Title

Association between indoor exposure to semi-volatile organic compounds and building-related symptoms among the occupantsof residential dwellings

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Key words

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Abstract

The aim of this study was to evaluate the levels of semi-volatile compounds (SVOCs) in residential detached houses in Sapporo, Japan, and whether exposure to these SVOCs was associated with the development of building related symptoms named 'sick house syndrome' (SHS). The definition of SHS is fundamentally the same as that of the sick building syndrome (SBS). The presence of symptoms of SHS was evaluated using a validated self-administered questionnaire. Surveys and samplings of air and house dust in 41 dwellings were performed from October 2006 to January 2007, and 134 occupants responded to questionnaires. Samples were analyzed to quantify the concentrations of eight plasticizers, eleven phosphate triester flame retardants, two alkyl phenols used as anti-oxidants, and one organochlorine synergist called s-421, by gas chromatography–mass spectrometry and gas chromatography–flame photometry. The compounds frequently detected were di-n-butylphthalate, di(2-ethylhexyl)phthalate (DEHP), and dibutylhydroxytoluene in air, and DEHP and tris(2-butoxyethyl) phosphate (TBEP) in dust. Tributylphosphate was strongly and directly associated with mucosal symptoms of SHS; s-421 was also directly associated with mucosal symptoms of SHS. On the contrary, some chemicals such as diethylphthalate and TBEP were inversely associated with SHS. In future studies, we plan to assess these associations in a larger population.

Introduction

A wide variety of chemicals derived from plastic products, electric apparatus, interior construction materials, and fabrics are found in homes. Even though their boiling points range from 240–260°C to 380–400°C, semi-volatile compounds (SVOCs), such as plastics additives, can vaporize from the surfaces of synthetic products because SVOCs are non-covalently bound to polymeric materials. These compounds are released from a number of sources in the standard home and partition among gas-phase, airborne particles, settled dust, and indoor surfaces (Clausen et al., 2008; Weschler and Nazaroff, 2008; Weschler et al., 2008). For instance, various phthalate diesters were detected in suspended particulate matter and in house dust found on polyvinylchloride (PVC) floors in residential dwellings (Øie et al., 1997). As well, ceilings, floors, TV sets, and computers

(Saito et al., 2007). In an earlier study (Weschler, 1980), various plasticizers such as di(2-ethylhexyl) phthalate (DEHP) and tris(2-butoxyethyl)phosphate (TBEP) have been found in aerosol collected within a building. Numerous SVOCs have been found in air and/or dust samples from homes (Otake et al., 2004; Rudel et al., 2003; Saito et al., 2004, 2007). In previous reports, plastic materials in homes were suspected of causing respiratory symptoms or different types of allergy symptoms. A relationship between the risk for respiratory symptoms and surface materials of plastics or textiles was observed in child populations in Norway (Jaakkola et al., 1999; Øie et al., 1999), Finland (Jaakkola et al., 2000), Sweden (Bornehag et al., 2004a), and Russia (Jaakkola et al., 2004) as well as an adult population in Finland (Jaakkola et al., 2006). Associations between phthalate diesters in house dust and children's asthma or allergy have been shown in Swedish (Bornehag et al., 2004a) and Bulgarian studies (Kolarik et al., 2008) (Table 1). Various phthalate diesters and phthalate monoesters displayed adjuvant properties in animal studies (Hansen et al., 2007; Larsen et al., 2001, 2004; Takano et al., 2006). Enhanced sensitization may be induced by phthalate exposure in humans and in rodents. In addition, it was reported that higher concentrations of phthalate diester metabolites were related to poor pulmonary function in men (Hoppin et al., 2004).

So far, little is known about levels and risks of human exposure to phosphate triesters used as plasticizers and/or flame retardants, which are used in plastic materials, rubbers, varnishes, lubricants, hydraulic fluids, and in other industrial applications. Adverse effects of these chemicals have been reported in animal studies (Carrington et al., 1990; Matthews et al., 1990; Weiner and Jortner, 1999) and human case studies (Camarasa and Serra-Baldrich, 1992; Carlsen et al., 1986). The association between phosphate triesters and buildingrelated symptoms has not received substantial attention, whereas interest in the health effect of phthalate diesters is increasing.

In this study, we assayed the levels of SVOCs inside residential detached houses in Sapporo, Japan, and evaluated the presence of ‘sick house syndrome (SHS)’ by self-reported questionnaire. Fundamentally, SHS, which occurs in residential dwellings (Saijo et al., 2002; Seki et al., 2007), is defined similarly as SBS, which occurs in offices or in schools (Redlich et al., 1997). Similar to symptoms of SBS, SHS symptoms, which include irritation of the eyes, nose and throat, headache, and general fatigue, are varied, subjective, non-specific, and have no clear etiology. However, all symptoms are attributed to exposure to the home environment. This study targeted abundantly produced compounds identified in the annual report of the Chemical Diary, as well as compounds detected frequently, albeit in small amounts, in a survey conducted by the Tokyo metropolitan government. The target compounds consisted of eight plasticizers, 11 phosphate triester flame retardants, two alkyl phenols used as anti-oxidants, and one organochlorine synergist called s-421 or S-2. S-421 is widely used as a synergist in pyrethroid-based insecticides in Japan. We determined the levels of these compounds in both air and settled dusts in residential dwellings and evaluated whether these compounds, particularly phosphate triesters, were related to SHS based on a survey of a population in Sapporo during 2006 and 2007.

Materials and methods

Protocol

This cross-sectional study was conducted from October 2006 to January 2007; 134 occupants participated (33 with SHS, 101 without SHS), and 41 dwellings were evaluated (20 with at least one occupant with SHS, and 21 without SHS). Residential environment was surveyed in the dwellings, and all occupants of each dwelling, who varied widely in age, provided answers about health problems. As described in Figure 1, this study was conducted in Sapporo as follow-up to 2005, 2004 (Takeda et al., 2009) and 2003 (Kishi et al., 2009) surveys.

During the first visit, self-administered questionnaires were distributed to all occupants in each dwelling; these were collected during the second visit when the air and dust samples were taken from the living room. No room cleaning occurred within 24 h of the sampling. This study was conducted according to the Guidelines of the Ethical Board for Epidemiological Studies at Hokkaido University Graduate School of Medicine.

Questionnaire

The questionnaires consisted of two sections concern- ing dwelling and personal characteristics. A represen- tative of the household answered the questions about the characteristics of the dwelling such as the number of occupants, materials used to construct the floor and walls (PVC, cloth, paper, wood, plywood, or others), the presence of flame retardants in the interior mate- rials, presence or absence of pets indoors, dampness signs (such as condensation on window panes and/or walls, visible mold growth, moldy odor, slow drying wet towels in the bathroom), water leakage, the frequency of room cleanings, the frequency of window operations, and mechanical ventilation in all rooms. All occupants of each dwelling answered the questions about personal characteristics and the health problems including history of allergy and the presence or the absence of SHS-like symptoms. We used the part of the Japanese version of MM040EA, a validated self- administered questionnaire designed for epidemiologic assessment of SBS symptoms (Mizoue et al., 2001). Parents of pre-school children answered questions about their children's health. The survey included questions about the presence of symptoms during the preceding 3-month period, including eye symptoms (burning and/or irritation), nose symptoms (irritated, stuffy and/or runny nose), throat and respiratory symptoms (hoarse and/or dry throat, or cough), skin symptoms (dry and/or flushed facial skin; scaling/ itching of the scalp or ears; dry, itching and/or red- skinned hands), and general symptoms (fatigue, feeling heavy-headed, headache, nausea/dizziness, difficulty in concentrating, or itching). The questions about general symptoms were omitted for pre-school children. There were three answers for each symptom: often (every week), sometimes, and never. There was an additional question on each symptom concerning its attribution to the home environment, that is, 'are you relieved from the symptom when you leave home?' Symptoms that occurred mainly at home weekly or sometimes were attributed to SHS.

