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12-2011

## Understanding SVOCs

Ying Xu

Jianshun Zhang

*Syracuse University*, [jszhang@syr.edu](mailto:jszhang@syr.edu)

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### Recommended Citation

Xu, Y. and J.S. Zhang. 2011. "Understanding SVOCs." *ASHRAE Journal* 53(12):121-125.

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# Understanding SVOCs

By Ying Xu, Ph.D., Member ASHRAE; and Jensen Zhang, Ph.D., Fellow ASHRAE

**S**emi-volatile organic compounds (SVOCs) are an important class of indoor pollutants that are of great health concern. However, they have not received much attention within the ASHRAE community. This column provides an overview of the sources, sinks, transport mechanisms, and potential health effects, and discusses how HVAC systems may affect occupants' exposure to SVOCs.

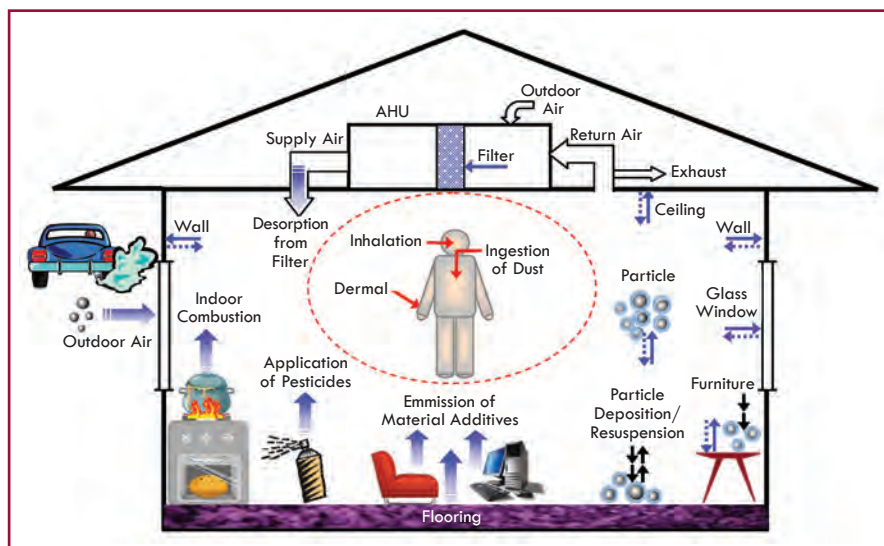
**Occurrence and sources of SVOCs.** Building materials, consumer products and furnishings contain a vast array of chemicals that are emitted to indoor environments. Among the chemicals found indoors, SVOCs constitute an important class<sup>1</sup> that includes phthalate esters, brominated flame-retardants, polychlorinated biphenyls, nonionic surfactants and pesticides (*Table 1*). Many SVOCs are high production volume chemicals used in plastics, detergents, furniture, building material components such as insulation and caulking, and other household and consumer products, making them ubiquitous in indoor environments.<sup>2</sup> Additionally, SVOCs persist for long periods of time, even after the primary source is removed.<sup>1</sup>

**Potential health effects.** SVOCs have been linked to serious adverse health effects (*Table 1*). Many SVOCs are endocrine-disrupting chemicals, which mean they interfere with, mimic or block endogenous hormones. For example, recent studies show that exposure to some phthalates results in profound and irreversible changes in the development of the reproductive tract in males;<sup>3</sup> exposure to polybrominated diphenyl ethers (PBDEs) causes impairment of brain and nerve tissues.<sup>4</sup>

Concentrations of SVOC's metabolites, measured in the general population using biomonitoring methods (blood and urine), provide direct evidence of widespread human exposure.<sup>3</sup> Biomonitoring data suggest that more than 95% of the U.S. population is exposed to phthalates.<sup>5</sup> For PBDEs, the body burden in North Americans is 10 to 100 times higher than in Europeans, due to the much higher indoor exposure experienced by the U.S. population.<sup>6</sup> Therefore, we need to ad-

vance strategies to control and reduce exposure to SVOCs in indoor environments.

