (21519)
124 exp glue/ (2952)

125 glue.tw. (14203)
126 exp incense/ (290)
127 incense.tw. (669)
128 internal source*.tw. (470)
129 exp nonionic surfactant/ (46702)
130 nonionic surfactant*.tw. (3673)
131 (oil adj3 repellent*).tw. (157)
132 (water adj3 repellent*).tw. (443)
133 exp paint/ (5498)
134 paint.tw. (7036)
135 exp perfume/ (1921)
136 perfume*.tw. (2390)
137 exp cosmetic/ (111657)
138 cosmetic*.tw. (68259)
139 personal care product*.tw. (3256)
140 exp pesticide/ (342808)
141 pesticide*.tw. (58120)
142 exp plastic/ (22926)
143 plastic*.tw. (220771)
144 polishes.tw. (146)
145 exp preservative/ (293754)
146 preservative*.tw. (13739)
147 renovation*.tw. (2231)
148 exp sealant/ (2208)
149 sealant*.tw. (7630)
150 exp surfactant/ (239494)
151 surfactant.tw. (59026)
152 stain repellent*.tw. (22)
153 termiticide*.tw. (122)
154 terpene oxidation product*.tw. (13)
155 vinyl floor*.tw. (100)
156 wallpaper.tw. (208)
157 water disinfection product*.tw. (4)
158 exp wax/ (4311)
159 waxes.tw. (1731)
160 exp wood protecting agent/ (404)
161 wood preservative*.tw. (540)
162 or/82-161 (4589020)
163 indoor.tw. (34435)
164 exp indoor air pollution/ (13379)
165 exp ambient air/ (25496)
166 dwelling.tw. (39796)
167 domestic.tw. (83261)
168 exp home/ (8083)
169 home.tw. (306935)
170 homes.tw. (51676)
171 exp household/ (38767)
172 exp building/ (7510)
173 ((new or green or sick) adj build*).tw. (2002)
174 "low carbon".tw. (1476)
175 exp home environment/ (4806)

176	"home environment*".tw. (7143)
177	"sick building syndrome*".tw. (739)
178	ventilation.tw. (173638)
179	"energy efficien*".tw. (6943)
180	airtight*.tw. (1064)
181	"air permeability".tw. (276)
182	exp air conditioning/ (22678)
183	air conditioning.tw. (2510)
184	carbon neutral.tw. (329)
185	decay.tw. (74309)
186	or/163-185 (792951)
187	emission*.tw. (258318)
188	emission rate*.tw. (3662)
189	environmental chamber*.tw. (1369)
190	exp measurement/ (1728870)
191	exp monitoring/ (598505)
192	exp exposure/ (613219)
193	"decay rate*".tw. (4615)
194	exp concentration ratio/ (1234)
195	exp health impact assessment/ (4784)
196	(health adj (impact* or assessment* or effect*)).tw. (63034)
197	or/187-196 (3010795)
198	81 and 162 and 186 and 197 (4988)
199	limit 198 to english language (4680)
200	limit 199 to conference abstract (543)
201	199 not 200 (4137)
202	limit 201 to yr="2000 -Current" (3511)

Scopus and Environmental Complete search strategy:

TITLE-ABS-KEY("volatile organic compound*" or VOC or VOCs or "semi volatile organic compound*" or "semi volatile compound*" or SVOC or SVOCs or dust or benzene or formaldehyde or toluene or styrene or acetaldehyde or a-pinene or D-Limonene or naphthalene or tetrachloroethylene or trichloroethylene or m-xylene or p-xylene or o-xylene or ethylbenzene or benzopyrene or "carbon monoxide" or "nitrogen dioxide" or ozone or "Diethyl phthalate" or "Diisobutyl phthalate" or "di-n-butyl phthalate" or galaxolide or tonalide or acenaphthene or acenaphthylene or phenanthrene or anthracene or benzo or chrysene or dibenz* or fluoranthene or fluorene or indenol or pyrene or phenol* or plasticiser* or plasticizer*) AND TITLE-ABS-KEY(fragrance or "air freshener*" or antimicrobial or antioxidant* or biocide or "building material*" or cable* or candle* or carpet* or "cleaning agent*" or "coalescing agent*" or "combustion byproduct*" or decoration* or deodorant* or deodoriser* or deodorizer* or diffuser* or disinfectant* or "electronic component*" or "emulsifying agent*" or "essential oil*" or fixture* or "flame retardant*" or "floor covering*" or fungicide* or furnish* or furniture or "heat transfer fluid*" or herbicide* or glue or incense or "internal source*" or "nonionic surfactant*" or "oil repellent*" or "water repellent*" or paint or perfume* or cosmetic* or "personal care product*" or pesticide* or plastic* or polishes or preservative* or renovation* or sealant* or surfactant or "stain repellent*" or termiticide* or "terpene oxidation product*" or "vinyl floor*" or wallpaper or "water disinfection product*" or wax or waxes or "wood protecting agent" or "wood preservative*") AND TITLE-ABS-KEY(indoor or "indoor air pollution" or "ambient air" or dwelling or domestic or home or homes or household or building* or "low carbon" or "home environment*" or "sick building syndrome*" or ventilation or "energy efficien*" or airtight* or "air permeability" or "air conditioning" or "carbon neutral" or decay) AND TITLE-ABS-KEY(emission* or "emission rate*" or "environmental chamber*" or measurement or monitoring or exposure* or "decay rate*" or "concentration ratio" or "health impact*" or "impact assessment*" or "health assessment*" or "health effect*") AND PUBYEAR AFT 2000

