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# Indoor pollutants emitted by office equipment: A review of reported data and information needs

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**Abstract**

There is concern that potentially harmful pollutants may be emitted from office equipment. Although office equipment has been a focal point for governmental efforts to promote energy efficiency through programs such as the US EPA's *Energy Star*, little is known about the relationship between office equipment use and indoor air quality, and information on pollutant emissions is sparse. In this review, we summarize available information on emission rates and/or ambient concentrations of various pollutants that are related to office equipment use. Experimental methods used in the characterization of emissions are briefly described. The office equipment evaluated in this review includes computers (desktops and notebooks), printers (laser, ink-jet and all-in-one machines) and photocopy machines. Reported emission rates of the following pollutant groups are summarized: volatile organic chemicals (VOCs), ozone, particulate matter and several semivolatile organic chemicals (SVOCs). The latter include phthalate esters, brominated flame retardants, organophosphate flame retardants and polycyclic aromatic hydrocarbons (PAHs). We also review studies reporting airborne concentrations in indoor environments where office equipment was present and thought to be a significant contributor to the total pollutant burden (offices, residences, schools, electronics recycling plants). For certain pollutants, such as organophosphate flame retardants, the link between emission by office equipment and indoor air concentrations is relatively well established. However, indoor VOCs, ozone, PAHs and phthalate esters can originate from a variety of sources, and their source apportionment is less straightforward. This literature review identifies substances of toxicological significance, with the purpose of serving as a guide to evaluate their potential importance with respect to human exposures.

**Keywords:** VOCs, SVOCs, ozone, indoor particulate matter, indoor pollutants, flame retardants. (Note: some terms not included above: Polybrominated diphenyl ethers (PBDEs); printer; personal computer.

## 1. Introduction

The last few decades have seen major changes in the work environment. The economies of the US and other industrialized nations have undergone profound transformations, with their bases shifting from manufacturing towards services in which information technologies are central. This means fewer people spend their workdays in factories and conversely a higher proportion can be found in offices. Revolutionary developments in information technology have increased the quantity and transformed the nature of equipment to be found in proximity to office workers. Tabletop printers serve individual users in their workspace, or clusters of users in an office suite. Fax machines and photocopiers are prevalent in office environments. It is now common for each person's workspace to contain a desktop computer and a display unit. Office equipment is also prevalent in home environments. By 2000 more than half of U.S. households had at least one computer (Newburger E.C., 2001). In addition, the use of notebook computers spanning both work and non-work environments is on the rise.

There is concern that potentially harmful pollutants may be emitted from office equipment. As summarized below, office equipment has been found to be a source of ozone, particles, volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs). Among the chemicals emitted by office equipment are VOCs and SVOCs that have been associated with occupational symptoms such as eye, nose or throat irritation, headache and fatigue (Mendell et al. 2002; Wolkoff et al. 2006).

The widespread and growing use of office equipment by a large fraction of the population in their workplaces, homes, and schools and the incomplete and fragmented evidence of this equipment as a source of health-relevant indoor air pollutants provide compelling arguments for a systematic evaluation of pollutant emissions. Since distributed desktop computers and associated displays are in close proximity to people, research on pollutant emissions from office equipment logically should emphasize distributed equipment rather than large central units.

## 2. Overview of existing studies

In this section we provide a brief overview of pollutant emissions that have been reported from various types of office productivity devices. Laser printers and photocopiers generate ozone in varying amounts (Smola et al, 2002; Lee et al, 2001; Leovic et al, 1996; Leovic et al, 1998). Toner and paper dust from printing devices become airborne resulting in the generation of respirable particles, including ultrafine aerosol particles (Wensing et al, 2006, Lee et al, 2001). Printers and photocopiers also are sources of volatile organic compounds (VOCs), which derive at least in part from the toner that undergoes heating during the printing process. VOCs identified in the emissions from printing and copying devices include chemicals listed on the State of California's Toxic Air Contaminants (TACs) list (OEHHA, 2000), such as benzene, toluene, ethylbenzene, xylenes, and styrene, formaldehyde and acetaldehyde (Lee et al, 2001; Leovic et al, 1996; Leovic et al, 1998). The plastic covers of video-display units (VDUs) have been shown to contain and emit triphenylphosphate and other organophosphate esters used as flame retardants (Carlsson et al. 2000). Electronic devices including office equipment contain and emit a number of brominated flame retardants such as the polybrominated diphenyl ethers (PBDEs), among other identified semi-volatile organic compounds (SVOCs). Printed circuit boards held at elevated temperature (60° C) were shown to emit several PBDEs (Kemmlein et al. 2003). Production and use of PBDE formulations has been phased-out in Europe, and Japanese industries have voluntarily restricted the production and use of polybrominated biphenyls (PBBs), hexabromodiphenyl ether and tetrabromodiphenyl ether (Kemmlein et al. 2003b). However, use of recycled plastics containing high residual PBDE levels may re-introduce these chemicals in the manufacture of new units even after governmental regulations or voluntary restrictions are in place (Morf et al. 2005).

We report here exclusively data published in peer reviewed journal articles, as well as a recent conference proceedings that properly identify emission sources.

## 3. Experimental methods used in emission characterization

Characterizing emissions from office equipment can be difficult due to the diversity of available equipment; the rapid evolution and turnover of product lines; and the variability in environmental and operating conditions. Studies designed to investigate emissions of office equipment are therefore limited by necessity to a narrow spectrum of equipment, pollutants and operational conditions. For that reason, a large variability in reported emission levels is often observed.

### 3.1. Emission chambers

Direct determination of pollutant emissions by office equipment is typically carried out using controlled environmental chambers. In Table 1, we present an overview of chamber dimensions, materials and operation conditions that have been used to measure emissions from office equipment. In most cases, emissions from computers or printers are measured in glass or stainless steel chambers in the size range 1-35 $m^3$, operating at room temperature (21-23 $^oC$) and intermediate humidity conditions (45-55 %RH). To improve the comparability of results from emissions studies for electronic equipment, the European Computer Manufacturers Association (ECMA) recently developed detailed test procedures to measure VOCs, ozone and particulate matter along with algorithms to relate the measurements to emission rates (ECMA, 2006).

