A survey of organic flame retardants and plasticizers in building materials on the Swedish market and their occurrence in indoor environments

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Summary

Man-made and industrial organic chemicals are ubiquitous in the indoor environments due to their frequent usage in building materials, interior decorations and consumer products. These chemicals are classified as volatile organic compounds (VOCs) or semivolatile organic compounds (SVOCs) depending on their physical characteristics such as boiling points and vapor pressures. The VOCs are mostly released to the indoor environment via volatilization processes, whereas the emission mechanisms of SVOCs is a more complex mix of volatilization, abrasion and/or direct transfer to other contact materials or skin. Exposure to certain SVOCs has been linked to adverse human health effects such as allergies, chronic asthma, endocrine disruption and neurodevelopmental issues. The aim of this report was to investigate two groups of SVOCs that are frequently used as additives in building materials; organic flame retardants (FRs) and plasticizers. A literature search was performed in order to identify currently used FRs and plasticizers as well as some new alternatives, which totaled to almost 300 compounds. These were further investigated for their presence in building materials available on the Swedish market with the help of two building material assessment databases SundaHus and Byggvarubedömningen. In all, around 2 500 building materials in the two databases were identified to contain the listed FRs and plasticizers. Plasticizers were frequently used in adhesives, jointing mastics, paints and indoor flooring while FRs were frequently used in different lighting articles, fireproof paints and jointing mastics. Interestingly, more than half of the FRs and plasticizers in our list were not registered in the material databases. This could be owing to the absence or low usage of these compounds in building materials in Sweden.

There is currently still a lack of knowledge on the chemical content in building materials and their emission characteristics to the indoor environment and the potential exposure risks to occupants. Future work such as combining field emission tests of building materials with indoor air and dust sampling in the same room is recommended to fill some of the knowledge gaps. Another strategy is to conduct suspect screening chemical analysis by high resolution mass spectrometry on representative indoor matrices such as dust, and link detected compounds to specific chemical additives found in different building products. The database which was established within this survey could then be useful for this purpose.

Sammanfattning

Idag är våra inomhusmiljöer fulla av syntetiska och industriella kemikalier på grund av deras användning i byggmaterial, inredning och konsumentprodukter. Dessa kemikalier kan klassas som flyktiga organiska föreningar (VOC:er) eller mindre flyktiga organiska föreningar (SVOC:er) efter deras kokpunkter och flyktighet. VOC:erna emitterar till inomhusmiljön från byggmaterial främst via förångningsprocesser medan SVOC:er kan emittera via förångningsprocesser, genom nötningsprocesser och även vid överföring via fysisk kontakt mellan byggmaterialet och andra material samt hud. Samband mellan exponering för vissa SVOCer och hälsoeffekter, som exempelvis allergier, kronisk astma och störning av det endokrina systemet, har påvisats hos människor. Syftet med denna rapport var att undersöka förekomsten av två grupper av SVOCer som används regelbundet i byggvaror, nämligen organiska flamskyddsmedel och mjukgörare. Omkring 300 flamskyddsmedel och mjukgörare valdes ut med hjälp av en litteraturstudie. För att undersöka om dessa ämnen används i byggmaterial som finns på den svenska marknaden användes materialdatabaserna SundaHus och Byggvarubedömningen.

Omkring 2500 byggmaterial innehållande dessa flamskyddsmedel och mjukgörare identifierades i materialdatabaserna. Mjukgörare förekom främst i lim, tätningsprodukter, färg samt inomhusgolv medan flest flamskyddsmedel identifierades i olika belysningsprodukter, brandskyddsfärg och tätningsprodukter. Mer än hälften av flamskyddsmedlen och mjukgörarna i vår lista fanns inte registrerade i materialdatabaserna vilket kan bero på att de inte används eller att de enbart används i mindre utsträckning i svenska byggvaror.

Idag finns stora kunskapsluckor om hur och i vilken omfattning som kemikalieemissioner från byggmaterial bidrar till vår totala exponering av farliga kemikalier. Framtida forskning som att kombinera fältemissionstester av byggmaterial med provtagning och analys av inomhusprover som damm från samma rum som byggmaterialen används i skulle kunna ge en utökad förståelse. En annan inriktning är att använda en så kallad förutsättningslös screeninganalys med hjälp av högupplösande masspektrometri och sammanlänka resultaten med kemiska tillsatsämnen i byggvaror som anges i olika databaser.

1. Introduction

Today, we spend up to 90% of our time in different indoor settings which has led to a constant exposure to synthetic and industrial chemicals from building materials, furnishing, interior decorations, and consumer products (Salthammer and Bahadir, 2009). These products could emit volatile organic compounds (VOCs) which can affect the indoor air quality (IAQ) and the health of the residents of the buildings (Swedish Chemicals Agency, 2015a, Sundell, 2004). Studies have shown that up to 40% of the VOCs in an indoor environment could be released from building materials (Missia et al., 2010). These substances could be residual products from the manufacturing process or intentionally added to the material (Swedish Chemicals Agency, 2015b). Due to their prevalent presence in indoor environments, exposure to VOCs can cause health issues such as rashes, nausea, headaches, and irritation of the eyes, nose, and throat which could be further developed into allergies and chronic asthma (Crook and Burton, 2010, Swedish Chemicals Agency, 2014b, KEMI (Swedish Chemicals Agency), 2015). A recent environmental health survey from 2015 indicated that 20% of the Swedish population have experienced health symptoms related to the indoor environment, which might be related to chemical exposure (The Publich Health Agency of Sweden, 2017). Furthermore, functional building materials usually contain chemical additives such as flame retardants, plasticizers, stabilizers, modifiers and colorants to gain or improve specific properties (Ambrogi et al., 2016, Bergman et al., 2012, Bui et al., 2016). Compared to VOCs which have boiling points between 50 and 260˚C, these additives tend to have higher molecular weight and boiling point and are usually considered to be semivolatile organic compounds (SVOCs) (Henneuse-Boxus and Pacary, 2003). Therefore, the release of SVOCs from their products to the indoor environment is usually much slower since their low vapor pressure and high relative molecular weight lead to slow migration to the material surface and subsequent volatilization or abrasion processes (Rauert and Harrad, 2015, Salthammer and Bahadir, 2009, Sukiene et al., 2016, Weschler, 2009). Different definitions have been suggested for compounds that are SVOCs; based on a boiling point range between 240 and 400˚C, vapor pressures between 10^{-9} to 10 Pa, or from elution time in gas chromatography that falls between C_{16} and C_{22} alkanes (AgBB, 2015, Henneuse-Boxus and Pacary, 2003, Weschler and Nazaroff, 2008). Exposure to some SVOCs have been linked to adverse health effects such as allergies, mutagenic effects, cancer, neurotoxicity and endocrine disruption (Duty et al., 2005, Dishaw et al., 2014, Gray et al., 2006, Hauser et al., 2006, Meeker and Stapleton, 2010, Roze et al., 2009, Swan, 2008, Wei et al., 2015, WHO, 1998). In comparison to VOCs, SVOCs are less investigated in the indoor environment, mainly because they are more difficult to measure and occur at much lower concentrations (Barro et al., 2009, Salthammer and Bahadir, 2009). Subsequently, there is limited information about SVOCs that are used as additives in consumer products and building materials. In view of this, the aim of this review was to survey and compile a report on the usage of different chemical additives in building materials available on the Swedish market. In order to provide a more focused survey, we restricted our investigation to include organic substances that are mainly used as flame retardants (FRs) and plasticizers in building construction (such as building boards and indoor flooring) and interior decoration (such as chairs and lamps). A database was compiled for different FRs and plasticizers along with their predicted physical-chemical properties as well as their usage in building materials in Sweden.

2. Additives in building materials

The specific properties of functional building materials, such as flexibility, flame retardancy, moisture resistance and UV stabilization, are usually achieved with additives (Ambrogi et al., 2016, Kemmlein et al., 2003, Salthammer and Bahadir, 2009, Sukiene et al., 2016). The amount of these additives in building materials typically range from low parts per thousand (‰) to a few percent (%) by weight, but in some cases amounts of more than 50% has been added in order to fulfill the specified requirements (Ambrogi et al., 2016, Swedish Chemicals Agency, 2014c, SSNC, 2014, Weschler, 2009, Weschler and Nazaroff, 2008, Wittassek et al., 2011). As mentioned before, most additives are SVOCs and can be either chemically bonded into the chemical structure of the material (reactive process) or physically mixed with the material (additive process). In particular, additively mixed compounds have a higher risk of being releasing from building products to the surroundings (DTI, 2013, Lassen and Lokke, 1999, Rauert and Harrad, 2015, Salthammer and Bahadir, 2009, Sukiene et al., 2016). The release of SVOCs from materials to the indoor environment mainly occur via three major pathways; (i) volatilization/diffusion to the bulk air from the material surface, (ii) direct contact between other solid materials (e.g. dust, soil or skin) and the building material, and (iii) by abrasion of particles through wear and tear of the building material (Rauert and Harrad, 2015, Cousins et al., 2018). The release of SVOCs are considered relatively constant over time due their relatively high molecular weight and low vapor pressure (Weschler and Nazaroff, 2008, Salthammer and Bahadir, 2009, Xu and little, 2006). Below, we report and discuss the occurrence and usage of the two most commonly used groups of additives in building materials, namely organic FRs and plasticizers. These two groups were identified as additives of particular interest by the Organic Chemicals Emitted from Technosphere Articles (ChEmiTecs) research program due to their high storage volume in building materials and their physical-chemical properties (Cousins et al., 2018).

2.1. Organic flame retardants

In Sweden, there are no specific fire requirements on building materials (KEMI (Swedish Chemicals Agency), 2006). Instead the overall perspective of the building is considered when the fire safety is controlled. The fire requirements can therefore be achieved by different means in accordance to the rules stipulated by National Board of Housing, Building and Planning (Boverket, 2017). For example, sprinkler systems and fuses can be installed in order to prevent the spread of fire (Boverket, 2017, KEMI (Swedish Chemicals Agency), 2006). However, the increasing usage of plastic in modern buildings has led to the increasing usage of FRs to prevent the spread of fire from the materials (KEMI (Swedish Chemicals Agency), 2006, SSNC, 2014). The worldwide consumption of FRs reached 2.5 million tonnes in 2015, of which 600 000 tonnes were used in Europe (Grand-View-Research, 2017). These additives prevent the spread of fire mainly via two major mechanisms; (i) reaction in the gas phase by removal of radicals from the combustion process, or (ii) forming a shielding layer of charred solids around the material (Bergman et al., 2012, Chen et al., 2008, Gustavsson et al., 2017, Schmitt, 2007, van der Veen and de Boer, 2012). The FRs can be incorporated into the polymer structure during the manufacturing process (i.e. reactive FRs) or physically mixed with the material (i.e. additive FRs) (Bergman et al., 2012, Fisk et al., 2003, Gustavsson et al., 2017, van der Veen and de Boer, 2012).

Organic FRs can roughly be grouped into four different groups; (i) chlorinated flame retardants (CFRs), (ii) brominated flame retardants (BFRs), (iii) phosphorus flame retardants (PFRs), and (iv) nitrogen flame retardants (NFRs) (Bergman et al., 2012, van der Veen and de Boer, 2012). It should be noted that the chemical structure of some FRs include moieties from the different groups, such as the case for chlorinated PFRs, and thus a clear distinction between the groups cannot always be made. Some FRs have been of high environmental health concern due to their bioaccumulative, persistent and toxic properties. Most of these are CFRs, such as polychlorinated biphenyls (PCBs) and Dechlorane Plus, as well as BFRs, such as polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCDD), and tetrabromobisphenol-A (TBBPA) (Covaci et al., 2006, Covaci et al., 2009, Gustavsson et al., 2017). This has led to national, regional or even global restriction and bans of certain halogenated FRs (Table 1). For example, PCBs, tetrabromodiphenyl ether (tetraBDE), pentabromodiphenyl ether (pentaBDE), hexabromodiphenyl ether (hexaBDE), heptabromodiphenyl ether (heptaBDE), decabromodiphenyl ether (decaBDE) and HBCDD have been listed in the Stockholm Convention on Persistent Organic Pollutants (SC POPs) in order to eliminate their production and uses around the globe (UNEP, 2018). Furthermore, decaBDE and HBCDD are also listed on the Candidate list provided by the European Chemical Agency (ECHA) as Substances of Very High Concern (SVHCs) (ECHA, 2018b). In addition, HBCDD is listed on the

ECHA authorization list, and approval is therefore needed if the compound needs to be used in a specific product (ECHA, 2018a). Furthermore, all PBDEs have been banned in electronic equipment within EU since 2008 (EU, 2002) and short chain chlorinated paraffins (SCCPs), which has replaced PCBs as FRs in some applications, has recently been listed in the Stockholm Convention (UNEP, 2018), as well as being classified as SVHCs and listed in the ECHA Candidate list (ECHA, 2018b).

Table 1. Examples of some restrictions on organic flame retardants in the EU and globally.

Compound	Restriction
Tetra-, octa-, decaBDE	Stockholm convention on POPs
DecaBDE	ECHA Candidate list
HBCDD	Stockholm convention on POPs and ECHA Candidate list
PBDEs	Directive 2002/95/EG
SCCPs	Stockholm convention on POPs and ECHA Candidate list

Due to these restriction and bans, alternative FRs has been introduced and increasingly used on the market such as other BFRs, e.g. decabromodiphenyl ethane (DBDPE) and hexabromobenzene (HBB), and PFRs such as tris(1,3-dichloroisopropyl) phosphate (TDCIPP) and tris(2-butoxyethyl) phosphate (TBOEP). However, some of these compounds have also shown to be bioaccumulative, persistent and have the potential to undergo long range atmospheric transport (Covaci et al., 2011, van der Veen and de Boer, 2012, Wei et al., 2015). In addition, studies have shown that some of these compounds could cause adverse health effects such as carcinogenicity, neurotoxicity, allergy and endocrine disruption (Covaci et al., 2011, van der Veen and de Boer, 2012, Wei et al., 2015). In view of this, legacy FRs as well as the new alternative FRs were included in this study for investigating their usage in commercial building materials in Sweden.

2.2. Plasticizers

Plasticizers are chemical additives added to building materials in order to increase their flexibility, resilience, durability and handling (Bui et al., 2016, Kemi, 2014, Wypych, 2017). Throughout the years, around 300 plasticizers have entered the market, although about 50-100 are currently in commercial use (Kemi, 2014). A primary plasticizer is the sole or main substance which is added to the material to give the plasticizing effects. However, sometimes a secondary plasticizers can also be added to enhance the performance of the primary plasticizer (Kemi, 2014). The worldwide consumption of plasticizers reached

6.4 million tonnes in 2011, of which 1 million tonnes was consumed in Europe (Swedish Chemicals Agency, 2014a).

A widely used group of plasticizers is phthalates. However, some phthalates have been restricted within the EU due to their potential reproductive toxicity and endocrine disrupting properties (Duty et al., 2005, Gray et al., 2006, Hauser et al., 2006, Swedish Chemicals Agency, 2014b, Swan, 2008, Wittassek et al., 2011). Currently, 12 phthalates are classified as SVHC compounds on the ECHA Candidate list; see Table 2 (ECHA, 2018b). Among these, four phthalates have also been added to the ECHA Authorization list, and thus approval is needed in order to use di-(2-ethylhexyl) phthalate (DEHP), diisobutyl phthalate (DIBP), dibutyl phthalate (DBP) and butylbenzyl phthalate (BBzP) in specific products (ECHA, 2018a). Also, two EU directives regulate the usage of phthalate in the EU market, EU 1907/2006 (EU, 2006) and 2009/48/EG (EU, 2009). EU 1907/2006 stipulate that DEHP, DBP and BBP are not allowed in toys or in baby care products in concentration above 0.1 % (w/w) (EU, 2006). Also, the regulation stipulates that diisononyl phthalate (DINP), diisodecyl phthalate (DIDP), and di(n-octyl) phthalate (DNOP) are not allowed in toys or in baby care products that are used by children and toys that are intended to be placed in the mouth in concentration above 0.1% (w/w) (EU, 2006). The second directive, 2009/48/EG, stipulates that carcinogenic, mutagenic, and toxic (CMR) compounds categorized as 1A and 1B are not allowed in toys used by children under 14. This includes some of the phthalates listed on the ECHA Candidate list (EU, 2009). The usage of five phthalates, DEHP, DBP, BBP, DINP, and DIDP, are also restricted in plastic materials in contact with food articles (EU, 2011b).

Table 2. Examples of some current restrictions within the EU regarding plasticizer usage.

Compound	Restriction
Di-(2-ethylhexyl) phthalate (DEHP)	ECHA Candidate and Authorization list, EU 1907/2006, 2009/48/EG, Regulation No 10/2011
Diisobutyl phthalate (DIBP)	ECHA Candidate and Authorization list, 2009/48/EG
Dibutyl phthalate (DBP)	ECHA Candidate and Authorization list, EU 1907/2006, 2009/48/EG
Butylbenzyl phthalate (BBzP)	ECHA Candidate and Authorization list, EU 1907/2006, 2009/48/EG
Bis(2- methoxyethyl) phthalate; Di(2-methoxyethyl) phthalate (BMEP; DMEP)	ECHA Candidate list, 2009/48/EG

Dipentyl phthalate (DPP)	ECHA Candidate list, 2009/48/EG
Diisopentyl phthalate (DIPP)	ECHA Candidate list, 2009/48/EG
1,2-Benzenedicarboxylic acid, di-C7-11-alkyl esters (DHNUP)	ECHA Candidate list, 2009/48/EG
1,2-Benzenedicarboxylic acid, di-C6-8-branched alkyl esters (DIHP)	ECHA Candidate list, 2009/48/EG
N-Pentylisopentyl phthalate (PIPP)	ECHA Candidate list, 2009/48/EG
Dihexyl phthalate (DHP)	ECHA Candidate list, 2009/48/EG
1,2-Benzendicarboxylic acid dipentyl ester, branched and linear	ECHA Candidate list, 2009/48/EG
Diisononyl phthalate (DINP)	EU 1907/2006
Diisodecyl phthalate (DIDP)	EU 1907/2006
Di(n-octyl) phthalate (DNOP)	EU 1907/2006
Bisphenol A (BPA)	ECHA Candidate list, 2009/48/EC, Regulation No 10/2011, 2011/8/EU

Another plasticizer with restriction is Bisphenol A (BPA). This compound is listed in the ECHA Candidate list (ECHA, 2018b) and has not been allowed to be used in infant feeding bottles since 2011 (EU, 2011a). Within EU, a migration limit value of 0.05 mg/kg has been applied for food in contact with plastic materials and 0.04 mg/L for plastic toys (EU, 2011b, EU, 2009). From the year 2020, BPA will also be forbidden in thermal papers used for tickets and receipts (ECHA, 2018c).

Due to these restrictions, alternative plasticizers has entered the marked, such as diisononylcyclohexane-1, 2-dicarboxylate (DINCH) and dibutyl adipate (DBA) (Bui et al., 2016, Plasticisers-Information-Center, 2018). These alternatives accounted for 22% of the Europe plasticizer consumption volume in 2011 and the worldwide consumption of alternative plasticizers are expected to have a yearly increase of 5.7% between 2011 and 2018 (Swedish Chemicals Agency, 2014a). Information regarding the potential health effects on humans from exposure to the alternative plasticizers are to date quite limited, although some are suspected to be persistent and toxic (Bui et al., 2016). In this review, we included conventional and legacy as well as alternative plasticizers to further investigate their usage in building materials available on the Swedish market.

3. Literature search

A first step in the data collection involved searching both scientific citation indexing services (Web of Science) and "grey" literature (web sites and reports from governmental bodies, trade associations and industry). Specific search terms inserted into Web of Science were mainly focused on organic flame retardants and plasticizers in combination with key words related to products and the environment. Table 3 shows the specific search terms used to assess of the number of published items in Web of Science using the advanced and refined search settings. It should be noted that these search terms are mainly used to provide an indication about the trends of published scientific literature on these subjects. Therefore, a comprehensive overview of all published literature on this subject is outside the scope of this survey and we mainly focus on information that are most relevant and have high significance to this review topic.

Table 3. Number of published items (as of 2018-03-15) found in Web of Science (from 1975-2017) using search tags for topics (TS) related to organic flame retardants and plasticizers in building materials and environment. For plasticizers, exclusion where made for the number of hits within the scientific field categories nanotechnology, pharmacology, food science technology and electrochemistry to filter out unrelated items.