Appendix B. Glossary of SVOCs abbreviations, full names, CAS numbers and chemical Group identified within in this paper.

Chemical	Name	CAS	Group
1,2-benzanthracene	1,2-benzanthracene	56-55-3	POLY AROMATIC HYDROCARBONS
10:2 diPAP	10:2 Fluorotelomer phosphate diester	1895-26-7	PER-AND POLY FLUOROALKYL SUBSTANCES
10:2 FTAC	10:2 Fluorotelomer acrylate	17741-60-5	PER-AND POLY FLUOROALKYL SUBSTANCES
10:2 FTOH	10:2 fluorotelomer alcohols	865-86-1	PER-AND POLY FLUOROALKYL SUBSTANCES
10:2 monoPAP	10:2 Fluorotelomer dihydrogen phosphate	57678-05-4	PER-AND POLY FLUOROALKYL SUBSTANCES
2,4-DDE (o,p-DDE)	2,2-(2-Chlorophenyl-4'-chlorophenyl)-1,1-dichloroethene	3424-82-6	PESTICIDE
2,4-DDT + 4,4-DDD	2,4'-dichlorodiphenyltrichloroethane; Dichlorodiphenyldichloroethane	2,4-DDT: 789-02-6; 4,4-DDD: 72-54-8	PESTICIDE
4:2 FTOH	4:2 fluorotelomer alcohol	60699-51-6	PER-AND POLY FLUOROALKYL SUBSTANCES
4:2/6:2 diPAP	4:2/6:2 Fluorotelomer phosphate diester	1158182-59-2	PER-AND POLY FLUOROALKYL SUBSTANCES
OP	4-tert-octylphenol	140-66-9	ALKYLPHENOL
6:2 diPAP	bisperfluorooctyl phosphate	57677-95-9	PER-AND POLY FLUOROALKYL SUBSTANCES
6:2 FTMAC	6:2 Fluorotelomer methacrylate	2144-53-8	PER-AND POLY FLUOROALKYL SUBSTANCES
6:2 FTOH	6:2 fluorotelomer alcohol	647-42-7	PER-AND POLY FLUOROALKYL SUBSTANCES
6:2 FTS (6:2 FTSA)	6:2 Fluorotelomer sulfonic acid	27619-97-2	PER-AND POLY FLUOROALKYL SUBSTANCES
6:2 monoPAP	6:2 fluorotelomer phosphate monoester	57678-01-0	PER-AND POLY FLUOROALKYL SUBSTANCES