Standard chamber methods designed for measuring VOCs, ozone and particulate matter, may not be appropriate for SVOCs. Compounds with low vapor pressures will partition between air and surfaces in a chamber with potentially large fractions of mass transferred to surfaces. Evidence of this sink effect for PBDEs has been described by Kemmlein et al (2003) in a study where chamber concentrations of tri-, tetra- and penta-congeners emitted by a printed circuit board held at 60°C increased with time over a period of 50 or more days. In another experiment, the same authors found that heating the chamber following removal of the test specimen evolved a significant mass of sorbed PBDEs. This procedure was used to quantitatively recover sorbed SVOCs, thus overcoming chamber effects (Hoshino et al. 2003). In a similar experimental chamber study for the determination of phthalate esters released by PVC-coated wall coverings, Uhde et al., (2001) employed a cooled plate (fogging chamber) to collect and quantify the SVOCs that condensed on the chamber walls. During a 14-days test period, analyte

concentrations calculated from the masses collected on the cooled plate were in the same range as those determined in the air samples collected during the same period.

Modifications to the chamber or experimental conditions such as using Teflon surfaces, decreasing chamber surface to volume ratios, and decreasing contact times by increasing air change rates may reduce wall effects for SVOC emission rates. However, it is likely that the losses of some compounds to chamber surfaces still will be substantial. An alternate approach is to quantify sorption rates and partitioning for SVOCs interacting with chamber surfaces then use mass balance models to relate measured temporal concentration patterns in the chambers to device specific emission rates. This general technique has been demonstrated by Maddalena et al. (2002). Methods to determine SVOCs emission from surfaces using passive flux samplers have also been implemented for a variety of plastic materials (Fujii et al. 2003).

### 3.2. Equipment operation modes

Typically the experimental conditions used during emissions studies have multiple phases including off, idle, operating and sometimes power saving modes. For printing devices, the operating mode typically includes a printing cycle representative of a normal duty cycle for the unit being tested and for a specified period that is typically limited by the paper capacity. It is often recommended that the test be completed without opening the test chamber. For computers, the operating mode is poorly defined. Typically the unit is simply turned on (Nakagawa et al, 2003) or a series of keystrokes are used to simulate use (ECMA, 2006). These approaches do not necessarily access all the various sub-systems in the computer in a controlled and systematic way. Emission studies with computers often do not take advantage of existing software to specify and execute a representative duty cycle that stresses all components of the computing system.

### 3.3. Analytes and methods

In most applications, samples were collected during both operation and idle periods. Ozone was measured continuously with photometric monitors (Brown 1999). Particles were also continuously monitored using a $PM_{10}$ aerosol monitor (Brown 1999; Lee et al. 2001), or integrated by collection on preconditioned filters (Ecma, 2006).

Particle counts are collected using either optical particle counters or condensation particle counters and size resolution is determined with scanning mobility particle scanners (Seeger et al. 2006, Wensing et al., 2006; Uhde et al., 2006). Total VOCs were in some cases monitored continuously with a photoionization detector (Lee et al. 2001). In most cases, we report the sum of VOC concentrations determined as ΣVOC. All other samples were collected on various substrates that integrate emissions over a defined period. Speciation of organic analytes of interest was carried out subsequently by chromatography after sample preparation steps involving extraction and, in some cases, derivatization.

Volatile organic chemicals (VOCs) were typically collected on sorbent tubes filled with Tenax-TA® (Leovic et al. 1998; Nakagawa et al. 2003) or with Tenax-TA in combination with other sorbent material such as Ambersorb and charcoal (Brown 1999). Other VOC collection methods used a canister (Lee et al. 2001). In all cases, VOCs were identified and quantified by GC/MS. Volatile carbonyls were collected in DNPH-coated silica cartridges (Leovic et al. 1998; Nakagawa et al. 2003) or by direct absorption in an aqueous solutions with further derivatization (Brown 1999).

SVOCs were collected on sorbent matrices. After extraction the analytes were identified and quantified by GC/MS for most analytes. HPLC/DAD was used as an alternative technique for those analytes that were not amenable to GC analysis, such as bisphenol A bis(diphenylphosphate), BDP (Kemmlein et al. 2003). In a test where the whole chamber was heated to 200 $^{o}$C after the emissions ended and the specimen was removed, SVOCs were directly collected on Tenax and analyzed by GC/MS by thermal desorption (Hoshino et al. 2003). This simple method was possible to carry out with a notebook computer in a relatively small chamber, but is less practical for larger systems.

## 4. Characterization of emissions from office equipment

### 4.1 Emissions from desktop and notebook computers

VOCs emission rates from desktop and notebook computers are reported in Table 2. When available, chamber concentration data are also reported in the same Table. Emission rates are reported separately for computers operating with cathode-ray tube

(CRT) monitors and with thin-film transistor (TFT) monitors. Typically, the added VOC emissions (ΣVOC) were higher for computers with CRT than with TFT monitors. Reported VOC emissions include aromatic hydrocarbons and volatile carbonyls, particularly formaldehyde. Reported notebook VOC emission rates were significantly lower, both for idle and operating conditions. In that study, the chemical composition of emissions included alcohols, carboxylates and ketones. The number of studies is limited but generally the results indicate that a wide range of VOCs are emitted at rates between 100 and 200 $\mu g\ h^{-1}\ unit^{-1}$.

In Table 3, we report SVOC emission rates for a desktop computer in operation, together with chamber concentrations corresponding to the same study and for the notebook study. Organophosphorous flame retardants were measured during computer operation, but brominated flame retardants sorbed to the chamber walls and were only detected after computer operation by heating the chamber to 120 $^{o}$C and collection of an air sample during the heating period. Where calculated, the emission rates for the SVOCs are in the low ng $h^{-1}$ per computer range.

### 4.2 Emissions from printers and copiers

In Table 4 we present VOC, ozone and particulate matter ($PM_{10}$) chamber concentrations determined during idle and operation periods for laser printers, ink-jet printers and an all-in-one machine (which included fax, color printer, copier and scanner). Little quantitative information is available for size-resolved characterization of particulate matter emitted by office equipment. Wensing et al (2006) reported particle size distribution of aerosol emitted by ten different hardcopy devices (laser printers and multi-functional devices). Ultrafine particles (< 100 nm) predominated in every case: measured particle numbers were in the range 500 – 343,000 #/cm$^3$ for particles > 7nm, but significantly lower (6 – 38,000 #/cm$^3$) for particles > 100 nm.

Elevated levels of VOCs were highest from laser printers in all categories reported in Table 4, and, although the difference was generally small, operating units had higher levels than idle units. A relatively larger body of experimental data is available for emissions of VOCs and ozone from copier machines and this information is summarized

in Table 5. In general, the emissions from photocopiers are much higher than for printers and multifunctional devices but the variability among the studies is also high.