Search word	Number of hits
TS = ((flame retardant*) AND (*plastic* OR polymer* OR indoor OR environment OR emission OR building* OR product*))	9791
TS = ((plasticizer* OR plasticiser*) NOT (electrolyte* OR nano*)) Refined by: [excluding] WEB OF SCIENCE CATEGORIES: (PHARMACOLOGY PHARMACY OR FOOD SCIENCE TECHNOLOGY OR ELECTROCHEMISTRY) Timespan: 1975-2017. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI.	9603

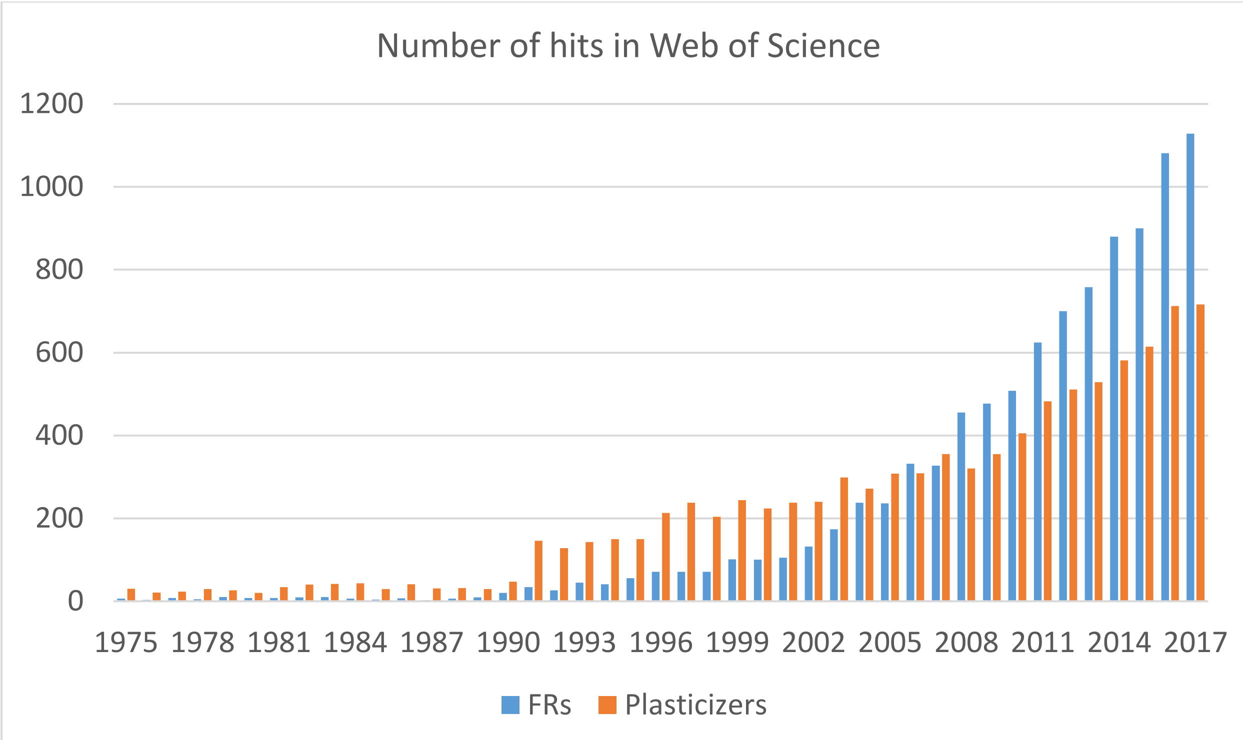

Figure 1. Number of hits in Web of Science using the search terms stated in Table 3.

Published items on the subjects were further grouped by the year of publication and the time trend is displayed in Figure 1. As can be seen, there has been a significant increase in the number of published items for plasticizers (from ~100 in 1990 to more than 700 in 2017). The time trend for FRs increased even more dramatically, especially during the 2000s, and even surpasses the number of hits for plasticizers. This gives an indication about the intensification in research on the synthesis and manufacturing processes of FRs due to an increased market demand driven by stricter fire safety requirements, and also the subsequent environmental contamination and health concerns. Interestingly, the increasing awareness on the environmental contamination and potential health effects of FRs could be perceived by comparing the number of hits in Web of Science for the same search term for FRs stated in Table 3 but refined by grouping the items to different scientific fields that are either related to synthesis and manufacturing or related to environmental contamination and health effects (see Figure 2).

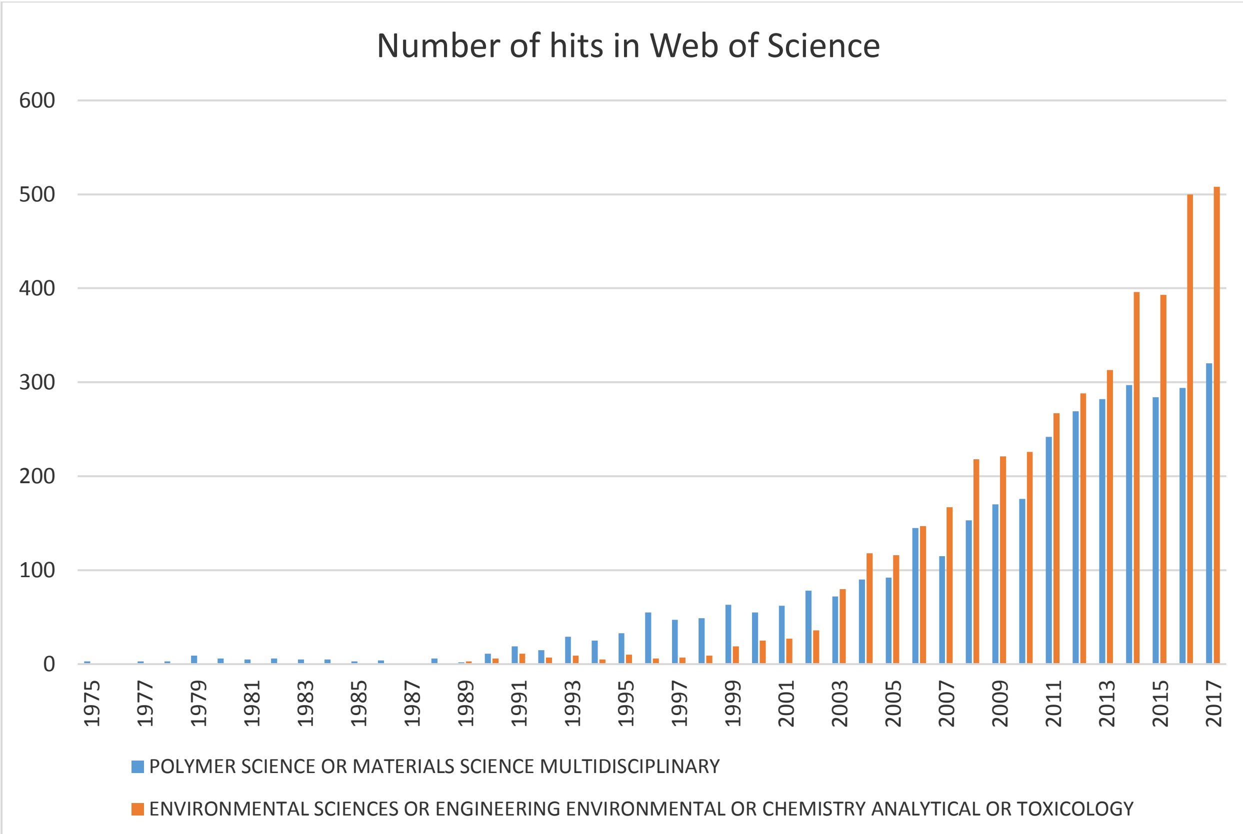

Figure 2. Number of hits in Web of Science for the top six scientific research fields for FRs within the search term stated in Table 3 and grouped by polymer and material sciences (total 3684 number of hits) or by environmental sciences, environmental engineering, chemical analysis and toxicology (4288 number of hits).

4. Identified flame retardants and plasticizers

A list of organic FRs and plasticizers were mainly compiled from available literature and reports (Bergman et al., 2012, Bui et al., 2016, ECHA, 2018c, Gustavsson et al., 2017, Swedish Chemicals Agency, 2014b, Lassen and Lokke, 1999, Larsson et al., 2017, van der Veen and de Boer, 2012). If available, their CAS number were directly used from the sources and if not available, then a search was conducted in Pubchem, Chemspider and Chemistry Dashboard as well as in online search engines. It should be noted that this is not a complete list of all commercial FRs and plasticizers, but should nevertheless cover a majority of those available in the market. A total of 216 different FRs and 81 plasticizers were selected for further investigation and a full list of the compounds can be found in Appendix 1. Among these substances, CAS numbers for 50 of the FRs and 26 of the plasticizers were for mixtures or substances of unknown or variable composition, complex reaction products or of biological materials (UVCB), while one substance (tetramethylene dimelamine) was designated as a salt. It should also be noted that some of the substances could be used as both flame retardants and plasticizers and for other purposes as well, but were only placed into one category by their perceived main usage in building products whenever this information was available. This was done to simplify the statistical analysis. In this report, we treat each CAS number as one individual substance or a mixture of different substances but have in mind that the same compound or compound group could have multiple CAS numbers. For example, 20 CAS numbers were found for chlorinated paraffins (CPs) as these relate to different technical mixtures. Some individual PBDE congeners such as BDE-183 (CAS 207122-16-5) are major constituents in the technical mixture octaBDE (CAS 32536-52-0). Some of the listed substances have previously been banned such as the PCB Aroclor mixtures, polychlorinated naphthalene mixtures Halowax and technical PBDE mixtures, and are not expected to be in use anymore but these were still included to further verify their absence in the building material.

Among the FRs, 95 were brominated and 60 were chlorinated (Figure 3), and six contained both halogens (CAS numbers 34571-16-9, 56890-89-2, 51936-55-1, 58495-09-3, 87-84-3 and 39569-21-6). Furthermore, 58 of the FRs were phosphorous compounds, and among these nine were also halogenated. Also, 24 substances (all used as FRs) contained nitrogen, which are mainly melamine and its derivatives. It can therefore be perceived that the halogenated and phosphorous additives are dominating among the FRs on the list. There is however a trend to move away from lower molecular weight halogenated flame retardants and towards higher weight monomeric or polymeric halogenated FRs, since these have lower migration potential through the material and should thus be released to a lower extent by vaporization (BSEF, Danish Environmental Protection Agency, 2014). However, the costs associated with higher molecular weight substances is usually higher, and is currently one of the limiting factors for widespread usage of polymeric FRs and plasticizers (Hansen et al., 2013). Among the plasticizers, almost half were phthalates (n = 34) which corroborates the dominance of this compound class (Figure 3). None of the additives that were primarily designated as plasticizers contained any chlorine, bromine or nitrogen heteroatoms in their structure.

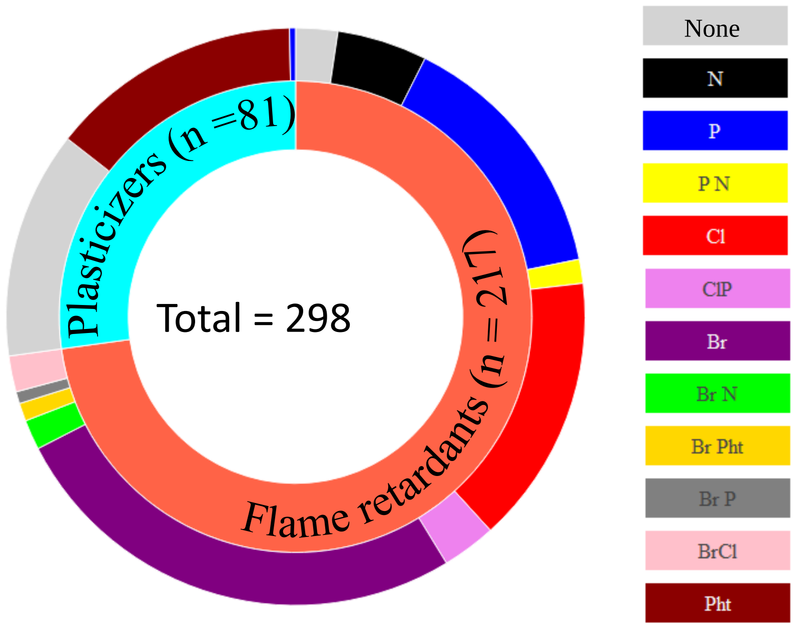

Figure 3. Sunburst chart of the relative numbers of plasticizers and flame retardants that contain specific heteroatoms or specific substructure or a combination of these. Legend text: N = nitrogen, P = phosphorous, Cl = chlorine, Br = bromine, Pht = phthalate. "None" refers to substances not containing any of the specified heteroatoms or substructures.

5. Building material assessment systems

To evaluate the number and types of building materials that contain the FRs and plasticizers in our list, a search was performed using their corresponding CAS number in the databases of two building material assessment systems: SundaHus (SH) and Byggvarubedömningen (BvB) (Byggvarubedömningen, 2018, SundaHus, 2018). Another main building material assessment system in Sweden, BASTA, was not included in this survey as it is currently not possible to search individual chemicals in their online platform. The databases available within the two included assessment systems contain information about building materials that suppliers and manufacturers in the Swedish market have voluntarily registered for assessment. The registered building materials are then evaluated according to their potential environmental and health impacts as well as life cycle aspects. Building materials that contain substances listed in different authoritative lists on hazardous chemicals such as the REACH regulation, the Classification, Labelling and Packaging (CLP) regulation or the Swedish Chemicals Agency, will be given a lower score which affects the overall evaluation. In the SH database, the building materials containing substances not present in specified lists at a significant amount are given a mark of A, and a descending scale down to a C- is used for those that contain substantial amounts of hazardous substances, while D marks are given to materials with incomplete documentation for evaluation (SundaHus, 2018). The classification system in the BvB database are based on a color scale, where green-marked building materials are “recommended” since they have satisfactorily documentation and do not contain substances that are classified as hazardous at any significant amount. The chemical content criteria of a green label (usually ≤0.01 - 0.3% depending on substance class) is based on a safety factor which is ten times lower than the content criteria for yellow labelled building materials which are “accepted” since they satisfy the current regulations about the content of harmful substances (usually ≤0.1 - 3%). Red-marked building materials contain listed substances at levels above the “accepted” criteria and are recommended to be “avoided” (Byggvarubedömningen, 2018). These two databases provide valuable information to building constructors and property owners in choosing building materials with low environmental and health impact (Byggvarubedömningen, 2018, SundaHus, 2018).

5.1. Usage of flame retardants and plasticizers in building materials

The database search for the FRs and plasticizers in Appendix 1 resulted in hits for 15 different building material categories (see Table 4). These categories are based on the BK04 classification system, which is a standardized grouping system of building materials used in Sweden. In this system, the building materials are grouped into 27 main categories which are in turn divided into different subcategories. Within each subcategory, the individual products are further specified by the product line codes (Byggmaterialhandlarna, 2018, Byggvarubedömningen, 2018, SundaHus, 2018). The intent of the BK04 system was to standardize the classification of products that are commonly traded in the building material, hardware and paint retail market. It therefore also include some product categories that might not by definition belong to building materials, such as “11 - Household articles” or “08 – Gardens”. Upon registration into the two building material assessment systems, the registrants choose the most appropriate product category for their specific product. If no category has been chosen, then the evaluator in the assessment system will assign an appropriate category for the product. This self-classification process might lead to misclassification since some products can be classified into different categories.

Table 4. A shortened list of the main categories (two digit number) and subcategories (three digit number) of the BK04 classification system for building materials investigated in this report. A complete list also containing the five digit product line codes can be found in Appendix 2.

Main category	Sub category
01 - Building material	010 - Binding agents and mortars
	011 - Building blocks and aggregates
	012 - Sheet materials
	013 - Insulation materials
	014 - Weatherproofing systems, tape and sealing strip
	015 - Reinforcement, steel and metal goods
	016 - Roof and wall cladding
	017 - Chemico-technical goods
	018 - Subfloor system
	019 - Home remodelling
03 - Fit-out materials and paint	030 - Ceramic goods
	031 - Flooring articles
	032 - Wallpapers
	033 - Ceiling and wall systems
	034 - Paint goods
04 - Interior decor and joinery articles	040 - Doors
	041 - Windows and glass goods
	042 - Kitchen fixtures
	043 - Bathroom fixtures
	044 - Room fitting-out
	045 - Storage
05 - Fasteners	051 - Screws
	052 - Bolt articles, nuts and washers
	054 - Securing and expanders
06 - Ironmongery	060 - Locks and handles
	061 - Ironmongery
07 - Safety	070 - Safety

08 - Gardens	082 - Tools and implements
10 - Structural components	100 - Structural components
11 - Household articles	110 - Kitchen equipment
	112 - Furniture
	114 - Cleaning articles
13 - Hobby, sport and leisure	130 - Games and play
14 - Hand tools	145 - Instruments
18 - Electrical goods	180 - White goods
	181 - Electrical appliances
	182 - Lighting articles
	183 - Electrical wiring material
20 - Heating and plumbing	200 - Heating
	201 - Plumbing
	202 - Groundworks
	203 - Hoses and hose fittings
	205 - Installation systems
	207 - Fittings
21 - Ventilation	210 - Ventilation
24 - Climate and air-conditioning	240 - Heating
	241 - Air

Among the 297 additives in our list, only 68 substances (26 FRs and 42 plasticizers) were found in the building materials in the two databases (Figure 4). Additionally, 172 FRs and 49 plasticizers were not found in SH, while some substances (21 FR and 24 plasticizers) were registered in this database but have not been listed as a component in any building materials. Also, 173 FRs and 42 plasticizers were not registered in the BvB database. These are further discussed in section 5.1.6.

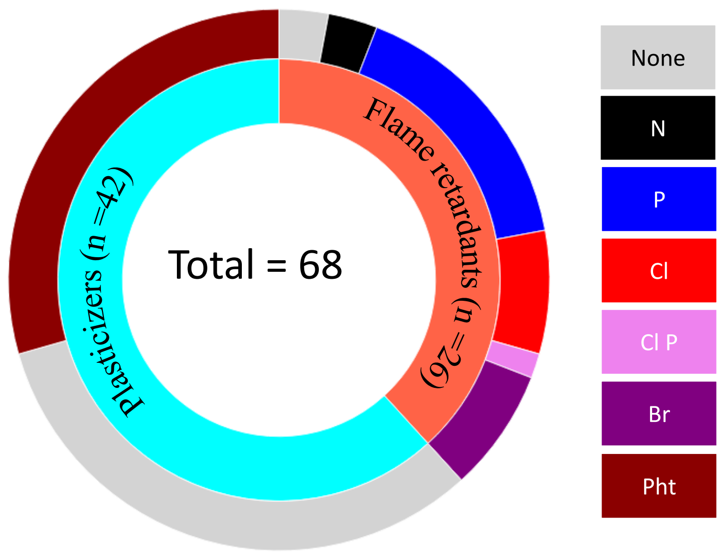

Figure 4. Sunburst chart of the relative numbers of plasticizers and flame retardants found in the building materials in the two databases. Legend text: N = nitrogen, P = phosphorous, Cl = chlorine, Br = bromine, Pht = phthalate. "None" refers to substances not containing any of the specified heteroatoms or substructures.

The number of building materials containing FRs and plasticizers are shown in Figure 5. A total of 810 building products in BvB and 267 in SH were found to contain at least one of the FRs in our list, whereas plasticizers were found in 788 products in BvB and 633 in SH. However, it should be noted that not all building materials on the Swedish market are registered in the databases since building products are only voluntarily registered in these systems by suppliers and producers. Furthermore, building articles from the same company might be registered in both databases and thus the total number of products could be overestimated. However, an examination of the compiled list by product names and companies showed only a small proportion of products that were registered in both databases. In the following discussions, we combined the products from both databases with the assumption that these represented individual products, unless otherwise specified.

The main category with the highest number of products containing FRs was "18 - Electrical goods" (n = 553). This was followed by "01 - Building materials" (n = 182) and "03 - Fit-out materials and paints" (n = 86). For plasticizers, the highest number of products was found for "Fit-out materials and paints" (n = 549) and followed by "Building materials" (n = 437) and "Electrical goods" (n = 139).