Target compounds

Chemical names and properties of target compounds are presented in Table 2.

Sampling and determination of SVOCs

Air sampling was performed at a height of 1.0–1.5 m from a floor and about 1 m from a wall. Dust samples were collected from all over the floor or from multi- surfaces such as tops of doors, shelves, cupboards, frames, etc. The background levels of all materials used for sampling were examined and confirmed to be negligible. During air-sampling, temperature and rela- tive humidity in the living room were monitored by a Thermo

Recorder TR-72U (T&D Corporation, Mat- sumoto, Japan), and average readings were calculated. Air-sampling and gas-chromatography (GC) analy- ses of chemicals were carried out according to Saito et al. (2007), and chemical analyses were performed in Tokyo Metropolitan Institute of Public Health. Solid phase 10-mm diameter extraction disks were stamped out from 47-mm Empore™ Disks C18 and rinsed with acetone. After drying, the disks were immersed in 500 ppm ascorbate in acetone (about 0.03 mg ascor-bate was absorbed per disk) for the purpose of reducing oxidative decomposition of the phenolic compounds during sampling and transportation. Then, the dried disks were installed in stainless steel holders and air was passed through them at 200 ml/min for 48 h using a vacuum pump. The disks, including the ravel blanks and samples, were stored separately in aluminum bags at)20°C during transportation to the laboratory in Tokyo. The disks were ultrasonicated in 0.3 ml of acetone, the effluents were centrifuged, and aliquots of the supernatants were analyzed by GC (see Appendix).

Dust samples were collected using a vacuum cleaner (National HC-V15, Matsushita Electric Works, Ltd., Osaka, Japan) equipped with a paper dust bag (LCD Allergic Center, Osaka, Japan), and removed from paper bags using stainless steel tweezers and placed in glass tubes previously cleaned with acetone. The tubes were capped, sealed with polytetrafluoroethylene tape, and stored at)20°C during transportation. After removing contaminants, such as pieces of foods and a hair, from dust samples, 1 ml of acetone was added to a 25–50 mg dust sample and the sample was ultraso- nicated for 20 min and allowed to stand overnight. After centrifuging, aliquots of the supernatants were analyzed by GC (see Appendix).

Statistical analysis

The independences of SHS and the characteristics of dwellings or occupants were assessed by Pearson's chi-square test. The correlations between the concen- trations of chemicals in multi-surface and floor dust samples were assessed by Pearson's test, and the differences in concentrations between multi-surface and floor dust samples were assessed by Wilcoxon matched rank test. When the detection rate exceeded 30%, the chemical concentrations were split into two groups, using either the median or MDL as the split point. Then, the independence of any symptom of SHS or mucosal symptoms of SHS including eye, nose or throat and respiratory symptoms, and the categorized chemical concentrations were assessed by Pearson's chi-square test.

When the P values from Pearson's chi-square test for any one of air, multi-surface dust and floor dust were <0.1, the crude and adjusted ORs and respective 95% confidential intervals (CIs) for associations between mucosal symptoms of SHS and SVOC levels were determined, for all of air, multi-surface dust, and floor dust, as follows: The log-transformed concentra- tions were introduced separately into the models of binomial logistic regression. The adjustment allowed for personal factors such as gender, age as an ordinal variable in increments of 10 years, history of allergy and time spent at home (h/day; £ 12, > 12) in Model 1. In addition to the covariables in Model 1, moldy odor was introduced in Model 2; condensation and moldy odor in Model 3. Regardless of the P value for the Pearson's chi-square test, BBzP and DEHP were analyzed by binominal logistic regression because adverse effects of these compounds have been previ- ously reported (Bornehag et al., 2004a; Kolarik et al., 2008). The ORs for skin symptoms and general symptoms were not determined due to low numbers of cases numbers.

Finally, stepwise logistic regression analyses were performed to include several chemicals in the same model simultaneously. Gender, age as an ordinal variable in increments of 10 years, history of allergy, time spent at home (h/day; £ 12 vs. > 12), conden- sation and moldy odor were forcibly entered into the model, and the selection for chemical variables was performed using backward stepwise elimination. In each step, non-significant variables ($P > 0.1$) were eliminated. In the first step, the model included eight chemical variables selected from 12 variables with $P < 0.1$ in Model 3 (Table 8). When results for same chemical in two different samples (for example, air and floor dust) showed $P < 0.1$, the sample with the higher P value was excluded to avoid multi-collinearity problems. DMP, which was strong linearly correlated with DEP, was also excluded. Because TBP in both air and floor dust was strongly associated with mucosal symptoms of SHS in Model 3 (Table 8), TBP in both air and TBP in floor dust were valuated separately by stepwise logistic regression. All analyses were conducted using SPSS software for Windows (SPSS, Chicago, IL, USA).

Results

Characteristics of dwellings and occupants

All 41 dwellings were detached houses, 3- to 8-years old (mean = 5 years), and their living rooms had wood or plywood flooring. The number of inhabitants of each dwelling was 3.3 ± 1.0, and ranged from 2 to 5 (mean = 3). The number of the dwelling with at least one respondent claiming any symptom of SHS was 20 (48.9%), and prevalence rate of SHS among these 20 dwellings was 50.3%, and among the other 21 dwell- ings was 0%. PVC was used most frequently (68.3%) as wall material, as shown in Table 3. In about one- third of the dwellings, the inhabitant did not know whether the ceiling, walls, or curtains contained flame retardants. Most of dwellings (80.5%) had at least one dampness indicator. There was condensation on win- dow panes or walls in 20 dwellings (48.8%) and visible mold growth in 29 dwellings (70.7%).

Table 4 presents the characteristics of the respon- dents. About one-half of respondents reported a history of diagnosed allergy, such as bronchial asthma, atopic dermatitis, rhinitis, conjunctivitis, and other allergic symptom; the sum of 'currently' and 'former' was 53.7%. Currently, smoking was reported by 19% of the respondents. Thirty-three respondents (24.6% of total), consisting of 12 males and 21 females, reported having at least one SHS symptom weekly or sometimes (Table 4). The number of respondents reporting mucosal symptoms (i.e., any eye, nose, and/or throat and respiratory symptoms) was 29 (21.6% of total).

SVOC content in indoor air including both gas-phase and airborne particle

During the sampling period, mean (±s.d.) temperature and humidity were 20.7 ± 1.5 and 45.3 ± 9.7%, respectively. Table 5 presents the detection rates and the concentrations of SVOCs in the living room air. The reported values are total concentrations of an SVOC in air, representing the sum of gaseous and particulate phases. One of the 41 dwellings was not sampled at all due to a pump error and another sample was short of the 48-h sampling time by a few hours; data for 39 or 40 samples of each compound were tabulated. For the sample with insufficient sampling time, some of the target compounds were not quantified.

