AN EXPOSURE ASSESSMENT STUDY OF VOLATILE ORGANIC
COMPOUNDS (VOCS) IN RESIDENTIAL INDOOR ENVIRONMENT USING
THE CANADIAN HEALTH MEASURES SURVEY (CYCLE 2: 2009-2011) AND A
MULTIPLE RECEPTORS BASED APPROACH

by

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ABSTRACT

Brief summary

Volatile organic compounds (VOCs) are organic chemicals, which are commonly found in indoor environments, and evaporate rapidly at room temperature. VOCs are ubiquitous and present in the residential indoor environment.

Rationale

Low-level long-term exposures to VOCs have been associated with asthma, chronic obstructive pulmonary disease (COPD) and lung cancer. Research over the past 20 years has focused on the effects of VOCs in children in relation to asthma and other respiratory conditions. More research is necessary to understand the effects on children's overall health and ways to mitigate VOC exposures of this vulnerable and susceptible population.

Methods

I analyzed the Canadian Health Measures Survey data Cycle 2 for indoor air exposure to benzene, ethylbenzene, toluene, the xylenes (BTEX), chloroform, carbon tetrachloride, naphthalene, *alpha*-pinene, acetone and benzaldehyde. I quantified personal exposures to VOCs in two populations: children (3-11 years old) and youth-adults (12-79 years old) and described their environment (residential indoor air). I analyzed VOCs stratified by the age and sex of respondents, age of the dwelling, region (BC, the Prairie Provinces, Ontario, Quebec and the Atlantic Provinces) and urbanicity of the dwelling. I performed univariate and multivariate linear regressions to describe the variations in log transformed total BTEX, chloroform, naphthalene and *alpha*-pinene in separate analyses. I found that the CHMS oversampled in urban centres and failed to capture biomonitoring data in children.

In another part of this research project, I performed small laboratory studies to optimize the use of thermal desorption tubes during indoor air research. I performed three descriptive studies of VOCs in homes of volunteers in Halifax, NS.

Results

Total BTEX concentrations were associated with the dwelling type, dwelling age (built before 1980), number of persons living in the dwelling and a mortgage on the residence; however, the multivariable regression accounted poorly for the variation in total BTEX concentrations. The concentrations of naphthalene and *alpha*-pinene were significantly associated with the presence of a child in the dwelling. The descriptive studies sampled VOCs that were not part of the CHMS Cycle 2 dataset. A volunteer and indoor-only companion cat successfully wore thermal desorption tubes as a test for the use of a multi-receptor approach to VOC exposure assessment.

Conclusion

The analysis of CHMS Cycle 2 dataset and the descriptive studies allowed for new insights into VOC exposures. Behaviours such as increased cleaning and the presence of toys may account for the different VOC profiles in homes with children compared to dwellings that may or may not have a child present.

LIST OF ABBREVIATIONS USED

ARDC: Atlantic Research Data Centre
ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATD: automatic thermal desorption
ATSDR: Agency for Toxic Substances and Disease Registry
BTEX: benzene, toluene, ethylbenzene and the xylenes
CA: census agglomeration
CEPA, 1999: Canadian Environmental Protection Act
CHMS: Canadian Health Measures Survey
ECC-Canada: Environment and Climate Change Canada
ETS: environmental tobacco smoke
GC-MS: gas chromatograph – mass spectrometer
HAP: hazardous air pollutants
HERC: Health and Environment Research Centre
K_{oc}: high water solubility
kPa: kilopascals
LOD: limit of detection
m: meter
MEC: mobile examination centre
MIZ: metropolitan influenced zone
NS: Nova Scotia
OSHA: Occupational Safety and Health Administration
OSHAEL: Occupational Safety and Health Administration exposure limits
PCCF+: Postal Code[OM] Conversion File Plus by the Canada Post Corporation
ppm: parts per million
REB: Research Ethics Board
SAC type: statistical area classification type, part of the PCFF+
TD: thermal desorption
US EPA: United States of America Environmental Protection Agency
VOC(s): volatile organic compound(s)

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CHAPTER 1. INTRODUCTION: EXPOSURES AND HEALTH EFFECTS OF VOCS

1.1 VOCs – Exposures and sources

Indoor air quality (IAQ) is defined as the quality of air inside buildings and structures; IAQ is an important determinant of health and comfort in people's lives (4). It has been shown that the amount of time that people spend indoors has increased substantially over recent decades and that the majority of this time is in residential indoor environments (5). In 2002, Leech et al. (6) reported that Canadians spend 66 % of their time indoors at home, 23 % in other indoor environments, 5 % in their vehicles and only about 6 % in outdoor locations. They also reported that children who were less than 11 years of age spend 72 % of their time indoors at home and that Canadian youth spend significantly more time indoors at home than American youth (6). Toddlers and infants, as well as those who are frail or ill, likely spend an even greater percentage of time inside the home. Indoor pets are another category of residential environment inhabitants for which little is known about their volatile organic compound (VOC) exposures. Residential IAQ is therefore important because of the amount of time spent indoors compared to outdoor ambient environments and we all depend on clean air for our healthy existence.

Over the past fifty years, there has been a demographic shift of people moving from rural to urban settings in Canada. According to Statistics Canada 2011 census information (7), approximately 22 % of Canadians lived in urban areas compared to approximately 34 % in 1961. This has meant that there have also been changes in the environments where people live and the associated neighbourhoods in which these dwellings are located.

Over the past fifty years, residential construction practices have also evolved. New materials, other innovations and tighter construction technologies have been introduced to accommodate cost efficiencies and energy demands and result in lower air circulation in the residential indoor environment (8); decreased ventilation has resulted in an increase of concentrations of the indoor pollutant radon (9,10). The nature of household products and consumer goods has also changed significantly (for example, phthalate (DEHP) ban in cosmetics (11) and illegal importation of kids' jewellery that contains lead and cadmium (12)). Within the domain of residential IAQ, volatile organic compounds (VOCs) have emerged as a major focus of IAQ research (13-15). The sheer number of VOCs found in residential environments, the contributions of human activity, as well as VOC volatility and aspects of the dynamic nature of residential indoor conditions (e.g. temperature, ventilation, humidity) and features of the exterior ambient environment (e.g. climate, wind) (16-21) contribute to the complexity of assessing VOCs in dwellings. VOCs are known to photochemically react with other airborne

gases, particulates and vapours to form secondary contaminants in residential indoor environments (22-24). Furthermore, VOCs and VOC mixtures are part of the total lifetime exposure of a person, and this will vary according to where a person lives, their occupation and habits, and other life course considerations (25-28). Despite this complexity, the extent of time spent inside the home is a consistent and important feature of the total lifetime environmental exposure history. It is worthy, therefore, to examine residential indoor exposures to VOCs to enable us to understand the potential impact that these exposures may have on people's health.

1.2 What are VOCs?

Volatile organic compounds (VOCs) are organic chemicals that quickly vaporize at room temperature and are classified as very volatile, volatile and semi-volatile based upon boiling point (29). The cut-off boiling point for volatile organic compounds is less than or equal to 250°C at the standard atmospheric pressure of 101.3 kPa (30).

As introduced in Section 1.1 above, there are many sources of VOCs in residential indoor environments, including cigarette smoke, scented candles, glues and binding agents in composite wood products, preservatives in carpets and textiles, paints and solvents, stored fuels, plasticizers, household cleaning

products, dry cleaning agents, moth repellents, air fresheners, pesticides, food products, cooking oils and infiltrating pollutants from the external environment (e.g. industry, adjacent apartments, and plants) (31).