**Indoor transport and exposure pathways.** As shown in *Figure 1*, SVOCs enter indoor environments along several pathways, including infiltration of outdoor air, indoor combustion, spray products, and material additives. Because the vapor pressures of SVOCs at 25°C (77°F) ( $10^{-9}$  to 10 Pa) are low compared to volatile organic compounds (VOCs) (10 to  $10^4$  Pa), they are commonly found in gas and condensed phases, redistributing from their original source to indoor air and interior surfaces including airborne particles, dust, and skin.<sup>3</sup> Therefore, indoor exposure (via inhalation of air and airborne particles, dermal absorption from air and deposited particles, and non-dietary ingestion of dust) occurs following emission from sources into air and subsequent migration to different media, and reemission/



**Figure 1:** Representation showing the fate, transport and exposures of SVOCs in indoor environments.

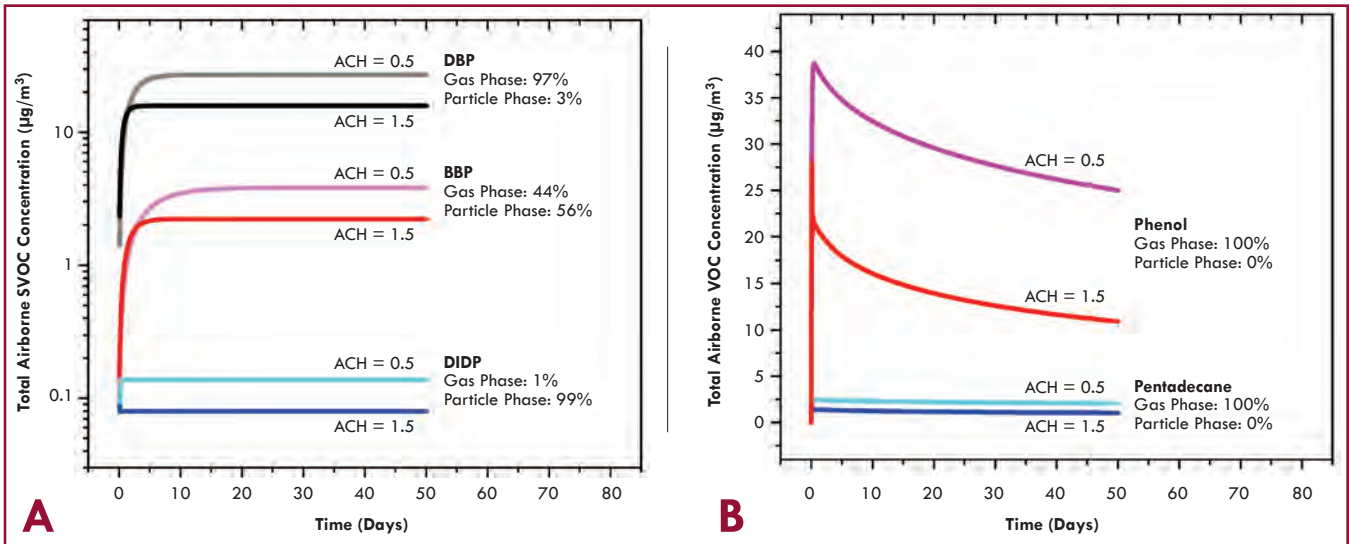
SVOC Compounds	Uses	Sources	Potential Health Effects
<b>Alkylphenols</b>  <i>Example:</i> 4-nonylphenol, 4-octylphenol	Nonionic Surfactants	Detergents, Disinfectants, Surface Cleaners	May Interfere With, Mimic or Block Hormones
<b>Organochlorines</b>  <i>Example:</i> DDT, Chlordane	Pesticides, Termiticide, Bactericide (Some Have Been Banned or Restricted in the 1980s)	Outdoor and Indoor Air, Tracked-In Dust, Disinfecting Products	Neurotoxicity, Effects on Developing Reproductive Systems And on Lactation, Cancer
<b>Organophosphorus Compounds</b>  <i>Example:</i> Tris(2-chloroethyl)phosphate (TCEP), Tris(chloropropyl)phosphate (TCPP)	Plasticizers, Antifoaming Agents, Flame Retardants, Pesticides	Polymeric Materials, Fabrics, Polyurethane Foams, Electronics (Cable Sheathing and Casings), Outdoor and Indoor Air, Dust	Effects on Neurodevelopment and Growth in Developing Tissue, Relate To Respiratory Disease in Children Through Dysregulation of the Autonomic Nervous System
<b>Phthalates</b>  <i>Example:</i> Di(2-ethylhexyl)-phthalate (DEHP), Di-iso-nonyl-phthalate (DINP)	Plasticizers, Solvents, Fixing Fragrances (Use of DEHP And BBP Reduced Due to the Concern on Health Effects)	Flexible PVC, PVC Flooring, Wall Covering, Electrical Cable and Casings, Personal Care Products	Effects on the Development of Male Reproductive Tract, Prenatal Mortality, Reduced Growth and Birth Weight, May Relate to Asthma and Allergies in Children
<b>Polybrominated Diphenyl Ethers (PBDEs)</b>  <i>Example:</i> Hexabromodiphenyl ether (BDE-153), Tetrabromodiphenyl ether (BDE-47)	Flame Retardants (Use of Penta- and Octa-BDEs Have Been Restricted)	Carpet Padding, Wall Coverings, Electronics (Casings), Furniture (Foam Cushioning and Mattress)	Effects on the Development of Brain And Nerve Tissues, Permanent Learning and Memory Impairment, Behavioral Changes, Delayed Puberty Onset, Fetal Malformations, Thyroid Hormone Disruption
<b>Polychlorinated Biphenyls (PCBs)</b>  <i>Example:</i> 2,2',5,5'-tetrachloro-1,1'-biphenyl (PCB 52), 2,2',4,4',5,5'-hexachloro-1,1'-biphenyl (PCB 153)	Heat Transfer Fluids, Stabilizers, Flame Retardants, (Have Been Banned or Restricted in the 1970s)	Floor Finishes, Foam Cushioning and Mattresses, Oil-Filled Transformers, Capacitors	Developmental Neurotoxins, Effects on Immune, Reproductive, Nervous, and Endocrine Systems, Cancer (Including Breast Cancer)
<b>Polycyclic Aromatic Hydrocarbons (PAHs)</b>  <i>Example:</i> Benzo(a)pyrene, Pyrene	Combustion Byproducts	Outdoor Air, Cooking, Smoking	Cataracts, Kidney and Liver Damage, Jaundice, Increased Risk Of Skin, Lung, Bladder, and Gastrointestinal Cancers
<b>Pyrethroids</b>  <i>Example:</i> Cyfluthrin, Permethrin	Insecticides	Outdoor and Indoor Air, Tracked-In Dust, Cleaning Products	Weak Anti-Androgenic, Anti-Estrogenic, or Estrogenic Effect
<b>Parabens</b>  <i>Example:</i> Butyl paraben, Methyl paraben	Bactericides, Antimicrobial Agents, Preservatives	Personal Care Products, Canned Food, Fabrics	Weak Environmental Estrogens