Among phthalate diesters, DMP, DEP, DiBP, DnBP, and DEHP were detected in all samples, while the detection rates of BBzP and DiNP were low. The highest observed concentration of a phthalate diester was for DEHP, at 1660 ng/m3. The detection rate of DEHA, which is an adipate diester, was also low. Among phosphate triesters, TEP, TBP, and TCiPP were detected in all or most air samples, while TMP, TPP, TEHP, TPhP, and TCP were detected at very low rates or were undetectable. The highest observed concentration was for TCiPP at 2660 ng/m3. BHT was detected in all samples at high concentrations (maximum = 3510 ng/m3), whereas the detection rate of 4-NP was low. S-421 was detected in about 40% of air samples.

SVOC contamination in house dust

Dust samples of the living rooms in 41 dwellings were analyzed: however, some of the target compounds were not quantified if the sample amounts were <25 mg. As presented in Table 6, the highest concentration of all compounds was found for DEHP in multi-surface dust. DEHP ranged from 220 to 10,200 mg/kg of multi-surface dust and from 98.2 to 5850 mg/kg of floor dust. Among phthalate diesters, the detection rates of DiBP, DnBP, BBzP, DEHP, and DiNP exceeded 90%. The concentrations of DiBP, BBzP, DEHP, and DiNP in multi-surface dust were significantly correlated with those in floor dusts. The concentrations of DiBP and BBzP were significantly higher in floor dust than in multi-surface dust. DEHA was detected in all samples. Among the phosphate triesters, the detection rates of TBP, TCiPP, TCEP, TEHP, TBEP, TDCPP, and TPhP ranged from 70 to 100%, whereas TMP, TEP, TPP, and TCP were detected at lower rates or were not detected. The concentrations of TCiPP, TEHP, TBEP, and TPhP in multi-surface dust were significantly correlated with those in floor dust. The concentrations of TCiPP, TDCPP, TPhP, and TCP were significantly higher in multi-surface dust than those in floor dust, whereas those of TBP, TEHP, and TBEP were significantly lower in multi-surface dust than those in floor dust. The concentration of TBEP ranged from 5.9 to 749 mg/kg of multi-surface dust and from 61.8 to 5890 mg/kg of floor dust. The detection rates of alkylphenols, 4-NP, and BHT were high in multi-surface and floor dusts. The concentrations in multi-surface dust were significantly correlated with those in floor dust, and were significantly higher than in floor dust. The detection rate of s-421 in multi-surface dust was 30.8% and that in floor dust was 46.2%. There was a significant correlation between the concentration in multi-surface dust and that in floor dust.

Associations between personal and dwelling characteristics and sick house syndrome

Table 7 presents the relationships between personal and dwelling characteristics and SHS. There was a significant relationship between SHS and history of allergy (any, $P = 0.03$; mucosal, $P = 0.01$), but not gender, age, or current smoking. In terms of dwelling characteristics, significant relationships were found between SHS and frequency of room cleaning (any, $P = 0.01$; mucosal, $P = 0.01$), frequency of window opening ($P = 0.01$; mucosal, $P = 0.03$), moldy odor (any, $P = 0.02$; mucosal, $P = 0.045$), and stuffy air (any, $P = 0.05$; mucosal, $P = 0.02$). For both room cleaning and window opening, the incidence of SHS was higher in the high-frequency group than in the lowfrequency group. Renovation within 1 year was significantly related to any symptom of SHS ($P = 0.03$), but not to mucosal symptoms of SHS. Condensation and moldy odor was significantly related to symptoms of SHS (any, $P = 0.01$; mucosal, $P = 0.01$), but condensation and visible mold growth was not. There was no significant relationship between SHS symptoms and mechanical ventilation in all rooms. Table 8 presents the crude and adjusted ORs and respective 95% CIs for associations between mucosal symptoms of SHS and 10-fold increase in SVOC levels as determined by binomial logistic regression analysis. Skin and general symptoms were excluded, because those apparently differ in pathogenic mechanism from mucosal symptoms including eyes, nasal, throat and respiratory symptoms. The selection of the compounds was described in Section 'Statistical analysis'. Inverse associations were found between mucosal symptoms of SHS and several compounds, that is, DEP and TBEP in air in Model 1, DMP and DEP in multi-surface dust in Models 1 and 2, DnBP in multi-surface dust in Model 1, DEHA in multi-surface dust and TBEP in floor dust in all Models. On the contrary, TBP in floor dust was directly and very strongly associated with mucosal symptoms of SHS in all models (ORs from 14 to 16), and the adjustments for moldy odor, condensation and moldy odor led the OR for TBP in air from 2.9 to 5.2 and 4.4, respectively, however, the associations were not significant (Model 2, $P = 0.07$; Model 3, $P = 0.09$). TDCPP in floor dust was directly associated with mucosal symptoms in Models 1 and 3, and s-421 in multi-surface dust was also directly associated with mucosal symptoms of SHS in Model 3. There were suggestions of positive associations between mucosal symptoms and DEHP in floor dust, although not statistically significant (Model 3, $P = 0.08$).

The chemical variables associated with mucosal symptom of SHS in Model 3 of Table 8 at a level of $P < 0.10$ were TBP and TBEP in air, DMP, DEP, DnBP, DEHA, and s-421 in multi-surface dust, DEHP, TBP, TBEP, TDCPP, and s-421 in floor dust. Several chemicals from these twelve variables were introduced into the same model as described in Section 'Statistical analysis', and the results present in Table 9. Strong direct association between mucosal SHS and TBP in air was observed (Model 1). The OR for TBP in floor dust was also high (Model 2). TBEP in floor dust was inversely associated with mucosal symptoms of SHS (Models 1 and 2).

Discussion

Semi-volatile organic compounds released from indoor surfaces partition between the gas-phase, airborne particles, and house dust. The distribution of SVOCs between multi-surface dust and floor dust may equilibrate via the gas-phase, thus explaining the observed correlations between chemical concentrations in multisurface dust and those in floor dust (Table 6). In addition, chemical concentrations are likely to be much higher in dust samples that have been in contact with the source of the chemicals. For example, TBEP is commonly used in floor polish, which could explain the high concentration of TBEP found in floor dust. Larger molecular weight compounds with lower vapor pressures tend to predominate in dust (Clausen et al., 2008; Weschler and Nazaroff, 2008; Weschler et al., 2008). We detected the larger molecular weight compounds such as BBzP, DiNP, DEHA,TDCPP, and TPhP, at high rates in dust, rather than in air, in addition, TEHP and TCP were found only in dust (Tables 5 and 6). Elevated concentrations of DEHP in both air and dust samples reflect its ubiquitous use indoors coupled with its presence in airborne particles. On the contrary, TEP and DMP were found in a small number of dust samples and their concentrations were very low in dust. Thus, lower molecular weight compounds probably existed mostly in the air, particularly in gas-phase. The negligible detection of TMP and TPP in both air and dust suggests infrequent use of these chemicals. Because of its chemical properties, TBP should be distributed more in air, primarily in the gas-phase.

The mean or median concentrations of DEHP in air and dust detected in this study were higher than those reported in studies from USA (Rudel et al., 2003), Sweden (Bornehag et al., 2004a), and Bulgaria (Kolarik et al., 2008), whereas the concentration of BBzP in dust in this study was considerably lower than that reported in the other studies. In addition, the air concentrations of various compounds, such as 4-NP, DEHA, DEP, DiBP, DnBP and BBzP, were lower in the present study than those reported in the US study (Rudel et al., 2003).