1.2.1 What are sources of VOCs in residential indoor environments?

One practical framework which is derived from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Indoor Air Quality Guidebook (32) identifies six source categories of VOCs in residential indoor environments:

1. VOC indoor sources from building materials and products
   a. Foam insulation (formaldehyde)
   b. Composite wood products (chip board)
   c. Paint products
2. VOC indoor sources from consumer goods
   a. Off-gassing from furniture and carpets
   b. Plasticizers in toys and other plastic goods used in the home
   c. Fabric and textile preservatives
   d. Dry cleaning
   e. Pesticides (naphthalene)
   f. Hobbies (solvents)

      g. Carpentry

3. VOC emissions from smoking, cooking, gas and oil combustion

      a. Tobacco smoke

      b. Gas cooking (nitrogen dioxide)

      c. Wood burning in fireplaces, woodstoves, and wood boilers

4. VOC emissions associated with cleaning and maintenance

      a. Pine-scented detergents

      b. Chlorine bleach

      c. Ammonia-containing cleaning products

5. VOC emissions associated with dwelling characteristics

      a. Dwelling age

      b. Attached garage

6. VOC infiltration from the ambient environment

      a. Air pollutants

      b. Traffic

      c. Industrial sources

In the following sections, current VOC literature will be discussed according to what has been reported for these different categories. Some VOCs, such as benzene and the other BTEX compounds (toluene, ethylbenzene, *o*-xylene and *m,p*-xylene), and certain well established VOCs such as formaldehyde, acetaldehyde, and naphthalene, are emitted from multiple sources and will be

covered in detail. Detailed information about specific VOCs and household products can also be found in the US Department of Health and Human Services Household Products Database (33).

1.2.2. Indoor sources of VOCs from building materials and products

VOCs are emitted from construction materials such as insulating material, particle board, and paint. Berglund et al. (34) noted certain VOCs were emitted constantly from samples of the floor, walls and ceiling that were placed in a climate chamber. However, the authors also observed that other VOCs were released and decayed within a few days of the experiment suggesting those VOCs were adsorbed into the materials and subsequently released (34). Floor coverings (PVC, carpet, linoleum, adhesives, concrete and screed) were evaluated using an emission test chamber and cells; these materials released multiple VOCs, semi-VOCs (including alkylbenzenes, propylene glycol and benzaldehyde) and unidentified compounds into the environment (35).

Wheeler et al. (16) concluded that having renovations in the past month resulted in increased VOC concentrations. Héroux et al. (18) determined that VOCs found in 96 Quebec city dwellings were released from renovation activities. In the Halifax Indoor Air Quality Study in 2009, newer dwellings tended to have higher aldehyde concentrations (17,18), while older dwellings studied

had higher levels of *n*-pentane, isopentane, benzene, toluene, ethylbenzene, *m,p*-xylene and 1,2,4-trimethylbenzene (36). During construction of new houses, formaldehyde and other VOCs were found to be present and were likely released by adhesives, paint and other construction materials (36,37).

Chin et al. (38) commented that regional differences in Detroit, Michigan, USA, in building design (including attached garages), building materials, and climate can influence air exchange rates and VOC emissions. Elevated concentrations of *n*-alkanes (C7-C13) were found in 14 homes, which suggested a recent renovation, and 9 of these had an attached garage (38).

Other indoor environments also contribute to exposures to VOCs, but are not the focus of this study. VOCs can be found in the workplace, from sources such as photocopiers and printers that contribute a small percentage to overall personal exposure (39). Harrison et al. (24) studied the environments in pubs, restaurants, a library and a museum in London as alternative exposure environments to the dwelling and office. Pubs were found to have the highest concentrations of polycyclic aromatic hydrocarbons compared to the other locations. The pub environment was affected by cigarette smoking, which contributed to the release of air pollutants. (24)

1.2.3 VOC emissions from smoking, cooking, gas and oil combustion

Cigarette smoking in the dwelling has been found to be a strong predictor for indoor air concentration of VOCs (25). Chin et al. (38) discussed the much higher VOC concentrations in homes outside of North America in relation to individuals with asthma. The Chin study (38) study employed an environmental tobacco smoke (ETS) tracer technique and observed that where the ETS tracer indicated the presence of tobacco smoke, there were higher concentrations of benzene, tetrachloroethene, styrene, phenol, *n*-butylbenzene, naphthalene, 2-methylnaphthalene, 1-methylnaphthalene, and *n*-pentadecane, but lower levels of *alpha*-pinene. The authors also commented that while smoking has been associated with high increases in particulate matter concentrations, the effects of VOC emissions tend to be small. Chin et al. (38) also referenced a Regina-Saskatchewan study where benzene concentrations averaged 3.4 $\mu g/m^3$ in residential dwellings with at least one smoker compared with 2.5 $\mu g/m^3$ in non-smoking homes. In another study, Johnson et al. (40), found that residences which included smokers had higher indoor/outdoor ratios of benzene, ethylbenzene and the xylenes.

Héroux et al. (18) concluded that VOCs found in 96 Quebec City dwellings were released by combustion from automobile exhaust, cooking and furnaces. Zhu et al. (41) completed a principal components analysis of 47 VOCs which

were above the 50 % detection limit threshold. Four VOC component clusters of alkylbenzenes and aliphatic hydrocarbons were identified; these VOCs are often found in gasoline and oil-based solvents (41). The discovery of VOC component clusters suggested to the authors that the VOCs measured were emitted by different products. Having a dwelling with an attached garage has been shown to increase the concentrations of the VOCs *n*-pentane and isopentane (36) and influence personal benzene exposure (21).

1.2.4 VOC emissions associated with cleaning and maintenance

Cleaning frequency and the products utilized, as well as behaviours such as opening windows, have been found to affect the concentration of residential indoor VOC concentrations (26-28). Nazaroff and Weschler (42) reviewed cleaning products and air fresheners as sources for HAP (e.g. benzene from liquid detergent, toluene from disinfectant bathroom cleaner and acetaldehyde from wood-floor cleaning spray). Zhu et al. (41) performed principal components analysis from VOC data obtained from the CHMS Cycle 2 and noted two clusters ((1) 2-butoxyethanol and 2-butanone, and (2) limonene, *alpha*-pinene, acetone, hexanal and 2-propanol) that likely represented water-based cleaning products. Wheeler et al. (16) concluded that the use of paint remover also lead to an increase in indoor VOC concentrations.

1.2.5 VOC emissions associated with dwelling characteristics

1.2.5.1 Dwelling age

A major contributor to indoor VOCs is the age of the dwelling. Gilbert et al. (17) measured the concentrations of formaldehyde, acetaldehyde and acrolein in 59 dwellings in Prince Edward Island. Formaldehyde presence was strongly predicted by the age of the dwelling, which may be due to different air exchange rates and home building materials (17). In the Halifax Indoor Air Quality study in 2009, investigators measured formaldehyde, acrolein and acetaldehyde in residential dwellings of all ages and categorized as follows: 1945 and earlier, 1946-1960, 1961-1980, 1981-200 and 2001-2008. In comparison, established dwellings (average age 30 years) studied by Brown et al. (36) had higher levels of *n*-pentane, isopentane, benzene, toluene, ethylbenzene, *m,p*-xylene and 1,2,4-trimethylbenzene. During the winter, Gilbert et al (17) found that formaldehyde was present at higher concentrations in dwellings built after 1970, and acrolein and acetaldehyde were present in dwellings with at least one smoker and in dwellings built between 1970 and 1985.

1.2.5.2 Dwelling type: single detached, double, row or terrace, duplex, low rise apartment and high rise apartment

A previous publication that utilized the CHMS Cycle 2 dataset presented a comparison of concentrations of specific VOCs in attached or semi-detached

homes versus apartments (41). Residential dwellings (attached or semi-detached homes) without smokers had significantly higher concentrations of *alpha*-pinene, *o*-xylene, *m,p*-xylene, 1,2,3-trimethylbenzene, ethylbenzene, 1,2,4-trimethylbenzene, toluene, hexane, pentane, 2-butanone, 1-ethylethyl, benzene, tetrahydrofuran, hexanal, cyclohexane, 2-furancarboxyaldehyde, camphene, heptane, 2-methyl-2-propanol, 4-methyl-2-pentanone, styrene, cyclohexanone, 2-butoxyethanol, benzene, decane, benzaldehyde, undecane, 2-pentanone, 1-pentanol, tetrachlorocarbon, 2-propanol, 1-butanol, decamethylcyclopentasiloxane and dodecane compared to apartments without smokers. Wheeler et al. (16) presented arithmetic mean values for the BTEX compounds by dwelling type using the CHMS Cycle 2 dataset as well, and observed that benzene concentrations were greatest in low-rise and high-rise apartments (2.13 $\mu g/m^3$) followed by double and semi-detached row houses (1.76 $\mu g/m^3$) and then single detached homes (1.47 $\mu g/m^3$); however, these differences were not statistically significant at the 5 % level. A similar descending, yet highly significant pattern was observed for toluene, ethylbenzene, *o*-xylene and *m,p*-xylene in the different dwelling types. The arithmetic mean for toluene and *m,p*-xylene concentrations found in apartments was 23.70 $\mu g/m^3$ and 16.72 $\mu g/m^3$, respectively. (16)

1.2.5.3 Attached garage

Wheeler et al. (16) also examined the BTEX compounds in association with garage configuration (non-apartment dwellers only) and observed that having an attached garage compared to not having an attached garage affected a higher concentration in BTEX compounds. Notably, the concentration of toluene in residential dwellings with an attached garage and connecting door was 34.72 $\mu g/m^3$ and *m,p*-xylene was 21.62 $\mu g/m^3$ compared to concentrations of 11.50 $\mu g/m^3$ and 11.10 $\mu g/m^3$, respectively, without an attached garage (16). The arithmetic means were higher than those observed in apartment dwellings (toluene: 0.1545 $\mu g/m^3$ and *m,p*-xylene: 0.1288 $\mu g/m^3$) (16).