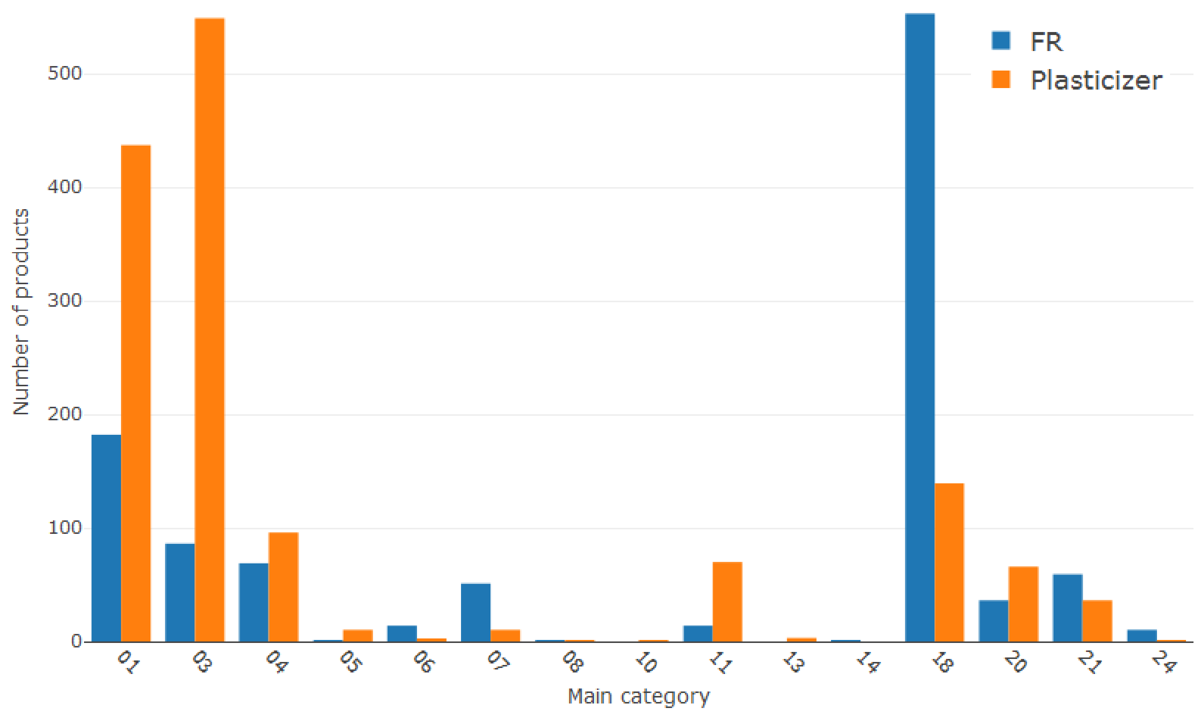

Figure 5. Number of building materials containing FRs and plasticizers registered in the material databases of SundaHus (SH) and Byggvarubedömningen (BvB). For explanation of the BK04 main category codes, please see Table 4. The three main categories with most product lines containing the two compound groups were “01 - Building materials”, “3 - Fit-out materials and paints” and “18 - Electrical goods”.

Some of the main categories with the lowest number of building materials containing FRs and plasticizers were “08 - Gardens ” (FRs = 1, plasticizers = 1), “13 - Hobby, sport and leisure ” (plasticizers = 3), and “14 Hand tools“ (plasticizer = 1). The main categories may not be specifically associated with building materials and are applied for outdoor activities which could result in a low registration number by the suppliers.

Detailed discussions on FRs and plasticizers among the different main categories can be found below.

5.1.1. Electrical goods

A total of 9 FRs and 11 plasticizers were found among the 692 products within the “18 – Electrical goods” main category (Figure 6). The subcategories that contain the highest number of products were “182 -

Lighting articles” (n = 525) and “183 - Electrical wiring material” (n = 147). Three FRs (melamine, melamine cyanurate and TBBPA) and six plasticizers were identified in different lighting articles intended for indoor and/or outdoor usage. TBBPA was by far the most frequently used additive within the “lighting articles” (n = 466). This compound is used as a reactive FR in epoxy resins and commonly used for circuit boards in electronic equipment such as emergency lamps (Covaci et al., 2009, KEMI (Swedish Chemicals Agency), 2006, Lassen and Lokke, 1999). It is also used as an additive FR in acrylonitrile butadiene styrene (ABS) plastics which could be used as envelopes for electronic equipment such as lamps (Covaci et al., 2009, KEMI (Swedish Chemicals Agency), 2006, Lassen and Lokke, 1999). The content of TBBPA in the products listed in the two databases were mostly around or below 0.1%. According to the Substance in Preparations in Nordic Countries (SPIN) database, the production/import of TBBPA was relatively low (29 tonnes) in 2015 compared to melamine (3 740 tonnes) (SPIN, 2018). In the SPIN database, only substances in chemical products and preparations are registered and thus does not specifically include finished non-chemical products such as building materials. The same trends can been seen within EU, the production/import volume of melamine were 100 000- 1000 000 tonnes and for TBBPA 1000-10 000 tonnes in 2017 (ECHA, 2018c). The lower amounts of TBBPA could have been caused by the phase-out of the compound and the introduction of the alternative FRs, such as melamine (Gustavsson et al., 2017, Lassen and Lokke, 1999). The high tonnage band for melamine could also be explained by its widespread usage in many different areas such as raw material for thermosetting plastics in consumer goods and as plasticizer for concrete.

The plasticizers DEHP, DiDP, and DINP were found in lamps used indoors. DEHP has been one of the primary phthalates in polyvinylchloride (PVC) plastics which are a commonly used for wire and lamp compartments (Wensing et al., 2005, Weschler, 2009). Furthermore, two alternative plasticizers to DEHP was identified, bis(2-ethylhexyl) adipate (DEHA) and TOTM (Bui et al., 2016, Kemi, 2014, Rahman and Brazel, 2006). Among these two, TOTM is more frequently used in products that could reach high temperature and it has improved migration resistant properties compared to DEHP (Bui et al., 2016, Rahman and Brazel, 2006). The production/import volumes of DEHA, DEHP and TOTM were in the range 10 000-100 000 tonnes in 2017 within the EU region (ECHA, 2018c) which indicates in a high demand for these plasticizers. However, in Sweden, the production/import of DEHP (153 tonnes) was less than for DEHA (968 tonnes) and TOTM (614 tonnes) possibly owing to stricter regulations (SPIN, 2018). Furthermore, the restricted compound BPA, were also found in 31 lighting products which was probably due to its usage in polycarbonate and epoxy resins (Corrales et al., 2015, Swedish Chemicals Agency, 2011, Staples et al., 1998). The latter polymer is commonly used in circuit boards and photo resistors used in lighting products (Swedish Chemicals Agency, 2011). Addition of BPA strengthens the epoxy plastic and provide good insulation properties and resistance against chemicals, moisture and corrosion, which are desirable properties for plastic materials that could be subjected to high temperatures (Swedish Chemicals Agency, 2011, Levchik and Weil, 2004, Sato et al., 2005).

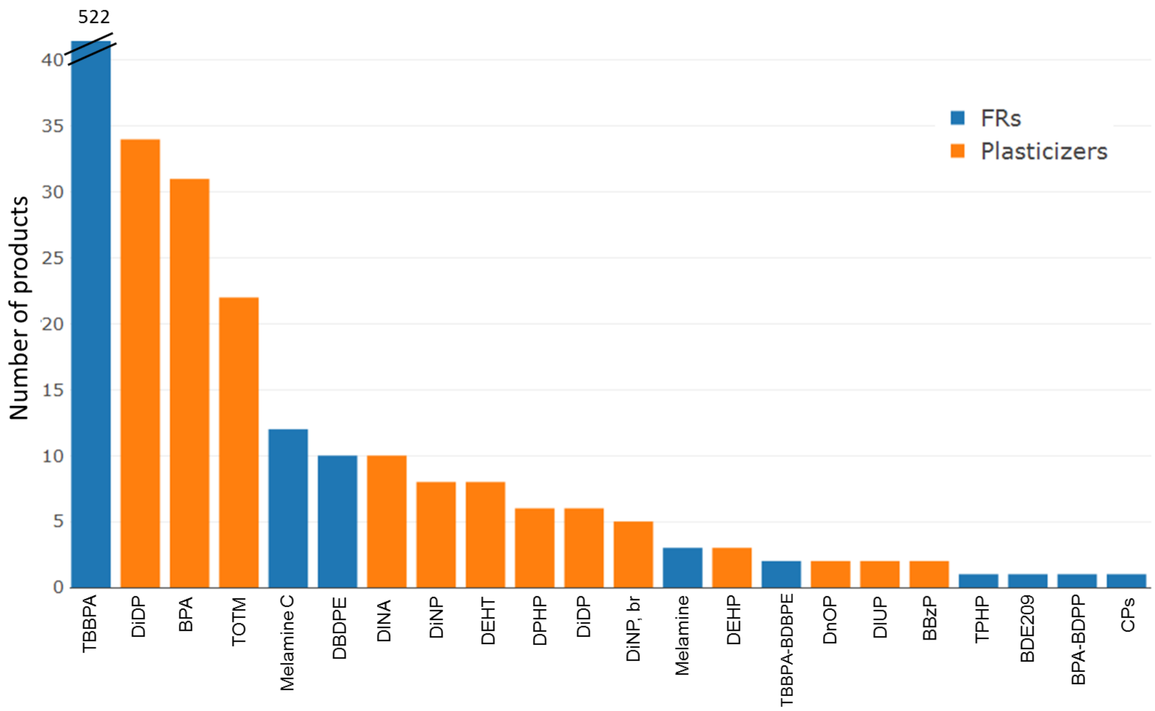

Figure 6. Number of products containing FRs and plasticizers within the electrical goods category. The y-axis for TBBPA (n = 522) is broken in order to facilitate viewing of the other substances.

The "electrical wiring material" subcategory contained 78 products containing FRs and 69 that contained plasticizers. The identified FRs were CPs, DBDPE, TBBPA, bisphenol A bis(diphenyl phosphate) (BPA-BDPP), melamine cyanurate, tetrabromobisphenol A bis(2,3-dibromopropyl) ether (TBBPA-BDBPE), decabromodiphenyl ether (decaBDE), TPHP, melamine and pentaerythritol (PETP). Among these, TBBPA were most frequently used possible owing to its usage in epoxy resins and ABS plastics that are two common formulas used for different electronic equipment (Covaci et al., 2009, KEMI (Swedish Chemicals Agency), 2006, Lassen and Lokke, 1999). The identified plasticizers in "electrical wiring material" subgroup were BBzP, DEP, BPA, DIDP, DEHT, DINA, TOTM, DINP, di(propylene glycol) dibenzoate (DPGDB), DNOP and DEHP. As discussed previously, many of these plasticizers are used in plastics aimed for high temperatures, good insulation properties and resistance against moisture and chemicals (Bui et al., 2016, Corrales et al., 2015, Swedish Chemicals Agency, 2011, Rahman and Brazel, 2006, Levchik and Weil, 2004, Sato et al., 2005, Staples et al., 1998, Wensing et al., 2005, Weschler, 2009).

5.1.2. Building materials

In total, 619 products categorized under the “01 - Building materials” main category were found to contain at least one of the compounds in our list. Almost 72% of the products (n = 444) where found within the “017 - Chemico-technical goods” subcategory. This subcategory mainly consisted of 242 jointing mastics, adhesives (n = 77), putty/fillers (n =10) and oils/grease (n =7). Various products were registered as “Chemico-technical goods in general” (n = 90). Figure 7 illustrates the specific FRs and plasticizers identified in the building materials category.

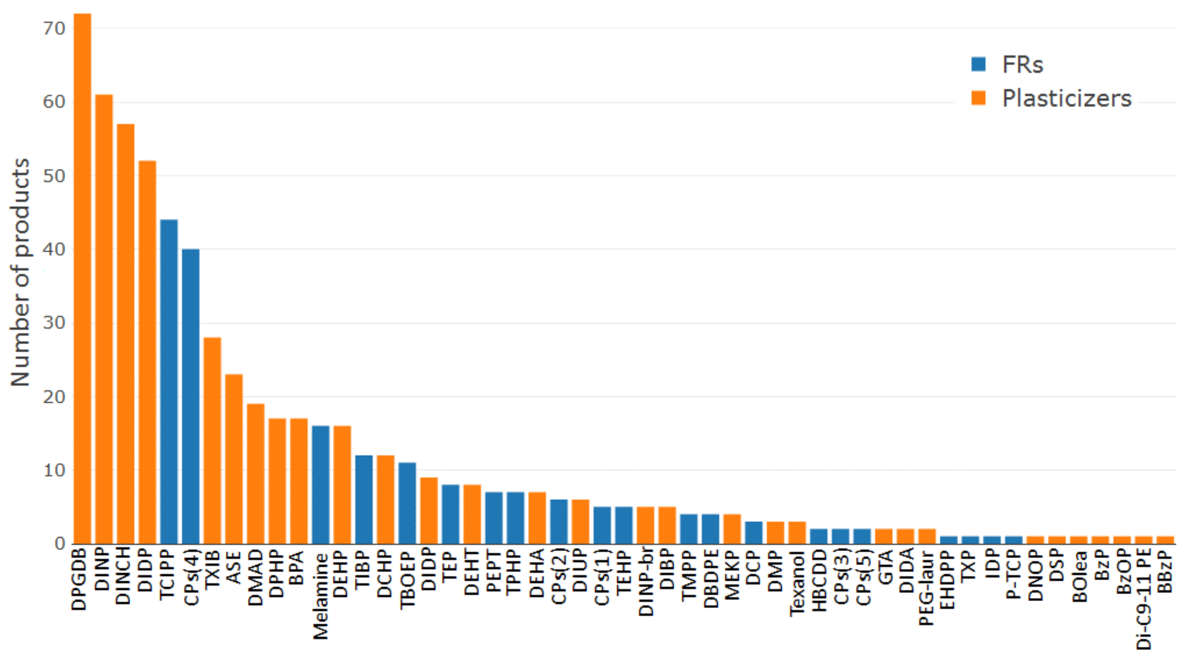

Figure 7. Number of products within the building materials main category that contained flame retardants (FRs) and plasticizers. The CAS numbers for the CPs mixtures included in the axis title are: CPs(1): 61788-76-9, CPs(2): 63449-39-8, CPs(3): 85422-92-0, CPs(4): 85535-85-9, CPs(5): 85535-86-0. Preferred names of the different CPs can be found in Table 5.

Among the 17 identified FRs, chlorinated paraffins (CPs) were most frequently encountered among the chemico-technical goods registered in SH and BvB (n = 55), and most of the applications were for sealants. The amount of CPs in the sealants ranged between a few percentages up to 60%. Other applications identified for CPs in the building materials were adhesives, lubricants and fire proof paints. CPs is a complex substance group consisting of thousands of individual polychlorinated n-alkanes and usually divided into short-chain CPs (10-13 carbons, SCCPs), medium-chain CPs (14-17 carbons, MCCPs) and long-chain CPs (>17 carbons, LCCPs). They can be used as both FR and plasticizer due to the flexibility of varying their carbon chain lengths, variation of chlorine content (30-70%), resistance towards chemical degradation and heat, low vapor pressure, and low production costs (Bayen et al., 2006, Chaemfa et al., 2014, van Mourik et al., 2016). The diversity of the carbon chain together with the different number and positions of the chlorine atoms has resulted in over 40 different CAS numbers for different CP technical formulations (Bayen et al., 2006, Chaemfa et al., 2014, van Mourik et al., 2016). They are commonly used in plastics, rubber, and sealants (Bayen et al., 2006, Chaemfa et al., 2014, ECHA, 2018c, van Mourik et al., 2016) whereupon the identification in jointing mastic and adhesive products can be explained. A list of the CAS numbers of the CPs and additional information are found in Table 5.

*Table 5. List of chlorinated paraffins together with their CAS numbers, preferred names and abbreviations used in this survey, together with their registered annual tonnage band within the EU. * denotes a CP technical product which was found in at least one building product in the two databases.*

Abbreviation	Preferred name	CAS	Tonnage band per annum
CPs-1*	Chloroalkanes	61788-76-9	NA
CPs-2*	Chlorinated paraffin wax	63449-39-8	10000 - 100000
CPs-3*	Chlorinated paraffin oils	85422-92-0	NA
CPs-4*	Cercelor S 52 (C14-17, 40-52 %Cl)	85535-85-9	10000 - 100000
CPs-5*	C18-28 Chloroalkanes (20-50 %Cl)	85535-86-0	NA
CPs-6	Alkanes, C10-21, chloro	84082-38-2	NA
CPs-7	Alkanes, C10-32, chloro	84776-06-7	NA
CPs-8	Alkanes, C16-27, chloro	84776-07-8	NA
CPs-9	Alkanes, C16-35, chloro	85049-26-9	NA
CPs-10	C10-13 chloro alkanes	85535-84-8	0 - 10
CPs-11	Alkanes, C12-14, chloro	85536-22-7	NA
CPs-12	Chloroalkanes, C10-14	85681-73-8	NA
CPs-13	Paraffins (petroleum), normal C >10, chloro	97553-43-0	NA
CPs-14	Alkanes, C10-26, chloro	97659-46-6	NA
CPs-15	Alkanes, C18-20, chloro	106232-85-3	NA
CPs-16	Alkanes, C22-40, chloro	106232-86-4	NA

CPs-17	C10-12 chloroalkanes	108171-26-2	NA
CPs-18	Chloro C22-26 alkanes	108171-27-3	NA
CPs-19	Alkanes, C6-18, chloro	68920-70-7	NA
CPs-20	Alkanes, C12-13, chloro	71011-12-6	NA

In 2008, the SCCPs were classified as SVHCs by ECHA and they has also been listed into the Stockholm Convention as persistent organic pollutants (POPs) for elimination in production and use (ECHA, 2018b, UNEP, 2018). None of the CAS numbers associated with SCCPs were found in the databases. However, the usage of CP technical mixtures such as “Chlorinated paraffin wax” and “Cereclor S52” could reach 10 000-100 000 tonnes within the EU (ECHA, 2018c). These high volumes are probably owing to the increasing usage of MCCPs and LCCPs in products such as plasticizers and FRs as well as in industrial processes such as metal cutting (Bayen et al., 2006, ECHA, 2018c, van Mourik et al., 2016). However, there is still some exempted usage of SCCPs within the EU in e.g. the mining industry where they are used as a FR in conveyor belts and dam sealants (Bayen et al., 2006, ESWI, 2011, van Mourik et al., 2016). Furthermore, CPs has also been identified as a replacement to legacy BFRs (Gustavsson et al., 2017).

Among the other FRs in this subcategory, melamine, PETP, tris(isobutyl) phosphate (TIBP), tris(2-chloroisopropyl) phosphate (TCIPP), DBDPE, TPHP, diphenylcresylphosphate (DCP), isodecyl diphenyl phosphate (IDP), tris(2-ethylhexyl) phosphate (TEHP) and trixylenyl phosphate (TXP) have also been identified as replacements for some legacy FRs such as PBDEs and HBCDD (Gustavsson et al., 2017, Lassen and Lokke, 1999). The non-chlorinated organophosphates, TIBP, TPHP, DCP, IDP, TEHP, and TXP could also act as a plasticizer in the various listed products (Lassen and Lokke, 1999, Marklund et al., 2003, van der Veen and de Boer, 2012). In fact, Wang et al. (2017) observed that the non-chlorinated organophosphates represented half of the total PFR concentration in different sealing products.

Among the 81 plasticizers in our report, 28 were found in different chemico-technical goods registered in SH and BvB. Seven of these are restricted in different regulations within the EU (EU, 2006, EU, 2009, EU, 2011b, ECHA, 2018b, ECHA, 2018a). These restricted compounds are all phthalates and were found in around a hundred products including adhesives, jointing mastics, putty and fillers with relative amounts of phthalates mostly ranging between 5 to 30%. Most of these restrictions are not applied to building materials whereupon the usage is still allowed. Six other phthalates without any restrictions in EU or Sweden were also identified; dimethyl phthalate (DMP), di(2-propyl heptyl) phthalate (DPHP), dicyclohexyl phthalate (DCHP), distearyl phthalate, diisotridecyl phthalate (DIUP) and bis(2-ethylhexyl) terephthalate (DEHT). However, the number of building materials (around 30) containing the alternative phthalates was lower and mainly represented adhesives, jointing mastics, putty and fillers, and hardeners. Moreover, non-phthalates were also identified, such as glycerin triacetate (GTA), DEHA, diisononylcyclohexane-1,2-dicarboxylate (DINCH), (3-hydroxy-2,2,4-trimethylpentyl) 2-methylpropanoate (texanol), DPGDB, diisodecyl adipate (DIDA), diisononyl adipate (DINA), trimethyl pentanyl diisobutyrate (TXIB), BPA, alkylsulfonic phenyl ester (ASE) and methyl ethyl ketone peroxide (MEKP). These compounds were found in almost 200 different chemico-technical goods, with main uses in jointing mastics and adhesives, and minor occurrence in putty, fillers, oil and grease. The only plasticizer which has a restriction among the non-phthalates is BPA which was found in 13 chemico-technical goods (mainly glue and hardeners). This compound has been decreasingly used since 2002 and usage during 2015 was around 18 tonnes in Sweden (SPIN, 2018). According to the SPIN database, DINCH (found in 50 chemico-technical goods) is currently the most frequently used plasticizer in Swedish building materials reaching 13 072 tonnes in 2015, and followed by ASE (21 chemico technical goods) at about 2 198 tonnes (SPIN, 2018). DINCH has been identified as a replacement for DEHP and DINP and the usage has increased globally since its introduction in 2002 (Biedermann-Brem et al., 2008, Bui et al., 2016, Kemi, 2014, Larsson et al., 2017, Schutze et al., 2014). Furthermore, DPGDB (70 chemico-technical goods) was the most frequently encountered plasticizers in the registered chemico-technical goods in SH and BvB. This compound has been identified as a potential replacement for DBP (Kemi, 2014) and the usage reached 75 tonnes in Sweden in 2015 (SPIN, 2018).