Both the inhalation of air and the ingestion of house dust are pathways of exposure for the inhabitants of contaminated houses. The SVOCs with ester bonds, such as phthalate diesters and phosphate triesters, can be hydrolyzed by lipase in the lung or in the digestive tract, allowing the resulting compounds to be absorbed into the human body. Direct air to skin transfer followed by dermal absorption may also be an important route of exposure for some of the SVOCs listed in Table 2 (Weschler and Nazaroff, 2008). Therefore, to evaluate exposures and potential health effects of SVOCs, it is useful to determine their concentrations in both dust and air.

Associations between DEHP in house dust and allergies in children were previously reported in studies conducted in Sweden and Bulgaria (Bornehag et al., 2004a; Kolarik et al., 2008). The Swedish study also found an association between BBzP in house dust and allergy symptoms, such as rhinitis and eczema. Our data did not reveal any associations between phthalate diesters and current diagnosed allergy, most likely because of lack of power. The population in the current study included only four persons with asthma, 11 persons with rhinitis, 14 persons with dermatitis, and four persons with conjunctivitis.

Although we found direct associations between mucosal symptoms of SHS and some SVOCs, the association between TDCPP in floor dust and mucosal symptoms of SHS was attenuated considerably by introducing TBP into the model together with TDCPP (data not shown). On the contrary, the strong direct association between TBP in floor dust and mucosal symptoms of SHS persisted even after adjusting for frequency of room cleaning as well as after adjusting for the chemicals that correlated with the log-translated concentration of TBP in floor dust, such as DiBP in multi-surface dust and DiBP and

DEHA in floor dust (data not shown). TBP is emitted from wall and ceiling coverings (Saito et al., 2007). Thus, the presence of TBP in floor dust could suggest emission of large amounts of TBP from walls and/or ceiling into the air. If the room had been closed and not ventilated for a few days, the concentration of TBP in air would be expected to be higher than the concentrations reported in this study. Based on its Koa, TBP is expected to distribute predominantly in gas-phase, and the route of exposure to TBP would have been primarily via inhalation of gas-phase TBP. TBP is known to be irritating to the skin, eyes, mucous membranes, and respiratory tract in humans (WHO/IPCS, 1991). In our study, TBP, particularly in air, was strongly associated with mucosal symptoms of SHS in the multi-chemical models (Table 9). The organochlorine synergist, s-421 is a persistent, lipophilic, chlorinated hydrocarbon that is used widely in Japan as a synergist for pyrethroids and other insecticides against mosquitoes, houseflies, cockroaches, and termites; it is also sometimes used in building materials and carpet and vacuum cleaner dust bag. It is possible that the results for s-421 are surrogates for those of one or more pyrethroids or other insecticides with which s-421 is commonly used.

We found inverse associations between mucosal symptoms of SHS and some SVOCs such as DMP, DEP, DnBP, DEHA, and TBEP (Table 8). After adjusting for frequency of room cleaning (times/week) or frequency of window operation (times/week), these inverse associations persisted (data not shown). These inverse associations could imply an elevated level of dampness in the dwellings. Dampness is known to be associated with building-related symptoms (Bornehag et al., 2005; Kim et al., 2007; Park et al., 2004; Saijo et al., 2004; Tham et al., 2007). It is possible that some of the SVOCs, at least DEP and TBEP, were degraded by fungi that inhabit damp dwellings, probably in/on walls, floors, or in dust. Previous studies demonstrated the biodegradation of plasticizers or plasticized PVCs by a variety of microorganisms (Nakamiya et al., 2005; Nalli et al., 2006a,b; Webb et al., 2000). Although we did not obtain enough data to explain these inverse associations, airborne Penicillium sp. was found to be inversely correlated with the concentrations of some compounds (for example, Penicillium sp. vs. DEP in air: R =)0.403, $P < 0.05$ by Pearson’s test). In addition, the concentrations of DEP in air and TBEP in floor dust were lower in the dwellings with moldy odors than in those without moldy odors: DEP in air, $P = 0.09$; TBEP in floor dust, $P = 0.03$ in t-test of log-transformed data (data not shown). Some toxic compounds could have been produced by the degradation of SVOCs with ester bonds, albeit in amounts too small to induce sub acute mucosal symptoms by themselves. The metabolites of phthalate diesters or adipate diesters are often more toxic than their parent compounds (Gartshore et al., 2003; Nalli et al., 2002). For example, monoethylphthalate, a degradation product of DEP, was suspected having an adverse effect on pulmonary function (Hoppin et al., 2004).

In damp dwellings, plasticizers are likely to decompose into monoesters and alkyl alcohols, and phosphate triesters decompose into diesters or monoesters and alcohols. Indeed, previous studies reported that the existence of 2-ethyl-1-hexanol in indoor air and/or in the emissions from floor coverings (Norbäck et al., 2000; Tuomainen et al., 2004; Wa˚ linder et al., 2001; Wieslander et al., 1999) was often associated with nasal symptoms (Wieslander et al., 1999) or asthma (Norbäck et al., 2000) in the occupants. Emission of halogenated degradation products such as 1-chloro-2- propanol, 2-chloro-1-propanol and 1,2-dichloropropane from polyurethane was observed during chamber experiments involving phosphate triester flame retardants (Salthammer et al., 2003). 2-Butoxyethanol, which is likely produced from TBEP breakdown, can be absorbed via inhalation and dermal contact in humans (Kezic et al., 2004; Korinth et al., 2007) and has induced skin irritation and immune response alterations in animals (Singh et al., 2001). We found that the incidence of SHS was higher when the frequency of room cleaning or window opening was higher (Table 7). Possibly, the existence of symptoms provoked frequent room cleaning and window opening. The concentrations of several compounds were higher in the dwellings with high frequency of room cleaning (‡5 times/week) than in those with low frequency: 4-NP in multi-surface dust, $P = 0.1$; TBP in multi-surface dust, $P = 0.03$; TBEP in air, $P = 0.1$ (t-test of log-transformed data). There are several limitations of this study that should be addressed. Firstly, the population evaluated in this study was very small. To detect differences in proportions when evaluating the association between BBzP in multi-surface dust and mucosal symptoms of SHS using a 2 · 2 contingency table, we would need to evaluate >1000 participants. The small sample size made it difficult to clarify whether SVOCs were associated with each individual symptom of SHS. Secondly, we asked about health problems of all occupants in each dwelling. We analyzed data using single level logistic regression analysis, not multi-level analysis. Therefore, the results were not corrected for the intraclass correlations and precision could be overstated. Thirdly, the estimation of SHS was less than entirely objective, particularly in children, because the symptoms of SHS were self-reported or were reported by parents. Finally, there was potential population bias. One-third of the participants recruited in 2004 remained in the survey in 2006 and their dwellings were surveyed for three consecutive years, suggesting the possibility for participant bias in the 2006 sample. However, the gender ratio and the prevalence of allergy, asthma, and SHS in 2006 were similar to those in 2004; thus, any bias in the association between SVOCs and SHS is probably negligible. Evaluating health risks and reducing the risks associated with chronic indoor exposure to SVOCs have important public health implications. Among SVOCs found in residential dwellings, TBP, which is common in ceiling and wall coverings, was associated with a risk for mucosal symptoms of SHS. DEHP and BBzP, phthalate diesters, were possibly associated with an increased risk for SHS. In addition, the association between SHS and s-421 suggested that the use of pyrethroid insecticides could elicit symptoms of SHS. Although some SVOCs such as DnBP, DEHA, and TBEP were inversely associated with SHS, these associations should be further evaluated in relation to other environmental factors including dampness, microbial growth, and/or toxic degradation products of SVOCs. The preliminary findings obtained in this study should be evaluated in a larger population in future studies.