1.2.5.4 Drinking water disinfection by-products from chlorination

Zhu et al. (41) observed a cluster of three halogenated hydrocarbons (bromodichloromethane, trichloroethylene and tetrachlorocarbon) occurring together during their analysis of the CHMS Cycle 2 dataset. The authors proposed that bromodichloromethane was a by-product of the chlorination disinfection process of drinking water (41), and trichloroethylene and carbon tetrachloride are solvents in cleaning products that subsequently contaminate water.

1.2.5.5 Air exchange rates, air conditioning and windows

Héroux et al. (18) found that the air exchange rate in a dwelling did not affect the VOCs in the indoor environment. However, in daycares, it was found that insufficient ventilation led to higher carbon dioxide, formaldehyde and acetaldehyde levels (19). Air conditioners have been found to increase indoor air concentrations of VOCs, but they also limit the movement of outdoor emissions into the dwelling (20). Chin et al. (38) reported that 87 % of Detroit, Michigan, residential dwellings had forced air heating/cooling systems and that indoor air was often well mixed and within home gradients were small. There was a median difference of 30 % in the concentrations of the 41 VOCs they studied. They also reported that air exchange rates were negatively correlated with VOC concentrations, especially for toluene, styrene, *alpha*-pinene and limonene. (38)

1.2.6 VOC infiltration from the ambient environment

It is necessary to consider outdoor ambient air when discussing residential indoor air because ambient air VOCs can enter the residential dwelling via windows and poorly insulated homes. Matysik et al. (43) evaluated the air in apartments in Cairo, Egypt, and observed similar concentrations of the BTEX compounds to the ambient air using 4 week monitoring by passive diffusion monitors. The authors concluded there was evidence of infiltration of ambient

VOCs into the residential indoor air. Similar research was performed in Munich, Germany, and VOC (alkanes, cycloalkanes, aromatic hydrocarbons, halogenated hydrocarbons and terpenes) measurement was combined with the measurement of nitrous oxides (ambient air sources, no indoor air sources); infiltration of ambient air pollutants did occur (43).

In a study by Zhu et al. (44), 75 dwellings in Ottawa, ON were studied and 46 % (17/37) of the VOCs (including BTEX, acetone, dichloromethane, chloroform and others) monitored were identified more frequently in indoor air compared to outdoor air. Su et al. (45) found that outdoor VOCs accounted for 5 -81 % ((*d*-limonene) and carbon tetrachloride, respectively) of adult personal exposure. One study found that children aged 7-13 years old had higher VOC exposures (BTEX, chloroform, *p*-dichlorobenzene, *d*-limonene, methylene chloride, α-pinene, β-pinene, styrene, tetrachloroethylene) at their school (indoor/outdoor) than their personal exposure and their exposure at their residential dwelling (46).

VOCs in the ambient air are affected by multiple factors, including season, urbanicity, traffic and wind. Su et al. (45) utilized the Relationship of Indoor, Outdoor and Personal Air (RIOPA) study database and determined that outdoor concentrations of VOCs were mainly affected by the urbanicity and wind. Wind speed was negatively correlated to concentrations of BTEX, styrene, α-pinene, methyl tert-butyl ether, trichloroethylene and perchloroethylene, while 1,4-

dichlorobenzene, chloroform, tetrachloroethylene and trichloroethylene were associated with the city (45). Jia et al. (47) performed factor analyses and found that the urban centre, season and measurement variation accounted for the majority of ambient air VOC concentration variation. Between-city variation accounted for 29 +/- 15 % and seasonal differences contributed an average of 43 +/- 17 % of the VOC total variance (47).

1.2.6.1 Urban vs. rural

In a study of 126 Detroit, Michigan, residential dwellings of children with asthma, 56 VOCs were quantified. Concentrations varied between dwellings, mostly due to between residence and seasonal variation, and the effect of nearby traffic was not apparent. The authors observed that the amount of traffic exposure varied considerably among homes; the amount of traffic within 100 meter or 300 meter buffer zones showed only weak and statistically inconsistent effects on indoor benzene and total BTEX levels. They noted that BTEX compounds were also found in vehicle exhaust, gasoline, ETS, paints, adhesives, solvents, oils and incense. (38) Chin et al. (38) compared their findings with three other studies of Michigan communities (40,48,49), and one Canadian study of Windsor, ON (50). They noted that while there was significant variability within each study, median concentrations of benzene and *d*-limonene concentrations were similar, 1-4-dichlorobenzene concentrations varied and toluene concentrations were lowest in the study by Chin et al. (38).

1.2.6.2 Seasons

During the winter, Gilbert et al. (17) found that formaldehyde was present at higher concentrations in dwellings built after 1970, and acrolein and acetaldehyde were present in dwellings with at least one smoker and in dwellings built between 1970 and 1985. Chin et al. (38) observed that VOC concentrations were highest in the spring and fall, and lowest in the summer and winter months during their Detroit, Michigan, study. The authors attributed these variations to air exchange rates caused by the presence and use of air conditioners, window opening behaviours, wind speed, condition and age of the dwelling. Higher air exchange rates in the winter were linked to large indoor-outdoor temperature differences and high wind speeds; whereas lower air exchanged rates were associated with closed windows. (38) Chin et al. (38) also indicated that other studies have observed similar seasonal trends (51-54).

1.2.6.3 Climate change

The effect of climate change on the indoor environment is discussed in the report by the National Academies Press (55). In summary, occupants of an indoor environment are affected by climate change in connection to dampness, moisture, flooding, temperature changes, infectious agents and pests. However, the literature is sparse in relation to the intersection of climate change and the indoor environment, and there is a lack of commentary on the effects of VOCs

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(55). The report acknowledges ventilation of the building as a factor that influences the indoor environment (55), and ventilation was found to affect VOC concentrations in the residential indoor environment (19,20).

1.2.7 Other sources of variability in VOC concentrations

As noted by Chin et al. (38), sampling and analytical methods for VOCs can influence research findings. Some studies report sampling for five days or less, and these tend to show greater variability. In their study, Chin et al. (38) analyzed between and within household variation by comparing bedroom and living room VOC concentrations. In a study of Swedish residential dwellings, toluene averaged 120 µg/m^3 in living rooms and bedrooms (56). Chin et al. (38) noted that the largest sources of VOC concentrations were related to the between household differences, which included the different VOC products used and stored in the residence, the within-home smoking practices and the air exchange rates of the dwelling. However, they also reported that seasonal variation was nearly as important as the between household variation (38).

1.3 Known VOCs that have been demonstrated to occur in residential indoor environments

The majority of research on the health effects of BTEX and other important VOCs are summarized in reports published by the USA Centers for Disease Control and Prevention, namely the Agency for Toxic Substances and Disease Registry (ATSDR) Public Health Statements (57). There are no published ATSDR reports on *alpha*-pinene and acetaldehyde at this time; this information was obtained from the National Center for Biotechnology Information (57). Subsequent sections present a summary of important aspects for each of the BTEX, as well as *alpha*-pinene, carbon tetrachloride and acetaldehyde from the relevant ATSDR Public Health Stateemnts.