## 5. Ambient measurements of pollutants emitted from office equipment

Several studies reported ambient measurements of pollutants emitted by office equipment in the indoor environment. In many cases, the source of certain chemicals present in the air or in dust cannot be attributed exclusively to emissions from office equipment. However, the authors of the cited studies indicate computers, printers and/or copier machines as one possible source. The data are reported in Table 6 through Table 11, indicating the country or region of origin of the samples. This information is relevant considering that the formulation of additives such as plasticizers and flame retardants may vary due to different practices or regulations.

### 5.1. Volatile organic chemicals (VOCs)

In Table 6, we list VOCs reported in two studies as primarily emitted by office equipment. Several other VOCs listed in the studies (Wolkoff et al. 2006) were not included in Table 6 if originated in other sources, different from office equipment. Such is the case of VOCs derived from the use of cleaning products (terpenes or 2-butoxyethanol) and of ozone, which is usually present in indoor environments as a consequence of intrusion from outdoor air. In a study performed in three photocopy centers (Stefaniak et al. 2000), a large variability was observed across centers, with ambient concentrations differing by 2 or 3 orders of magnitude in some cases.

### 5.2. SVOCs: Phthalate esters

We report in Table 7 phthalate esters from two different studies carried out recently in the USA and Germany. Notably, four of the most common constituents of this class (DEP, DBP, BBP and DEHP) were present at relatively similar levels in both studies. However, other analytes were only reported in one of the studies. Phthalate esters are used as plasticizers in a wide variety of plastic and polymeric materials. For that reason, it is difficult to apportion the contribution of office equipment to the total pollutant measured in each case.

### 5.3. SVOCs: Brominated flame retardants (BFR)

In Table 8 we summarize concentrations of BFRs measured in home dust and in air from several indoor environments where occupational exposure to BFRs was expected to be high. Those included the dismantling hall of a recycling plant for electronic products, a plant for assembly of circuit boards, a teaching hall and an office with computers. We also report data for total PBDE measured in four houses and two laboratories in the US. The highest levels of BFRs were detected in the dismantling plant. By contrast, samples carried out in homes only detected BFRs associated with dust particles, but not in air samples although the sources of the BFRs in the house dust is not known.

### 5.4. SVOCs: Organophosphate flame retardants (OPFR)

Data for OPFR from five studies are reported in Table 9. These samples include residential and occupational indoor environments (including a recycling plant and an electronics store) where exposure to OPFR is likely to be dominated by office equipment. Some OPFR were present in all or almost all the samples considered: TBP, TCEP, TPP, TBEP and TEHP. However, each of these studies also identified OPFR that were unique for those samples, indicating also a large variability of possible sources and additive formulations. In one of the studies (Marklund et al. 2003), the analysis of surface wipes from a computer screen and cover showed high levels of these chemicals which clearly indicated that the computer is a potential source of the OPFR detected in the environments but the magnitude of this source is unknown.

### 5.5. SVOCs: Polycyclic aromatic hydrocarbons (PAHs)

In a recent study (Ren et al, 2006), the amount of dust released during operation of computers was found to be between 4.0 and 6.3 mg dust per day, suggesting a significant potential for exposure to chemicals associated with resuspended dust particles. PAHs were quantified in dust collected from the interior of computers at levels that were higher than those measured in outdoor air samples by a factor of up to 3. Notably, outdoor air samples included one measurement performed at an intersection with heavy traffic in the vicinity of the indoor sampling sites. Data corresponding to this study are

reported in Table 10. The level and composition of PAHs in computer dust was influenced by the indoor air burden of these pollutants, particularly when smoking was allowed. To better illustrate this effect, values corresponding to smoking and non-smoking rooms are presented separately in Table 10. In selected samples, simultaneous indoor air dust samples (not reported in Table 10) were also collected and compared with computer dust, showing a general tendency to higher PAH levels in computer dust. Furthermore, in some samples levels of four compounds (BbF, Chry, Flu, Phe) were significantly higher than in indoor dust. Since these compounds are present in outdoor air and can be emitted by various indoor sources, this study could not estimate the contribution of computer emissions, but it is suggested that a fraction of measured PAHs might have been emitted from the heated plastic materials, chips and other computer components.

### 5.6. Emerging indoor SVOCs: Perfluoroalkyl compounds (PFAs)

In Table 11 we summarize air concentrations of perfluoroalkyl sulfonamides measured in houses and laboratories. These chemicals are derived from perfluorinated surfactants that are widely used in a variety of applications that include coatings and surface treatment for electronic equipment. Potential health effects of these chemicals are relatively unknown, but their environmental persistence and their transformation into stable degradation products/metabolites such as perfluorooctane sulfonate (PFOS) is attracting increasing attention to this emerging class of indoor pollutants (Shoeib et al, 2004; Shoeib et al, 2005).

## 6. Implications

### 6.1. Public health implications

Pollutants emitted from office equipment can have potentially serious adverse health effects. Ozone emissions from office equipment have been studied in the context of understanding indoor ozone exposures (Wolkoff 1999). Inhalation exposure to toner dust has been implicated in case reports as causing respiratory impairment (Gallardo et al. 1994; Armbruster et al. 1996). Acetaldehyde and a number of the volatile aromatic

hydrocarbons emitted by printers and photocopiers are Category IIa Toxic Air Contaminants (TACs), with one or more health values under development by the California Office of Environmental Health Hazard Assessment (OEHHA). Formaldehyde, acetaldehyde and benzene are carcinogens listed by the Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65) with relatively low No Significant Risk Levels (NSRLs). Formaldehyde and acetaldehyde also have low (i.e., <10 $\mu g\ m^{-3}$) chronic Reference Exposures Levels (RELs) for noncancer effects. Formaldehyde was recently listed by IARC as a Group I (proven) carcinogen (Cogliano et al, 2005). In California, its NSRL for cancer is a 70-year intake rate of 40 mg $day^{-1}$ (OEHHA, 2005); its non-cancer RELs are 68 ppb for acute (1 h) and 2.2 ppb for chronic (10 yr or more) exposures (OEHHA, 2000), and an interim 8-h REL of 27 ppb was based on the acute value (CARB, 2005). Triphenyl phosphate is an inhibitor of human blood monocyte carboxylesterase, has shown hemolytic toxicity, and has contact allergenic effects in humans (see references in Carlsson et al., 2000). PBDEs, which are classified as endocrine-disrupting compounds (Rudel et al. 2003), have been shown to accumulate in human breast milk (Noren and Meironyte 2000). Recent evidence suggests that increased contact with office equipment leads to higher doses and tissue levels of these pollutants. Thirteen PBDE congeners and tetrbromobisphenol-A were quantified in serum collected from computer technicians at levels that were significantly higher than those measured in control samples corresponding to other occupational exposures (Jakobsson et al. 2002).