6:2/10:2 diPAP	6:2/10:2 Fluorotelomer phosphate diester	57677-95-9	PER-AND POLY FLUOROALKYL SUBSTANCES
6:2/12:2 diPAP	6:2/12:2 Fluorotelomer phosphate diester	cannot find	PER-AND POLY FLUOROALKYL SUBSTANCES
6:2/8:2 diPAP	6:2/8:2 Fluorotelomer phosphate diester	943913-15-3	PER-AND POLY FLUOROALKYL SUBSTANCES
8:2 diPAP	8:2 Fluorotelomer phosphate diester	678-41-1	PER-AND POLY FLUOROALKYL SUBSTANCES
8:2 FTAC	8:2 Fluorotelomer acrylate	27905-45-9	PER-AND POLY FLUOROALKYL SUBSTANCES
8:2 FTOH	8:2 fluorotelomer alcohol	678-39-7	PER-AND POLY FLUOROALKYL SUBSTANCES
8:2 FTS	8:2 Fluorotelomer stearate monoester	99955-83-6	PER-AND POLY FLUOROALKYL SUBSTANCES
8:2/12:2 diPAP	(Perfluorooctyl)ethyl (perfluorododecyl)ethyl hydrogen phosphate	1578186-42-1	PER-AND POLY FLUOROALKYL SUBSTANCES
9Cl-PF3ONS	Perfluoro(2-((6-chlorohexyl)oxy)ethanesulfonic acid)	756426-58-1	PER-AND POLY FLUOROALKYL SUBSTANCES
acenaphthene	acenaphthene	83-32-9	POLY AROMATIC HYDROCARBONS
Acenaphthylene	Acenaphthylene	208-96-8	POLY AROMATIC HYDROCARBONS
AHTN	tonalide	21145-77-7	Musks
Aldrin	Aldrin	309-00-2	PESTICIDE
Anthracene	Anthracene	120-12-7	POLY AROMATIC HYDROCARBONS
antiDDC-CO	Anti-dechlorane plus	135821-74-8	FIRE RETARDANT
anti-DP	Anti-dodecachloropentacyclooctadecadiene	135821-74-8	FIRE RETARDANT
ATBC	tributyl O-acetylcitrate	77-90-7	(PHTHALATE sub)
Atrazine	Atrazine	1912-24-9	PESTICIDE
BATE	Barium telluride	12009-36-8	FIRE RETARDANT
BBP (BBzP, BzBP)	Benzylbutyl PHTHALATE	85-68-7	PHTHALATE
BDE 99	2,2',4,4',5-Pentabromodiphenyl ether	60348-60-9	FIRE RETARDANT
BDE 100	1,3,5-Tribromo-2-(2,4-dibromophenoxy)benzene	189084-64-8	FIRE RETARDANT
BDE 153	2,2',4,4',5,5'-Hexabromodiphenyl ether	68631-49-2	FIRE RETARDANT
BDE 154	2,2',4,4',5,6'-Hexabromodiphenyl ether	207122-15-4	FIRE RETARDANT
BDE 17	2,2',4-tribromodiphenyl ether	147217-75-2	FIRE RETARDANT

BDE 182	2,2',3,4,4',5,6'-Heptabromodiphenyl ether	442690-45-1	FIRE RETARDANT
BDE 184	2,2',3,4,4',6,6'-Heptabromodiphenyl ether	117948-63-7	FIRE RETARDANT
BDE 191	2,3,3',4,4',5',6-Heptabromodiphenyl ether	446255-30-7	FIRE RETARDANT
BDE 196	Benzene, 1,2,3,4-tetrabromo-5-(2,3,4,6-tetrabromophenoxy)-	446255-39-6	FIRE RETARDANT
BDE 197	2,2',3,3',4,4',6,6'-Octabromodiphenyl ether	117964-21-3	FIRE RETARDANT
BDE 201	2,2',3,3',4,5',6,6'-Octabromodiphenyl ether	446255-50-1	FIRE RETARDANT
BDE 203	2,2',3,4,4',5,5',6-Octabromodiphenyl ether	337513-72-1	FIRE RETARDANT
BDE 206	Nonabromodiphenyl ether	63387-28-0	FIRE RETARDANT
BDE 207	2,2',3,3',4,4',5,6,6'-nonabromodiphenyl ether	437701-79-6	FIRE RETARDANT
BDE 208	2,2',3,3',4,5,5',6,6'-nonabromodiphenyl ether	437701-78-5	FIRE RETARDANT
BDE 209	Decabde - Decabromodiphenyl ether	1163-19-5	FIRE RETARDANT
BDE 28/33	2,4,4'-tribromodiphenyl ether (BDE 28)	41318-75-6	FIRE RETARDANT
BDE 35	3,3',4-Tribromodiphenyl ether	147217-80-9	FIRE RETARDANT
BDE 47	2,2',4,4'-Tetrabromodiphenyl ether	5436-43-1	FIRE RETARDANT
BDE 49	2,2',4,5'-Tetrabromodiphenyl ether	243982-82-3	FIRE RETARDANT
BDE 66	2,3',4,4'-tetrabromodiphenyl ether	189084-61-5	FIRE RETARDANT
BDE 77	3,3',4,4'-Tetrabromodiphenyl ether	93703-48-1	FIRE RETARDANT
BDE 85	2,2',3,4,4'-Pentabromodiphenyl ether	182346-21-0	FIRE RETARDANT
BDE 99	2,2',4,4',5-Pentabromodiphenyl ether	60348-60-9	FIRE RETARDANT
BDE-49&71	71: 2,3',4',6-Tetrabromodiphenyl ether	49: 243982-82-3; 71: 189084-62-6	FIRE RETARDANT
BDP	Fyrolflex BDP	5945-33-5	FIRE RETARDANT
BEHTBP	Bis(2-ethylhexyl) tetrabromoPHTHALATE	26040-51-7	FIRE RETARDANT
BEH-TEBP	2-methylhexyl 2,3,4,5-tetrabromobenzoate	26040-51-7	FIRE RETARDANT
Benz[a]anthracene	Benz[a]anthracene	56-55-3	POLY AROMATIC HYDROCARBONS
Benzo[a]pyrene	Benzo[a]pyrene	50-32-8	POLY AROMATIC HYDROCARBONS
Benzo[b]fluoranthene	Benzo[b]fluoranthene	205-99-2	POLY AROMATIC HYDROCARBONS