1.3.1 BTEX compounds: benzene, toluene, ethylbenzene and the xylenes

1.3.1.1 Benzene

Benzene (C_6H_6, CAS no. 71-43-2) is a colourless, highly flammable liquid that has a sweet odour. Common sources for benzene in the residential indoor environment include tobacco smoke, emissions from automobile exhaust from vehicles stored in attached garages, and evaporation from stored petroleum products (58). Benzene can be released naturally by volcanoes and forests, and is also found in food and drugs such as fruits, fish, eggs and barbiturates (59,60).

After exposure via inhalation by human subjects, approximately 12 % of benzene was exhaled unchanged and 0.1 % was excreted unchanged in urine; the remaining absorbed benzene was metabolized by the liver into highly toxic oxidative products (61). The bone marrow can also act as a site of metabolism for benzene. Within 48 hours, 51 to 87 % of absorbed benzene was excreted as phenol (62) and other metabolites in the urine (58). Urine phenol (63), muconic acid (64) and s-phenylmercapturic acid (65) were identified after occupational exposure in workers exposed to benzene. Benzene and its metabolites are temporarily stored in marrow and fat, and most of the metabolites are excreted in the urine within 48 hours of exposure. (58)

Benzene metabolites are synthesized primarily in the liver through oxidation by the cytochrome P450 2E1 enzyme (58). The metabolites phenol, quinone and others were found to cause genetic damage (66,67).

Acute high exposure scenarios to benzene have resulted in unicellular cytopenia or pancytopenia. Inhalational exposure to benzene resulted in ventricular fibrillation, congestive gastritis and renal injury, while ingestional exposure caused toxic gastritis, pyloric stenosis and hepatic edema (58). These effects were determined from accidental or occupational exposure to benzene and described in case studies prior to 2000 (68). In severe acute exposures, mortality can result from the vascular congestion of the brain. Benzene can also

induce neural damage and produce myelofibrosis and myalgia; the central nervous system is affected during acute exposure and the peripheral nervous system during chronic exposure (58). Myelofibrosis was identified in a gas station attendant that worked in that position for 17 years (69). Dermal exposure to benzene in occupationally exposed shipboard gasoline removal workers at concentrations above 60 ppm resulted in irritation (70).

Chronic low-level benzene exposure studies in animals have demonstrated distal neuropathy, insomnia, memory loss, central nervous system depression, tremors, loss of involuntary reflexes, narcosis, and decreased hind limb strength. In comparison, chronic ingestion of benzene in rats and mice demonstrated endometrial polyps, and preputial gland and ovary lesions. Genotoxicity was noted at or over 47 ppm benzene in air. Some of the benzene metabolites can cause chromosomal aberrations in white blood cell precursors in the bone marrow and peripheral lymphocytes. (58) A meta-regression estimated the risk of leukemia to be high with occupational exposure as low as 10 ppm-years (71). Benzene is classified as Group 1 "Carcinogenic to humans" by the International Agency for Research on Cancer (IARC, World Health Organization) (72).

1.3.1.2 Ethylbenzene

Ethylbenzene (C_8H_{10}, CAS no. 100-41-4) is a colourless liquid that smells like gasoline. It is present in tobacco, pesticides, paint, gasoline, carpet glue and other products (73).

The main exposure route for ethylbenzene is via inhalation; however, it can be ingested or absorbed through dermal contact. The majority of absorbed ethylbenzene is metabolized and excreted mainly via exhalation and in small amounts in the feces (73).

Acute exposure to ethylbenzene in the air results in irritation of the eyes and throat. At high levels, it can result in vertigo and dizziness. In animal studies, very high levels have resulted in mortality due to moderate pulmonary edema and congestion. Ethylbenzene has also been found to result in loss of the hair cells in the organ of Corti in the inner ear, resulting in hearing loss during acute and intermediate exposures in animals, and occupationally and non-occupationally exposed persons. Acute exposure in pregnant rats resulted in changes to the fetal skeleton and decreased fetal body weight. (73)

Chronic exposure to ethylbenzene has also resulted in irreversible damage to the inner ear. In animals, ethylbenzene caused kidney and liver damage and a mean increase in lymphocytes and decrease in hemoglobin. There are no known correlations between chronic exposure in occupationally exposed persons and cancers. In rats and mice, there was an increase incidence of renal tubule neoplasm, testicular adenomas, alveolar/bronchiolar neoplasm and hepatocellular neoplasm after exposure via inhalation. (73) Ethylbenzene is classified as IARC Group 3 "Not classifiable as to its carcinogenicity to humans" (72).

1.3.1.3 Toluene

Toluene (C_7H_8, CAS no. 108-88-3) is a clear and colourless liquid that has its own distinctive smell. It is naturally found in crude oil and the tolu tree. It is used in the production of paints, paint thinners, adhesives, rubber, nylon, leather, benzene and more. Toluene is normally found at higher levels indoors because of the presence of solvents, paint thinners and tobacco products. (74)

The main exposure route to toluene is through inhalation, and it is easily absorbed into the bloodstream via the alveoli. Dermal contact can also result in absorption of toluene. Toluene is usually metabolized within a few days and excreted as hippuric acid, but it can accumulate in fat tissue during daily

exposure. Excretion is usually through exhalation, but a small amount is excreted via the urine. (74)

Acute and high dose exposures to toluene can result in reversible damage to the nervous system that is demonstrated as headaches, dizziness, sleepiness and unconsciousness. Death can result secondary to the depression of the respiratory and cardiac systems. In rats exposed to high concentrations, respiratory irritation and pulmonary lesions occurred. In people and animals, inhalation of concentrations above 1000 ppm has resulted in reversible cardiac arrhythmias. However, persons with underlying cardiovascular conditions may suffer from fatal cardiac changes. (74)

Chronic exposures, as in persons that abuse solvents, have produced permanent incoordination, cognitive impairment, and vision and hearing loss. Low to moderate dose chronic exposures to toluene in occupational exposures have resulted in tiredness, confusion, weakness, incoordination, memory loss, nausea and decreased appetite. Affected persons can recover from these clinical signs; however, they may still suffer from vision and hearing loss. It may also impact the immune, kidney, liver and reproductive systems. The association with immunological toxicity may have been due to benzene contamination of the toluene utilized during studies prior to 1955. In dogs and rats, high dose exposure to toluene was found to decrease total white blood cell counts. *In vitro*

toluene exposure has resulted in decreased ability to combat infections by respiratory pathogens. Hearing loss was noted to be more severe in persons that were exposed to toluene in combination with administration of aspirin and acetaminophen. Renal acidosis was noted to be transient secondary to chronic exposures. In gestating women who abused solvents, children had retardation of mental abilities and growth. There may also be an increased risk of spontaneous abortion in occupationally exposed pregnant women, but analysis was complicated by the confounding variables of smoking and alcohol use during gestation. No reproductive effects were noted in animals exposed to toluene. It is believed that toluene will preferentially be deposited in maternal adipose tissue before traversing into fetal tissues. Five cohort studies with mixed solvents did not conclude that toluene is a carcinogen. (74) The IARC classifies toluene as Group 3 (72).

1.3.1.4 Xylenes

The xylenes (C_8H_{10} *meta*-xylene, CAS no. 108-38-3; *ortho*-xylene, CAS no. 95-47-6; *para*-xylene, CAS no. 106-42-3; mixed xylenes CAS no. 1330-20-7) are isomers based on the location of the methyl group on the benzene ring. Mixed xylene usually contains 6-15 % ethylbenzene. Xylenes are colourless and flammable liquids that have a sweet odour. They occur naturally in petroleum, coal tar and secondary to forest fires. The xylenes are used as solvents during

the production of printing inks, rubber, leather industries, cleaning agents, paint thinner, varnishes, chemicals, plastics and synthetic rubbers. (75)

Exposures to the xylenes in the general public are usually the result of exposure to paint thinners, varnish, gasoline, rust preventative products, automobile exhaust and cigarette smoke. The main exposure and excretion routes are inhalation and exhalation, respectively, but they can also be absorbed rapidly by the skin and in the gastrointestinal tract. In the body, the xylenes are metabolized within 18 hours by the liver into hydrophobic compounds that can be excreted via the urine. About 10 % of the xylenes may be stored in adipose tissue. (75)

All three isoforms of xylenes have similar effects on health. High dose acute exposure can result in irritation of the skin, eyes, nose, and throat, difficulty breathing, impaired function of the lungs, delayed response to visual stimulus, impaired memory, gastric discomfort, and possible changes to the liver and kidneys. Long and short-term exposure can have negative effects on the nervous system such as headaches, lack of muscle coordination, dizziness, confusion and changes in the sense of balance. Acute high-level exposures have resulted in death. Acute exposure in gestating animals may result in harmful effects on the foeti. Animal studies have shown that xylenes absorbed by the mother can cross the placenta to reach the fetus and cause reduced foeti body weights,

delayed bone mineralization and decreased motor coordination noted after birth. (75)

In occupationally exposed persons, an increase in liver enzymes was noted. In lab animals, there was increased liver weight, serum enzymes and cytochrome P450, but no changes were observed on histopathology of the liver. There is a possibility of renal effects in people including distal renal tubular acidemia and abnormal clinical chemistry values, but conclusions could not be made because there were mixed exposures. In animals, renal effects were noted during chronic exposures, which included increased renal enzyme activity, increased cytochrome P450 and increased kidney to body weight ratio after inhalation or oral exposure. (75) The xylenes are classified as IARC Group 3 (72).