Other adverse human consequences also may be attributed to office equipment. A study of sick building syndrome (SBS) among office workers in Copenhagen, Denmark, revealed a positive association between SBS symptoms and office equipment (Skov et al. 1989). In this study, significant involvement in either photocopying or the use of a video display terminal was positively associated with symptom prevalence for work-related mucosal irritation and work-related general symptoms. The Helsinki Office Environment Study, conducted in 1991, assessed symptoms and associated factors among 2,700 office workers in 41 buildings (Jaakkola and Jaakkola 1999). These researchers found that "photocopying was related to nasal irritation, and video display terminal work to eye symptoms, headache, and lethargy." Such symptoms may be a consequence of factors

other than, or in addition to air pollutant emissions. However, a recent panel study, which isolated the effect of pollutant exposure from other factors, found that exposure to emissions from new computers caused degradation in perceived air quality, some increase in SBS symptoms, and decreased performance of office work (Bakó-Biró et al. 2004). On that study, personal computers were found to be strong indoor pollution sources, even after they had been in service for 3 months. The presence of new PCs increased the percentage of people dissatisfied with the perceived air quality from 13 to 41% and increased by 9% the time required for text processing. The most significant VOCs reported in that study included phenol, toluene, 2-ethylhexanol, formaldehyde, and styrene.

### 6.2. Economic implications

Indoor air pollutants emitted by office equipment can affect work performance and productivity. In the USA, asthma and allergies affect 6% and 20% respectively of the 89 millions workers in nonagricultural, nonindustrial indoor settings. More than 20% also report nonspecific acute effects of indoor work exposures or conditions –SBS – including irritation symptoms, headache and fatigue with a frequency higher than weekly. The estimated productivity losses due to building-related symptoms are substantial, between 20 and 70 $B yr-1 (Mendell et al. 2002). Identification of chemical sources that induce or exacerbate these health effects is complicated by the combined presence of various possible sources in the office environment.

Other critical economic implications involve the impacts of office equipment in building energy use, including two different aspects: the energy efficiency of individual units and additional energy requirements to compensate for heat gain and/or remove indoor pollutants by increased ventilation rates. In the first case, office equipment has been a focal point for governmental efforts to promote energy efficiency through programs such as *Energy Star*. This is because energy use associated with office equipment is substantial, currently estimated at 3% of all electric power use in the U.S. (http://enduse.lbl.gov/Projects/InfoTech.html). Kawamoto et al (2000) estimated that the total energy use for office equipment in the U.S. in 1999 was 71 terawatt-hours (TWh), with the largest categories being desktop computers (20%), displays (20%),

minicomputers (17%), copiers (11%), mainframe computers (9%), and laser printers (9%). This breakdown reflects the trend of desktop computers accounting for an increasing share of computing resources in modern offices.

Emission of airborne pollutants by office equipment also requires additional ventilation, thus increasing the overall building energy consumption. Data from developed countries show that 30-50% of primary energy is consumed in non-industrial buildings (residences, offices, schools, hospitals, etc), representing an energy demand comparable to the transport sector and larger than the industrial consumption. Nearly half of building energy is dissipated through air exchange, and additional losses are estimated from the operation of mechanical ventilation systems (Liddament and Orme 1998). For that reason, improving the energy efficiency of buildings and residences is an effective way of reducing the environmental footprint of urban development. Those energy savings should be compatible with preserving indoor air quality and the health and comfort of building occupants. By avoiding the need for increased ventilation, reduction of pollutant emissions from office equipment can have important indirect energy benefits in addition to the benefits derived from energy-savings features.

## 7. Summary

Computers studied to date have been found to emit VOCs, but are not a source of ozone or particulate matter although re-emission of ambient particulate matter deposited in the units has been demonstrated. Considering SVOC emissions, a limited number of estimated emission factors are available, showing for brominated and organophosphate flame retardant compounds levels in the ng per hour range. However, these compounds are found indoors and computers are suspected as possible sources. In most studies, the operating mode of computers is poorly defined. Work is needed to develop more realistic standard operational modes, and these modes should be reported along with emissions data.

Emissions of VOCs from printers and copiers are higher than for desktop computers particularly for certain compounds (styrene, toluene, xylene, other alkylbenzenes). The contribution from printers to indoor ozone levels is unclear.

Significant levels of particulate matter are generally found during operation of printers, copiers and multifunctional devices. Better physical and chemical characterization of aerosol particle emissions during the printing process, particularly those involving nanoparticles, is required to better assess exposure to potentially harmful or irritant indoor aerosols.

Contribution of emissions by computers and other office equipment to the indoor burden of PAHs has been suggested in one recent study (Ren et al, 2006), and deserves further investigation. The possible role of aerosol and dust particles as a vehicle for the emissions of semivolatile compounds from office equipment is also an interesting aspect that deserves investigation. Future studies should also isolate and quantify phthalate emissions from office equipment independent from background indoor levels.

Considering the diversity of the available equipment, the rapid evolution and turnover of product lines and the variability in operating conditions, the values reviewed and summarized in this study should only be seen as guidelines to estimate emissions and indoor levels of the reported pollutants. Some of the reported emission rates of air pollutants from office equipment may be relatively low in comparison to other known and ubiquitous sources such as building materials. However, office machines are potentially important sources of human exposure due to their very close proximity to people who use the devices both at home and in offices. This proximity can result in higher personal exposures than would be estimated from pollutant concentrations measured in well-mixed building air (McBride et al. 1999). Besides, even low levels of ozone emitted by printers and copier machines can combine with other commonly present indoor VOCs, triggering the formation of harmful secondary pollutants and ultrafine aerosol particles (Destaillats et al, 2006a; Singer et al, 2006; Destaillats et al, 2006b).

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commercial office equipment or their use in connection with the material reported herein is not to be construed as actual or implied endorsement of such products. All work at LBNL was conducted under U.S.DOE Contract No. XXX. We thank Prof. W.W. Nazaroff (UC Berkeley) for his contributions during the early stages of this work, and XXX, YYY, ZZZ for their review comments on a draft version of the manuscript.