Among the 15 substances found within the “013 - Insulating materials” subcategory, 10 were FRs. Here, the chlorinated organophosphate TCIPP were found in 22 products, which were mainly polyurethane insulation materials. Five different mixtures of CPs were found in 14 products which were mainly elastomers and foams.

The ”014 - Weatherproofing systems, tape and sealing strip” subcategory consist of building materials such as plastic films (used in the construction as a moisture resistant barrier in order to reduce the heat losses) and tape used to seal the plastic film. The database search showed eight building materials that contained FRs such as CPs (n =4) and the rest contained both chlorinated and non-chlorinated PFRs. Plasticizers (n = 11) were found in 44 building materials within this subcategory. Half of these products contained phthalates such as DINP (n = 14) and DIDP (n = 9) and DEHP (n = 5) indicating more frequent usage of these compounds within this group of building materials.

5.1.3. Fit-out materials and paints

Fit-out materials relates to interior surface cover such as flooring, wallpaper, ceiling and paints. In total, 636 products were found within this main category to contain the listed FRs and plasticizers, in which the majority was for “031 - Flooring articles” (n = 436) and “034 - Paint goods” (n = 185). Eleven products were labelled in the “030 - Ceramic goods” subcategory, but upon closer inspection we found that these all had the product line code “03002 - Adhesive, joint sealants and accessories” (n = 11) and could therefore be misclassified when they should be listed in the building material main category instead.

An overview of the number of products within the fit-out materials and paints main category grouped by their product line codes can be seen in Figure 8.

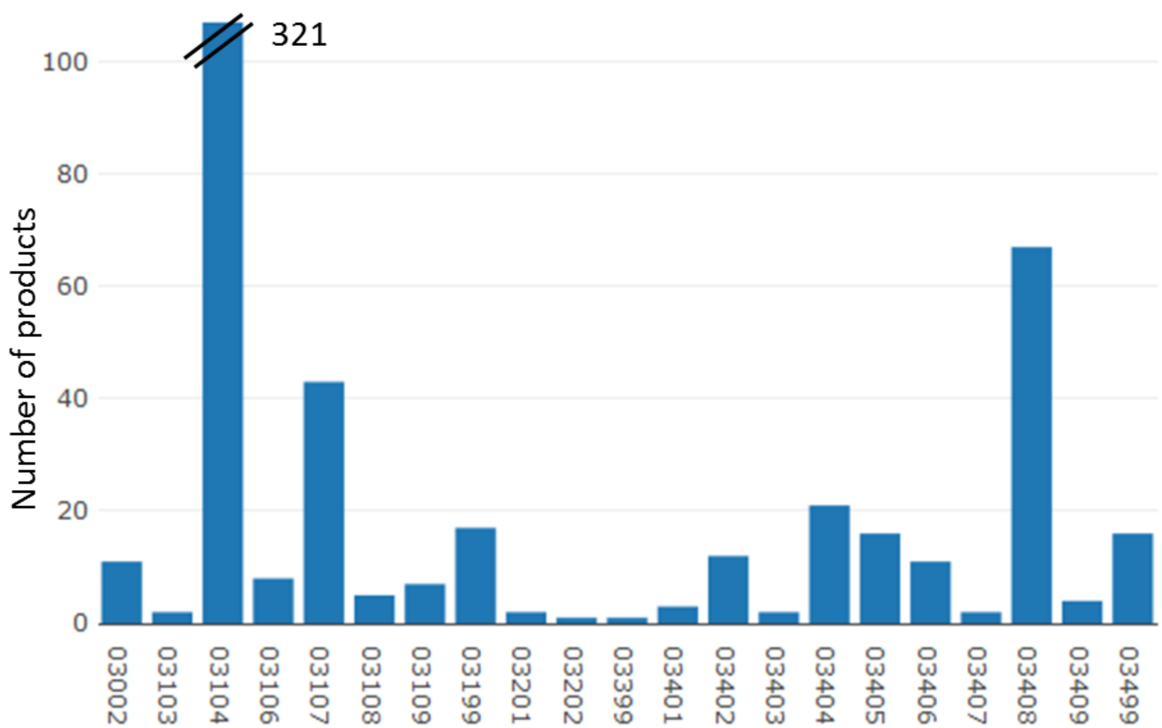

Figure 8. Number of products found within the “Fit-out materials and paints” main category. The BK04 product line codes are: ***03002*** - Adhesives, joint sealants and accessories*,* ***03103*** - Laminate flooring*,* ***03104*** - Plastic flooring*,* ***03106*** - Textile flooring*,* ***03107*** - Flooring materials in general*,* ***03108*** - Skirting boards*,* ***03109*** - Entrance matting*,* ***03199*** - Flooring articles in general*,* ***03201*** - Wallpapers*,* ***03202*** - Wetroom wall coverage*,* ***03399*** - Ceiling and wall systems in general*,* ***03401*** - Primers, outdoors*,* ***03402*** - House paint, outdoors*,* ***03403*** – Roofing paint, outdoors*,* ***03404*** - Wall and ceiling paints, indoors*,* ***03405*** - Wood paint, indoors*,* ***03406*** - Floor paint, oil, lye and soap***, 03407*** - Oils and wood preservation*,* ***03408*** - Other paint*,* ***03409*** - Chemico-technical paint accessories*,* ***03499*** - Paint goods in general. *See Appendix 2 for full list of BK04 codes.*

Seven FRs and 20 plasticizers were present in the different flooring materials. Similar to the building material category, CPs was also identified in floorings and can be used both as a FR and a plasticizer (Bayen et al., 2006, Chaemfa et al., 2014, van Mourik et al., 2016). One mixture (CAS 63449-39-8), which denotes CPs of unspecific carbon chain length and unspecific degree of chlorination (US EPA, 2009), was found in two polyurethane plastic floors with a declared content of 10-20%. Another CPs mixture (CAS 85535-85-9, which is for MCCPs, was present in an artificial grass turf and an indoor flooring used in sports halls.

Melamine and the other five PFRs (TIBP, IDP, TPHP, EHDPP, and TEHP), have all been reported as potential replacements for legacy FRs (Gustavsson et al., 2017). Furthermore, TPHP and TEHP can also act as plasticizers (Lassen and Lokke, 1999, Marklund et al., 2003, van der Veen and de Boer, 2012). The usage of melamine in laminate flooring could be owing to the urea-melamine-formaldehyde resin used to glue the parts together (high-density fiberboard, overlay paper, deco paper and valance paper). Furthermore, the overlay, deco, and valance paper are also impregnated with a resin consisting of melamine and formaldehyde (Kim, 2010).

Among the 20 plasticizers found in the databases relating to flooring products, nine were phthalates. DIBP is listed on the ECHA Candidate and Authorization list (ECHA, 2018b, ECHA, 2018a) and was present in a polyvinyl chlorine (PVC) floor aimed for use in sport centers. Furthermore, DNOP, DIDP, and DINP, that are not allowed to be used in toys and baby care product intended to be placed in the mouth (EU, 2009), was found in plastic floor used in sport centers and indoor environments, and in polyurethane based floors. Further, four non-restricted phthalates, DPHP, DEHT, DCHP and di-C6-10-alkyl phthalate (di-C9-11 PE), were also found in plastic and textile floors. Due to the suspected endocrine disrupting properties and toxic effects on reproduction of phthalates, non-phthalate containing substances has entered the market as alternative plasticizers (Kemi, 2014). Some non-phthalate plasticizers such as DEHA, DINA, DINCH, glycerides, castor oil-mono, hydrogenated, acetates (COMGHA), DPGDB, tributyl o-acetylcitrate (ATBC), BPA, 1,2-benzenedicarboxylic acid, di-C6-8-branched alkyl esters (DIHP) and ASE were also present in plastic floors. Among these, DINCH was the most frequently used plasticizer as discussed above (Biedermann-Brem et al., 2008, Bui et al., 2016, Kemi, 2014, Larsson et al., 2017, Schutze et al., 2014, SPIN, 2018).

Two other material categories that cover a large part of the indoor surfaces are “032 - Wallpapers” and “034 - Paint goods”. Only three products were found within the “Wallpaper” subcategory which contained the plasticizers DINCH or DINP. However, another related subcategory is “016 - Roof and wall cladding” which include wall coverings made of polymeric materials to increase thermal insulation and water resistance in indoor environments with such needs such as wet rooms and occupational settings such as hospitals. Around 14 products were found for this subcategory which mainly contained DINCH (n = 3) and DINP (n = 6). It should be noted that DINP was registered with two different CAS numbers because the production processes result in a complex mixture of linear and branched isomers (ECHA, 2003). The organophosphates DCP and TCIPP were found in one product each, which could be used as both flame retardant and plasticizer (Lassen and Lokke, 1999, Marklund et al., 2003, van der Veen and de Boer, 2012).

Within the “Paint goods” subcategory, 69 building materials were found to contain FRs and 116 contained plasticizers. Ten plasticizers were found in the paint goods; texanol, TXIB, BPA, DEHA, DPGDB, dimethyl adipate, Di-C9-11 PE, DINP, DIDP and ATBC. Among these, texanol and TXIB were the most commonly found and was used in acrylate and latex paint, lacquers, floor paint and paint for outdoor usage.

Ten FRs were found in fireproof paints, among which pentaerythritol (CAS 115-77-5) was found in almost half of the products (n = 31) and followed by melamine (n = 14). These two substances are frequently used together in intumescent paints which forms a foamed char layer on the surface of the burning material (Daniliuc et al., 2012). Seven other substances were PFRs, and CPs was also found in four products. However, some fireproof paints were also listed under the rather ambiguous product line code “07003 - Fire safety” where an additional 14 fireproof paint products contained melamine and 12 others contained pentaerythritol.

5.1.4. Household articles

Although not entirely related to the construction frame of buildings, one main category within the BK04 system is “11 - Household articles” which include “110 - Kitchen equipment”, “112 - Furniture” and “114 - Cleaning articles”. Within the main category, the “Furniture” subcategory showed records of 14 building materials containing FRs and 70 that contained plasticizers. Among the four different FRs, melamine was found in three furniture products. The usage of melamine could also be owing to usage of urea-melamine-formaldehyde resin for the construction of the wood based frame (Kim, 2010). The other three FRs were TBOEP, TCIPP and TIBP which are potential replacements of the legacy BFRs (Gustavsson et al., 2017, Lassen and Lokke, 1999). The nine identified plasticizers were: DINCH, BPA, DEHT, DINP, DNBP, DPGDB, MEKP, DEP and dimethyl adipate (DMAD).

The other major subcategory “Cleaning article” contained two organophosphate esters, TBOEP and TIBP in ten cleaning and floor polish products. In fact, TBOEP is a common component of floor polishes and waxes (Langer et al., 2016, Marklund et al., 2003, van der Veen and de Boer, 2012). Among the 47 cleaning products that contain plasticizers, DMAD was found in 42 products that are mostly graffiti removers and hand wipes, while DEP was found in air fresheners (n = 3) and DPGDB in floor polish (n = 2).

5.1.5 Relationships between additives among the different building materials

The number of FRs and plasticizers that were found in at least one product from this database survey are summarized in Figure 9. In the heatmap, the total number of products that contained the specific additive within each subcategory was summed and the correlations between the chemicals are outlined in the dendrogram. The closer the distance between the linkage of additives in the dendrogram, the more related they are in terms of presence in the same products among the subcategories. TBBPA was found in the highest number of products (n = 629), of which the majority was within the lighting articles subcategory (n = 466). The three plasticizers, DEHT, DINCH and DINP were present in similar products and were therefore closely clustered in the dendrogram, indicating same usage in building materials (mainly plastic flooring). Interestingly, the two plasticizers ASE and DIDP-1 (CAS 68515-49-1) and the two FRs TCIPP and CP-4 were grouped closely due to their similar presence in building materials, mainly in jointing mastics and adhesives. The additives located at the right hand side of the dendrogram are only sporadically found in a few products, such tri-*p*-cresylphosphate (*p*-TCP) which was found in a concrete powder product (categorized as “01799 - Chemico-technical goods in general”), distearyl phthalate (DSP) which was found in a concrete sealer and benzyl phthalate (BzP) which was found in a glass wool insulation product. Although these chemicals are found in a very limited number of building material, if they are detected in a specific indoor environment then tracking their sources might be facilitated due to the limited or specialized usage in building materials (Goldsmith et al., 2014).

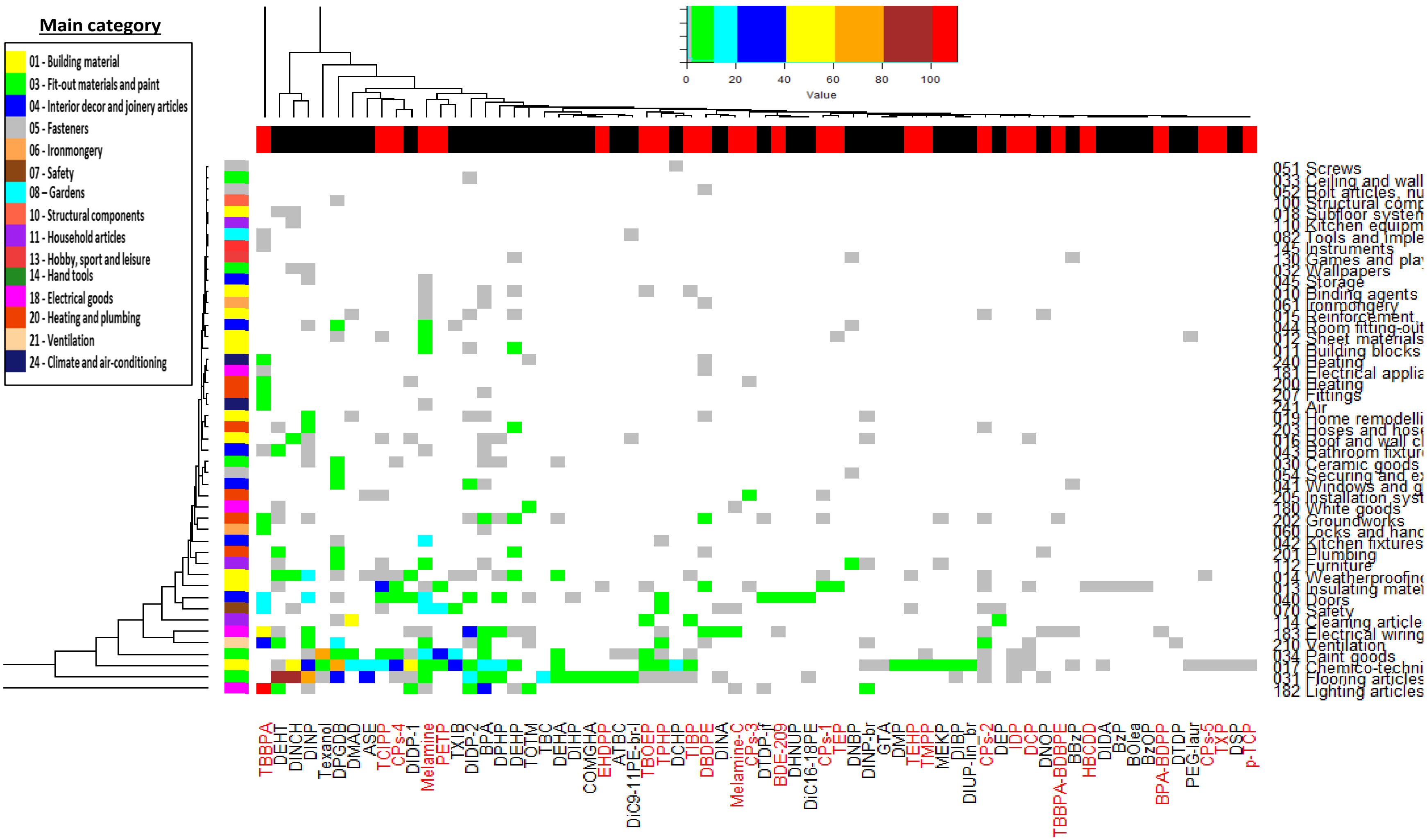

Figure 9. Heatmap of FRs and plasticizers found in the two building material databases grouped by main categories (2 digit colored bars at the left hand side) and subcategories (3 digits, right hand side). Red color on the substance names and the topside bars below the dendrogram denote flame retardants while black color denote plasticizers. The dendrogram at the top shows the linkage distance and clustering between substances: shorter distances can be interpreted as being closely related in terms of having similar presence in the same building products (the extreme distances and subcategory names have been broken to facilitate viewing). The color keys in the heatmap show the number of products that contained the specific substance: white (not found), grey (n =1), green (between 2-10), cyan (11-20), blue (21-40), yellow (40-60), orange (60-80), brown (80-100), red (>100).

5.1.6 Additives not registered in SundaHus or Byggvarubedömningen

Our investigation showed that many FRs and plasticizers in our list were not registered in SH and BvB. Among the FRs in our list, almost 60% were not found in neither the BvB nor the SH database. For the plasticizers in our list, 50% were not registered in the BvB and 60% in SH. Among the FRs, about 22 are produced/imported within EU and only six are produced/imported in Sweden (ECHA, 2018c, SPIN, 2018). They are used as additives in hydraulic oils and greases, as binding agent in paint and as components during plastic production (SPIN, 2018). Among the plasticizers not registered in the two databases, only 15 are produced/imported within EU and seven in Sweden (ECHA, 2018c, SPIN, 2018). The compounds were used as additives in hydraulic oils and greases, antifoaming agents, raw material in rubber production, used in cosmetics and pharmaceutical preparation, cleaning and polishing products, and produced for export (SPIN, 2018). Even though their application areas are broad, their production/importation volumes were relatively low in Sweden in 2015. The volumes of the six FRs varied between 1 and 7 tonnes while the volumes for the seven plasticizers varied between 1 and 71 tonnes (SPIN, 2018). Furthermore, the high proportion of non-registered FRs and plasticizers in the two databases could also be explained by the fact that (i) these compounds are not used in building materials that are available in the Swedish market, (ii) the compounds are only used in specific countries and has not, to date, been imported to Sweden, (iii) the compounds are no longer used in building materials due to regulations and restrictions, and (iv) their content in the products are below the reporting criteria.

6. Emission of flame retardants and plasticizers from building products

The emission of FRs and plasticizers from building materials can influence the chemical compositions in the indoor environment (Salthammer and Bahadir, 2009, Wensing et al., 2005, Cousins et al., 2018). Their distribution and presence depends on the number of potential emissions sources and the ambient indoor parameters such as indoor air temperature, relative humidity and air exchange rate of the room (Wensing et al., 2005, Rauert and Harrad, 2015). The emissions of SVOCs, which most FRs and plasticizers belongs to, are considered to be relatively constant over time from a building material to the indoor environment. Potential adverse health effects from human exposure of indoor contamination of some FRs and plasticizers have led to increasing concerns from the public and regulators in recent years (Duty et al., 2005, Dishaw et al., 2014, Gray et al., 2006, Hauser et al., 2006, Meeker and Stapleton, 2010, Roze et al., 2009, Rauert and Harrad, 2015, Salthammer and Bahadir, 2009, Sukiene et al., 2016, Swan, 2008, Wei et al., 2015, Weschler, 2009, WHO, 1998).

7. The occurrence and distribution of flame retardants and plasticizers in indoor environments

Once FRs and plasticizers are emitted from their building materials, they can partition between the gas phase, airborne particulate matter, settled dust and various indoor surfaces (Cousins et al., 2018, Sukiene et al., 2016, Weschler and Nazaroff, 2010, Weschler and Nazaroff, 2017). Indoor contamination of FRs and plasticizers are also influenced by physical abrasion processes of the building materials and via direct contact between building materials and solid matters (Sukiene et al., 2016, Weschler and Nazaroff, 2010). Therefore, the presence and concentrations of various FRs and plasticizers in indoor dust, air and surfaces have also been investigated in order to assess the overall contamination of chemical emissions from building materials (Marklund et al., 2003, Lioy et al., 2002, Lucattini et al., Melymuk et al., 2016, Persson et al., 2018, Weschler, 2011).