1.3.2 Emerging VOCs found in residential indoor environments

1.3.2.1 Naphthalene

The ATSDR profile for naphthalene ($C_{10}H_8$, CAS no. 91-20-3) includes 1-methylnaphthalene and 2-methylnaphthalene. Naphthalene is a white solid that evaporates easily, has its own distinctive and strong smell, and is flammable as a gas. It is most commonly used as mothballs, moth flakes, white tar and tar camphor. Naphthalene is used to produce polyvinyl chloride (PVC) plastic, toilet

deodorant blocks, dyes, leather tanning agents and the insecticide carbaryl. Natural sources include fossil fuels, cigarette smoke and burning wood. (76)

Exposure to naphthalene occurs via inhalation and dermal contact. An example of dermal contact is the handling of mothballs or clothing that has been treated with mothballs. Naphthalene does not bioaccumulate but may be stored in adipose tissue; it can be transported via milk and eggs and can be present in the meat of shellfish and fish. Naphthalene is usually metabolized within one to three days and excreted in the urine. (76)

Acute and high dose exposures to naphthalene have resulted in hemolytic anemia. Children have developed anemia after being exposed to high doses by ingesting mothballs and wearing diapers treated with mothballs. Children may be more susceptible to naphthalene-induced hemolytic anemia due to decreased metabolic capability. Newborn mice were more susceptible to the effects of pulmonary damage than adult mice. Persons of African and Mediterranean descent may be predisposed to hemolytic anemia secondary to exposure to naphthalene. The clinical signs of toxicity to naphthalene include fatigue, decreased appetite, restlessness, pale skin, nausea, vomiting, diarrhea, hematuria and jaundice. Rabbits, guinea pigs, mice and rats developed cataracts at high dose ingestion exposure. (76)

In chronic exposures to naphthalene in animals, there was damage to the epithelial cells of the respiratory system and development of nasal tumours. Naphthalene exposure in gestating mothers may cause anemia in unborn children. There are four published cases of laryngeal cancer after naphthalene exposure, but two had concurrent cigarette smoking addiction, which limits the ability to conclude associations. (76) Naphthalene is classified as IARC Group 2B "Possibly carcinogenic to humans" (72).

1.3.2.2 *Alpha*-pinene

Alpha-pinene ($C_{10}H_{16}$, CAS no. 80-56-8) is a colourless and clear liquid that has the odour of pine or turpentine. It occurs naturally in the oils of many species of conifers. It is used as a food additive, paint thinner and in household cleaning products. *Alpha*-pinene has medical applications as an anti-asthmatic and expectorant. (77)

Alpha-pinene exposure occurs via inhalation, and approximately 50 % is absorbed into the bloodstream. Exposure can also result from dermal contact and ingestion. It is excreted via exhalation unchanged and metabolites are excreted in the urine. (77)

Acute exposure can result in eye, nose, throat and gastrointestinal disease. High doses can result in kidney damage, coma, ataxia, heart palpitations, dizziness, bronchitis. Overdose in children can occur at a concentration as low one tablespoon of ingested turpentine. (77)

Chronic occupational exposures have occurred in pottery workers, fine china painters and other artists resulting in dermatitis. Part of the reaction is due to an allergy to the turpentine and its derivatives. In one case study, there was decreased forced expiratory volume, while in another study there was no change in forced expiratory volume, but there was a decrease in lung diffusion capacity. Other chronic exposure toxicity signs include eye irritation, transient excitement, ataxia, and confusion. (77) *Alpha*-pinene is not classified by the IARC.

1.3.2.3 Chloroform

Chloroform ($CHCl_3$, CAS no. 67-66-3) is also known as trichloromethane or methyltrichloride. It is a colourless liquid that has a non-irritating odour and slightly sweet taste. (78) It was used prior to 1976 as an anesthetic agent (79).

Chloroform is released into the environment via paper mills and chemical industries. It is also present in sewage treatment plant water when chlorine is added as a sterilizing agent. Small amounts of chloroform are present in drinking

water because of the presence of chlorine. It can contaminate the soil, groundwater, and evaporate. In the air, it slowly degrades into phosgene and hydrogen chloride, which are both more toxic than the parent compound. (78)

Exposure to chloroform is mainly via inhalation and ingestion of drinking water. Chloroform accumulates in adipose tissue. It may combine with endogenous chemicals. Chloroform and its metabolites are excreted via exhalation. (78)

During anesthesia with chloroform, there is usually an increase in respiratory rate followed by a deep and prolonged depression of the respiratory system. It also affects the heart, kidneys and liver. Less than 10 % of anesthetic patients suffered from bradycardia and 2 % had arrhythmias. An association between hypotension and chloroform exposure was more difficult to ascertain due to the concurrent use of thiopentone as a pre-anesthetic drug. Dermal contact results in sores. Deaths have occurred secondary to the use of chloroform as an anesthetic; doses of 40,000 ppm for several minutes may result in overdose and death, however a concentration of 22,500 ppm may be safe for anesthesia. When used in women in labour, it resulted in acute hepatotoxicity from the combination of the drug, exhaustion, anorexia and dehydration. Acute exposure in animals has also resulted in mortality, but at a lower rate than observed in people. Male mice died of kidney and liver damage secondary to exposure.

Hepatotoxicity is the result of sulfobromophthalein retention resulting in impaired liver function and may present as transient jaundice. (78)

At low doses, chloroform results in fatigue, dizziness, headaches, insomnia, somnolence, increased dreaming, hypomnesia, anorexia, palpitations, nausea and vomiting. Chronic exposure in rats resulted in interstitial pneumonia, thickening of the bone in the nasal passages and loss of olfactory glands. During occupational exposures, it has resulted in toxic hepatitis, but there was no measured changes of kidney function. In competitive swimmers, who are chronically exposed to chlorinated water, there was an increase in beta-2-microalbumin, a marker for changes in kidney function. Intermediate duration exposure to chloroform has resulted in swelling of the kidney and increase in its weight in mice and rats, but this was not found in rabbits and guinea pig exposure studies. Male rat kidneys had lesions of the proximal convoluted tubules of the kidney and mineralization of the cortex. Chronic exposure in people has resulted in splenomegaly, but this was not confirmed in lab animals. There was miscarriage and increase in fetal resorption in gestating rats and mice exposed to chloroform via inhalation. Chloroform is fetotoxic and teratogenic in animals; chloroform exposure in gestation has led to multiple developmental abnormalities, including delayed ossification, wavy or missing ribs, acaudate feti, imperforate anus, decrease fetal weight, decreased crown to rump length, slight growth retardation and cleft palate. Exposure of a few days duration in male

animals has resulted in abnormal sperm. Chronic exposure in chlorinated drinking water may be associated with an increased risk of colon and urinary bladder neoplasia. (78) Chloroform is categorized as IARC Group 2B (72).