**Glossary of terms, abbreviations and symbols**

General abbreviations

| | |
|---|---|
| BFR | Brominated flame retardants |
| GCMS | Gas chromatography – Mass spectrometry |
| HPLC | High performance liquid chromatography |
| NSRL | No significant risk level |
| OEHHA | Office of Environmental Health Hazard Assessment (California) |
| OPFR | Organophosphate flame retardants |
| PAH | Polycyclic aromatic hydrocarbon |
| PBDE | Polybrominated diphenylether |
| PM | Particulate matter |
| REL | Reference exposure level |
| SBS | Sick building syndrom |
| SVOC | Semivolatile organic chemicals |
| TAC | Toxic air contaminant |
| TVOC | Total volatile organic chemicals |
| US EPA | United States Environmental Protection Agency |
| VOC | Volatile organic chemicals |

Brominated Flame Retardants

| | |
|---|---|
| BB 1-209 | Brominated biphenyl congeners 1-209 |
| BDE 1-209 | Brominated diphenyl ether congeners 1-209 |
| BTBPE | 1,2-Bis(2,4,6-tribromophenoxy)ethane |

| | |
|---|---|
| TBBPA | Tetrabromo bisphenol A |

Organophosphate Flame Retardants

| | |
|---|---|
| BDP | Bisphenol A bis(diphenylphosphate) |
| DOPP | Di-*n*-octylphenyl phosphate |
| IPPDPP | Isopropylphenyl diphenyl phosphate |
| PPDPP:1-2 | Propylphenyl diphenyl phosphate |
| RDP | Resorcinol-bis-biphenyl phosphate |
| TBEP | Tris(2-butoxyethyl) phosphate |
| TBPDPP | *tert*-Butylphenyl diphenyl phosphate |
| TBP | Tributyl phosphate |
| TCEP | Tris(2-chloroethyl) phosphate |
| TCP | Tricresyl phosphate |
| TCPP:1-3 | Tris(chloropropyl) phosphate |
| TDCPP | Tris(1,3-dichloro-2-propyl) phosphate |
| TEEdP | Tetraethyl ethylene-diphosphonate |
| TEHP | Tris(2-ethylhexyl) phosphate |
| TNBP | Tri(n-butyl) phosphate |
| TPP | Triphenyl phosphate |

Phthalate Esters

| | |
|---|---|
| BBP | Butyl benzyl phthalate |
| BEHA | Bis(2-ethylhexyl) adipate |
| DBP | Di-*n*-butyl phthalate |
| DCHP | Dicyclohexyl phthalate |
| DEHP | Di(2-ethylhexyl) phthalate |
| DEP | Diethyl phthalate |
| DIP | Diisobutyl phthalate |
| DMP | Dimethyl phthalate |
| DMPP | Dimethylpropyl phtalate |
| DPP | Dipropyl phtalate |

Polycyclic Aromatic Hydrocarbons

| | |
|---|---|
| Nap | Naphthalene |
| Acy | Acenaphthylene |
| Ace | Acenaphthene |
| Flo | Fluorene |
| Phe | Phenanthrene |
| Ant | Anthracene |
| Flu | Fluoranthene |
| Pyr | Pyrene |
| BaA | Benzo[a]anthracene |
| Chry | Chrysene |
| BbF | Benzo[b]fluoranthene |
| BkF | Benzo[k]fluoranthene |
| BaP | Benzo[a]pyrene |
| DbA | Dibenz[a,h]anthracene |
| InP | Indeno[1,2,3-cd]pyrene |
| BgP | Benzo[g,h,i]perylene |

Perfluoroalkyl sulfonamides

| | |
|---|---|
| MeFOSE | *N*-methyl perfluorooctane sulfonamidoethanol |
| EtFOSE | *N*-ethyl perfluorooctane sulfonamidoethanol |
| MeFOSEA | *N*-methyl perfluorooctane sulfonamido ethylacrylate |
| EtFOSA | *N*-ethyl perfluorooctane sulfonamide |

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***Table 1: Exposure chamber conditions reported in various studies.***

| Dimensions ($m^3$) | Internal surfaces | Temp, RH | Equipment analyzed | Pollutants detected | Reference |
|---|---|---|---|---|---|
| Not indicated | Stainless steel, glass, aluminium | 23 ± 2 oC<br>50 ± 5 % RH | electronic equipment | VOC, ozone, PM | ECMA, 2006 |
| 0.02 and 0.001 | glass | 23 – 60 $^oC$<br>50 – 8 % RH | printed circuit boards | SVOCs | Kemmlein et al, 2003 |
| 6.5 $10^{-3}$ | glass | 35–200 $^oC$ [a]<br>50 ± 5 % RH | notebook computer | VOC<br>SVOC | Hoshino et al, 2003 |
| 1 | stainless steel | 23 ± 1 $^oC$<br>50 ± 3 % RH | computers | SVOCs | Kemmlein et al, 2003 |
| 1 | glass | 22 $^oC$ | computers | VOC<br>carbonyls | Nakagawa et al, 2003 |
| 2.4 | stainless steel | 23 ± 2 $^oC$<br>55 ± 5 % RH | copier<br>printer<br>all-in-one | VOCs, ozone, carbonyls, particles | Lee et al, 2001 |
| 12 | stainless steel and glass | 23 ± 2 $^oC$<br>50 % RH | printers | VOCs, ozone<br>particles | Heimann and Nies, 2001; Smola et al, 2002 |
| 23 and 35 | aluminum, stainless steel. | 26-31 $^oC$<br>30-35 % | copiers | VOCs, ozone, carbonyls,particles | Leovic et al, 1996; Leovic et al, 1998 |
| 33 | stainless steel | 23 ± 0.5 $^oC$<br>50 ± 5 % RH | copiers | VOC<br>particles | Brown, 1999 |

***a:*** Temperatures correspond to different operation (ambient T) and desorption (high T) phases.

***Table 2: Volatile organic chemicals (VOCs) and ozone emitted during operation of personal computers***

| **Chemical** | **Desktop PCs – CRT monitor** [a,b] | | **Desktop PCs – TFT monitor** [b] | **Notebook computers** [c] | |
|---|---|---|---|---|---|
| | **Emission rate ($\mu g\ h^{-1}\ unit^{-1}$)** | **Chamber conc ($\mu g/m^3$)** | **Emission rate ($\mu g\ h^{-1}\ unit^{-1}$)** | **Emission rate ($\mu g\ h^{-1}\ unit^{-1}$)** | **Chamber conc ($\mu g/m^3$)** |
| Phenol | 1.7 | | | | |
| Toluene | 47.0 | 1.3 | | 0.04 (0.15) | 12.5 (45.6) |
| Styrene | 7.6 | 0.2 | | | |
| Xylenes | 10.3 | 0.3 | | | |
| Ethylbenzene | | | | | |
| $C_6$-$C_{10}$ aromatics | 46 - 103 | 1.3 | 32 | | |
| >$C_{10}$ aromatics | 58.3 | 1.6 | | | |
| Bicyclic aromatics | 41.0 | 1.1 | | | |
| 2-Ethylhexanol | 19.6 | 0.5 | | | |
| *n*-Decane | 11.6 | 0.3 | | | |
| *n*-Undecane | 7.6 | 0.2 | | | |
| Pentadecane | | | | | |
| Formaldehyde | 5.2 – 12.8 | 0.1 | 9.7 | | |
| Acetaldehyde | 3.6 | | 1.5 | | |
| Propionaldehyde | 0.5 | | | | |
| *n*-Butyraldehyde | 1.4 | | | | |
| Valeraldehdye | 3.1 | | 0.5 | | |
| Hexaldehyde | 4.6 | | 2.7 | | |
| Benzaldehyde | | | | | |