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Appendix

GC analysis

An Agilent 5890 Series II GC connected with Agilent 5971A mass spectral detector (Agilent Technologies Inc., Palo Alto, CA, USA) was used for analysis of seven phthalate diesters, DEHA, 4-NP, BHT, and s-421 in the presence of DnBP-d_4 and fluoranthan-d_{10}. The column was Ultra-1 (12 m×0.2 mm [inner diameter]× 0.33μm; Agilent J&W Scientific Inc., Folsom, CA, USA). The oven temperature was programmed as follows: 120°C for 2 min, followed by 20°C /min up to 200°C, then 10°C /min up to 270°C, and finally 270°C for 10 min. Helium was used as the carrier gas (40 kPa, constant pressure mode). The injector was operated in the splitless mode at 280°C (2μl injection volume). The detector was operated in the SIM mode at a temperature of 280°C. The quantification ions of DnBP-d4 and fluoranthen-d10 were 153 and 212, respectively, and the quantification and confirmation ions of target compounds were as follows: DMP, 163, 194; DEP, 149, 177; DiBP, 149, 223; DnBP, 149, 223; BBzP, 149, 206; DEHP, 149, 167; DiNP, 149, 167; DEHA, 129, 147; 4- NP, 135, 107; BHT, 205, 220; and s-421, 130, 181. Organophosphate flame retardants were analyzed by GC/flame photometric detection (FPD) using an Agilent 6890 GC-FPD (Agilent Technologies Inc., Palo Alto, CA, USA) equipped with a DB-17 column (30 m · 0.53 mm [inner diameter] · 1μm; J&W Scientific Inc., Folsom, CA, USA). Helium was used as the carrier gas (20 ml/min, constant flow mode) and as a makeup gas (25 ml/min). The hydrogen flow was 75 ml/min. The injector was operated in the splitless mode at 250°C (2μl injection volume). The GC oven temperature was maintained at 90°C for 2 min, then increased at 15°C /min up to 200°C, 5°C /min up to 220°C, 20°C /min to 260°C, and maintained at 260°C for 10 min. The FPD was operated at 250°C with P-filter. An internal standard [tris(*1H,1H,5H*-

octafluoropentyl) phosphate] was monitored and used for quantification. Quality assurance was as described previously (Saito et al., 2007). The instrumental limits of detection (ILOD) were defined as the absolute amounts of analytes, except DnBP and DEHP, that yielded S/N = 5. For DnBP and DEHP, ILODs were defined as 10-fold of the standard deviations (s.d.) of six blank determinations because they were detected as contaminants in trace amounts in the blank tests. The method detection limits (MDLs) for air sampling were calculated by the ILODs, the area of the solid extraction disk, and the sampling period (48 h); and the MDLs for dust sampling were calculated by the ILODs, the volume of extracts, and the sample weights. These values are included in Tables 5 and 6.

Fig.1 Study population

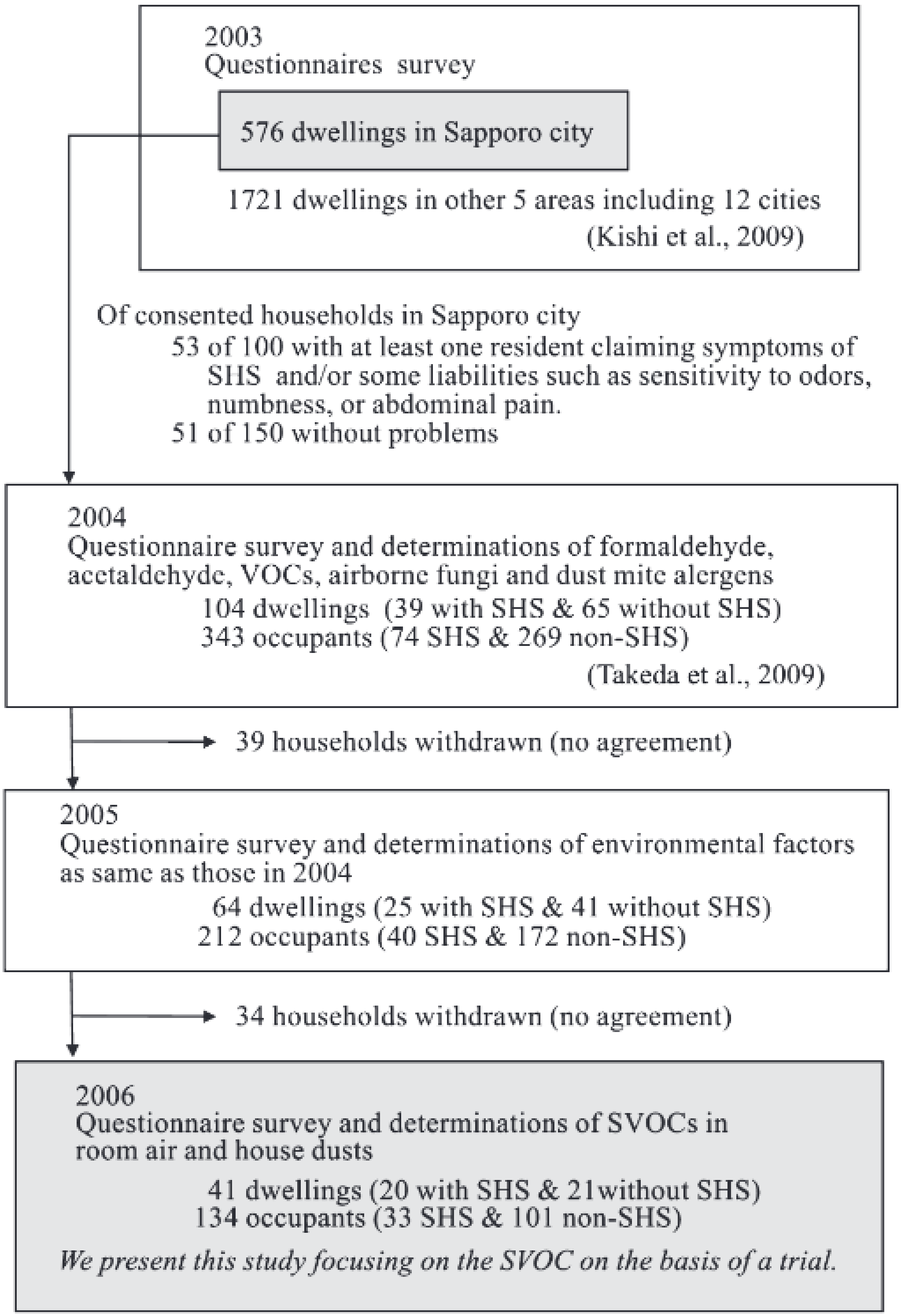

Table 1 Association of phthalate exposure and allergy or pulmonary function in previous studies