1.3.2.4 Carbon tetrachloride

Carbon tetrachloride (CCl_4, CAS no. 56-23-5) is a clear liquid that evaporates easily, has a sweet smell and it is not easily flammable. Carbon tetrachloride was present as part of refrigeration fluid, cleaning products, degreasing agents, grain fumigants and as a propellant for aerosol cans. Its use has declined significantly since it was determined that carbon tetrachloride contributes to ozone layer depletion in the atmosphere. (80)

The majority of carbon tetrachloride exposures occur via inhalation. However, exposure can also occur secondary to dermal contact and ingestion of contaminated water and soil. Ingested carbon tetrachloride is absorbed at a rate of 85-91 %. Carbon tetrachloride metabolites also have adverse effects on the body. The major excretion route is exhalation, unchanged. (80)

Carbon tetrachloride toxicity presents as intoxication, headache, sleepiness, blurred vision, weakness, lethargy, nausea and vomiting. Central nervous system signs and possible death are noted at doses higher than those necessary to

produce kidney and liver damage. Ingestion results in irritation of the gastrointestinal tract. Carbon tetrachloride metabolites may interfere with liver function and cause hepatitis secondary to cell protein damage. High exposures have resulted in hepatocellular necrosis, fibrosis, cirrhosis and carcinogenicity. Carbon tetrachloride and its metabolites cause renal failure and pleural effusion, as well. Death secondary to exposure to carbon tetrachloride is thought to be due to kidney failure; kidney failure occurs due to tubular cell degeneration and fatty accumulation. Severe cases of exposure to carbon tetrachloride can result in stupor or coma and permanent central nervous system damage. High dose inhalation and oral exposures have led to anemia, reduced lymphocyte counts, suppression of IgM antibody forming activity, and T-cell activity, and *in vitro* there was decreased ability to combat bacterial infection. (80)

In mild exposure cases, kidney and liver function may return to normal one to two days after the exposure to carbon tetrachloride is stopped. It results in the accumulation of lipids in hepatocytes, cellular vacuolization and fatty degeneration of the liver. Older persons suffering from age-related kidney disease are predisposed to carbon tetrachloride toxicity. Animals exposed during gestation had an increase in fetal deaths, but if the foeti survived, neonates were normal. Inhalation studies of intermediate duration have resulted in decreased fertility and testicular atrophy in male animals. Mice exposed to carbon tetrachloride via inhalation had an increased incidence of adrenal tumours. Case

studies found positive associations between exposure to carbon tetrachloride and mortality from multiple types of cancers secondary to the induced genotoxicity and DNA breakage. (80) Carbon tetrachloride is categorized as IARC Group 2B (72).

1.3.2.5 Acetaldehyde

Acetaldehyde (C_2H_4O, CAS no. 75-07-0) is colourless, flammable and has a strong fruity odour. It is part of the manufacturing process for the production of acetic acids, perfumes and flavours. It also occurs naturally in plants, ripe fruits and vegetables. It is produced in cigarette smoke, gasoline and diesel exhaust. It is a metabolite of alcohol after ingestion and it is present in the gastrointestinal tract secondary to microbial digestion. (81)

Exposure to acetaldehyde is primarily through inhalation and secondary to the digestion of alcohol. It irritates the eyes, skin and the respiratory tract. Acute high dose exposures can result in death secondary to respiratory depression. Acetaldehyde can transverse the blood-brain and placental barriers, and is distributed to all the organs of the body.

Chronic abuse of alcohol is known to cause liver fibrosis and cirrhosis and alcohol over-consumption in gestating mothers is associated with fetal alcohol

syndrome. Exposure to acetaldehyde generates reactive oxygen species and

inhibits mitochondrial enzyme function. (81) Acetaldehyde is categorized as

IARC Group 2B (82).

1.4 Fate of VOCs in the air, soil and water

The fate of most VOCs is the degradation of the molecules in the

atmosphere due to photochemical reactions. In the atmosphere, benzene reacts

with photochemical hydroxyl groups and other oxidants to produce hydroxyl

radicals within three days (58). The xylenes are degraded by these reactions,

too, within a few days (75). In the air, chloroform slowly degrades into phosgene

and hydrogen chloride, which are both more toxic than the parent compound

(78). Carbon tetrachloride remains in the atmosphere from previous use as it

takes years to degrade thus contributing to the degradation of the ozone layer

(80).

VOCs can also contaminate the soil and water and this depends on the

compounds' hydrophilicity. Benzene will contaminate both water and soil, while

the majority evaporates and a portion of benzene will remain in the soil and water

due to poor metabolism in these matrices (58). The xylenes can also

contaminate the soil and water; however these compounds are usually digested

by microorganisms (75). Similarly, microorganisms in the soil can degrade

naphthalene over one to three months (76). Carbon tetrachloride contaminates

surface water and also gets trapped in ground water; however, it does not remain

in the soil for long periods (80).

1.5 Health effects and toxicity

Exposure to VOCs has generally been associated with irritation of the throat,

nose, eyes and skin (83,84). As noted above, some VOCs are classified as

known or possible carcinogens (38,85). Several studies have linked exposure

with asthma exacerbation (86-89). The response of the respiratory tract to irritant

gases is dependent upon the physiology and hydrophilicity of the compound of

exposure. High water solubility (K_{oc}) is associated with higher toxicity of the

respiratory tract, relating to the absorption rate of the gas into the body. High K_{oc}

VOCs act primarily on the upper respiratory tract (nasal passages, throat and

trachea). Moderate K_{oc} compounds act primarily in the lower respiratory tract

(bronchi, bronchioles and alveoli). Examples of gases that are irritating to the

upper respiratory tract include ammonia, hydrochloric acid and hydrofluoric acid;

gases that irritate the lower respiratory tract include chlorine, fluorine and sulfur

dioxide. (90)

Acute high concentration VOC exposures have resulted in severe toxicities

under certain circumstances. Clinical signs of acute high concentration VOC

exposures include nausea, lethargy, depression, neoplasia and death. In acute high dose scenarios, acetonitrile (91), 1,1,2-trichlorotrifluoroethane (92), carbon disulfide (93), nitrobenzene (94), benzene (58,95) and acrolein (96) have resulted in mortality. The effects of acute high concentration VOC exposures are limited to occupational and intentional/recreational exposures in humans, and laboratory exposures under controlled circumstances in animals. Animals such as mice, rats, dogs and others are often utilized for toxicological studies in the laboratory to estimate lethal dose, and biochemical/physical results of exposure to VOCs.

VOCs at high levels have been associated with cancer, prolonged adverse events and death (58,58,92-95,95,96). However, certain VOCs are present at low concentrations, below the set limits, and may still contribute to disease (24). VOCs often exist as mixtures; more than one VOC is present in the residential indoor environment at the same time. These mixtures are difficult to study due to interactions between the VOCs and inherent complexity of our environment and populations (23). VOC mixtures vary according to characteristics of the dwelling (e.g. air exchange rate, humidity), and characteristics of the environment (e.g. climate, wind) (16-20). VOCs and VOC mixtures are part of the total lifetime exposure of a person, and this will vary according to the locations the person lives, their habits and other factors (25-27). Total lifetime exposures to VOCs are also difficult to study as environments change over time, and people's exposures

vary greatly over their lifespan. Despite the challenges in studying these complex concepts of VOC mixtures and total lifetime exposures, these may still result in disease and cancer, to a degree yet to be measured.

1.5.1 Susceptibilities to the effects of VOC exposures

As VOCs are ubiquitous, people of all ages and animals are exposed to them. The effects of VOCs vary by the age, sex and underlying disease conditions of the exposed. Susceptible populations for VOC exposure include children, the elderly and people with respiratory conditions. Bolden et al. (97) provide a critical review of the BTEX studies in adults and children, including indoor and outdoor exposures to VOCs.

1.5.1.1 Adults

Adults are generally less susceptible to the effects of toxic chemicals; however, there is more information on the toxicity of VOCs in this group due to occupational exposures and some laboratory studies. VOCs have also been associated with asthma (98-100), and chronic obstructive pulmonary disease (COPD) (101). Stocco et al. (21) provided strong evidence that indoor air exposure is a good predictor of personal exposure to VOCs in adults studied in Windsor, ON.