The occurrence of FRs and plasticizers in Swedish indoor environments from recent years are presented in Table 6 and 7, respectively. As can be seen in Table 6, BDE-209 was detected in indoor home dust with concentrations ranging between 500 and 5200 ng/g (Sahlstrom et al., 2012). Furthermore, in a recent study conducted in over 100 preschools in Stockholm the concentration of BDE-209 was between 41 and 3200 ng/g (Larsson et al., 2018). In that same study, high concentrations of HBCDD isomers were detected in indoor dust (α: 4.9-3200 ng/g, β: 1.2-1200 ng/g and γ: 1.3-12000 ng/g) (Larsson et al., 2018). However, few building materials registered in SH and BvB contained BDE-209 and HBCDD (see Figure 9) indicating the contribution from additional indoor sources than building materials (such as consumer products, textiles and electronics) or that some of these samples were taken from older buildings that still contained these BFRs. TBBPA was found in a large number of electrical goods and related electronic equipment (e.g. 18 - Electrical goods and 21 - Ventilation) registered in SH and BvB. However, few indoor contamination studies in Sweden include TBBPA in their target compound list. In one study conducted in 2018, TBBPA was found in preschool dust with a concentration range of <2.1 to 3500 ng/g (Larsson et al., 2018). Furthermore, since chlorinated and non-chlorinated PFRs has been identified as replacement for legacy FRs, investigations on their occurrence and distribution in the indoor environments have increased. Among these compounds, TCIPP (air: 1.3 – 93 pg/m^3, dust: <0.041-130 μg/g), TDCIPP (air: n.d. – 30 pg/m^3, dust: 0.066-1600 μg/g), TPHP (air: n.d. – 56000 pg/m^3, dust: 0.0069-79 μg/g), TBOEP (air: n.d. – 18000 pg/m^3, dust: 0.0078-4100 μg/g) and EHDPP (dust: 64 -16000 μg/g) have been found at significant amounts in preschool and school environments in Sweden (Bergh et al., 2011, Larsson et al., 2018, Persson et al., 2018). TCIPP was found in several insulation and sealant materials while few building materials contained TPHP, EHDPP and TBOEP. Although TDCIPP could be detected in the indoor environments, no registered building material in the databases was found to contain this additive. The seven BFRs (DBDPE, DBE-DBCH, EH-TBB, BEH-TEBP, BTBPE, PBT and HBB) detected in Swedish homes and preschools were found to be lower than the PFRs (Newton et al., 2015, Sahlstrom et al., 2012, Larsson et al., 2018). However, the information about the usage of these so called "emerging BFRs" in building materials are lacking (Lassen et al., 2014), and their presence were quite low among the building materials registered in SH and BvB. An exception was DBDPE which was found in different building material such as insulation materials, textiles, electronic details, and plastic pipes and tubes.

Table 6. Concentration ranges of flame retardants in Swedish homes, preschools and schools. Full names and CAS numbers can be found in Appendix 1.

Flame retardants					
Substance	**Indoor setting**				**Reference**
	Home		**Preschool/School**		
	Air (pg/m^3)	Dust (ng/g)	Air (pg/m^3)	Dust (ng/g)	
BDE-209				41-3200	(Larsson et al., 2018)
	<29-110	<11-140		<1.9-130	(Newton et al., 2015)
	<0.7-750	<50-10000	62-2300	180-3500	(Thuresson et al., 2012)
		500-5200			(Sahlstrom et al., 2012)
	n.d.-257	43.9-1560			(Karlsson et al., 2007)
HBCDD				α: 4.9-3200 β: 1.2-1200 γ: 1.3-12000	(Larsson et al., 2018)
		α: 17-55 β: 3.7-19 β: 3.7-19		α: 170-450 β: 52-88 γ: 98-160	(Newton et al., 2015)
	∑: <1.6-33	∑: <3-2400	∑: <1.6-35	∑: 190-1600	(Thuresson et al., 2012)
		α: 59-2900 β: 20-540 β: 14-660			(Sahlstrom et al., 2012)

TBBPA				<2.1-3500	(Larsson et al., 2018)
TEP	3.2-16		0.8-20	n.d.-4.7	(Bergh et al., 2011)
			<MDL-25000	<MDL-1400	(Persson et al., 2018)
TIBP	3.0-66	0.4-3.6	n.d.-63	0.5-1.5	(Bergh et al., 2011)
TNBP	3.5-45	n.d.-1.7	3.7-320	0.1-6.2	(Bergh et al., 2011)
			<MDL-150000	<MDL-2700	(Persson et al., 2018)
TCEP	n.d.-28	n.d.-33	7.8-230	2.5-150	(Bergh et al., 2011)
				<MDL-5400	(Persson et al., 2018)
				<1200-410000	(Larsson et al., 2018)
TCIPP	2.4-64	0.7-11	1.3-72	0.8-12	(Bergh et al., 2011)
			<MDL-93	<MDL-120000	(Persson et al., 2018)
				<2600-130000	(Larsson et al., 2018)
TDCIPP	n.d.-17	2.2-27	n.d-30	3.9-150	(Bergh et al., 2011)
				66-10000	(Persson et al., 2018)
				130-1600000	(Larsson et al., 2018)
TBOEP	n.d.-4.5	0.6-30	n.d-380	31-4100	(Bergh et al., 2011)
			<MDL-18000	<MDL-63000	(Persson et al., 2018)
				<2000-2800000	(Larsson et al., 2018)
TPHP	n.d.-0.8	0.6-30	n.d.-0.9	0.3-17	(Bergh et al., 2011)
			<MDL-56000	6.9-79000	(Persson et al., 2018)
				<390-38000	(Larsson et al., 2018)
EHDPP		n.d.-1.8	n.d.-2.2	0.2-160	(Bergh et al., 2011)
				<MDL-16000	(Persson et al., 2018)
TEHP		n.d.-0.2		n.d.-0.7	(Bergh et al., 2011)
TMPP		n.d.-3.0		n.d.-13	(Bergh et al., 2011)
TPP			<MDL-30000		(Persson et al., 2018)
		<MDL-0.041			(Newton et al., 2015)

DBDPE				<40-1100	(Larsson et al., 2018)
				<0.58-300	(Newton et al., 2015)
		470-24000			(Sahlstrom et al., 2012)
DBE-DBCH				α: <0.19-5.8 β: <0.15-4.4	(Larsson et al., 2018)
	α: n.d.-81 β: n.d.-50	α: 0.29-2.9 β: <0.27-1.1	α: n.d.-55 β: n.d.-33	α: 0.70-1.6 β: 0.71-1.1	(Newton et al., 2015)
EH-TBB				<0.98-690	(Larsson et al., 2018)
		<3.5-30		9.4-17	(Newton et al., 2015)
		25-440			(Sahlstrom et al., 2012)
BEH-TEBP				<18-2600	(Larsson et al., 2018)
			<46-120	84-140	(Newton et al., 2015)
		260-950			(Sahlstrom et al., 2012)
BTBPE		<2-550			(Sahlstrom et al., 2012)
	n.d.	2.52-8.15			(Karlsson et al., 2007)
PBT	n.d.-130	0.71-5.5	n.d.-9.1	0.85-1.6	(Newton et al., 2015)
HBB		1.4-9.7		1.1-69	(Newton et al., 2015)

The indoor concentrations of plasticizers (Table 7) were found to be consistently higher than the FRs. The plasticizers DNBP (air: 300 - 2300 ng/m^3, dust: 1.2 - 21000 µg/g), DEHP (air: 92 - 530 ng/m^3, dust: 0.27 - 40459 µg/g), DINP (dust: <40 - 66000 µg/g) and DINCH (dust: <0.04 - 5200 µg/g) have been frequently detected in homes, preschools and schools in Sweden (Bergh et al., 2011, Larsson et al., 2017, Bornehag et al., 2005, Miljöförvaltningen, 2016). Two of these, DINP and DINCH, have been used in large extent in different building materials such as different flooring products, jointing mastics and adhesives (Figure 9). Furthermore, DEHT was also frequently used in different flooring products. However, its concentration was considerably lower than DNBP, DEHP and DINP ranging between 6.8 and 3500 µg/g (Larsson et al., 2017). Furthermore, DIDP and BPA, that have been used in different electrical goods according to the building material databases, have also been found in preschool dust with concentrations varying between 11 - 1800 µg/g and <0.06 - 15 µg/g, respectively (Larsson et al., 2017).

Table 7. Concentration ranges of plasticizers in Swedish homes, preschools and schools. Full names and CAS numbers can be found in Appendix 1.

Plasticizers					
Substance	**Exposure data**				**Reference**
	Home		**Preschool/School**		
	Air (ng/m³)	Dust (µg/g)	Air (ng/m³)	Dust (µg/g)	
DNBP	300-2300	17-260	330-1700	38-560	(Bergh et al., 2011)
				1.2-21000	(Larsson et al., 2017)
		<40-5446			(Bornehag et al., 2005)
		GM: 226			(Bornehag et al., 2004)
DIBP	140-560	n.d.-18	46-810	n.d.-32	(Bergh et al., 2011)
				1.0-130	(Larsson et al., 2017)
		<40-3810			(Bornehag et al., 2005)
		GM: 97			(Bornehag et al., 2004)
BBzP	6.6-97	3.1-110	9.1-33	9.0-120	(Bergh et al., 2011)
				0.01-240	(Larsson et al., 2017)
		<40-45549			(Bornehag et al., 2005)
		GM: 319			(Bornehag et al., 2004)
DEHP	92-530	130-3200	130-480	260-5800	(Bergh et al., 2011)
				<LOD-4500	(Larsson et al., 2017)
		<40-40459			(Bornehag et al., 2005)
				<0.7-4500	(Miljöförvaltningen, 2016)
		GM: 1310			(Bornehag et al., 2004)
DMP	7.4-47	0.03-0.1	2.3-14	0.01-1.5	(Bergh et al., 2011)
				<LOD-12	(Larsson et al., 2017)
DEP	680-3900	1.3-63	650-2600	1.0-23	(Bergh et al., 2011)
				<LOD-390	(Larsson et al., 2017)
		<40-2425			(Bornehag et al., 2005)
		GM: 31			(Bornehag et al., 2004)

DINP				58-66000	(Larsson et al., 2017)
		<40-40667			(Bornehag et al., 2005)
				<0.06-3800	(Miljöförvaltningen, 2016)
		GM: 639			(Bornehag et al., 2004)
DPHP				0.15-2600	(Larsson et al., 2017)
DIDP				11-1800	(Larsson et al., 2017)
DEHT				6.8-3500	(Larsson et al., 2017)
DEHA				0.72-340	(Larsson et al., 2017)
ATBC				0.42-1200	(Larsson et al., 2017)
DINCH				4.7-5200	(Larsson et al., 2017)
				<0.04-5200	(Miljöförvaltningen, 2016)
BPA				<LOD-15	(Larsson et al., 2017)
BPS				<LOD-22	(Larsson et al., 2017)
BPF				<LOD-15	(Larsson et al., 2017)
BPAF				<LOD-2.8	(Larsson et al., 2017)

In order to guide more systematic screening investigations and exposure assessments on FRs and plasticizers originating from building materials to the Swedish indoor environments, a priority list which includes additives commonly found in building materials and frequently detected in indoor environments was proposed within the framework of this survey. The main factor for the inclusion into the list was the number of products that contained a specific FR or plasticizer. Some other considerations for the prioritization of substances were whether they are physically or reactively added, the relative amounts in the components of the building material and expected surface coverage of that material in the indoor environment. Physical-chemical properties, release pathways, toxicity and potential health effects was not considered for the inclusion into this list. As such, FRs and plasticizers most frequently found in flooring products, chemico-technical goods and paint goods could be prioritized for inclusion into the list. This would include most of those additives placed at the left hand side of the dendrogram in Figure 9. Table 8 presents the priority list for FRs and plasticizers to screen for in flooring products, chemico-technical goods and paint goods and in the indoor environment. Although high number of lighting products were found to contain FRs (mainly TBBPA), this product line was not included due to relatively low surface coverage, reactive addition as well as low additive amount. However, TBBPA was still included in the priority list without specifying associated building material group (Table 8). This non-specific category group also included DBDPE, PBDEs and HBCDD because of their ubiquitous presence in indoor environments. The plasticizers listed in this group are related to cleaning products (TBOEP) and paint removers (Texanol and DMAD) which are not building products per definition, are mainly intermittently used and also might be more prevalently applied at the outdoors. However, their widespread usage (hundreds of tonnes in Sweden) and large surface application area could warrant further investigations on their presence in the indoor environment (SPIN, 2018). Many phthalate and non-phthalate plasticizers in the list are ubiquitous in indoor environments due to their frequent usages in plastic floor, adhesives and sealants (Table 7). Therefore, monitoring the levels of these compounds in the indoor environments are important since some of them are known to cause health issues (Kemi, 2014). Furthermore, PFRs have a broad application area as some can be used both as FRs and plasticizers as well as having other uses such as hydraulic fluids. According to our database search, PFRs are used in insulation, paint, sealants, adhesives, floor polishes and cleaning products, fireproof doors and additives in concrete, which may explain their widespread occurrence in indoor air and dust (Table 6). Another chemical compound group that can be used both as FRs and plasticizers are the CPs. These compounds have been found in sealants, plastic floors, pipes and insulation material (Table 5 lists the CPs included in this survey). However, information about their occurrence and distribution in the Swedish indoor environments is limited, mainly due to difficulties in chemical analysis. Screening of CPs in building products and indoor environments should include the short-, medium- and long-chain homologs. Furthermore, triazine (melamine) containing compounds have been identified as a potential substitutes for legacy BFRs (Gustavsson et al., 2017). Their usage in paint products, mostly fireproof paint, has started to increase according to the database search. However, in similarity with CPs, studies on the presence of triazine FRs in the indoor environment are to date scare.

A more comprehensive analytical approach would be to perform a suspect screening analysis using chromatographic techniques hyphenated with high resolution mass spectrometry (HRMS) to screen for, not only the substances in Table 8, but for all additives found in the different building materials in the databases.

Table 8. Suggestion of a priority list for the screening of FRs and plasticizers frequently found in building materials in this survey and in indoor environments. Full names and CAS numbers can be found in Appendix 1.

Building material		Compounds	
Main category	Sub category	FRs	Plasticizers
01 - Building materials	018 - Chemico-technical goods	TCIPP, CPs, Melamine, PETP, TPHP, TIBP, TEHP, TMPP	DINCH, DINP, DPGDB, ASE, DIDP, TXIB, BPA, DPHP, DEHP, DEHA, DCHP
03 - Fit-out materials and paint	031 - Flooring articles	Melamine, EHDPP	DEHT, DINCH, DINP, DPGDB, ASE, DIDP, BPA, DPHP, TBC, DEHA, DIHP, ATBC, Di C9-11 PE br-lin
	034 - Paint goods	TCIPP, CPs, Melamine, PETP, TBOEP	DPGDB, TXIB, BPA, DEHA
Substances not specific to above product categories		TBBPA, DBDPE, PBDEs, HBCDD	TBOEP, Texanol, DMAD

8. Outlook for screening of flame retardants and plasticizers in the indoor environment

Humans are exposed to SVOCs in the indoor environment via multiple pathways (Dishaw et al., 2014, Covaci et al., 2006, Harrad et al., 2010). Inhalation of air, dust ingestion and dermal uptake have been identified as three major pathways to the total non-dietary exposure (Covaci et al., 2011, Harrad et al., 2010). Collection and analysis of indoor matrices such as dust and air can provide an estimation of the exposure potential by calculating daily intakes with e.g. the mean/median values (representing a normal exposure value) and 95th percentile values (representing the exposure level at a worst case scenario) (Fromme et al., 2016). Furthermore, the daily intake data can be combined with questionnaires regarding indoor activities and social behaviors in order to provide additional information on the most significant exposure pathways (Wittassek et al., 2011, Harrad et al., 2010). Many studies have shown that dust is a major exposure source of SVOCs owing to their physical-chemical properties such as low vapor pressure and relatively high hydrophobic properties (Dishaw et al., 2014, Larsson et al., 2017, Sahlstrom et al., 2014, Sukiene et al., 2016, Van den Eede et al., 2012). Since organic matter (settled dust and particulate matter) are ubiquitous on different surfaces in the indoor environment, measured dust concentrations can be used to provide a simple estimation of the indoor human exposure to FRs and plasticizers (Langer et al., 2010, Little et al., 2012). However, abiotic samples might not fully help elucidating the extent of human exposure and the actual uptake by the occupants. Therefore, most often biological samples would also need to be collected (Wittassek et al., 2011). For example, hand wipes have been collected in order to study the dermal uptake (Liu et al., 2017, Stapleton et al., 2014, Stapleton et al., 2008) while urine and blood samples have been collected in order to investigate the possible correlation between indoor SVOC levels and body burden levels (Larsson et al., 2017, Fromme et al., 2016, Stapleton et al., 2012).

A major issue of screening FRs and plasticizers in the indoor environment is the difficulty to identify their specific sources since they might also originate from other indoor sources such as consumer products (e.g. toys, textiles and electronics) and furnishing. A combination of sampling of indoor air and dust as well as emission testing of selected building materials collected from the same setting might help to elucidate the potential sources of FRs and plasticizers to the indoor environment. However, this could be a very demanding and time consuming task. Another interesting research direction is to utilize high resolution mass spectrometry to conduct suspect screening analysis on representative indoor samples such as dust (Moschet et al., 2018, Rager et al., 2016), and link the detected chemicals to chemical additives found in building products in different databases such as the priority list established in this survey. The list should then be expanded to also include other building material additives such as stabilizers, preservatives and modifiers.

9. Conclusions

In this survey, a list of 216 FRs and 81 plasticizers that are legacy or currently used as well as novel alternatives was compiled through a literature search. These additives were then investigated for their presence in building materials available on the Swedish market through cross-checking in two assessment systems, SundaHus and Byggvarubedömningen. Approximately 2500 building products spread among 15 main categories or 47 subcategories contained the listed FRs or plasticizers. Among the subcategories; “lighting articles”, “chemico-technical goods” and “electrical wiring material” were found to contain the largest number of products containing FRs. Plasticizers were mainly found in products within the subcategories “flooring articles”, chemico-technical goods” and “paint goods”. A majority of the FRs and plasticizers were not registered in the SH or BvB databases. This could be a result of (i) the regulations and restrictions implemented in EU and Sweden, (ii) the compounds are not used in building materials available on the Swedish market, (iii) the compounds are only used in specific countries, or (iv) their content in the products are below the reporting criteria. Several restricted phthalates were found in some building products which might be a cause of concern. Since most FRs and plasticizers are SVOCs, their emission pathways to the indoor environment mainly occur via volatilization and abrasion processes and most of these compounds have relatively high affinities towards organic matter. Therefore, suspect screening analysis using HRMS of indoor dust in combination with emission test of building materials could provide more in-depth insights into the potential human exposure of hazardous compounds present in building materials. Furthermore, target analysis of the compounds suggested in Table 8 on collected indoor dust could provide information about the potential exposure sources from building materials that have large surface coverage in different indoor environments.

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References

AGBB. 2015. *Ausschuss zur gesundheitlichen Bewertung von Bauprodukten (Committee for Health-related Evaluation of Building Products): Evaluation procedure for VOCs from building products* [Online]. http://www.umweltbundesamt.de/en/document/agbb-evaluation-scheme-2015. [Accessed 2018-03-24].

AMBROGI, V., CARFAGNA, C., CERRUTI, P. & MARTURANO, V. 2016. Chapter 4. Additives in Polymers.

BARRO, R., REGUEIRO, J., LLOMPART, M. & GARCIA-JARES, C. 2009. Analysis of industrial contaminants in indoor air: part 1. Volatile organic compounds, carbonyl compounds, polycyclic aromatic hydrocarbons and polychlorinated biphenyls. *J Chromatogr A,* 1216**,** 540-66.

BAYEN, S., OBBARD, J. P. & THOMAS, G. O. 2006. Chlorinated paraffins: a review of analysis and environmental occurrence. *Environ Int,* 32**,** 915-29.

BERGH, C., TORGRIP, R., EMENIUS, G. & OSTMAN, C. 2011. Organophosphate and phthalate esters in air and settled dust - a multi-location indoor study. *Indoor Air,* 21**,** 67-76.

BERGMAN, A., RYDEN, A., LAW, R. J., DE BOER, J., COVACI, A., ALAEE, M., BIRNBAUM, L., PETREAS, M., ROSE, M., SAKAI, S., VAN DEN EEDE, N. & VAN DER VEEN, I. 2012. A novel abbreviation standard for organobromine, organochlorine and organophosphorus flame retardants and some characteristics of the chemicals. *Environ Int,* 49**,** 57-82.

BIEDERMANN-BREM, S., BIEDERMANN, M., PFENNINGER, S., BAUER, M., ALTKOFER, W., RIEGER, K., HAURI, U., DROZ, C. & GROB, K. 2008. Plasticizers in PVC Toys and Childcare Products: What Succeeds the Phthalates? Market Survey 2007. *Chromatographia,* 68**,** 227-234.

BORNEHAG, C.-G., LUNDGREN, B., WESCHLER, C. J., SIGSGAARD, T., HAGERHED-ENGMAN, L. & SUNDELL, J. 2005. Phthalates in Indoor Dust and Their Association with Building Characteristics. *Environmental Health Perspectives,* 113**,** 1399-1404.

BORNEHAG, C.-G., SUNDELL, J., WESCHLER, C. J., SIGSGAARD, T., LUNDGREN, B., HASSELGREN, M. & HÄGERHED-ENGMAN, L. 2004. The Association between Asthma and Allergic Symptoms in Children and Phthalates in House Dust: A Nested Case-Control Study. *Environmental Health Perspectives,* 112**,** 1393-1397.

BOVERKET 2017. BFS 2017:5 - BBR 25.