Benzo[e]pyrene	Benzo[e]pyrene	192-97-2	POLY AROMATIC HYDROCARBONS
Benzo[g,h,i]perylen e	Benzo[g,h,i]perylene	191-24-2	POLY AROMATIC HYDROCARBONS
Benzo[j]fluoran-thene	Benzo[j]fluoranthene	205-82-3	POLY AROMATIC HYDROCARBONS
Benzo[k]fluoran-thene	Benzo[k]fluoranthene	207-08-9	POLY AROMATIC HYDROCARBONS
BiBP	Butyl isobutyl PHTHALATE	17851-53-5	PHTHALATE
BPA	BISPHENOL-A	80-05-7	BISPHENOL
BPA-BDPP	BISPHENOL A bis (diphe-nylphosphate)	5945-33-5	FIRE RETARDANT
BPAF	9,9-Bis(3,4-dicarboxyphenyl) flu-orine Dianhydride	135876-30-1	BISPHENOL
BPF	BISPHENOL F	620-92-8	BISPHENOL
BPS	BISPHENOL S	80-09-1	BISPHENOL
br-EtFOSAA	Branched isomer of N-Ethyl per-fluorooctane sulfonamidoacetic acid		PER-AND POLY FLUOROALKYL SUBSTANCES
br-PFOA	Branched isomer of Perfluorooc-tanoic acid	*335-67-1?*	PER-AND POLY FLUOROALKYL SUBSTANCES
br-PFOS	Branched isomer of Perfluorooc-tane sulfonic acid		PER-AND POLY FLUOROALKYL SUBSTANCES
BTBPE	1,2-BIS(2,4,6-TRIBROMOPHE-NOXY)ETHANE	37853-59-1	FIRE RETARDANT
BTHC	PHTHALATE substitue Butyr-yltri-n-hexylcitrate	82469-79-2	(PHTHALATE sub)
Chloroparafins	Chloroparaffin	85535-84-8	CHLORINATED PARAFFINS
chlorpyirifos	chlorpyirifos	2921-88-2	PESTICIDE
Chrysene	Chrysene	218-01-9	POLY AROMATIC HYDROCARBONS
cypermethrin	cypermethrin	52315-07-8	PESTICIDE
DBDPE	Decobromodiphenyl ethane	84852-53-9	FIRE RETARDANT
DBE-DBCH	1,2-Dibromo-4-(1,2-dibromo-ethyl)cyclohexane	3322-93-8	FIRE RETARDANT
DBP	Dibutyl PHTHALATE	84-74-2	PHTHALATE
DDC-CO	Dechlorane plus	13560-89-9	FIRE RETARDANT
DEHA	Bis(2-ethylhexyl) adipate, di(2-ethylhexyl) adipate	103-23-1	(PHTHALATE sub)
DEHP	Di(2-ethylhexyl)PHTHALATE	117-81-7	PHTHALATE
DEHT/DOTP	Dioctyl terePHTHALATE	6422-86-2	Non PHTHALATE plasticizer
DEP	Diethyl PHTHALATE	84-66-2	PHTHALATE
Diazinon	Diazinon	333-41-5	PESTICIDE
dibenz[a,h]anthra-cene	dibenz[a,h]anthracene	53-70-3	POLY AROMATIC HYDROCARBONS
DiBP	Diisobutyl PHTHALATE	84-69-5	PHTHALATE
DIDP	Bis(8-methylnonyl) PHTHALATE	26761-40-0	PHTHALATE