Authors (year)	Country	Design, subjects, outcome	Exposure assessment	Chemical concentration	Association
Bornehag et al. (2004a)	Sweden	Nested case-control study Children aged 3–8 years (198 cases and 202 controls), 390 homes Wheezing, rhinitis, eczema	Chemicals in multi-surface dusts (346 bedrooms)	Median, GM, range[a] (mg/kg dust): BBzP, 135, 319, 0–45549 DEHP, 770, 1310, 0–40459	Chemical, symptom, aOR (95% CI) (Q4 vs Q1): BBzP, rhinitis, 3.0 (1.3–6.9) BBzP, eczema, 2.6 (1.2–5.3) DEHP, asthma, 2.9 (1.4–6.3)
Hoppin et al. (2004)	USA	Cross-sectional study Adults (140 females and 100 males) Pulmonary function Forced vital capacity (FVC); forced expiratory volume at 1 s (FEV1); peak expiratory flow (PEF), maximum mid-expiratory flow (MMEF)	Phthalate monoesters in urine	GM, GSD, range (ng/g creatinine): Males MBP, 30, 2.5, 1.6–962 MBzP, 17, 2.5, 2.1–544 MEP, 240, 5.4, 0.2–6786 MEHP, 2, 3.2, 0.05–49 Females MBP, 45, 3.1, 4.7–2763 MBzP, 23, 2.4, 2.3–189 MEP, 321, 4.2, 0.5-4539 MEHP, 2, 5.0, 0.02–192	Chemical, pulmonary function, relation: Males MBP (25P → 75P), FEV1, −112 ml MBP (25P → 75P), FVC, −131 ml MBP (25P → 75P), −367 ml/sec MEP (25P → 75P), FEV1, −102 ml Females MEHP ((25P → 75P), FVC, ↑28 ml
Kolarik et al. (2008)	Bulgaria	Nested case-control study Pre-school children (102 cases and 82 controls), 177 homes Wheezing, rhinitis, eczema	Chemicals in multi-surface dusts	GM (mg/kg dust): BBzP, 320 DEHP, 960 (range,20–29450)	Chemical, Symptom, aOR (95% CI) (Q4 vs Q1): DEHP, wheezing, 3.7 (1.4–9.9)

aOR, odds ratio adjusted for potential confounders; Q1, first quartile; Q4, fourth quartile; GM, geometric mean; GSD, geometric standard deviation.
[a]Ranges were obtained from Bornehag et al. (2004b).

Table 2 Properties of target compounds

Chemical name	Abbreviations	CAS number	MW	Log *Ps* (25°C)	Log K_{oa} (25°C)
Phthalate diesters					
Dimethylphthalate	DMP	131-11-3	194.2	−5.8	7.3
Diethylphthalate	DEP	84-66-2	222.3	−6.4	8.0
Di(*iso*-butyl)phthalate	DiBP	84-69-5	278.4	−7.9	9.3
Di(*n*-butyl)phthalate	DnBP	84-74-2	278.4	−8.1	9.5
Butylbenzylphthalate	BBzP	85-68-7	312.4	−10.1	11.3
Di(2-ethylhexyl)phthalte	DEHP	117-81-7	390.5	−11.6	12.7
Di(*iso*-nonyl)phthalate	DiNP	28553-12-0	418.7	−12.7	13.8
Adipate diesters					
Di(2-ethylhexyl)adipate	DEHA	103-23-1	370.6	−10.1	11.4
Phosphate triesters					
Trimethylphosphate	TMP	512-56-1	140.1	0.3	1.4
Triethylphosphate	TEP	78-40-0	182.2	−1.0	2.4
Tripropylphosphate	TPP	513-08-6	224.2	−2.3	3.7
Tributylphosphate	TBP	126-73-8	266.3	−3.7	5.0
Tris(2-chloro-*iso*-propyl)phosphate	TCiPP	13674-84-5	327.6	−3.7	5.0
Tris(2-chloroethyl)phosphate	TCEP	115-96-8	285.5	−3.8	5.2
Tris(2-ethylhexyl)phosphate	TEHP	78-42-2	434.6	−7.4	8.5
Tris(2-butoxyethyl)phosphate	TBEP	78-51-3	398.5	−7.6	9.6
Tris(1, 3-dichloro-2-propyl)phosphate	TDCPP	13674-87-8	430.9	−5.8	7.1
Triphenylphosphate	TPhP	115-86-6	326.3	−6.35	7.8
Tricresylphosphate	TCP	78-30-8	368.4	−7.2	8.6
Alkylphenols					
4-Nonylphenol	4-NP	104-40-5	220.4	−7.7	9.7
Dibutylhydroxytoluene	BHT	128-37-0	220.4	−6.3	7.5
Organochlorine synergist					
2,3,3,3,2′,3′,3′,3′-Octachlorodipropylether	s-421	127-90-2	377.4	−6.8	7.9

Log K_{oa} was calculated according to Weschler and Nazaroff (2008): log K_{oa} = log K_{ow} + log H + 1.39. Log K_{ow} and log H were obtained using SPARC online Calculator v4.2 (http://ibmlc2.chem.uga.edu/sparc/). MW, molecular weight (g/mole); Ps, saturation vapor pressure (atm); K_{oa}, octanol–air partition coefficient; K_{ow}, octanol–water partition coefficient; H, Henry's law constant (M/atm).

Table 3 Dwelling characteristics

Variable	Overall (N = 41) *n* (%)
Dwellings with 'SHS problem'[a]	20 (48.9)
Wall materials	
Polyvinyl chloride	28 (68.3)
Cloth or paper	8 (19.5)
Wood or plywood	5 (12.2)
Use of flame retardant	
Walls	
Yes	17 (41.5)
No	9 (22)
Do not know	15 (36.6)
Ceilings	
Yes	16 (39)
No	10 (24.4)
Do not know	15 (36.6)
Curtains	
Yes	15 (36.6)
No	12 (29.3)
Do not know	14 (34.1)
Dampness	
Condensation on window panes and/or walls	20 (48.8)
Visible mold growth	29 (70.7)
Moldy odor	10 (24.4)
Slow drying wet towels in the bathroom	5 (12.2)
Water leakage	5 (12.2)
	Mean ± SD
Occupants (persons/dwelling)	3.3 ± 1.0
Room cleaning (times/week)	4.7 ± 2.7
Window opening (times/week)	4.1 ± 3.2

[a]There were at least one person reporting any symptom of SHS.

Table 4 Inhabitant characteristics

Characteristics	Overall (N = 134) n (%)
Gender	
Male	64 (47.8)
Female	70 (52.2)
Age (years)	
<20	47 (35.1)
20–39	31 (23.2)
40–59	40 (29.8)
≥60	16 (11.9)
History of allergy	
Current	27 (20.1)
Former	45 (33.6)
Never	62 (46.3)
Current smoking	
Yes	19 (14.2)
More than any one symptom of SHS[a]	33 (24.6)
Mucosal symptom of SHS[a] (any one symptom of eye, nose, and/or throat and respiratory symptoms)	29 (21.6)
Specific symptoms of SHS[a]	
Eye symptoms	5 (3.7)
Nose symptoms	20 (14.9)
Throat and respiratory symptoms	20 (14.9)
Skin symptoms	13 (9.7)
General symptoms	2 (3.7)

[a]Respondents reporting at least one symptom 'weekly' or 'sometimes' were accounted for.