| | | | | |
|---|---|---|---|---|
| d- Limonene | | | | |
| α-Pinene | | | | |
| | | | | |
| Methylcarbonate | | | 0.73 (1.3) | 223 (393) |
| Ethylcarbonate | | | 0.37 (0.78) | 112 (240) |
| Cyclohexanone | | | 0.07 (0.21) | 23 (65) |
| 2-Butoxyethanol | | | 0.82 (2.14) | 217 (618) |
| 2-Ethyl-1-hexanol | | | 0.14 (0.52) | 34 (150) |
| Acetophenone | | | 0.05 (0.11) | |
| Trimethyl | | | 0.13 (0.34) | 18 (86) |
| Cyclohexyl | | | 0.16 (0.81) | 50 (250) |
| ΣVOC | 180 | 113 | | |

***a:*** Bakó-Biró et al, 2004
***b:*** Nakagawa et al, 2003
***c:*** Hoshino et al, 2003 (values between parenthesis correspond to “idle” conditions)

***Table 3: Semivolatile organic chemicals (SVOCs) emitted by personal computers***
*When reported, time of operation is indicated in parenthesis.*

| **Chemical** | **Emission rate ($ng\ h^{-1}\ unit^{-1}$)** | **Chamber concentration ($ng/m^3$)** | **Equipment / experimental conditions** |
|---|---|---|---|
| Hexabromo benzene | | 1 | Desktop PCs in operation [a,b] |
| RDP | 2 | 13 (100 d) | |
| BDP | 44 | 20 (100 d) | |
| TCPP | 24 | | |
| TPP | 25 | 94 (1 d)<br>85 (100 d)<br>8.6 (183 d) | |
| BDE 47 | | 150 | Desktop PCs after operation (extracted from chamber surfaces) [a] |
| BDE 100 | | 28 | |
| BDE 99 | | 61 | |
| TBBPA | | 64-446 | |
| DBP | 110 / 650 | | Notebook computer [c] |

***a:*** Kemmlein et al, 2003
***b:*** Carlsson et al, 2000 (video display units)
***c:*** Hoshino et al, 2003

***Table 4: Volatile organic chemicals (VOCs), ozone and particulate matter ($PM_{10}$) emitted by printers.***
*When reported, time of operation is indicated in parenthesis.*

| **Chemical** | ***Laser printers*** [a,b] **Chamber concentration (ppbv)** | | ***Ink-jet printers*** [a] **Chamber concentration (ppbv)** | | ***All-in-one office machines*** [a] **Chamber concentration (ppbv)** | |
|---|---|---|---|---|---|---|
| | **idle** | **in operation** | **idle** | **in operation** | **idle** | **in operation** |
| Freon 12 | 0.48-0.52 | 0.61-0.66 | 0.36 | 0.43 | 0.3 | 0.45 |
| Methyl chloride | 0.53-0.60 | 0.71-0.82 | 0.48 | 0.55 | 0.52 | 0.62 |
| Freon 11 | 0.24-0.29 | 0.25-0.28 | 0.23 | 0.24 | n.d. | 0.27 |
| Methylene chloride | 0.38-0.42 | 0.46-0.58 | 0.57 | 0.61 | 0.69 | 0.74 |
| Chloroform | 0.96-1.07 | 1.17-1.31 | 0.81 | 0.94 | 0.74 | 0.96 |
| Benzene | 0.52-0.57 | 0.77-0.84 | 0.42 | 0.41 | 0.52 | 0.52 |
| Toluene | 14-15 | 15-16 | 6.22 | 6.43 | 7.9 | 8.2 |
| Tetrachloroethene | | | 0.23 | 0.21 | 0.52 | 0.43 |
| Ethylbenzene | 1.4-2.1 | 2.0-3.0 | 1.2 | 1.26 | 1.5 | 1.6 |
| *m,p*-Xylene | 1.2 | 1.6-1.7 | 0.86 | 0.92 | 0.9 | 0.9 |
| Styrene | 2.7-4.0 | 3.2-5.3 | 1.14 | 1.43 | 1.2 | 1.9 |
| *o*-Xylene | 0.9-1.0 | 2.0-2.3 | 0.69 | 0.68 | 0.58 | 0.58 |
| 1,4-Dichlorobenzene | | | 0.34 | 0.32 | 0.34 | 0.35 |
| 1,3-Dichlorobenzene | | | 0.34 | 0.32 | 0.34 | 0.35 |
| 1,2-Dichlorobenzene | | | 0.21 | 0.21 | 0.26 | 0.22 |
| 1,2,4-Trichlorobenzene | | | 0.86 | 0.63 | 0.23 | 0.2 |
| Hexachlorobutadiene | | | 0.37 | 0.36 | 0.88 | 0.64 |
| d-limonene | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Butoxymethyl oxirane | | | | | | |
| Ozone | | 9-10<br>1 – 13 *(20 m)* | | 5-6 | | 6 |
| $PM_{10}$ | | 65 | | 20-38 | | 41 |
| ΣVOC | | 300 – 1400<br>*(20 – 60 m)* | | | | |