Dieldrin	Dieldrin	60-57-1	PESTICIDE
DINCH	1,2-Cyclohexanedicarboxylic acid, 1,2-diisononyl ester	166412-78-8	PHTHALATE
DINP	Diisononyl PHTHALATE	28553-12-0	PHTHALATE
DMEP	Bis(2-methoxyethyl) *PHTHALATE*/di(2-methoxy-ethyl) PHTHALATE	117-82-8	PHTHALATE
DMP	Dimethyl PHTHALATE	131-11-3	PHTHALATE
DnBP	di-n-butyl PHTHALATE	84-74-2	PHTHALATE
DnOP	Di-n-octyl PHTHALATE	117-84-0	PHTHALATE
DOP	Dioctyl PHTHALATE	117-84-0	PHTHALATE
DPCP	Diphenylcyclopropenone	886-38-4	PHTHALATE
DPEHP	2-Ethylhexyl diphenyl phosphate	1241-94-7	FIRE RETARDANT
DPHP	Bis(2-propylheptyl) PHTHALATE/di(2-propylheptyl) PHTHALATE	53306-54-0	PHTHALATE
DPHP	Bis(2-propylheptyl) PHTHALATE	53306-54-0	FIRE RETARDANT
Dpsum	Dechlorane Plus	13560-89-9	FIRE RETARDANT
EHDPP	2-ethylhexyl diphenyl phosphate	1241-94-7	FIRE RETARDANT
EHDP	2-ethylhexyl diphenyl phosphate	1241-94-7	FIRE RETARDANT
EHTBB	2-Ethylhexyl-2,3,4,5-tetrabromobenzoate	183658-27-7	FIRE RETARDANT
EHTBB + BEHTBP	bis(2-ethylhexyl)-3,4,5,6-tetrabromo-PHTHALATE	26040-51-7	FIRE RETARDANT
Endrin	Endrin	72-20-8	PESTICIDE
EtFOSE (NEtFOSE)	N-ethyl perfluorooctane sulfonamidoethanol	1691-99-2	PER-AND POLY FLUOROALKYL SUBSTANCES
Fluoranthene	Fluoranthene	206-44-0	POLY AROMATIC HYDROCARBONS
Fluorene	Fluorene	86-73-7	POLY AROMATIC HYDROCARBONS
FOSA	Perfluorooctanesulfonamide	754-91-6	PER-AND POLY FLUOROALKYL SUBSTANCES
FOSAA	Perfluorooctane sulfonamidoacetic acid	2806-24-8	PER-AND POLY FLUOROALKYL SUBSTANCES
HBB	Hexabromobiphenyl	67774-32-7	FIRE RETARDANT
HBBz	Hexabromobenzene	87-82-1	FIRE RETARDANT
HBCD	1,2,5,6,9,10-Hexabromocyclodecane	3194-55-6	FIRE RETARDANT
HBCD	hexabromocyclododecane	3194-55-6	PESTICIDE
HCB	Hexachlorobiphenyl (mixed isomers)	26601-64-9	PESTICIDE
HCDBCO	Hexachlorocyclopentadienyl-dibromocyclooctane	51936-55-1	FIRE RETARDANT
iDPP	Isodecyl diphenyl phosphate	29761-21-5	FIRE RETARDANT

I-EtFOSAA	linear Isomer of N-Ethyl perfluorooctane sulfonamidoacetic acid		PER-AND POLY FLUOROALKYL SUBSTANCES
I-FOSA	linear Isomer of Perfluorooctane sulfonamide		PER-AND POLY FLUOROALKYL SUBSTANCES
I-MeFOSAA	Linear isomer of N-Methyl perfluorooctane sulfonamidoacetic acid		PER-AND POLY FLUOROALKYL SUBSTANCES
Indeno[1,2,3-cd]pyrene	Indeno[1,2,3-cd]pyrene	193-39-5	POLY AROMATIC HYDROCARBONS
I-PFHxS	Linear isomer of Perfluorohexane sulfonic acid		PER-AND POLY FLUOROALKYL SUBSTANCES
I-PFOS	Linear isomer of Perfluorooctane sulfonic acid		PER-AND POLY FLUOROALKYL SUBSTANCES
I-PF~~H~~OA	Linear isomer of Perfluorooctanoic acid		PER-AND POLY FLUOROALKYL SUBSTANCES
L-PFOS	1-perfluorooctanesulfonic acid	45298-90-6	PER-AND POLY FLUOROALKYL SUBSTANCES
MeFOSA (NMeFOSA)	Heptadecafluoro-N-methyloctanesulphonamide	31506-32-8	PER-AND POLY FLUOROALKYL SUBSTANCES
MeFOSE	N-Methylperfluorooctanesulfonamidoethanol	24448-09-7	PER-AND POLY FLUOROALKYL SUBSTANCES
MEHP	Mono-2-ethylhexyl PHTHALATE	4376-20-9	PHTHALATE
Metolachlor	Metolachlor	51218-45-2	PESTICIDE
MK	musk ketone	81-14-1	MUSK
mmp-TMPP	Meta, meta, para-Tris(methylphenyl) phosphate	1330-78-5	FIRE RETARDANT
4-NP	4-n-nonylphenol	104-40-5	ALKYLPHENOL
o,m,p - TCP	o,m,p-Tricresyl phosphate**?**	78-32-0	FIRE RETARDANT
o,o,o - TCP	o,o,o-Tricresyl phosphate	78-30-8	FIRE RETARDANT
o,p'-DDT (2,4-ddt)	2,4'-dichlorodiphenyltrichloroethane	789-02-6	PESTICIDE
OBIND	4,5,6,7-tetrabromo-1,1,3-trimethyl-3-(2,3,4,5-tetrabromophenyl)-indane	1084889-51-9	FIRE RETARDANT
4-n-octylphenol	4-n-octylphenol	1806-26-4	ALKYLPHENOL
o-TMPP	o,o,o-Tricresyl phosphate	78-30-8	FIRE RETARDANT
Oxadiazon	Oxadiazon	19666-30-9	PESTICIDE
OxC	oxychlordane	27304-13-8	PESTICIDE
p,p,p-TCP	p,p,p-tritolyl phosphate	78-32-0	FIRE RETARDANT
p,p'-DDD (4,4'-DDD)	Rhothane	72-54-8	PESTICIDE
PBB	Polybrominated biphenyls	84303-47-9	FIRE RETARDANT
PBBz	PBBbromobenzene	608-90-2	FIRE RETARDANT