BSEF. 2018. *The evolution of bromine flame retardants towards brominated polymers* [Online]. Available: http://lets-talk-bromine.bsef.com/2017/12/07/the-evolution-of-bromine-flame-retardants-towards-brominated-polymers/ [Accessed 2018-02-19].

BUI, T. T., GIOVANOULIS, G., COUSINS, A. P., MAGNER, J., COUSINS, I. T. & DE WIT, C. A. 2016. Human exposure, hazard and risk of alternative plasticizers to phthalate esters. *Sci Total Environ,* 541**,** 451-67.

BYGGMATERIALHANDLARNA. 2018. *BK04 codes* [Online]. http://www.byggmaterialhandlarna.se/vilma/bk04/. [Accessed 2018-02-14].

BYGGVARUBEDÖMNINGEN. 2018. *Material database* [Online]. https://www.byggvarubedomningen.se/. [Accessed 2018-01-31].

CHAEMFA, C., XU, Y., LI, J., CHAKRABORTY, P., HUSSAIN SYED, J., NASEEM MALIK, R., WANG, Y., TIAN, C., ZHANG, G. & JONES, K. C. 2014. Screening of atmospheric short- and medium-chain chlorinated paraffins in India and Pakistan using polyurethane foam based passive air sampler. *Environ Sci Technol,* 48**,** 4799-808.

CHEN, X., HU, Y. & SONG, L. 2008. Thermal behaviors of a novel UV cured flame retardant coatings containing phosphorus, nitrogen and silicon. *Polymer Engineering & Science,* 48**,** 116-123.

CORRALES, J., KRISTOFCO, L. A., STEELE, W. B., YATES, B. S., BREED, C. S., WILLIAMS, E. S. & BROOKS, B. W. 2015. Global Assessment of Bisphenol A in the Environment: Review and Analysis of Its Occurrence and Bioaccumulation. *Dose Response,* 13**,** 1559325815598308.

COUSINS, A. P., BRORSTRÖM-LUNDÉN, E., LEXÉN, J. & RYDBERG, T. 2018. Emissions from articles. Synthesis report of the ChEmiTechs Research Program. *Swedish EPA Report 6802.*

COVACI, A., GERECKE, A., LAW, R., VOORSPOELS, S., KOHLER, M., HEEB, N., LESLIE, H., ALLCHIN, C. & DE BOER, J. 2006. Hexabromocyclododecanes (HBCDs) in the Environment and Humans: A review. *Environmental science & technology,* 40**,** 3679-3688.

COVACI, A., HARRAD, S., ABDALLAH, M. A., ALI, N., LAW, R. J., HERZKE, D. & DE WIT, C. A. 2011. Novel brominated flame retardants: a review of their analysis, environmental fate and behaviour. *Environ Int,* 37**,** 532-56.

COVACI, A., VOORSPOELS, S., ABDALLAH, M. A., GEENS, T., HARRAD, S. & LAW, R. J. 2009. Analytical and environmental aspects of the flame retardant tetrabromobisphenol-A and its derivatives. *J Chromatogr A,* 1216**,** 346-63.

CROOK, B. & BURTON, N. C. 2010. Indoor moulds, Sick Building Syndrome and building related illness. *Fungal Biology Reviews,* 24**,** 106-113.

DANILIUC, A., DEPPE, B., DEPPE, O., FRIEBEL, S., FKRUSE, D. & PHILIPP, C. 2012. New trends in wood coatings and fire retardants. *European Coatings Journal,* 07-08**,** 20-25.

DANISH ENVIRONMENTAL PROTECTION AGENCY 2014. Survey of brominated flame retardants - Part of the LOUS-review.

DISHAW, L. V., MACAULAY, L. J., ROBERTS, S. C. & STAPLETON, H. M. 2014. Exposures, mechanisms, and impacts of endocrine-active flame retardants. *Curr Opin Pharmacol,* 19**,** 125-33.

DTI 2013. Hazardous substances in plastic materials.

DUTY, S. M., CALAFAT, A. M., SILVA, M. J., RYAN, L. & HAUSER, R. 2005. Phthalate exposure and reproductive hormones in adult men. *Hum Reprod,* 20**,** 604-10.

ECHA 2003. European Union Risk Assessment Report: 1,2-BENZENEDICARBOXYLIC ACID, DI-C8-10-BRANCHED ALKYL ESTERS, C9-RICH AND DI-"ISONONYL" PHTHALATE (DINP).

ECHA. 2018a. *Authorization list* [Online]. https://echa.europa.eu/sv/authorisation-list. [Accessed 2018-01-31].

ECHA. 2018b. *Candidate list* [Online]. https://echa.europa.eu/sv/candidate-list-table. [Accessed 2018-01-31].

ECHA. 2018c. *Substance search* [Online]. https://echa.europa.eu/. [Accessed 2018-01-31].

ESWI 2011. Study on waste related issus of newly listed POPs and candidate POPs. *Consortium Expert Team to Support Waste Implementation (ESWI) (Bipro, Umweltbundesamt and Enviroplan) for the European Commission*.

EU 2002. Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.

EU 2006. Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (Text with EEA relevance)

EU 2009. Directive 2009/48/EC of the European Parliament and of the Council of 18 June 2009 on the safety of toys (Text with EEA relevance).

EU 2011a. Commission Directive 2011/8/EU amending Directive 2002/72/EC as regards the restriction of use of Bisphenol A in plastic infant feeding bottles.

EU 2011b. Regulation No 10/2011.

FISK, P. R., GIRLING, A. E. & WILDEY, R. J. 2003. PRIORITISATION OF FLAME RETARDANTS FOR ENVIRONMENTAL RSIK ASSESSMENT. *Environmental Agency, UK*.

FROMME, H., SCHUTZE, A., LAHRZ, T., KRAFT, M., FEMBACHER, L., SIEWERING, S., BURKARDT, R., DIETRICH, S., KOCH, H. M. & VOLKEL, W. 2016. Non-phthalate plasticizers in German daycare centers and human biomonitoring of DINCH metabolites in children attending the centers (LUPE 3). *Int J Hyg Environ Health,* 219**,** 33-9.

GOLDSMITH, M. R., GRULKE, C. M., BROOKS, R. D., TRANSUE, T. R., TAN, Y. M., FRAME, A., EGEGHY, P. P., EDWARDS, R., CHANG, D. T., TORNERO-VELEZ, R., ISAACS, K., WANG, A., JOHNSON, J., HOLM, K., REICH, M., MITCHELL, J., VALLERO, D. A., PHILLIPS, L., PHILLIPS, M., WAMBAUGH, J. F., JUDSON, R. S., BUCKLEY, T. J. & DARY, C. C. 2014. Development of a consumer product ingredient database for chemical exposure screening and prioritization. *Food and Chemical Toxicology,* 65**,** 269-279.

GRAND-VIEW-RESEARCH 2017. Global flame retardant market projected to reach US$11.96 billion by 2025. *Additives for Polymers,* 2017**,** 10-11.

GRAY, L. E., JR., WILSON, V. S., STOKER, T., LAMBRIGHT, C., FURR, J., NORIEGA, N., HOWDESHELL, K., ANKLEY, G. T. & GUILLETTE, L. 2006. Adverse effects of environmental antiandrogens and androgens on reproductive development in mammals. *Int J Androl,* 29**,** 96-104; discussion 105-8.

GUSTAVSSON, J., FISCHER, S., AHRENS, L. & WIBERG, K. 2017. Replacement substances for the brominated flame retardants PBDE HBCDD and TBBPA. *Swedish Environmental Protection Agency*.

HANSEN, E., NILSSON, N., LITHNER, D. & LASSEN, C. 2013. Hazardous substances in plastic materials. COWI.

HARRAD, S., DE WIT, C. A., ABDALLAH, M., BJÖRKLUND, J. A., COVACI, A., DARNERUD, P., DE BOER, J., DIAMOND, M., HUBER, S., LEONARDS, P., MANDALAKIS, M., OSTMAN, C., HAUG, L. S., THOMSEN, C. & WEBSTER, T. F. 2010. Indoor Contamination with Hexabromocyclododecanes, Polybrominated Diphenyl Ethers, and Perfluoroakyl Compounds: An Important Exposure pathway for People? *Environ. Sci. Technol,* 44**,** 3221-3231.

HAUSER, R., MEEKER, J. D., DUTY, S., SILVA, M. J. & CALAFAT, A. M. 2006. Altered semen quality in relation to urinary concentrations of phthalate monoester and oxidative metabolites. *Epidemiology,* 17**,** 682-91.

HENNEUSE-BOXUS, C. & PACARY, T. 2003. Emissions from plastics. *Rapra Review Reports,* Report 161**,** 5.

KARLSSON, M., JULANDER, A., VAN BAVEL, B. & HARDELL, L. 2007. Levels of brominated flame retardants in blood in relation to levels in household air and dust. *Environment International,* 33**,** 62-69.

KEMI 2014. Kartläggning av ftalater i varor i Sverige. *Report 2*.

KEMI (SWEDISH CHEMICALS AGENCY) 2006. Hexabromcyklododekan (HBCDD) och tetrabrombisfenol - A (TBBPA).

KEMI (SWEDISH CHEMICALS AGENCY) 2015. Hälsoskadliga kemiska ämnen i byggprodukter - förslag till nationella regler.

KEMMLEIN, S., HAHN, O. & JANN, O. 2003. Emissions of organophosphate and brominated flame retardants from selected consumer products and building materials. *Atmospheric Environment,* 37**,** 5485-5493.

KIM, S. 2010. Control of formaldehyde and TVOC emission from wood-based flooring composites at various manufacturing processes by surface finishing. *J Hazard Mater,* 176**,** 14-9.

LANGER, S., FREDRICSSON, M., WESCHLER, C. J., BEKO, G., STRANDBERG, B., REMBERGER, M., TOFTUM, J. & CLAUSEN, G. 2016. Organophosphate esters in dust samples collected from Danish homes and daycare centers. *Chemosphere,* 154**,** 559-66.

LANGER, S., WESCHLER, C. J., FISCHER, A., BEKO, G., TOFTUM, J. & CLAUSEN, G. 2010. Phthalate and PAH concentrations in dust collected from Danish homes and daycare centers. *Atmospheric Environment,* 44**,** 2294-2301.

LARSSON, K., DE WIT, C. A., SELLSTROM, U., SAHLSTROM, L., LINDH, C. H. & BERGLUND, M. 2018. Brominated Flame Retardants and Organophosphate Esters in Preschool Dust and Children's Hand Wipes. *Environ Sci Technol,* 52**,** 4878-4888.

LARSSON, K., LINDH, C. H., JONSSON, B. A., GIOVANOULIS, G., BIBI, M., BOTTAI, M., BERGSTROM, A. & BERGLUND, M. 2017. Phthalates, non-phthalate plasticizers and bisphenols in Swedish preschool dust in relation to children's exposure. *Environ Int,* 102**,** 114-124.

LASSEN, C., JENSEN, A. A., CROOKES, M., CHRISTENSEN, F., JEPPESEN, C. N., CLAUSEN, A. J. & MIKKELSEN, S. H. 2014. Survey of brominated flame retardants. Part of the LOUS-review. *Dansih Ministry of the Environment - Environmental Protection Agency,* Environmental Project No. 1536.

LASSEN, C. & LOKKE, S. 1999. Brominated flame retardants - Substance flow analysis and assessment of alternatives. *Danish Environmental Protection Agency (EPA)*.

LEVCHIK, S. V. & WEIL, E. D. 2004. Thermal decomposition, combustion and flame-retardancy of epoxy resins - a review of the recent literature. *Polymer International,* 53**,** 1901-1929.

LIOY, P. J., FREEMAN, N. C. G. & MILLETTE, J. R. 2002. Dust: a metric for use in residential and building exposure assessment and source characterization. *Environmental Health Perspectives,* 110**,** 969-983.

LITTLE, J. C., WESCHLER, C. J., NAZAROFF, W. W., LIU, Z. & COHEN HUBAL, E. A. 2012. Rapid methods to estimate potential exposure to semivolatile organic compounds in the indoor environment. *Environ Sci Technol,* 46**,** 11171-8.

LIU, X., YU, G., CAO, Z., WANG, B., HUANG, J., DENG, S. & WANG, Y. 2017. Occurrence of organophosphorus flame retardants on skin wipes: Insight into human exposure from dermal absorption. *Environment International,* 98**,** 113-119.

LUCATTINI, L., POMA, G., COVACI, A., DE BOER, J., LAMOREE, M. & LEONARDS, P. A review of semi-volatile organic compounds (SVOCs) in the indoor environment: Occurrence in consumer products, indoor air and dust. *Chemosphere,* 201**,** 466-482.

MARKLUND, A., ANDERSSON, B. & HAGLUND, P. 2003. Screening of organophosphorus compounds and their distribution in various indoor environments. *Chemosphere,* 53**,** 1137-1146.

MEEKER, J. D. & STAPLETON, H. M. 2010. House dust concentrations of organophosphate flame retardants in relation to hormone levels and semen quality parameters. *Environ Health Perspect,* 118**,** 318-23.

MELYMUK, L., BOHLIN-NIZZETTO, P., VOJTA, S., KRATKA, M., KUKUCKA, P., AUDY, O., PRIBYLOVA, P. & KLANOVA, J. 2016. Distribution of legacy and emerging semivolatile organic compounds in five indoor matrices in a residential environment. *Chemosphere,* 153**,** 179-186.

MILJÖFÖRVALTNINGEN 2016. Lägesrapport - Ftalater i damm och PVC-golv på förskolor. *Stockholm stad*.

MISSIA, D. A., DEMETRIOU, E., MICHAEL, N., TOLIS, E. I. & BARTZIS, J. G. 2010. Indoor exposure from building materials: A field study. *Atmospheric Environment,* 44**,** 4388-4395.

MOSCHET, C., ANUMOL, T., LEW, B. M., BENNETT, D. H. & YOUNG, T. M. 2018. Household Dust as a Repository of Chemical Accumulation: New Insights from a Comprehensive High-Resolution Mass Spectrometric Study. *Environ Sci Technol,* 52**,** 2878-2887.

NEWTON, S., SELLSTROM, U. & DE WIT, C. A. 2015. Emerging Flame Retardants, PBDEs, and HBCDDs in Indoor and Outdoor Media in Stockholm, Sweden. *Environmental Science & Technology,* 49**,** 2912-2920.

PERSSON, J., WANG, T. & HAGBERG, J. 2018. Organophosphate flame retardants and plasticizers in indoor dust, air and window wipes in newly built low-energy preschools. *Sci Total Environ,* 628-629**,** 159-168.

PLASTICISERS-INFORMATION-CENTER. 2018. *What are plasticisers?* [Online]. http://www.plasticisers.org/. [Accessed 2018-01-31].

RAGER, J. E., STRYNAR, M. J., LIANG, S., MCMAHEN, R. L., RICHARD, A. M., GRULKE, C. M., WAMBAUGH, J. F., ISAACS, K. K., JUDSON, R., WILLIAMS, A. J. & SOBUS, J. R. 2016. Linking high resolution mass spectrometry data with exposure and toxicity forecasts to advance high-throughput environmental monitoring. *Environment International,* 88**,** 269-280.

RAHMAN, M. & BRAZEL, C. S. 2006. Ionic liquids: New generation stable plasticizers for poly(vinyl chloride). *Polymer Degradation and Stability,* 91**,** 3371-3382.

RAUERT, C. & HARRAD, S. 2015. Mass transfer of PBDEs from plastic TV casing to indoor dust via three migration pathways--A test chamber investigation. *Sci Total Environ,* 536**,** 568-74.

ROZE, E., MEIJER, L., BAKKER, A., VAN BRAECKEL, K. N., SAUER, P. J. & BOS, A. F. 2009. Prenatal exposure to organohalogens, including brominated flame retardants, influences motor, cognitive, and behavioral performance at school age. *Environ Health Perspect,* 117**,** 1953-8.

SAHLSTROM, L., SELLSTROM, U. & DE WIT, C. A. 2012. Clean-up method for determination of established and emerging brominated flame retardants in dust. *Anal Bioanal Chem,* 404**,** 459-66.

SAHLSTROM, L. M., SELLSTROM, U., DE WIT, C. A., LIGNELL, S. & DARNERUD, P. O. 2014. Brominated flame retardants in matched serum samples from Swedish first-time mothers and their toddlers. *Environ Sci Technol,* 48**,** 7584-92.

SALTHAMMER, T. & BAHADIR, M. 2009. Occurrence, Dynamics and Reactions of Organic Pollutants in the Indoor Environment. *Clean-Soil Air Water,* 37**,** 417-435.

SATO, Y., KONDO, Y., TSUJITA, K. & KAWAI, N. 2005. Degradation behaviour and recovery of bisphenol-A from epoxy resin and polycarbonate resin by liquid-phase chemical recycling. *Polymer Degradation and Stability,* 89**,** 317-326.

SCHMITT, E. 2007. Phosphorus-based flame retardants for thermoplastics. *Plastics, Additives and Compounding,* 9**,** 26-30.

SCHUTZE, A., KOLOSSA-GEHRING, M., APEL, P., BRUNING, T. & KOCH, H. M. 2014. Entering markets and bodies: increasing levels of the novel plasticizer Hexamoll(R) DINCH(R) in 24 h urine samples from the German Environmental Specimen Bank. *Int J Hyg Environ Health,* 217**,** 421-6.

SPIN. 2018. *Substances in Preparations in Nordic Countries* [Online]. http://spin2000.net/. [Accessed 2018-01-31].

SSNC 2014. Allt du (inte) vill veta om plast.

STAPLES, C. A., DONNE, P. B., KLECKA, G. M., OBLOCK, S. T. & R., H. L. 1998. A review of the environmental fate, effects, and exposures of bisphenol A. *Chemosphere,* 36**,** 2149-73.

STAPLETON, H. M., EAGLE, S., SJODIN, A. & WEBSTER, T. F. 2012. Serum PBDEs in a North Carolina toddler cohort: associations with handwipes, house dust, and socioeconomic variables. *Environ Health Perspect,* 120**,** 1049-54.

STAPLETON, H. M., KELLY, S. M., ALLEN, J. G., MCCLEAN, M. D. & WEBSTER, T. F. 2008. Measurement of Polybrominated Diphenyl Ethers on Hand Wipes: Estimating Exposure from Hand-to-Mouth Contact. *Environ. Sci. Technol,* 42**,** 3329-3334.

STAPLETON, H. M., MISENHEIMER, J., HOFFMAN, K. & WEBSTER, T. F. 2014. Flame retardant associations between children's handwipes and house dust. *Chemosphere,* 116**,** 54-60.

SUKIENE, V., GERECKE, A. C., PARK, Y. M., ZENNEGG, M., BAKKER, M. I., DELMAAR, C. J., HUNGERBUHLER, K. & VON GOETZ, N. 2016. Tracking SVOCs' Transfer from Products to Indoor Air and Settled Dust with Deuterium-Labeled Substances. *Environ Sci Technol*.

SUNDAHUS. 2018. *Material database* [Online]. http://www.sundahus.se/. [Accessed 2018-01-31].

SUNDELL, J. 2004. On the histroy of indoor air quality and health. *Indoor Air,* 14**,** 51-58.

SWAN, S. H. 2008. Environmental phthalate exposure in relation to reproductive outcomes and other health endpoints in humans. *Environmental Research,* 108**,** 177-184.

SWEDISH CHEMICALS AGENCY 2011. Bisfenol A - Rapport från ett regeringsuppdrag (in Swedish).