***a:*** Lee et al, 2001
***b*:** Smola et al, 2002

***Table 5: Volatile organic chemicals (VOCs), ozone and particulate matter emitted by photocopy machines***

| **Chemical** | **Emission rate ($\mu g\ h^{-1}\ unit^{-1}$)** | **Chamber concentration ($\mu g/m^3$)** | | **Reference** |
|---|---|---|---|---|
| | | **idle** | **in operation** | |
| Toluene | 110 - 760<br>540 – 2000<br>1336 | | | ***a***<br>***b***<br>***c*** |
| Ethylbenzene | <50 - 28000<br>23000 - 29000 | 4.1 | 552 - 608 | ***a***<br>***b***<br>***c*** |
| *m,p*-Xylene | 100 - 29000<br>22000 - 29000 | 4.5 | 467 – 515 | ***a***<br>***b***<br>***c*** |
| *o*-Xylene | <50 - 17000<br>12000 – 15000 | | | ***a***<br>***b*** |
| Styrene | 300 - 12000<br>6300 - 8400 | | | ***a***<br>***b*** |
| Styrene + *o*-Xylene | | 3.1 | 354 - 390 | ***c*** |
| Isopropylbenzene | 150 - 160 | | | ***b*** |
| *n*-Propylbenzene | <50 - 2100<br>360 - 460 | <0.4 | 7.8 | ***a***<br>***b***<br>***c*** |
| Benzaldehyde | <100 - 3800<br>980 – 1500 | 1.3 | 25 - 26 | ***a***<br>***b***<br>***c*** |
| α-Methylstyrene | <50 - 330<br>500 - 730 | 1.3 | 16 - 18 | ***a***<br>***b***<br>***c*** |
| 1,2,4-Trimethylbenzene | | 0.6 | 3.6 - 4.2 | ***c*** |
| Butylbenzene | | <0.4 | 14 - 15 | ***c*** |
| Acetophenone | | 1.6 | 11 - 13 | ***c*** |
| Methoxyethylbenzene | | 0.9 | 6.6 | ***c*** |
| $C_9$-ester | | <0.5 | 23 | ***c*** |
| Butenyl benzene | | 1.1 | 28 - 37 | ***c*** |
| *n*-Decane | <50 - 450 | | | ***a*** |

| | | | | |
|---|---|---|---|---|
| 2-Ethyl-1-hexanol | 130 - 14000 | | | ***a*** |
| Limonene | <50 - 1100 | | | ***a*** |
| *n* -Nonanal | 1100 - 3900 | | | ***a*** |
| *n* -Undecane | 62 - 2000 | | | ***a*** |
| *n* -Dodecane | 75 - 960 | | | ***a*** |
| Formaldehyde | <500 - 2600<br>1900 - 3200 | | | ***a***<br>***b*** |
| Acetaldehyde | <500 - 1200<br>510 - 1300 | | | ***a***<br>***b*** |
| Acetone | <100 - 2800 | | | ***a*** |
| Propionaldehyde | <100 - 260 | | | ***a*** |
| 2-Butanone | <100 - 380<br>n.d. - 600 | | | ***a*** |
| Butyraldehyde | <100 - 840<br>n.d. - 410 | | | ***a***<br>***b*** |
| Valeraldehyde | <100 - 540 | | | ***a*** |
| *n* -Hexanal | 100 - 1200<br>n.d. - 950 | | | ***a***<br>***b*** |
| ΣVOC | | 49 | 1630 - 1900 | ***c*** |
| Ozone | 1300 - 7900<br>1700 - 3000 | | | ***a***<br>***b*** |
| PM (respirable fraction) | 1420-2950 | 6-11 | 19-22 | ***c*** |

***a*** Leovic et al, 1996
***b*** Leovic et al, 1998
***c*** Brown, 1999

***Table 6: Measurements of office equipment-relevant volatile organic chemicals (VOCs) in the indoor environment***

| **Chemical** | **Photocopier centers (USA)** [a] | **Office environment (review of US and European data)** [b] |
|---|---|---|
| | **Concentration (ppb)** | **Concentration (μg m$^{-3}$)** |
| Pentane | 0.8-6.2 | |
| Toluene | 3-4800 | 28-9500 |
| *p*-Dichlorobenzene | 3.8 | |
| *m,p*-Xylene | 1.7-2.9 | 10-59 |
| Hexane | 1.6 | |
| Ethylbenzene | 1.0-0.4 | |
| 1,2,4-Trimethylbenzene | 0.4-269 | |
| *o*-xylene | 0.6-0.9 | |
| Phenol | 7.8 | |
| Nonane | 0.6-525 | |
| Decane | 0.6-639 | 3-2370 |
| Octane | 0.5 | |
| Undecane | 0.5 | |
| 1,3,5-Trimethylbenzene | 304 | |
| Formaldehyde | | 38-310 |
| Hexanal | | 34-520 |

***a:*** Stefaniak et al, 2000
***b:*** Wolkoff et al, 2006

***Table 7: Ambient levels of phthalate esters in the indoor environment***

| **Chemical** | **Indoor air and dust in residences (USA)** [a] | | **Indoor air and dust in apartments (Germany)** [b] | |
|---|---|---|---|---|
| | **Concentration in air (ng $m^{-3}$)** | **Concentration in dust (μg $g^{-1}$)** | **Concentration in air (ng $m^{-3}$)** | **Concentration in dust (μg $g^{-1}$)** |
| DEP | 130-4300 | nd –111 | 807-1860 | 45-160 |
| DBP | 52-1100 | nd –352 | 1218-2453 | 56-130 |
| BBP | nd-480 | 4-1310 | 37-75 | 86-218 |
| DEHP | nd –1000 | 17-7700 | 191-390 | 775-1542 |
| DCHP | nd –280 | nd –63 | | |
| DEHA | nd –66 | 1-391 | | |
| DPP | nd –27 | nd –31 | | |
| DIP | 11-990 | nd –39 | | |
| DMP | | | 1182-4648 | 11-46 |
| DMPP | | | 697-1466 | 55-144 |

***a:*** Rudel et al, 2003
***b:*** Fromme et al, 2004

***Table 8: Ambient levels of brominated flame retardants in the indoor environment***

| **Chemical** | **Electronics recycling plant (Sweden)** [a] | **Electronics assembly line (Sweden)** [a] | **Office with computers (Sweden)** [a] | **Teaching hall (Sweden)** [a] | **House and laboratory air (USA)** [b] | **Dust in residences (USA)**[c] |
|---|---|---|---|---|---|---|
| | **Concentration in air ($ng\ m^{-3}$)** | | | | | **Concentration in dust ($\mu g\ g^{-1}$)** |
| BDE 47 | 0.35-2.1 | <0.1-0.39 | | 0.72-0.8 | | nd-10 |
| BDE 100 | 0.063-0.52 | <0.009-0.058 | | 0.053-0.059 | | nd-3.4 |
| BDE 99 | 0.54-5.5 | <0.06-0.15 | | 0.35-0.41 | | nd-22 |
| BDE-85 | 0.1-0.24 | <0.006 | | 0.0085-0.011 | | |
| BDE-154 | 0.13-1.0 | <0.002-0.013 | | 0.012-0.013 | | |
| BDE-153 | 0.88-11 | <0.004-0.033 | | 0.022-0.023 | | |
| BDE-183 | 6.3-44 | 0.014-0.11 | 0.0046-0.012 | 0.011-0.012 | | |
| BDE-209 | 12-70 | <0.04-0.32 | <0.04-0.087 | <0.04-0.17 | | |
| BTBPE | 5.6-67 | <0.003-0.041 | <0.003-0.0058 | 0.003-0.0048 | | |
| BB-209 | 1.6-14 | <0.009-0.024 | | | | |
| TBBPA | 6.9-61 | 0.11-0.37 | 0.01-0.07 | 0.035-0.15 | | |
| Total PBDEs | | | | | 0.07 - 2.1 (house)<br>0.36 - 0.41 (lab) | |