PBDPP	resorcinol bis-(diphenylphosphate)	57583-54-7	FIRE RETARDANT
PBO	Piperonyl butoxide	51-03-6	PESTICIDE
PBT	PBT	24968-12-5	FIRE RETARDANT
PCB 101	2,2',4,5,5'-PENTACHLOROBIPHENYL	37680-73-2	POLYCHLORINATED BIPHENYL
PCB 105	PCB 105	32598-14-4	POLYCHLORINATED BIPHENYL
PCB 114	PCB 114	74472-37-0	POLYCHLORINATED BIPHENYL
PCB 118	2,3',4,4',5-PENTACHLOROBIPHENYL	31508-00-6	POLYCHLORINATED BIPHENYL
PCB 122	2,3,3',4',5'-Pentachlorobiphenyl	76842-07-4	POLYCHLORINATED BIPHENYL
PCB 123	2,3',4,4',5'-Pentachlorobiphenyl	65510-44-3	POLYCHLORINATED BIPHENYL
PCB 128	2,2',3,3',4,4'-HEXACHLOROBIPHENYL, AROCLOR 1260	38380-07-3	POLYCHLORINATED BIPHENYL
PCB 138	2,2',3,4,4',5'-HEXACHLOROBIPHENYL	35065-28-2	POLYCHLORINATED BIPHENYL
PCB 141	2,2',3,4,5,5'-HEXACHLOROBIPHENYL	52712-04-6	POLYCHLORINATED BIPHENYL
PCB 149	2,2',3,4',5',6-HEXACHLOROBIPHENYL	38380-04-0	POLYCHLORINATED BIPHENYL
PCB 153	2,2',4,4',5,5'-Hexachlorobiphenyl	35065-27-1	POLYCHLORINATED BIPHENYL
PCB 156	PCB 156	38380-08-4	POLYCHLORINATED BIPHENYL
PCB 157	2,3,3',4,4',5'-HEXACHLOROBIPHENYL	69782-90-7	POLYCHLORINATED BIPHENYL
PCB 167	PCB 167	52663-72-6	POLYCHLORINATED BIPHENYL
PCB 170	2,2',3,3',4,4',5-HEPTACHLOROBIPHENYL	35065-30-6	POLYCHLORINATED BIPHENYL
PCB 18	2,2',5-TRICHLOROBIPHENYL	37680-65-2	POLYCHLORINATED BIPHENYL
PCB 180	2,2',3,4,4',5,5'-HEPTACHLOROBIPHENYL	35065-29-3	POLYCHLORINATED BIPHENYL
PCB 183	2,2',3,4,4',5',6-HEPTACHLOROBIPHENYL	52663-69-1	POLYCHLORINATED BIPHENYL
PCB 187	2,2',3,4',5,5',6-HEPTACHLOROBIPHENYL	52663-68-0	POLYCHLORINATED BIPHENYL
PCB 189	2,3,3',4,4',5,5'-HEPTACHLOROBIPHENYL	39635-31-9	POLYCHLORINATED BIPHENYL
PCB 194	PCB 194	35694-08-7	POLYCHLORINATED BIPHENYL
PCB 206	2,2',3,3',4,4',5,5',6-NONACHLOROBIPHENYL	40186-72-9	POLYCHLORINATED BIPHENYL
PCB 28	2,4,4'-TRICHLOROBIPHENYL	7012-37-5	POLYCHLORINATED BIPHENYL