**Table 1:** SVOCs in indoor environments: sources and potential health effects.

desorption from these media as air conditions (temperature and concentration) change.

**Effect of the air change rate on indoor SVOC concentrations and exposures.** Based on experimental chamber data,<sup>7,8</sup>

Xu and Little<sup>9</sup> developed and validated a model to predict the emission rate of SVOCs from polymer materials. We extended this chamber-based model to examine the effect of the air change rate on SVOC concentrations and human exposures in



**Figure 2:** The influence of air change rate on total airborne SVOC (A) and VOC (B) concentrations.

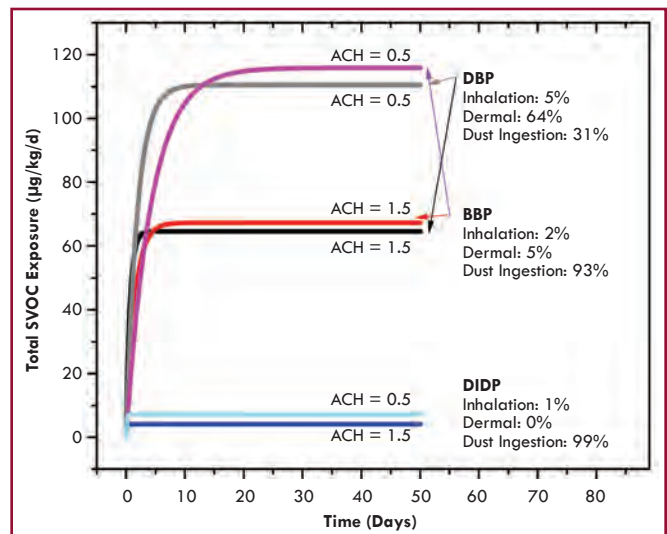
a realistic indoor environment, and compared it with the results for VOCs. Vinyl material covering the floor area is the only contamination source in the modeled room (5 m × 4 m × 3 m [16 ft × 13 ft × 10 ft]), while the walls and ceiling are the only sink surfaces. We selected a range of contaminating materials to investigate: VOCs (phenol and pentadecane) and SVOCs (di-butyl-phthalate [DBP], butyl-benzyl-phthalate [BBP], and di-iso-decyl-phthalate [DIDP]).

Two primary differences exist between the emissions of targeted VOCs and the SVOCs. First, the vapor pressures of the SVOCs are orders-of-magnitude lower than those of the VOCs. The much lower vapor pressures mean that the SVOC tend to be in the adsorbed phase, as opposed to the gas phase.

The second primary difference is that the material-phase concentrations of SVOCs are several orders-of-magnitude higher than those of VOCs. The high material-phase concentration and low emission rate mean that the material-phase concentration will be relatively constant, and that under these conditions, the in-material diffusion may not be an important mechanism. Instead, the mass transfer resistance across the boundary layer or “air film” over the surface becomes the factor that controls the rate.