Table 5 Detection rates and the concentrations of semi-volatile organic compounds in room air: Values shown are total concentration of given SVOC in air, representing the sum of gaseous and particulate phases

	n	MDL[a] (ng/m^3)	>MDL (%)	Median (ng/m^3)	Range (ng/m^3)
Phthalate diesters					
DMP	40	3.2	100	47.9	11.9–191
DEP	40	3.6	100	60.7	22.3–203
DiBP	40	0.79	100	75	13.2–321
DnBP	40	13.6	100	200	79.6–740
BBzP	39	2.9	25.6	<MDL	<MDL–26.6
DEHP	40	11.6	100	147	11.8–1660
DiNP	39	64.9	12.8	<MDL	<MDL–192
Adipate diester					
DEHA	39	5.4	25.6	<MDL	<MDL–14.0
Phosphate triesters					
TMP	39	10	2.6	<MDL	<MDL–21.1
TEP	40	5.1	100	62.3	18.1–511
TPP	39	4.8	7.7	<MDL	<MDL–17.5
TBP	40	7.1	97.5	27.1	<MDL–121
TCiPP	40	10.8	100	89.2	15.5–2660
TCEP	40	12.6	60	15.5	<MDL–297
TEHP	40	13	0	–	–
TBEP	40	11.8	64.1	23	<MDL–159
TDCPP	40	11.5	37.5	<MDL	<MDL–61.4
TPhP	39	15.6	7.7	<MDL	<MDL–32.1
TCP	39	77.9	0	–	–
Alkylphenols					
4-NP	39	57.3	12.8	<MDL	<MDL–194
BHT	40	2.5	100	550	29.2–3510
Organochlorine synergist					
s-421	39	8.1	42.5	<MDL	<MDL–184

Abbreviations for chemical compounds: see Table 2.
[a]MDLs for air samples were defined as described in Appendix; detections rates are reported as % above MDL.

Table 6 Detection rates and the concentrations of semi-volatile organic compounds in household dust

		Multi-surface				Floor					
	MDL[a] (mg/kg)	*n*	>MDL (%)	Median (mg/kg)	Range (mg/kg)	*n*	>MDL (%)	Median (mg/kg)	Range (mg/kg)	r^b	P^c
Phthalate diesters											
DMP	0.2	40	30	<MDL	<MDL–1.01	41	24.3	<MDL	<MDL–4.9	−0.04	0.36
DEP	0.24	41	65.9	0.35	<MDL–6.3	41	62.5	0.33	<MDL–1.9	0.19	0.23
DiBP	0.08	41	100	2.4	0.5–21.8	41	100	2.9	0.6–31.1	0.78**	< 0.01
DnBP	3.5	41	100	22.3	5.1–549	41	97.6	19.8	1.8–1476	−0.07	0.96
BBzP	0.2	41	92.7	2.4	<MDL–35.8	41	97.6	4.2	<MDL–52.1	0.51**	< 0.01
DEHP	0.84	41	100	1200	220–10200	41	100	880	98.2–5850	0.28**	0.05
DiNP	4	41	100	116	4.0–13100	41	100	126	10.6–1200	0.40**	0.64
Adipinate diesters											
DEHA	0.33	41	100	6.6	1.9–608	41	100	6.5	2.3–196	0.39*	0.08
Phosphate triesters											
TMP	1	40	0	–	–	40	0	–	–	–	–
TEP	0.52	40	30	<MDL	<MDL–2.1	40	20	<MDL	<MDL–2.1	−0.01	0.03
TPP	0.49	40	0	–	–	40	0	–	–	–	–
TBP	0.73	40	72.5	1.1	<MDL–2.7	40	90	1.4	<MDL–15.6	−0.21	0.04
TCiPP	1.1	41	100	50.9	10.3–462	41	100	18.7	5.4–291	0.46**	< 0.01
TCEP	1.3	41	92.7	9.8	<MDL–70.7	41	97.6	7.5	<MDL–308	−0.001	0.27
TEHP	1.3	40	70	2.1	<MDL–6.6	40	90	4.3	<MDL–16.2	0.53**	< 0.01
TBEP	1.2	41	100	164	5.9–749	41	100	1570	61.8–5890	0.60**	< 0.01
TDCPP	1.2	41	100	22.3	5.8–127	41	73.2	4	<MDL–105	−0.04	< 0.01
TPhP	1.6	41	97.6	14.3	<MDL–175	41	75.6	5.4	<MDL–78.4	0.69**	< 0.01
TCP	4	40	20	<MDL	<MDL–102	40	12.5	<MDL	<MDL–13.9	0.19	< 0.01
Alkylphenols											
4-NP	2.2	40	76.1	4.3	<MDL–36.2	40	73.1	3.1	<MDL–42.3	0.89**	0.01
BHT	0.15	41	100	2.4	0.6–428	41	100	1.5	0.6–28.5	0.53**	< 0.01
Organochlorine synergist											
s-421	0.68	40	30.8	<MDL	<MDL–17.5	40	46.2	<MDL	<MDL–4.3	0.44**	0.61

Abbreviations for chemical compounds: see Table 2.
[a]MDLs for dust samples were defined as described in Appendix; detections rates are reported as % above MDL.
[b]Correlation coefficients (r) values were calculated by Pearson's test: *$P < 0.05$; **$P < 0.01$.
[c]Significant differences between multi-surface and floor dusts were assessed by Wilcoxon matched rank test.

Table 7 Factors relating to sick house syndrome (SHS)

Factors	Total number	Any symptom of SHS[a] n (%)	P	Mucosal symptom of SHS[b] n (%)	P
Age (years)					
<20	47	14 (29.8)	0.31	13 (27.7)	0.21
≥20	87	19 (21.8)		16 (18.4)	
Gender					
Female	70	21 (30)	0.13	17 (24.3)	0.44
Male	64	12 (18.8)		12 (18.8)	
History of allergy					
Yes	72	25 (34.7)	0.03	22 (30.6)	0.01
No	62	8 (12.9)		7 (11.3)	
Current smoking (inhabitants older than 18 years)					
Yes	19	3 (15.8)	0.5	3 (15.8)	0.78
No	70	16 (22.9)		13 (18.6)	
Time spent at home (h/day)					
≤ 12	43	6 (14)	0.049	5 (11.6)	0.05
>12	91	27 (29.7)		24 (26.4)	
Renovation within 1 year					
Yes	12	6 (50)	0.03	4 (33.3)	0.3
No	122	27 (22.1)		25 (20.5)	
Room cleaning (times/week)					
<5	62	9 (14.5)	0.01	7 (11.3)	0.01
≥5	72	24 (33.3)		22 (30.6)	
Window operation (times/week)					
<5	53	7 (13.2)	0.01	6 (11.3)	0.03
≥5	77	24 (31.2)		21 (27.3)	
Condensation on window panes and/or walls					
Yes	73	19 (26)	0.68	17 (23.3)	0.61
No	61	14 (23)		12 (19.7)	
Visible mold growth					
Yes	104	28 (26.9)	0.25	25 (24)	0.21
No	30	5 (16.7)		4 (13.3)	
Moldy odor					
Yes	32	13 (40.6)	0.02	11 (34.4)	0.045
No	102	20 (19.6)		18 (17.3)	
Condensation and visible mold growth					
Yes	67	17 (25.4)	0.84	15 (22.4)	0.83
No	67	16 (23.9)		14 (20.9)	
Condensation and moldy odor					
Yes	18	9 (50)	0.01	8 (44.4)	0.01
No	116	24 (20.7)		21 (18.1)	
Slow drying wet towels in the bathroom					
Yes	18	6 (33.3)	0.36	6 (33.3)	0.2
No	116	27 (23.3)		23 (19.8)	
Water leakage					
Yes	17	4 (23.5)	0.91	2 (11.8)	0.29
No	117	29 (24.8)		27 (23.1)	
Pets indoors					
Yes	41	12 (29.3)	0.41	12 (29.3)	0.16
No	93	21 (22.6)		17 (18.3)	
Stuffy air					
Yes	10	6 (60)	0.05	5 (50)	0.02
No	103	21 (20.4)		19 (18.4)	
Mechanical ventilation in all rooms					
Yes	75	17 (22.7)	0.32	15 (20)	0.4
No	59	16 (27.1)		14 (23.7)	

P values were determined by chi-square test.
[a]Any of all SHS symptoms. [b]Any of eye, nasal, throat and respiratory SHS symptoms.