PCB 31	2,4',5-TRICHLOROBIPHENYL	16606-02-3	POLYCHLORIN-ATED BIPHENYL
PCB 33	2',3,4-TRICHLOROBIPHENYL	38444-86-9	POLYCHLORIN-ATED BIPHENYL
PCB 37	3,4,4'-TRICHLOROBIPHENYL	38444-90-5	POLYCHLORIN-ATED BIPHENYL
PCB 47	2,2',4,4'-TETRACHLOROBI-PHENYL	53469-21-9	POLYCHLORIN-ATED BIPHENYL
PCB 52	2,2',5,5'-TETRACHLOROBI-PHENYL	35693-99-3	POLYCHLORIN-ATED BIPHENYL
PCB 66	2,3',4,4'-TETRACHLOROBI-PHENYL	32598-10-0	POLYCHLORIN-ATED BIPHENYL
PCB 81	3,4,4',5-TETRACHLOROBI-PHENYL	70362-50-4	POLYCHLORIN-ATED BIPHENYL
PCP	Pentachlorophenol	87-86-5	PESTICIDE
PeCB	2,3',4,4',5-PENTACHLOROBI-PHENYL	31508-00-6	PESTICIDE
Penta-BDE	2,2',3,4,4'-Pentabromodiphenyl ether	182346-21-0	FIRE RETARDANT
permethrin	permethrin	52645-53-1	PESTICIDE
PFBS	Perfluorobutanesulfonic acid	375-73-5	PER-AND POLY FLUOROALKYL SUBSTANCES
PFDA (PFDcA)	Perfluorodecanoic acid	335-76-2	PER-AND POLY FLUOROALKYL SUBSTANCES
PFDoA	Perfluorododecanoic acid	307-55-1	PER-AND POLY FLUOROALKYL SUBSTANCES
PFDS (PFDcS)	Same as PFDcS? perfluorodecane sulfonate	335-77-3	PER-AND POLY FLUOROALKYL SUBSTANCES
PFHpA	Perfluoroheptanoic acid	375-85-9	PER-AND POLY FLUOROALKYL SUBSTANCES
PFHxA	Perfluorohexanoic acid	307-24-4	PER-AND POLY FLUOROALKYL SUBSTANCES
PFHxS	Perfluorohexanesulfonic acid	355-46-4	PER-AND POLY FLUOROALKYL SUBSTANCES
PFNA	Perfluorononanoic acid	375-95-1	PER-AND POLY FLUOROALKYL SUBSTANCES
PFOA	Perfluorooctanoic acid	335-67-1	PER-AND POLY FLUOROALKYL SUBSTANCES
PFOS (inc L-PFOS)	Perfluorooctanesulfonic acid	1763-23-1	PER-AND POLY FLUOROALKYL SUBSTANCES