The total airborne concentrations of SVOC and VOC following the installation of vinyl flooring were simulated under two air change rates ( $0.5 \text{ h}^{-1}$  and  $1.5 \text{ h}^{-1}$ ). After some period of time, emissions from vinyl flooring result in a steady-state SVOC airborne concentration (Figure 2a), but VOC concentrations decrease quickly (Figure 2b). Suspended particles account for the major portion of the total airborne SVOC concentration, while 100% of the VOCs appear in the gas phase. An increase of the air change rate reduces the total airborne concentrations; the dilution ratio was similar for the SVOCs and VOCs we investigated. For some SVOCs with different emission mechanisms, ventilation rate may not be as important as in the simulations.

The model results also indicate the need to evaluate exposure to vapor-phase SVOCs in the air, particle-bound SVOCs in the



**Figure 3:** The influence of air change rate on total exposures to SVOCs for adults.

air, and SVOCs in settled dust. The exposure pathways of interest are inhalation of vapor- and particle-bound SVOCs, dermal absorption of SVOCs, and non-dietary ingestion via household dust. As shown in Figure 3, the amount of SVOCs taken up via dermal absorption or dust ingestion is greater than the amount taken up through inhalation. Although inhalation is not the primary exposure pathway for SVOCs, dermal exposure and oral ingestion depend strongly on concentration of gas-phase SVOCs, so the air change rate still has a strong influence on total exposure for relatively light SVOCs (DBP, BBP and DIDP in Figure 3). In addition, particle resuspension due to occupant activity could increase particle inhalation exposure as high as 30%.<sup>10</sup> This further increases the exposure to light and heavy particle-bound SVOCs. The previous are results of preliminary studies, and more work, especially experimental, will be necessary to validate the results.

**The potential role of HVAC systems in controlling exposure to SVOCs.** The contamination of indoor environments has been recognized as a significant uptake pathway for SVOCs.<sup>2</sup> Ventilation is used to remove pollutants and improve indoor air quality, and the effect of ventilation has been studied extensively for VOCs. However, no experimental data in the literature support ventilation strategies to control indoor contamination by SVOCs. The previous analysis under two different air change rates indicates that adjusting the ventilation rate may reduce total indoor airborne SVOCs levels effectively, reducing human exposures.

Our recent computational fluid dynamics simulation<sup>11</sup> showed that not only ventilation rate, but also ventilation mode (and thus room air distribution) could also play an important role in controlling the occupants' exposure to indoor SVOCs. Although the gas-phase concentration of SVOCs in indoor air is normally lower than the concentration of VOCs, a relatively small change in the gas-phase concentration, such as 0.1 ppb, is sufficient for meaningful vapor transport of SVOCs and its consequent partitioning between the gas phase and surfaces of airborne particles and human skin, and has significant influences on indoor SVOC exposures.<sup>12</sup> Therefore, the ventilation system can

play important roles in controlling the occupants' exposure to SVOCs.

Furthermore, because SVOCs are expected to sorb on particles and dust, particle filtration in an HVAC system may be used to mitigate indoor SVOC exposures in combination with ventilation. With the increase of particles collected on a filter, SVOCs accumulate on the filter as well. As long as there is equilibrium between the adsorbed SVOC species and those in the ventilation airstream, no adverse effects are discernible. However, equilibrium can be perturbed by changes in climatic conditions, e.g., temperature and relative humidity. If the equilibrium is perturbed in a fashion that redistributes SVOCs from the filter into the airstream (e.g., an increase in temperature), the resulting release of SVOCs from a "loaded" filter may take place. Further investigation is needed to examine the degree to which this could happen, and how to prevent it from occurring.

The occurrence of SVOCs in indoor environments is emerging as an important research topic, but SVOCs have not been studied as widely as other classes of indoor pollutants, due in part to the analytical challenges in measuring SVOCs.<sup>1</sup> Theoretically, HVAC systems can play an important role in controlling the occupants' exposure to SVOCs. Research is needed to evaluate how HVAC



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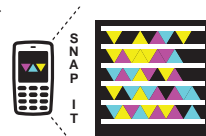
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systems affect SVOC emission and distribution to provide solid scientific evidence for potential guidelines to reduce harmful SVOCs exposure in indoor environments.

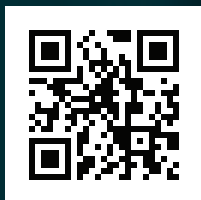
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*Ying Xu, Ph.D., Member ASHRAE, is an assistant professor at the Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin, Austin, Texas; and Jensen Zhang, Ph.D., Fellow ASHRAE, is a professor and director at Building Energy and Environmental Systems Laboratory, Department of Mechanical and Aerospace Engineering, Syracuse University, Syracuse, N.Y.●*

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