Formaldehyde, 1,4-dichlorobenzene, benzene and 1,3-butadiene have been identified as having the highest median cancer risk estimates and these risks were attributed to exposures within the dwelling (102). The Lifetime Cancer Risk for benzene, p-dichlorobenzene, chloroform, vinylidene chloride, ethylene dibromide, methylene chloride, and carbon tetrachloride ranged from 1×10^{-6} to 1×10^{-4}, where the negligible risk level is 1×10^{-6} (103). Chinese homemakers were observed to have had the highest lifetime cancer risk associated with VOCs when compared to food service and office workers (104). Villeneuve et al. (105,106) performed a case-control and cohort studies evaluating the associations between benzene and other hydrocarbons in ambient environments in Ontario. They found that there is an increased risk for lung cancer, and that further work needs to be performed to understand variations in VOC exposures (105). The cohort study completed by Villeneuve et al. (106) also allowed for the development of a multi-pollutant model that concluded benzene and nitrogen dioxide are responsible for increased cancer-related mortality and cardiovascular, respectively.

The phenomenon historically described as "sick building syndrome" (107) was associated with poor ventilation of a building and VOCs, which was difficult to assess and was based on building type rather than scientific recommendations for ventilation standards (108). Clinical signs and symptoms associated with "sick building syndrome" included allergies, chronic cough, chronic sputum production,

dyspnea or wheezing, and chest pains (108). Adding to the complicated nature of the syndrome were the personal factors of job stress and dissatisfaction, allergies and female gender (109).

1.5.1.2 Children

In comparison to adults, children are more susceptible to the toxic effects of VOCs, yet there have been fewer studies of their exposures. This is partially due to the challenges of recruiting children in scientific research (110). Children have a higher surface area to volume ratio, consume more contaminants on a per weight basis, undergo rapid physiological changes and have a developing metabolic system; these factors increase exposures to environmental toxicants compared to adults (111). Of special concern is the fact that children have approximately twice the inhaled volume of air per body weight compared to an adult (111).

Few studies have evaluated residential indoor air and personal exposures to VOCs in children. The main focus of research during the last 20 years was the exposure relationship of VOCs to wheezing and asthma (38,87,99,112), as well as the indoor air environments of child care facilities (19,100). Adgate et al. (46) performed a cross-sectional survey of personal, primary residence, school and outdoor exposures for children aged 7-13 years. The authors concluded that

measuring VOCs in the residential indoor environment correlated with children's

exposures (46). Sexton et al. (113) found a moderate to strong correlation

between residential indoor air and the blood concentration of VOCs in children

aged 6-10 years (R^2 = 0.77). There are no similar studies looking at the

association between personal exposure and the residential indoor air in children

younger than 6 years of age.

Sexton et al. (113) evaluated children's (age 6 to 10 years old) blood

concentrations of VOCs and noted high inter-child variability of blood VOC

concentrations. The School Health Initiative: Environment, Learning, Disease

(SHIELD) study demonstrated that for two of eleven VOCs (1,4-dichlorobenzene

and tetrachloroethylene) there was higher inter-child variability compared to intra-

child variability of VOC exposure (113). For seven VOCs (benzene, carbon

tetrachloride, styrene, toluene, trichloroethene, *m,p*-xylene, *o*-xylene) the intra-

child variability was higher (113). The inter-child variability was approximately the

same for ethylbenzene and 1,1,1-trichloroethane (113). The high inter-child

variability found in the study by Sexton et al. (113) indicates there are differences

in child metabolic capacity, rate and exposures.

In general, the effects of VOC exposures in children are lightly studied. There

are no scientific studies that the author is aware of that conclude a cause-effect

relationship between disease in children and VOC exposures in dwellings,

schools and daycares. Few studies have identified associations between VOC exposures and asthma and other respiratory diseases (38,112). Significant associations were observed between decreased lung function as measured by spirometry and exposures to residential indoor air pollutants in children aged 3 to 17 years (112). VOC exposure has also been associated with asthma and wheezing (98-100). Delfino et al. (99) found an association between VOCs and other criteria air pollutants in the outdoor air near their dwelling and asthma in children 10 to 16 years old. Another study reported no associations between total VOCs (BTEX, limonene and undecane) and wheezing in children; formaldehyde had a significant effect on exacerbation of wheezing (114). Zuraimi et al. (20) determined that the presence of ventilation and air conditioning affected the prevalence of phlegm, coughing and lower respiratory disease in 4759 children of child care centers in Singapore; there was a higher risk of rhinitis in children in non-ventilated daycare centres.

Exposure to air pollutants in utero may also have an effect on a child. A questionnaire administered in 2011-2012 to parents in Changsa, China, collected information on dwelling characteristics and compared this information to ambient air pollutants (PM_{10}, sulfur dioxide and nitrogen dioxide) averaged monthly during gestation and until the child was one year old (115). The authors identified an increase in the risk of asthma in children 3-6 years old in relation to new furniture

and dwelling redecoration (2490 respondents, new furniture: odds ratio 2.34, CI 1.16-4.74 and redecoration: odds ratio 2.21, CI 1.29-3.81) (115).

Massolo et al. (116) evaluated indoor and outdoor VOCs (alkanes: hexane, heptane, octane, nonane, decane, undecane, dodecane, tridecane; cycloalkanes: methylcyclopentane, cyclohexane, methylcyclohexane; aromatic hydrocarbons: BTEX, styrene, 4-ethyltoluene, 3-ethyltoluene, 2-ethyltoluene, naphthalene; chlorinated hydrocarbons: chlorbenzene, trichlorethylene, tetrachlorethylene; terpenes: α-pinene, *b*-pinene, 2-carene, 3-carene, and limonene) in and around La Plata, Argentina during the winters of 2000-2002. Ninety-two kindergartens participated in the study; in decreasing order the locations were industrial, urban, semi-rural and residential (26, 24, 23 and 14, respectively) (116). From their study, Massolo et al. (116) determined the Lifetime Cancer Risk to be over the acceptable risk level of 1×10^{-6} for benzene exposure in children, and the risk was higher still for children that lived in industrial areas.

1.5.2 Animal studies

Animal exposure to VOCs are studied under laboratory conditions to advise health risks and understand the pathogenicity of these toxicants. Sullivan et al. (107) stated that indoor environment quality is poorly studied in companion

animals, but there is increasing interest in future studies. Most of the effects of VOC usage on companion animals (cats and dogs) are extrapolated from human exposures (107). Animals may suffer from bronchitis and asthma that can be associated with or exacerbated by indoor air pollutants including VOCs.

A PubMed search using the terms "volatile organic compound" OR "VOCs" AND "cat" OR "dog" did not produce articles on the individual exposures of companion animals to VOCs. The measurement of individual exposures in the indoor-only cat is a novel project.

Holderman et al. (117) studied host released VOCs by way of a DuPont^{TM} Tedlar® polyvinyl fluoride plastic held by vinyl plastic at the midline of each of four dogs and connected to a vacuum pump with a flow rate of 500 mL/min and Tenax® thermal desorption (TD) tube by way of a Y-split piece of vacuum tubing. One hundred and eighty-two compounds were identified via gas chromatograph mass spectrometer (GC-MS) and comparison to the National Institute of Standards and Technology Mass Spectral Search Program. There were 41 common VOCs for all four dogs (117). Another study employed charcoal and octacecyl-bonded silica filter paper sachets attached to the skin of beagles for 12 hours, followed by elution with dichloromethane and GC-MS analysis (118). Another study captured VOCs via hair clippings and headspace GC-MS analysis

(119). Holderman et al. (117), Borges et al. (118) and Junior et al. (119) had the objectives to study the volatilome of canines and its effects on parasite attraction.

The feline companion animal lives in a similar environment as the infant, being low to the ground with frequent oral exposure to dust and debris (111). The pet cat may act as a sentinel (120) for infant exposure to VOCs. Companion animals (cat and dog) have been previously evaluated to be sentinel species for other environmental pollutants, such as flame-retardants (121-124). Backer et al. (121) found that dogs were exposed to radiation at Superfund sites (land in the United States that has been contaminated by hazardous waste and identified by the EPA as a candidate for cleanup because it poses a risk to human health and/or the environment) and may be useful to supplement human epidemiology studies in those areas. Dye et al. (124) concluded that cats had higher levels of polybrominated diphenyl ethers (PBDEs), a flame-retardant, compared to the median for adults in the US. The authors concluded that cats can improve monitoring for this flame-retardant in the residential indoor environment (124). van der Schalie (122) summarized a workshop on the use of sentinel species to aid the study of human health effects of environmental chemicals; the workshop participants concluded sentinel data is useful for risk assessment, monitoring and to provide an early warning of a problem.