PFPA	Pentafluoropropionic anhydride	356-42-3	PER-AND POLY FLUOROALKYL SUBSTANCES
PFPeA	Perfluoropentanoic acid	2706-90-3	PER-AND POLY FLUOROALKYL SUBSTANCES
PFPeDA	Perfluoropentadecanoic acid	141074-63-7	PER-AND POLY FLUOROALKYL SUBSTANCES
PFTrDA	Perfluorotridecanoic acid	72629-94-8	PER-AND POLY FLUOROALKYL SUBSTANCES
PFUnA (PFUnDA)	Perfluoroundecanoic acid	2058-94-8	PER-AND POLY FLUOROALKYL SUBSTANCES
pTBX	1,2,4,5-tetrabromo-3,6-dimethylbenzene	23488-38-2	FIRE RETARDANT
P-tmpp	tris(4-methylphenyl) phosphate	78-32-0	FIRE RETARDANT
RDP	Ribavirin Diphosphate	63142-70-1	FIRE RETARDANT
synDDC-CO	syn-dechlorane plus	135821-03-3	FIRE RETARDANT
TBB	4,5,6,7-tetrabromobenzotriazole	17374-26-4	FIRE RETARDANT
TBBPA	TetrabromoBISPHENOL A	79-94-7	FIRE RETARDANT
TBBPA-BDBPE	TetrabromoBISPHENOL A-bis(2,3-dibromopropyl ether)	21850-44-2	FIRE RETARDANT
TBCT	tetrabromo-o-chlorotoluene	39569-21-6	FIRE RETARDANT
TBE	1,1,2,2-Tetrabromoethane	79-27-6	FIRE RETARDANT
TBECH	1,2-Dibromo-4-(1,2-dibromoethyl)cyclohexane	3322-93-8	FIRE RETARDANT
TBEP	Tris(2-butoxyethyl) phosphate	78-51-3	FIRE RETARDANT
TBOEP	Tris(2-butoxyethyl) phosphate	78-51-3	FIRE RETARDANT
TBP	Tributylphosphate	126-73-8	FIRE RETARDANT
TBP	tri-n-butylphosphate	126-73-8	PLASTICIZER
TBP-AE	Allyl 2,4,6-tribromophenyl ether	3278-89-5	FIRE RETARDANT
TBP-DBPE	1,3,5-Tribromo-2-(2,3-dibromopropoxy)benzene	35109-60-5	FIRE RETARDANT
TBPH	Bis(2-ethylhexyl) tetrabromoPHTHALATE	26040-51-7	FIRE RETARDANT
TBPP	Tris(2,3-dibromopropyl) phosphate	126-72-7	FIRE RETARDANT
TBX	Tetrabromoxylene	13209-15-9	FIRE RETARDANT
TCEP	Tris(2-carboxyethyl)phosphine	5961-85-3	FIRE RETARDANT
TCIPP	Tris (1-chloro-2-propyl) phosphate TCPP/TCIP are these the same?	13674-84-5	FIRE RETARDANT
TCP	Tricresyl phosphate	96-18-4	FIRE RETARDANT
TCPP	tris(chloropropyl)phosphate	13674-84-5	FIRE RETARDANT
TCS	triclosan	3380-34-5	PHENOL
TDCPP (TDCIPP)	Tris(1,3-dichloro-2-propyl)phosphate	13674-87-8	FIRE RETARDANT
TEHP	Tris(2-ethylhexyl) phosphate	78-42-2	FIRE RETARDANT
TEP	Triethylphosphate	78-40-0	FIRE RETARDANT
tetramethrin	tetramethrin	7696-12-0	PESTICIDE

TIBP	Triisobutyl phosphate	126-71-6	FIRE RETARDANT
TIPP	Triisopropyl	513-02-0	FIRE RETARDANT
TMPP	tris(methylphenyl) phosphate	78-32-0	FIRE RETARDANT
TN	trans-nonachlor		PESTICIDE
TNBP	Tributylphosphate	126-73-8	FIRE RETARDANT
Tot bromobenzenes	Total Bromobenzene	108-86-1	FIRE RETARDANT
TOTM	trioctyl trimellitate	89-04-3	PHTHALATE alternative
TPHP	Triphenylphosphate	115-86-6	FIRE RETARDANT
TPP	Triphenylphosphate	115-86-6	FIRE RETARDANT
Trans-chlordane	Trans-chlordane	5103-74-2	PESTICIDE
TToP	Tritolyl	1330-78-5	FIRE RETARDANT
TXP	Trixylenyl phosphate	25155-23-1	FIRE RETARDANT
α-DBE-DBCH	rac-(1R,2R)-1,2-dibromo-(4S)-4-((1S)-1,2-dibromoethyl)cyclohexane	3322-93-8	FIRE RETARDANT
α-endosulfan	endosulfan	115-29-7	PESTICIDE
α-HCH	lindane	319-84-6	PESTICIDE
α-TBECH	rac-(1R,2R)-1,2-dibromo-(4S)-4-((1S)-1,2-dibromoethyl)cyclohexane	3322-93-8	FIRE RETARDANT
β-DBE-DBCH	rac-(1R,2R)-1,2-dibromo-(4S)-4-((1R)-1,2-dibromoethyl)cyclohexane	3322-93-8	FIRE RETARDANT
β-HBCD	beta-Hexabromocyclododecane	678970-16-6 134237-51-7	FIRE RETARDANT
β-HCH	lindane	319-84-6	PESTICIDE
β-TBECH	rac-(1R,2R)-1,2-dibromo-(4S)-4-((1R)-1,2-dibromoethyl)cyclohexane	3322-93-8	FIRE RETARDANT
γ-HBCD	gamma-Hexabromocyclododecane	134237-52-8	FIRE RETARDANT
γ-HCH	Lindane	319-84-6	PESTICIDE
PTBP	4-tert-butylphenol	98-54-4	PHENOL
4,4, DDT	4,4'-Dichlorodiphenyltrichloroethane	50-29-3	PESTICIDE

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