SWEDISH CHEMICALS AGENCY 2014a. Förslag till utfasning av fortplantningsstörande och hormanstörande ftalater i Sverige (in Swedish).
SWEDISH CHEMICALS AGENCY 2014b. Handlingsplan för en giftfri vardag 2015-2020 - Skydda barnen bättre (in Swedish).
SWEDISH CHEMICALS AGENCY 2014c. Kartläggning av ftalater i varor i Sverige (in Swedish).
SWEDISH CHEMICALS AGENCY 2015a. Hälsoskadliga kemiska ämnen i byggprodukter - förslag till nationella regler (in Swedish).
SWEDISH CHEMICALS AGENCY 2015b. Kartläggning av farliga ämnen i byggprodukter i Sverige (in Swedish).
THE PUBLICH HEALTH AGENCY OF SWEDEN 2017. Environmental Health Survey 2017 (in Swedish). The Public Health Agency of Sweden.
THURESSON, K., BJORKLUND, J. A. & DE WIT, C. A. 2012. Tri-decabrominated diphenyl ethers and hexabromocyclododecane in indoor air and dust from Stockholm microenvironments 1: levels and profiles. *Sci Total Environ,* 414**,** 713-21.
UNEP. 2018. *Stockholm Convention on Persistent Organic Pollutants* [Online]. http://chm.pops.int/. [Accessed 2018-01-31].
US EPA 2009. Short-Chain Chlorinated Paraffins (SCCPs) and Other Chlorinated Paraffins Action Plan. *In:* US EPA (ed.).
VAN DEN EEDE, N., DIRTU, A. C., ALI, N., NEELS, H. & COVACI, A. 2012. Multi-residue method for the determination of brominated and organophosphate flame retardants in indoor dust. *Talanta,* 89**,** 292-300.
VAN DER VEEN, I. & DE BOER, J. 2012. Phosphorus flame retardants: properties, production, environmental occurrence, toxicity and analysis. *Chemosphere,* 88**,** 1119-53.
VAN MOURIK, L. M., GAUS, C., LEONARDS, P. E. G. & DE BOER, J. 2016. Chlorinated paraffins in the environment: A review on their production, fate, levels and trends between 2010 and 2015. *Chemosphere,* 155**,** 415-428.
WANG, Y., HOU, M., ZHANG, Q., WU, X., ZHAO, H., XIE, Q. & CHEN, J. 2017. Organophosphorus Flame Retardants and Plasticizers in Building and Decoration Materials and Their Potential Burdens in Newly Decorated Houses in China. *Environ Sci Technol,* 51**,** 10991-10999.
WEI, G. L., LI, D. Q., ZHUO, M. N., LIAO, Y. S., XIE, Z. Y., GUO, T. L., LI, J. J., ZHANG, S. Y. & LIANG, Z. Q. 2015. Organophosphorus flame retardants and plasticizers: sources, occurrence, toxicity and human exposure. *Environ Pollut,* 196**,** 29-46.
WENSING, M., UHDE, E. & SALTHAMMER, T. 2005. Plastics additives in the indoor environment--flame retardants and plasticizers. *Sci Total Environ,* 339**,** 19-40.
WESCHLER, C. J. 2009. Changes in indoor pollutants since the 1950s. *Atmospheric Environment,* 43**,** 153-169.
WESCHLER, C. J. 2011. Chemistry in indoor environments: 20 years of research. *Indoor Air,* 21**,** 205-18.
WESCHLER, C. J. & NAZAROFF, W. W. 2008. Semivolatile organic compounds in indoor environments. *Atmospheric Environment,* 42**,** 9018-9040.
WESCHLER, C. J. & NAZAROFF, W. W. 2010. SVOC partitioning between the gas phase and settled dust indoors. *Atmospheric Environment,* 44**,** 3609-3620.
WESCHLER, C. J. & NAZAROFF, W. W. 2017. Growth of organic films on indoor surfaces. *Indoor Air,* 27**,** 1101-1112.
WHO 1998. Environmental Health Criteria 209: Flame retardants: Tris(chloropropyl) phospahte and tris(2-chloroethyl) phosphate.
WITTASSEK, M., KOCH, H. M., ANGERER, J. & BRUNING, T. 2011. Assessing exposure to phthalates - the human biomonitoring approach. *Mol Nutr Food Res,* 55**,** 7-31.
WYPYCH, A. 2017. Databook of plasticizers. *ChemTec Publishing,* 2nd Edition.

XU, Y. & LITTLE, J. C. 2006. Predicting Emissions of SVOCs from Polymeric Materials and Their Interaction with Airborne Particles. *Environ. Sci. Technol,* 40**,** 456-61.

APPENDIX 1

List of flame retardants and plasticizers included in this survey.

Bold text indicated that the substance was found in at least one product in the databases of the two building product assessment systems. **Acronym:** common abbreviation or commercial name (if available). **Sub:** substance type affiliated with the CAS number, where S = single (mono-constituent) substance, M = multi-constituent substance or substance of unknown or variable composition, complex reaction product or of biological materials. **Main use**: P = plasticizer, FR = flame retardant. **Formula**: for mono-substituents only.

Common name	Acronym	CAS	Sub	Main use	Formula
(3-hydroxy-2,2,4-trimethylpentyl) 2-Methylpropanoate	**Texanol**	**25265-77-4**	**S**	**P**	**C12H24O3**
1,2- Benzenedicarboxylic acid, bis(methylcyclohexyl) ester	DMcHP	27987-25-3	S	P	C22H30O4
1,2-Benzendicarboxylic acid dipentyl ester, branched and linear		84777-06-0	M	P	
1,2-Benzenedicarboxylic acid, di-C1-13 alkyl esters	Di C1-13 PE	84852-02-8	M	P	
1,2-Benzenedicarboxylic acid, di-C16- 18-alkyl esters	**Di C16-18 PE**	**90193-76-3**	**M**	**P**	
1,2-Benzenedicarboxylic acid, di-C6-8-branched alkyl esters	**DIHP**	**71888-89-6**	**M**	**P**	
1,2-Benzenedicarboxylic acid, di-C7-11-alkyl esters	**DHNUP**	**68515-42-4**	**M**	**P**	
1,2-Benzenedicarboxylic acid, di-C8-10- alkyl esters	Di C8-10 PE	71662-46-9	M	P	
1,2-Benzenedicarboxylic acid, di-C8-10-branched alkyl esters, C9-rich	**DINP-br**	**68515-48-0**	**M**	**P**	
1,3-Isobenzofurandione, polymer with 2,2'-(1,2-ethanediylbis(oxy))bis(ethanol), benzoate		68186-30-1	M	P	
1,2,3-Propanetricarboxylic acid, 2-(acetyloxy)-, triethyl ester	Citroflex A2 (ATEC)	77-89-4	S	P	C14H22O8
2-hydroxy-1,2,3-propanetricarboxylic acid, tributyl ester	**TBC**	**77-94-1**	**S**	**P**	**C18H32O7**
2-hydroxy-1,2,3-propanetricarboxylic acid, triethyl ester	TEC	77-93-0	S	P	C12H20O7
4,4'-(hexafluoroisopropylidene)diphenol	BPAF	1478-61-1	S	P	C15H10F6O2

4,4''-(propane-2,2-diyl)diphenol	**BPA**	**80-05-7**	**S**	**P**	**C15H16O2**
4,4'-Methylenediphenol	BPF	620-92-8	S	P	C13H12O2
4,4''-Sulfonyldiphenol	BPS	80-09-1	S	P	C12H10O4S
Alkylsulfonic phenyl ester	**ASE**	**91082-17-6**	**M**	**P**	
Benzyloctyl phthalate	BzOP-2	1248-43-7	S	P	C23H28O4
Benzyl phthalate	**BzP**	**16883-83-3**	**S**	**P**	**C27H34O6**
Benzyloctyl phthalate	**BzOP**	**68515-40-2**	**M**	**P**	
Bis(2-ethylhexyl) adipate	**DEHA**	**103-23-1**	**S**	**P**	**C22H42O4**
Bis(2-ethylhexyl) terephthalate	**DEHT**	**6422-86-2**	**S**	**P**	**C24H38O4**
Bis(2-ethylhexyl)phosphate	DEHPA	298-07-7	S	P	C16H35O4P
Bis(2-ethylhexyl)sebacates	DOS	122-62-3	S	P	C26H50O4
Bisphenol AP	BPAP	1571-75-1	S	P	C20H18O2
Bisphenol B	BPB	77-40-7	S	P	C16H18O2
Bisphenol P	BPP	2167-51-3	S	P	C24H26O2
Bisphenol Z	BPZ	843-55-0	S	P	C18H20O2
Butyl oleate	**BOlea**	**142-77-8**	**S**	**P**	**C22H42O2**
Butylbenzyl phthalate	**BBzP**	**85-68-7**	**S**	**P**	**C19H20O4**
butylphthalyl butyl glycolate	morflex 190	85-70-1	S	P	C18H24O6
Di(2- methoxyethyl) phthalate	DMEP	117-82-8	S	P	C14H18O6
Di-(2-ethylhexyl) phthalate	**DEHP**	**117-81-7**	**S**	**P**	**C24H38O4**
Di(2-propyl heptyl) phthalate	**DPHP**	**53306-54-0**	**S**	**P**	**C28H46O4**
Di(ethylene glycol) dibenzoate	DEGDB	120-55-8	S	P	C18H18O5
Di(n-octyl) phthalate	**DNOP**	**117-84-0**	**S**	**P**	**C24H38O4**
Di(propylene glycol) dibenzoate	**DPGDB**	**27138-31-4**	**S**	**P**	**C20H22O5**

Dialkyl (C9-C11)phthalate	Di C9-11 PE	68648-92-0	M	P	
Diallyl phthalate	DAP	131-17-9	S	P	C14H14O4
Dibutyl adipate	DBA	105-99-7	S	P	C14H26O4
Dibutyl sebacates	DBS	109-43-3	S	P	C18H34O4
Di-C6-10-alkyl phthalate	Di C6-10 PE	68515-51-5	M	P	
Di-C9-11-acyl phthalate	**Di C9-11 PE br-lin**	**68515-43-5**	**M**	**P**	
Dicyclohexyl phthalate	**DCHP**	**84-61-7**	**S**	**P**	**C20H26O4**
Diethyl phthalate	**DEP**	**84-66-2**	**S**	**P**	**C12H14O4**
Dihexyl phthalate	DHP	68515-50-4	M	P	
Di-n-hexyl phthalate	DNHP	84-75-3	S	P	C20H30O4
Diisobutyl phthalate	**DIBP**	**84-69-5**	**S**	**P**	**C16H22O4**
Diisodecyl hexanedioate	**DIDA**	**27178-16-1**	**S**	**P**	**C26H50O4**
Diisodecyl phthalate	**DIDP-2**	**26761-40-0**	**M**	**P**	
Diisodecyl phthalate	**DIDP-1**	**68515-49-1**	**M**	**P**	
Diisononyl adipate	**DINA**	**33703-08-1**	**M**	**P**	
Di-isononyl phthalate	**DINP**	**28553-12-0**	**M**	**P**	
Diisononylcyclohexane-1,2-dicarboxylate	**DINCH**	**166412-78-8**	**M**	**P**	
Diisooctyl phthalate	DIOP	131-20-4	S	P	C24H38O4
Diisopenty phthalate	DIPP	605-50-5	S	P	C18H26O4
Diisotridecyl phthalate	DITP	27253-26-5	M	P	
Diisotridecyl phthalate	**DTDP-jf (Jayflex)**	**68515-47-9**	**M**	**P**	
Diisoundecyl phthalate, linear	DIUP-lin	3648-20-2	S	P	C30H50O4
Diisoundecyl phthalate, linear and branched	**DIUP-lin_br**	**85507-79-5**	**M**	**P**	
Dimethyl adipate	**DMAD**	**627-93-0**	**S**	**P**	**C8H14O4**

Dimethyl phthalate	**DMP**	**131-11-3**	**S**	**P**	**C10H10O4**
Dimethyl sebacate	DMS	106-79-6	S	P	C12H22O4
Di-n-butyl phthalate	**DNBP**	**84-74-2**	**S**	**P**	**C16H22O4**
Dipentyl phthalate	DPP	131-18-0	S	P	C18H26O4
Distearyl phthalate	**DSP**	**14117-96-5**	**S**	**P**	**C44H78O4**
Ditridecyl phthalate	**DTDP**	**119-06-2**	**S**	**P**	**C34H58O4**
Epoxidized soybean oil	ESBO	8013-07-8	M	P	
Glycerides, castor oil-mono, hydrogenated, acetates	**COMGHA**	**736150-63-3**	**M**	**P**	
Glycerin triacetate	**GTA**	**102-76-1**	**S**	**P**	**C9H14O6**
methyl ethyl ketone peroxide	**MEKP**	**1338-23-4**	**S**	**P**	**C8H18O6**
Methyl O-acetylricinoleate	MAR-N	140-03-4	S	P	C21H38O4
n-butyltri-n-hexyl citrate	BTHC	82469-79-2	S	P	C28H50O8
N-Pentylisopentyl phthalate	PIPP	776297-69-9	S	P	C18H26O4
poly(ethylene glycol) monolaurate	**PEG-laur**	**9004-81-3**	**M**	**P**	
Tributyl O-acetylcitrate	**ATBC**	**77-90-7**	**S**	**P**	**C20H34O8**
triisononyl trimellitate	TINTM	53894-23-8	M	P	
Trimethyl pentanyl diisobutyrate	**TXIB**	**6846-50-0**	**S**	**P**	**C16H30O4**
tri-n-hexyl trimellitate	THTM	1528-49-0	S	P	C27H42O6
Tris-2-ethyhexyl trimellitate	**TOTM**	**3319-31-1**	**S**	**P**	**C33H54O6**
1-(2,3-Dibromopropyl)-3,5-diallyl-1,3,5-Triazine-2,4,6(1H,3H,5H)-trione	DBP-TAZTO	57829-89-7	S	FR	C12H15Br2N3O3
1,1'-Biphenyl, 2,2',3,3',4,4',5,6'-octabromo-		69278-61-1	S	FR	C12H2Br8
1,1'-Biphenyl, 2,2',3,3',4,4',6,6'-octabromo-		119264-59-4	S	FR	C12H2Br8
1,2,3,4,5,6,7,8,,12,12,13,13-Dodecachloro-1,4,4a,5,8,8a,9,9a,10,10a-decahydro-1,4:5,8:9,10-trimethanoanthracene	DDC-Ant	13560-92-4	S	FR	C17H8Cl12

1,2,3,4,5,6,7,8-Octachloronaphthalene	PCN-75	2234-13-1	S	FR	C10Cl8
1,2,3,4,5-Pentabromobenzene	PBBZ	608-90-2	S	FR	C6HBr5
1,2,3,4,6,7,8,9,10,10,11,11-Dodecachloro-1,4,4a,5a,6,9,9a,9b-octahydro-1,4:6,9-dimethanodibenzofuran	DDC-DBF	31107-44-5	S	FR	C14H4Cl12O
1,2,3,4,7,7-hexachloro-5-(2,3,4,5-tetrabromophenyl)-Bicyclo[2.2.1]hept-2-ene	HCTBPH	34571-16-9	S	FR	C13H4Br4Cl6
1,2,3,4,7,7-hexachloro-5-(tribromophenyl)bicyclo[2.2.1]hept-2-ene		56890-89-2	S	FR	C13H5Br3Cl6
1,2,4,5-Tetrabromo-3,6-dimethylbenzene	TBX	23488-38-2	S	FR	C8H6Br4
1,2,5,6-Tetrabromocyclooctane	TBCO	3194-57-8	S	FR	C8H12Br4
1,2-Bis(2,4,6-tribromophenoxy)ethane	BTBPE	37853-59-1	S	FR	C14H8Br6O2
1,3,5-Tris(2,3-dibromopropyl)-1,3,5-triazine-2.4.6-trione	TDBP-TAZTO	52434-90-9	S	FR	C12H15Br6N3O3
1,3-Bis(2,3-dibromopropyl)-5-allyl-1,3,5-Triazine-2,4,6(1H,3H,5H)-trione	BDBP-TAZTO	75795-16-3	S	FR	C12H15Br4N3O3
1,3-hexylene dimelamine			S	FR	
1,3-phenylene-bis(dixylenyl phosphate)			S	FR	
1,4,5,6,7,7-Hexachlorobicyclo(2.2.1)het-5-ene-2,3-dicarboxylic acid	HCBCH-DCA	115-28-6	S	FR	C9H4Cl6O4
1,4,5,6,7,7-Hexachlorobicyclo[2.2.1]het-5-ene-2,3-dicarboxylic anhydride	HCBCH-DCAnh	115-27-5	S	FR	C9H2Cl6O3
2-(2-Hydroxyethoxy)ethyl 2-hydroxypropyl 3,4,5,6-tetrabromophthalate	HEEHP-TEBP	20566-35-2	S	FR	C15H16Br4O7
2,2',,4,4',5-Pentabromodiphenyl ether	BDE-99	60348-60-9	S	FR	C12H5Br5O
2,2',3,3',4,4',5,5',6-Nonabromo-1,1'-biphenyl		69278-62-2	S	FR	C12HBr9
2,2',3,3',4,4',5,6,6'-Nonabromo-1,1'-biphenyl		119264-62-9	S	FR	C12HBr9
2,2',3,3',4,5,5',6,6'-Nonobromobiphenyl		119264-63-0	S	FR	C12HBr9
2,2',3,3',4,5,5',6'-Octabromobiphenyl		69887-11-2	S	FR	C12H2Br8
2,2',3,3',4,5',6,6'-Octabromobiphenyl		119264-60-7	S	FR	C12H2Br8

2,2',3,4,4',5,6,6'-Octabromobiphenyl		119264-61-8	S	FR	C12H2Br8
2,2',3,4,4',5',6-Heptabromodiphenyl ether	BDE-183	207122-16-5	S	FR	C12H3Br7O
2,2',3,4,4',5'-Hexabromodiphenyl ether	BDE-138	182677-30-1	S	FR	C12H4Br6O
2,2',3,4,4'-Pentabromodiphenyl ether	BDE-85	182346-21-0	S	FR	C12H5Br5O
2,2',4,4', 5,6'-Hexabromodiphneyl ether	BDE-154	207122-15-4	S	FR	C12H4Br6O
2,2',4,4',5,5'-Hexabromodiphenyl ether	BDE-153	68631-49-2	S	FR	C12H4Br6O
2,2',4,4',6-Pentabromodiphenyl ether	BDE-100	189084-64-8	S	FR	C12H5Br5O
2,2',4,4'-Tetrabromodiphenyl ether	BDE-47	5436-43-1	S	FR	C12H6Br4O
2,2_Bis(chloromethyl)-1,3-propanediol bis]bis(2-chloroethyl) phosphate]	BCMP-BCMEP	1047637-37-5	S	FR	C17H32Cl6O8P2
2,2-Bis(chloromethyl)-1,3-propanediol bis[bis(2-chloroethyl)phosphate]	BCMP-BCEP	38051-10-4	S	FR	C13H24Cl6O8P2
2,3,4,5-tertabromo-6-chloromethylbenzene	TBCT	39569-21-6	S	FR	C7H3Br4Cl
2,3,5,6,2',3',5',6'-Octabromobiphenyl		59080-41-0	S	FR	C12H2Br8
2,3'4,4'-Tetrabromodiphenyl ether	BDE-66	189084-61-5	S	FR	C12H6Br4O
2,4,4'-Tribromodiphenyl ether	BDE-28	41318-75-6	S	FR	C12H7Br3O
2,4,6-Tribromopenyl allyl ether benzene	TBP-AE	3278-89-5	S	FR	C9H7Br3O
2,4,6-Tribromophenol	TBP	118-79-6	S	FR	C6H3Br3O
2,4,6-Tribromophenyl 2,3-dibromopropyl ether	TBP-DBPE	35109-60-5	S	FR	C9H7Br5O
2,4-Dibromophenol	2,4-DBP	615-58-7	S	FR	C6H4Br2O
2,6-Dibromophenol	2,6-DBP	608-33-3	S	FR	C6H4Br2O
2-Bromoallyl 2,4,6-tribromphenyl ether	BATE	99717-56-3	S	FR	C9H6Br4O
2-Bromophenol	2-BP	95-56-7	S	FR	C6H5BrO
2-Ethylhexyl 2,3,4,5-tetrabromonezoate	EH-TBB	183658-27-7	S	FR	C15H18Br4O2
2-Ethylhexyldiphenyl phopsphate	**EHDPP**	**1241-94-7**	**S**	**FR**	**C20H27O4P**
3-(Tetrabromopentadecyl)-2,4,6-tribromophenol	TBPD-TBP	168434-45-5	S	FR	

3,3',4,4'-Tetrabromodiphenyl ether	BDE-77	93703-48-1	S	FR	C12H6Br4O
3,3',5,5'-Tetrabromobisphenol A bisacetate	TBBPA-BOAc	33798-02-6	S	FR	C19H16Br4O4
3,4:5,6-Dibenzo-2H-1,2-oxaphosphorin-2-oxide	DOPO	35948-25-5	S	FR	C12H9O2P
3.4.5.6-Tetrabromophthalic anhydride	TEBP-Anh	632-79-1	S	FR	C8Br4O3
3-Bromobiphenyl	PBB-3	2113-57-7	S	FR	C12H9Br
3-Bromophenol	3-DP	591-20-8	S	FR	C6H5BrO
4-(1,2-Dibromoethyl)-1,2-dibromocyclohexane	DBE-DBCH	3322-93-8	S	FR	C8H12Br4
4,4'-dibromobiphenyl		92-86-4	S	FR	C12H8Br2
4-Bromobiphenyl		92-66-0	S	FR	C12H9Br
4-Bromophenol	4-BP	106-41-2	S	FR	C6H5BrO
5,6-Dibromo-1-10-11-12,13,13-hexachloro-11-tricyclo[8.2.1.02,9]tridecene	DBHCTD	51936-55-1	S	FR	C13H12Br2Cl6
Acetoguanamine		542-02-9	S	FR	C4H7N5
Ammeline/Cyanurodiamide		645-92-1	S	FR	C3H5N5O
Aroclor 1016		12674-11-2	M	FR	
Aroclor 1221		11104-28-2	M	FR	
Aroclor 1232		11141-16-5	M	FR	
Aroclor 1242		53469-21-9	M	FR	
Aroclor 1262		37324-23-5	M	FR	
Aroclor 1268		11100-14-4	M	FR	
Aroclor 5432		63496-31-1	M	FR	
Aroclor 5442		12642-23-8	M	FR	
Benzoguanamine		91-76-9	S	FR	C9H9N5
Bis(2,3-Dibromopropyl) phoshate	bBDBP	5412-25-9	S	FR	C6H11Br4O4P
Bis(2-ethylhexyl) tetrabromophthalate	BEH-TEBP	26040-51-7	S	FR	C24H34Br4O4