***a:*** Sjodin et al, 2001
***b:*** Shoeib et al, 2004
***c:*** Rudel et al, 2003

***Table 9: Ambient levels of organophosphate flame retardants in the indoor environment***
*When reported, time of sampling is indicated in parenthesis.*

| **Chemical** | **Electronics recycling plant air (Sweden)** [a] | **School air (Sweden)** [b] | **Office air (Sweden)** [b,c] | **Office air (Switzerland)** [d] | **Electronics store air (Switzerland)** [d] | **Home dust (Sweden)** [e] | **Office dust (Sweden)** [e] | **Wipe samples from computer screens and covers (Sweden)** [e] |
|---|---|---|---|---|---|---|---|---|
| | **Concentration in air ($ng\ m^{-3}$)** | | | | | **Concentration in dust ($\mu g\ g^{-1}$)** | | **Surface concentration ($ng\ m^{-2}$)** |
| TPP | 12-40 | nd-0.8 | 94 (1d)<br>8.6 (183 d) | 2.0-3.1 | 1.4-5.7 | 0.85-0.99 | 6.8 | 3300-4000 |
| IPPDPP | 3.4-15 | | | | | | | |
| PPDPP:1 | 1.3-5.1 | | | | | | | |
| PPDPP:2 | 0.7-3.1 | | | | | | | |
| TBPDPP | 0.2-1.9 | | | | | | | |
| TBP | 9-18 | 7.6-35 | 2.5 - 17 | 4.5-8.1 | 1.7-17 | 0.21-0.61 | 0.35 | 30-70 |
| TCEP | 15-36 | 18-250 | 7.4 - 11 | 23-56 | 2.2-8.2 | 0.19-0.27 | 48 | 210-220 |
| TCPP:1 | 10-19 | 14-35 | 7 - 31 | | | | | |
| TCPP:2 | 3.7-7.1 | 5.1-16 | 2- 12 | | | | | |
| TCPP:3 | 0.6-1.5 | nd-2.9 | 0.2 - 1.4 | | | | | |
| TBEP | 20-36 | 1.4-5.9 | 2.2 | nd-1.2 | | 18-25 | 270 | 170-940 |
| TNBP | | 9.8-64 | 10 - 18 | | | | | |
| TEHP | | nd-10 | | nd-0.6 | nd-2.8 | 0.06-0.07 | 0.43 | |
| TCPP | | | | nd-130 | | 0.47-0.93 | 73 | 220-370 |
| TDCPP | | | | | | 0.39-1.1 | 67 | 170-290 |
| TEEdP | | | | | | 0.29-0.56 | 0.44 | 290-560 |
| DOPP | | | | | | <0.03-0.2 | | 130-450 |
| CLP1 | | | | | | 0.03-0.04 | | |
| TPrP | | | | | | 0.02 | | |
| TCP | | | | nd-0.37 | nd-0.21 | | | |

***a:*** Sjodin et al, 2001
***b:*** Carlsson et al, 1997
***c:*** Carlsson et al, 2000
***d:*** Hartmann et al, 2004
***e:*** Marklund et al, 2003

***Table 10: Levels of polycyclic aromatic hydrocarbons (PAHs) in dust collected inside computers (placed in smoking and non-smoking rooms) and outdoor air***

| **Chemical** | **Non-smoking rooms (dorms, chemical labs and offices, China)** [a] ($n$ = 11) | **Smoking room (offices and bar, China)** [a] ($n$ = 16) | **Outdoor air (China)** [a] ($n$ = 2) |
|---|---|---|---|
| | **Dust concentration (μg g$^{-1}$)** [b] | | |
| Nap | 0.06-0.52 | 0.14-0.28 | 0.09-0.39 |
| Acy | n.d.-0.08 | 0.08-0.10 | 0.04-0.06 |
| Ace | n.d. -0.02 | n.d.-0.02 | 0.02-0.03 |
| Flo | 0.04-0.15 | 0.06-0.18 | 0.09-0.17 |
| Phe | 0.32-1.46 | 0.62-1.50 | 1.21-1.59 |
| Ant | 0.16-0.94 | 0.28-0.40 | 0.27-0.28 |
| Flu | 0.60-2.39 | 0.84-1.50 | 1.40-1.80 |
| Pyr | 0.29-1.37 | 0.44-0.92 | 0.87-1.11 |
| BaA | 0.28-0.67 | 0.24-1.00 | 0.29-0.48 |
| Chry | 0.64-2.10 | 0.68-3.24 | 0.63-1.33 |
| BbF | 0.66-3.34 | 1.58-9.76 | 0.73-1.82 |
| BkF | 0.35-1.08 | 0.30-1.17 | 0.28-0.46 |
| BaP | 0.44-2.20 | 0.44-2.52 | 0.30-1.10 |
| DbA | 0.68-1.13 | 0.79-5.12 | 0.30-0.31 |
| InP | 0.54-1.25 | 0.58-5.34 | 0.20-0.77 |
| BgP | 0.48-2.84 | 1.28-9.06 | 0.65-1.57 |
| Total PAH | 8.22-16.22 | 8.44-42.04 | 8.18-12.46 |

***a:*** Ren et al, 2006
***b:*** data reported are ranges corresponding to *n* samples in each category.

***Table 11: Ambient levels of fluorinated semivolatile chemicals in the indoor environment***

| **Chemical** | **House air (North America)** [a] | **Lab air (North America)** [a] | **House air (Ottawa, Canada)** [b] | **House dust (Ottawa, Canada)** [b] |
|---|---|---|---|---|
| | **Concentration in air ($pg\ m^{-3}$)** [c] | | | **Concentration in dust ($ng\ g^{-3}$)** [c] |
| MeFOSE | 667-4046 | 11.1-1698 | 366-8190 ($n$ = 59) | 3-8860 ($n$ = 66) |
| EtFOSE | 364-1799 | 4.75-1917 | 227-7740 ($n$ = 59) | 1-75440 ($n$ = 66) |
| MeFOSEA | 4.53-283 | | 12-109 ($n$ = 10) | 0.7-44 ($n$ = 16) |
| EtFOSA | | | 6-646 ($n$ = 52) | |

***a*:** Shoeib et al, 2004
***b*:** Shoeib et al, 2005
***c*:** data reported are ranges corresponding to *n* samples in each category.