Table 8 Associations between concentrations of SVOCs and mucosal symptoms of SHS evaluated by logistic regression models including single chemical

Chemical	Sample	Total (*n*)	Mucosal symptom (*n*)	Crude OR (95% CI)	Model 1 OR (95% CI)	Model 2 OR (95% CI)	Model 3 OR (95% CI)
Phthalate diesters							
DMP	Air	130	28	0.4 (0.1–2.0)	0.3 (0.05–1.6)	0.4 (0.1–2.3)	0.3 (0.1–2.0)
	Multi-surface dust	134	29	0.4 (0.1–1.1)	0.3 (0.1–0.9)*	0.3 (0.1–1.0)*	0.3 (0.1–1.0)
DEP	Air	130	28	0.1 (0.02–0.9)*	0.1 (0.01–0.9)*	0.2 (0.02–1.4)	0.2 (0.02–1.5)
	Multi-surface dust	134	29	0.4 (0.1–1.1)	0.3 (0.1–0.9)*	0.3 (0.1–1.0)*	0.3 (0.1–1.0)
	Floor dust	132	29	0.5 (0.2–1.7)	0.4 (0.1–1.6)	0.5 (0.1–1.8)	0.5 (0.1–2.0)
DnBP	Air	130	28	0.4 (0.05–2.6)	0.5 (0.1–3.6)	0.5 (0.1–3.6)	0.4 (0.05–3.3)
	Multi-surface dust	134	29	0.4 (0.2–1.2)	0.3 (0.1–1.0)*	0.4 (0.2–1.1)	0.4 (0.1–1.1)
	Floor dust	134	29	0.4 (0.2–1.1)	0.5 (0.2–1.2)	0.5 (0.2–1.3)	0.6 (0.2–1.4)
BBzP	Multi-surface dust	134	29	2.0 (0.9–4.6)	1.9 (0.8–4.7)	1.7 (0.7–4.2)	2.0 (0.8–4.8)
	Floor dust	132	29	2.3 (0.7–7.3)	1.7 (0.5–6.0)	1.7 (0.5–5.8)	1.9 (0.5–6.6)
DEHP	Air	130	28	0.7 (0.3–1.8)	0.8 (0.3–2.2)	1.0 (0.3–2.7)	0.9 (0.3–2.4)
	Multi-surface dust	134	29	0.7 (0.3–1.9)	0.5 (0.2–1.5)	0.6 (0.2–1.7)	0.6 (0.2–1.7)
	Floor dust	134	29	2.4 (0.7–7.9)	2.8 (0.8–9.9)	3.0 (0.8–11)	3.3 (0.9–12)
Adipate diester							
DEHA	Multi-surface dust	134	29	0.2 (0.1–0.7)*	0.2 (0.1–0.6)**	0.2 (0.1–0.6)**	0.2 (0.1–1.2)
	Floor dust	134	29	1.5 (0.7–3.5)	1.3 (0.5–3.1)	1.3 (0.5–3.2)	1.2 (0.5–3.0)
Phosphate triesters							
TBP	Air	130	28	2.7 (0.6–12)	2.9 (0.6–14)	5.2 (0.9–30)	4.4 (0.8–24)
	Multi-surface dust	130	28	1.6 (0.4–7.1)	1.2 (0.3–5.9)	2.2 (0.4–12)	2.1 (0.4–12)
	Floor dust	132	29	14 (3.1–66)**	16 (3.3–82)**	14 (2.7–75)**	15 (2.7–80)**
TBEP	Air	127	25	0.3 (0.1–0.9)*	0.3 (0.1–1.0)*	0.4 (0.1–1.2)	0.4 (0.1–1.1)
	Multi-surface dust	134	29	0.4 (0.2–1.0)	0.4 (0.1–1.2)	0.5 (0.2–1.5)	0.5 (0.2–1.5)
	Floor dust	134	29	0.3 (0.1–0.6)**	0.3 (0.1–0.6)**	0.3 (0.1–0.7)**	0.3 (0.1–0.7)**
TDCPP	Multi-surface (mg/kg)	134	29	1.1 (0.3–4.3)	1.0 (0.3–4.0)	1.5 (0.4–6.5)	1.9 (0.4–8.3)
	Floor (mg/kg)	134	29	2.1 (1.1–4.0)*	2.1 (1.0–4.3)*	2.1 (1.0–4.4)	2.2 (1.0–4.6)*
Alkylphenols							
4-NP	Multi-surface dust	130	28	2.6 (1.0–6.5)*	2.8 (1.0–8.3)	2.3 (0.7–7.2)	2.2 (0.7–6.9)
	Floor dust	132	29	1.7 (0.8–3.9)	2.0 (0.9–4.8)	1.6 (0.6–4.1)	1.6 (0.7–4.1)
Organochlorine synergist							
s-421	Air	130	28	1.5 (0.7–3.1)	1.7 (0.8–3.7)	1.7 (0.8–3.9)	1.8 (0.8–4.1)
	Multi-surface dust	134	29	1.9 (0.9–4.0)	2.1 (1.0–4.5)	2.1 (1.0–4.6)	3.0 (1.3–7.3)*
	Floor dust	132	29	1.5 (0.7–3.6)	1.7 (0.7–4.4)	2.1 (0.8–5.4)	2.4 (0.9–6.1)

Abbreviations for chemical compounds: see Table 2.
Odds ratio of 10-fold increase in chemical concentration was calculated by binominal logistic regression. Each variable was introduced into the models separately and adjusted for age (ordinal variable in increments of 10 years), gender, history of allergy and time spent at home (h/day; ≤ 12, >12) in Model 1, for age (ordinal variable in increments of 10 years), gender, history of allergy, time spent at home (h/day; ≤ 12, >12) and moldy odor in Model 2, and for age (ordinal variable in increments of 10 years), gender, history of allergy, time spent at home (h/day; ≤ 12, >12), and condensation and moldy odor in Model 3.
* $P < 0.05$; ** $P < 0.01$.

Table 9 Associations of concentrations of SVOCs with mucosal symptoms of SHS evaluated by logistic regression models including several chemicals

	OR (95% CI)	
	Model 1	Model 2
Number (total, SHS)	(130, 28)	(132, 29)
Chemicals (sample)		
DnBP (multi-surface dust)		0.3 (0.1–0.9)*
DEHP (floor dust)	4.3 (0.9–20)	
DEHA (multi-surface dust)	0.3 (0.1–1.2)	
TBP (air)	38 (2.5–579)**	
TBP (floor dust)		24 (2.9–192)**
TBEP (floor dust)	0.4 (0.1–1.0)*	0.3 (0.1–0.7)**
S-421 (multi-surface dust)	4.5 (1.2–17)*	

Abbreviations for chemical compounds: see Table 2.
Logistic regression: Stepwise logistic regression analyses were performed including several chemicals simultaneously. Gender, age (ordinal variable in increments of 10 years), history of allergy, time spent at home (h/day; ≤ 12, >12) and condensation and moldy odor were forcibly entered into the model and the selection for chemical variables was performed using backward stepwise elimination. Chemical variables entered into the model in the first step: DEP, DnBP, DEHA, and s-421 in multi-surface dust, DEHP, TBEP, and TDCPP in floor dust, and either TBP in air (Model 1) or in floor dust (Model 2).
$*P < 0.05$; $**P < 0.01$.