Bis-(isopropylphenyl) phenyl phosphate	DIPPP	101299-37-0	S	FR	C30H39O4P
Bis-(t-butylphenyl) phenyl phosphate	DBPPP	65652-41-7	S	FR	C26H31O4P
Bisphenol A bis(diphenyl phosphate)	**BPA-BDPP**	**5945-33-5**	**S**	**FR**	**C39H34O8P2**
Brominated paraffins			M	FR	
Butyldiphenyl phosphate	BdPhP	2752-95-6	S	FR	C16H19O4P
Butylene diguanamine			S	FR	
Chlordene Plus	CPlus	13560-91-3	S	FR	C15H6Cl12
Chlorinated paraffins	CPs-15	106232-85-3	M	FR	
Chlorinated paraffins	CPs-16	106232-86-4	M	FR	
Chlorinated paraffins	CPs-17	108171-26-2	M	FR	
Chlorinated paraffins	CPs-18	108171-27-3	M	FR	
Chlorinated paraffins	**CPs-1**	**61788-76-9**	**M**	**FR**	
Chlorinated paraffins	**CPs-2**	**63449-39-8**	**M**	**FR**	
Chlorinated paraffins	CPs-19	68920-70-7	M	FR	
Chlorinated paraffins	CPs-20	71011-12-6	M	FR	
Chlorinated paraffins	CPs-6	84082-38-2	M	FR	
Chlorinated paraffins	CPs-7	84776-06-7	M	FR	
Chlorinated paraffins	CPs-8	84776-07-8	M	FR	
Chlorinated paraffins	CPs-9	85049-26-9	M	FR	
Chlorinated paraffins	**CPs-3**	**85422-92-0**	**M**	**FR**	
Chlorinated paraffins	CPs-10	85535-84-8	M	FR	
Chlorinated paraffins	**CPs-4**	**85535-85-9**	**M**	**FR**	
Chlorinated paraffins	**CPs-5**	**85535-86-0**	**M**	**FR**	
Chlorinated paraffins	CPs-11	85536-22-7	M	FR	

Chlorinated paraffins	CPs-12	85681-73-8	M	FR	
Chlorinated paraffins	CPs-13	97553-43-0	M	FR	
Chlorinated paraffins	CPs-14	97659-46-6	M	FR	
Decabromo-1,1'-biphenyl	BB-209	13654-09-6	S	FR	C12Br10
Decabromodibenzyl ether	DBDBE	497107-13-8	S	FR	C14H4Br10O
Decabromodiphenyl ethane	**DBDPE**	**84852-53-9**	**S**	**FR**	**C14H4Br10**
Decabromodiphenyl ether	**BDE-209**	**1163-19-5**	**S**	**FR**	**C12Br10O**
Dibromoneopentyl glycol	DBNPG	3296-90-0	S	FR	C5H10Br2O2
Dibromostyrene	DBrS	31780-26-4	S	FR	C8H6Br2
Dibutyl 1,4,5,6,7,7-hexachlorobicyclo[2.2.1]-hept-5-ene-2,3-dicarboxylate	DiBChl	1770-80-5	S	FR	C17H20Cl6O4
Dibutyl phenyl phosphate	DBPhP	2528-36-1	S	FR	C14H23O4P
Diethyl phosphate (mono/di)	mDEP/dDEP	598-02-7	S	FR	C4H11O4P
Diethylphosphinic acid	DEPA	813-76-3	S	FR	C4H11O2P
Dimethyl phosphate	DMPA	813-78-5	S	FR	C2H7O4P
Dioctyl phenyl phosphate	DOPP	6161-81-5	S	FR	C22H39O4P
Diphenyl 4-tolyl phosphate	DPCP	78-31-9	S	FR	C19H17O4P
Diphenylcresylphosphate	**DCP**	**26444-49-5**	**M**	**FR**	
Dodecachlorodimethanodibenzocyclooctane	DDC-CO	13560-89-9	S	FR	C18H12Cl12
Ethylene dimelamine			S	FR	
Halowax 1000		58718-66-4	M	FR	
Halowax 1013		1321-64-8	M	FR	
Halowax 1099		39450-05-0	M	FR	
Hexabromo-1,1'-biphenyl, mixture of isomers		36355-01-8	M	FR	
Hexabromo-1,1'-biphenyl; 2,2',3,3',4,4'-Hexabromo-1,1'-biphenyl	BB-128	82865-89-2	S	FR	C12H4Br6

Hexabromobenzene	HBB	87-82-1	S	FR	C6Br6
Hexabromocyclodecane	HBCYD	25495-98-1	S	FR	C10H14Br6
Hexabromocyclododecane	**HBCDD**	**3194-55-6**	**S**	**FR**	**C12H18Br6**
Hexachlorocyclopentadiene	HCCPD	77-47-4	S	FR	C5Cl6
Hexamethylene dimelamine			M	FR	
Isodecyl diphenyl phosphate	**IDP**	**29761-21-5**	**S**	**FR**	**C22H31O4P**
Isopropyl phenyl phosphate	IPPP	46355-07-1	S	FR	C9H13O4P
Isopropylphenyl diphenyl phosphate	IPDPP	28108-99-8	S	FR	C21H21O4P
Melamine	**Melamine**	**108-78-1**	**S**	**FR**	**C3H6N6**
Melamine cyanurate	**Melamine-C**	**37640-57-6**	**M**	**FR**	
Melamine phosphate	Melamine-P	41583-09-9	M	FR	
Melamine pyrophosphate	Melamine-PP	15541-60-3	M	FR	
Methyl-2,3,4,5-tetrabromobenzoate	MeTBBA		S	FR	
Methylene diguanamine			S	FR	
m-terphenyl		92-06-8	S	FR	C18H14
m-Tetradecachloroterphenyl		42429-89-0	S	FR	C18Cl14
N,N'-Ethylenebis(tetrabromophthalimide)	EBTEBPI	32588-76-4	S	FR	C18H4Br8N2O4
Nonabromo-1,1'-biphenyl	PBB-207	27753-52-2	M	FR	
Norbornene diguanamine			S	FR	
Octabromotrimethylphenyl indane	OBTMPI	1084889-51-9	S	FR	C18H12Br8
Octabromotrimethylphenyl indane	OBTrMePhIn	893843-07-7	M	FR	
Octyl diphenyl phosphate	ODPP	115-88-8	S	FR	C20H27O4P
o-terphenyl		84-15-1	S	FR	C18H14
o-Tetradecachloroterphenyl		42429-88-9	S	FR	C18Cl14

Pentabromobenzyl acrylate	PBB-Acr	59447-55-1	S	FR	C10H5Br5O2
Pentabromobenzyl bromide	PBBB	38521-51-6	S	FR	C7H2Br6
Pentabromobenzyl chloride	PBBC	58495-09-3	S	FR	C7H2Br5Cl
Pentabromochlororcyclohexane	PBCH	87-84-3	S	FR	C6H6Br5Cl
Pentabromoethylbenzene	PBEB	85-22-3	S	FR	C8H5Br5
Pentabromophenol	PBP	608-71-9	S	FR	C6HBr5O
Pentabromophenol allyl ether	PBP-AE	3555-11-1	S	FR	C9H5Br5O
Pentabromotoluene	PBT	87-83-2	S	FR	C7H3Br5
Pentaerythritol	**PETP**	**115-77-5**	**S**	**FR**	**C5H12O4**
Phthalodiguanamine		5118-79-6	S	FR	C12H12N10
Piperazine (poly)phosphate		1951-97-9	M	FR	
Piperazine pyrophosphate		66034-17-1	M	FR	
p-terphenyl		92-94-4	S	FR	C18H14
p-Tetradecachloroterphenyl		31710-32-4	S	FR	C18Cl14
Resorcinol bis(diphenyl phosphate)	PBDPP	57583-54-7	S	FR	C30H24O8P2
Resorcinol bis[di(2,6dimethylphenyl) phosphate]	PBDMPP	139189-30-3	S	FR	C38H40O8P2
t-Butylphenyl diphenyl phosphate		83242-23-3	S	FR	C22H23O4P
Technical octaBDE	OctaBDE	32536-52-0	M	FR	
Technical pentaBDE	PentaBDE	32534-81-9	M	FR	
Tetrabromo(tetrebromophenyl) benzene	octaPBB	27858-07-7	M	FR	
Tetrabromobisphenol A	**TBBPA**	**79-94-7**	**S**	**FR**	**C15H12Br4O2**
Tetrabromobisphenol A bis(2,3-dibromopropyl) ether	**TBBPA-BDBPE**	**21850-44-2**	**S**	**FR**	**C21H20Br8O2**
Tetrabromobisphenol A bis(2-hydroxyethyl) ether	TBBPA-BHEE	4162-45-2	S	FR	C19H20Br4O4
Tetrabromobisphenol A bis(2-hydroxyethyl)ether bisacrylate	TBBPA-BHEEBA	66710-97-2	S	FR	C25H24Br4O6

Tetrabromobisphenol A bis(allyl) ether	TBBPA-BAE	25327-89-3	S	FR	C21H20Br4O2
Tetrabromobisphenol A bis(glycidyl) ether	TBBPA-BGE	3072-84-2	S	FR	C21H20Br4O4
Tetrabromobisphenol A bisacrylate	TBBPA-BA	55205-38-4	S	FR	C21H16Br4O4
Tetrabromobisphenol A bismethyl ether	TBBPA-BME	37853-61-5	S	FR	C17H16Br4O2
Tetrabromobisphenol A bispropanoate	TBBPA-BP	37419-42-4	S	FR	
Tetrabromobisphenol S bis(2,3-dibromopropyl ether)	TBBPS-DBPE	42757-55-1	S	FR	C18H14Br8O4S
Tetrabromobisphenol S bismethyl ether	TBBPS-BME	70156-79-5	S	FR	C14H10Br4O4S
Tetrabromobisphenol S	TBBPS	39635-79-5	S	FR	C12H6Br4O4S
Tetrachlorobisphenol A	TCBPA	27360-90-3	S	FR	C15H12Cl4O2
Tetrachlorphthalic anhydride	TECP-Anh	117-08-8	S	FR	C8Cl4O3
Tetradecabromo-,4-diphenoxybenzene	4-PeBPOBDE208	58965-66-5	S	FR	C18Br14O2
Tetraethyl(ethylene)diphosphonate	TEEdP	995-32-4	S	FR	C10H24O6P2
Tetramethylene dimelamine		61-73-4	M	FR	C16H18ClN3S
Tri(2-Isopropylphenyl) phosphate	TIPPP-2	64532-95-2	S	FR	C27H33O4P
Tribromoneopentylalcohol	TBNPA	1522-92-5	S	FR	C5H9Br3O
Trihexyl phosphate	THP	2528-39-4	S	FR	C18H39O4P
Triisopropyl phosphate	TiPP	513-02-0	S	FR	C9H21O4P
Tri-m-cresylphosphate	m-TCP	563-04-2	S	FR	C21H21O4P
Trimethylene dimelamine			S	FR	
Tri-o-creylphosphate	o-TCP	78-30-8	S	FR	C21H21O4P
Tri-p-cresylphosphate	**p-TCP**	**78-32-0**	**S**	**FR**	**C21H21O4P**
Tripentyl phosphate	TPeP	2528-38-3	S	FR	C15H33O4P
Triphenylphosphine oxide	TPPO	791-28-6	S	FR	C18H15OP
Tris(1,3-dichloroisopropyl) phosphate	TDCIPP	13674-87-8	S	FR	C9H15Cl6O4P

Tris(2,3-dibromopropyl) phosphate	TDBPP	126-72-7	S	FR	C9H15Br6O4P
Tris(2,3-dichloroisopropyl) phosphate	TDCPP	78-43-3	S	FR	C9H15Cl6O4P
Tris(2,4,6-tribromophenoxy)-s-triazine	TTBP-TAZ	25713-60-4	S	FR	C21H6Br9N3O3
Tris(2-butoxyethyl) phosphate	**TBOEP**	**78-51-3**	**S**	**FR**	**C18H39O7P**
Tris(2-chloroethyl) phosphite	TCEPi	140-08-9	S	FR	C6H12Cl3O3P
Tris(2-chloroisopropyl) phosphate	**TCIPP**	**13674-84-5**	**S**	**FR**	**C9H18Cl3O4P**
Tris(2-Chloropropyl)phosphate	TMCPP	6145-73-9	S	FR	C9H18Cl3O4P
Tris(2-ethylhexyl) phosphate	**TEHP**	**78-42-2**	**S**	**FR**	**C24H51O4P**
Tris(3-Chloropropyl)phosphate	TCPP	1067-98-7	S	FR	C9H18Cl3O4P
Tris(4-isopropylphenyl) phosphate	TIPPP-4	2502-15-0	S	FR	C27H33O4P
Tris(4-tert-butylphenyl) phosphate	TBPP	78-33-1	S	FR	C30H39O4P
Tris(butyl) phosphate	TNBP	126-73-8	S	FR	C12H27O4P
Tris(chloroethyl) phosphate	TCEP	115-96-8	S	FR	C6H12Cl3O4P
Tris(ethyl) phosphate	**TEP**	**78-40-0**	**S**	**FR**	**C6H15O4P**
Tris(isobutyl) phosphate	**TIBP**	**126-71-6**	**S**	**FR**	**C12H27O4P**
Tris-(isopropylphenyl) phosphate, mixture of isomers		26967-76-0	M	FR	
Tris(methyl) phosphate	TMP	512-56-1	S	FR	C3H9O4P
Tris(methylphenyl) phosphate, mixture of isomers	**TMPP**	**1330-78-5**	**M**	**FR**	
Tris(phenyl) phosphate	**TPHP**	**115-86-6**	**S**	**FR**	**C18H15O4P**
Tris(propyl) phosphate	TPP	513-08-6	S	FR	C9H21O4P
Tris(tribromoneopentyl) phosphate	TTBNPP	19186-97-1	S	FR	C15H24Br9O4P
Trixylenyl phosphate	**TXP**	**25155-23-1**	**M**	**FR**	
Xylenyl diphenyl phosphate	XDP	25155-24-2	S	FR	C20H19O4P

APPENDIX 2

Complete list of the main categories (two digit number), subcategories (three digit number) and product line codes (five digit number) for building materials investigated in this report.

Category	Sub category	Product line codes
01 - Building material	010 - Binding agents and mortars	01001 - Cement 01099 - Binders and mortars in general
	011 - Building blocks and aggregates	01101 - Concrete blocks 01108 – Concrete pipes, earthenware pipes and moulds/forms 01199 Building blocks and aggregate in general
	012 - Sheet materials	01208 – Chipboard 01210 - Panelling and lining boards 01212 - Gypsum wall boards 01299 - Sheet materials in general
	013 - Insulation materials	01301 - Mineral (rock) wool 01302 - Expanded foamed plastic 01303 - Expanded foamed plastic, extruded 01305 - Foam plastic 01399 - Insulation materials in general
	014 - Weatherproofing systems, tape and sealing strip	01405 - Water bar 01406 - Plastic film 01407 - Tapes 01408 - Sealing strip 01409 - Weatherproofing systems 01499 - Weatherproofing systems, tape and sealing strip in general
	015 - Reinforcement, steel and metal goods	01504 - Girders 01505 - Sheet metal 01510 - Metals 01511 - Thin-steel sections 01599 - Reinforcement, steel and metal goods in general
	016 - Roof and wall cladding	01601 - Roof tiles, concrete 01602 – Roofing sheet 01699 - Roof and wall cladding in general
	017 - Chemico-technical goods	01701 – Concrete additives 01702 - Adhesive 01703 - Jointing mastic 01704 - Asphalt and sealants 01705 - Putty and filler 01706 - Oils and grease 01799 - Chemico-technical goods in general
	018 - Subfloor system	01899 - Subfloor system in general
	019 - Home remodelling	01901 – Rainwater system 01903 - Sun shading 01905 – Rubbish, inspection, cleaning and smoke lids/hatches/covers 01999 – Home remodeling in general
03 - Fit-out materials and paint	030 - Ceramic goods	03002 - Adhesives, joint sealants and accessories
	031 - Flooring articles	03103 - Laminate flooring

		03104 - Plastic flooring 03106 - Textile flooring 03107 - Flooring materials in general 03108 - Skirting boards 03109 - Entrance matting 03199 - Flooring articles in general
	032 - Wallpapers	03201 - Wallpapers 03202 - Wetroom wall coverage
	033 - Ceiling and wall systems	03399 - Ceiling and wall systems in general
	034 - Paint goods	03401 - Primers, outdoors 03402 - House paint, outdoors 03403 – Roofing paint, outdoors 03404 - Wall and ceiling paints, indoors 03405 - Wood paint, indoors 03406 - Floor paint, oil, lye and soap 03407 - Oils and wood preservation 03408 - Other paint 03409 - Chemico-technical paint accessories 03499 - Paint goods in general
04 - Interior decor and joinery articles	040 - Doors	04001 - Outer doors 04002 - Garage doors 04003 - Lightweight residential doors 04005 - Special-purpose doors 04099 - Doors in general
	041 - Windows and glass goods	04199 - Windows and glass goods
	042 - Kitchen fixtures	04201 - Kitchen joinery 04202 - Worktops
	043 - Bathroom fixtures	04399 - Bathroom fixtures in general
	044 - Room fitting-out	04499 - Room fitting-out in general
	045 - Storage	04502 - Shelving systems 04599 - Storage in general
05 - Fasteners	051 – Screws	05112 - Anchor screws
	052 - Bolt articles, nuts and washers	05201 - Hexagon screws
	054 - Securing and expanders	05404 - Chemical anchors for embedment
06 - Ironmongery	060 - Locks and handles	06001 - Locks and accessories 06004 - Door handles and accessories
	061 - Ironmongery	06103 - Curtain articles and sun shading 06104 - Hat and coat racks, hooks and brackets
07 - Safety	070 - Safety	07001 - Alarms 07003 - Fire safety 07099 - Safety in general
08 - Gardens	082 - Tools and implements	08204 - Construction trolleys and wheelbarrows
10 - Structural components	100 - Structural components	10006 - Roof components
11 - Household articles	110 - Kitchen equipment	11099 - Kitchen equipment in general
	112 - Furniture	11201 - Sofas and settees 11202 - Armchairs 11204 - Chairs with fabric seats 11205 - Chairs with wooden seats

		11208 - Benches 11213 - Storage units 11216 – Shelves 11217 – Dining tables 11221 – Rugs 11299 - Furniture in general
	114 - Cleaning articles	11402 - Cleaners and detergents 11499 – Cleaning articles in general
13 - Hobby, sport and leisure	130 - Games and play	13099 - Games and play in general
14 - Hand tools	145 - Instruments	14501 - Measuring instruments
18 - Electrical goods	180 - White goods	18002 - Kitchen fans
	181 - Electrical appliances	18104 - Home electronics
	182 - Lighting articles	18201 - Indoor lighting 18202 - Outdoor lighting 18204 - Work place lighting 18299 - Lighting articles in general
	183 - Electrical wiring material	18301 - Cabling 18303 - Hand lamps, torches, bulbs and fluorescent strip lights 18304 – Distribution boards 18306 - Batteries, battery chargers, transformers 18307 - Electrical materials in general 18399 - Electrical wiring materials in general
20 - Heating and plumbing	200 - Heating	20003 Expansion tanks and systems 20005 - Single-residence boilers and heat-exchangers 20010 – Solar collector systems
	201 - Plumbing	20101 - Bathtubs 20103 - Sanitary ware, lavatory pans 20105 - Shower cubicles and partitions 20106 – Sink units and draining boards 20198 – Plumbing accessories
	202 - Groundworks	20201 - Buried drains 20202 - Pressure discharge pipes 20203 - Water supply and sewerage fittings 20204 - Nodular iron pipes 20211 - Geotextiles and groundwork products 20213 - Tanks, traps and separators 20299 - Groundworks in general
	203 - Hoses and hose fittings	20301 - Plastic hoses 20399 - Hoses and hose fittings in general
	205 - Installation systems	20506 – Waterborne underfloor heating 20509 - Sound-proofed indoor sewage system 20513 - HVAC pipe suspension 20599 – Installation systems in general
	207 - Fittings	20799 - Fittings in general
21 - Ventilation	210 - Ventilation	21001 - Valves 21002 - Ducting systems 21003 - Units and assemblies 21004 - Air terminal devices 21005 – Fans and ventilators 21099 - Ventilation in general
	240 - Heating	24001 - Electric heating

24 - Climate and air-conditioning		24002 - Underfloor heating 24099 - Heating in general
	241 - Air	24101 - Air-conditioning systems