1.6 How are air pollutants, including VOCs, classified as standards in relation to residential indoor environments?

There are two classes of air pollutants with diverse chemical and physical properties (125), which can impact air quality in residential indoor environments. The first are referred to as criteria air pollutants (PM 2.5, ozone, nitrogen dioxide, sulphur dioxide, lead and carbon monoxide) which are ambient gases and particulates regulated by Environment and Climate Change (ECC-Canada) and by the US EPA under the Clean Air Act of 1971. These air pollutants are not normally considered as agents of concern in residential indoor environments with the exception of those that infiltrate into home environments from a nearby contaminated site or high traffic area. In contrast, the second class, toxic or hazardous air pollutants (HAP), are those compounds that are known to cause cancer and other serious health impacts. HAPs are regulated by the US EPA (under the Clean Air Act), but not by ECC-Canada. However, Canada is one of only a few jurisdictions that have developed indoor air exposure guidelines (126) for short (1 hour) and long term (24 hour) exposure for a number of compounds, including the VOCs: benzene, toluene, formaldehyde, acetaldehyde, and naphthalene. These guidelines are not enforceable but are provided for guidance only. They have also identified a set of Indoor Reference Values for 25 different VOCs commonly found in indoor air (127). The Indoor Reference Values represent concentrations that are associated with acceptable levels of risk after long-term exposure (several months to years) that is considered relevant to

human health (127). The sources for most of these reference values are identified as toxicological review documents issued by either US EPA or CalEPA.

1.7 What is the role of building standards and building codes in managing residential exposure to VOCs and other air pollutants?

In both the US and Canada, indoor air quality is guided by professional building standards and codes overseen by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASRAE). They work in conjunction with other professional agencies, the EPA and the US Green Council to produce building standards and have committees with international representation (including Canada) that provide regular reviews and updated standards. Their focus is primarily on office towers, hospitals and other buildings (including apartment complexes and hotels), and not personal residences. Their work generally includes consideration for exposure standards and intervention strategies to eliminate or reduce contaminants in the indoor air that includes residential environments.

VOCs are acknowledged by ASHRAE as a cornerstone for IAQ assessments and the characterization of building material emissions (32). Seventy percent of the hazardous air pollutants on the US EPA's regulatory list are VOCs (128). No federally enforceable standards have been set for VOCs in non-industrial settings

in the US (129). VOCs are described by ASHRAE as a vague term for which there is no universally agreed upon term. For example, the US EPA limits VOCs to those compounds that contribute to smog formation via atmospheric photochemical reactions. AHSRAE indicates this is limiting to those compounds that are present in indoor air that may be important from a hazard reduction perspective. Moreover, studies have shown that concentrations for most HAPs are higher indoors as compared to levels found in outdoor environments (24).

Given the complexity of VOC emission profiles, ASHRAE advises against simply grouping all VOCs together as total VOCs. They stress that individual compounds have highly variable health impacts and the total VOC concentration alone is not predictive of overall effect. They also indicate that VOC detection and quantification is highly method dependent. A given sampling and analysis system cannot capture or fully respond to all the VOCs present in any indoor environment or in the test chamber for a given material. (32)

Research attention has recently shifted to semi-volatile organic compounds and to the transient, highly reactive secondary intermediates created through indoor chemistry interactions between indoor contaminants (information can be found in Section 5.1 of the Indoor Air Quality Guide) (32). Common semi-VOCs include plasticizers such as phthalic acid esters (phthalates) and organophosphate flame retardants used in fabrics and textiles, plastics and

wood-based materials. Certain pesticides are also classified as semi-VOCs (4).

As noted by Wensing et al. (130), potential emission sources for semi-VOC

include wall coverings, wall paints, floor coverings, and electronic devices.

1.8 VOC standards and guidelines

The Government of Canada has developed residential indoor air quality

guidelines for the VOCs acetaldehyde, benzene, formaldehyde, naphthalene and

toluene (126). The European office of the World Health Organization has

published guidelines for indoor air quality on benzene, formaldehyde,

naphthalene, trichloroethylene and tetrachloroethylene (83). There are also

guidelines for public places such as offices and public swimming pools as

regulated by the Canadian Committee on Indoor Air Quality and Buildings

(131,132).

Indoor air quality is important because we all depend on clean indoor

environments for our commute to work, in our workplaces and in our dwellings.

Using the Canadian Health Measures Survey (CHMS) database, Wheeler et al.

(16) found that Canadians are exposed to measurable, but low levels of

benzene, toluene, ethylbenzene and the xylenes (BTEX) in the indoor air.

Wheeler et al. (16) also found that BTEX has been decreasing in Canadian

dwellings since 1991. Gilbert et al. (17) and four other studies provided

information on indoor air quality in Canada (16,18,44,133-135). These studies

evaluated formaldehyde, acetaldehyde, acrolein, BTEX and other VOCs in light

of the age of the dwelling, the presence of a smoker, temperature, humidity and

air exchange rates (16-18,44,133-135). These studies concluded that the VOCs

in most Canadian dwellings are below the USA's Agency for Toxic Substances

and Disease Registry (ATSDR) chronic and acute health risk limits (17) and

Health Canada, ECC-Canada guidelines (136).

1.9 VOC technologies

There are many ways to examine residential VOCs in indoor air. Samples

can be collected using:

- Summa® canisters (19,21,137,138),

- SiloCan^{TM} canisters (Scientific Instrumention Specialist, Inc., Moscow, ID, USA) (137),

- 3 M organic vapour monitors (3 M, St. Paul, MN, USA) (18),

- TraceAir organic vapour monitors (K&M Environmental, Virginia Beach, VA, USA) (105,106,139),

- PerkinElmer Thermal Desorption Tube (PerkinElmer, Inc., Shelton, CT, USA) (16), and

- Gilian 5 personal samplers (Sensidyne, Florida) (44).

Questionnaires were also used to obtain information about the dwelling and house management practices in recent results (16-19,21,44,106,138,140). Questionnaires are particularly important to obtain information on dwelling characteristics and household behaviours that affect the exposure to VOCs (140). Loo et al. (140) determined self-reported responses to questions on the age of the dwelling, presence of a gas stove, cat, mice (pest), and musty odours predicted levels of pollutants that may be associated with adverse health outcomes. The authors concluded that questionnaires are a useful tool to assess a large population's exposures to residential indoor air pollutants (140); however, conclusions cannot be made about personal exposure in children because these associations have not yet been characterized.

Finally, an additional method to study VOC exposures is through biomonitoring methods. VOCs and their metabolites can be measured in urine, breath and blood, as humans release VOCs via their breath, skin, urine, feces, etc. (for a review on the human volatilome see Amann et al. (141)). These biomonitoring tools have not been utilized in animals to study their exposures to VOCs.

CHAPTER 2. RATIONALE

I evaluated the exposure pathway for VOCs in the residential indoor air environment using the ATSDR approach (142) and identified the need for an indoor environmental VOC exposure assessment that included young children under the age of 12 years. There is limited toxicity information on sources of VOCs in residential indoor environments, which are released from a multitude of personal care products, cleaning products, cooking oils, combustion of wood, and other fuel sources. Exposure information is mostly limited to acute high concentrations from occupational exposures and in lab animals (73).

There is a particular concern regarding VOC exposures in vulnerable and susceptible populations, such as young children. Young children share physiological and behavioural characteristics that put them at higher risk of toxicity to a large number of chemicals (111). Children are not often part of scientific studies due to the ethical challenges of the involvement of children in such investigations (110). This research project will help address this paucity of research on VOC exposure in children. The CHMS is a database that collects information on environmental pollutants, including VOCs, and will be used for comparisons between populations of youth-adults and children and their VOC exposures and associations.

An exposure assessment investigation of indoor VOCs was completed to

assess the correlation between VOC exposures in the indoor air environment of

children (3-11 years old) and youth-adults (12-79 years old) from the CHMS data.

CHAPTER 3. GOAL AND OBJECTIVES

The main goal of this study is to improve our understanding of the exposures of young children to VOCs in residential indoor air environments. Specifically, I am interested in what predicts elevated individual VOC exposures and VOC metabolites in urine in children (3-11 years old) and in youth-adults (12-79 years). My analyses involved examination of airborne exposure measurements in relation to household and community characteristics from data available in the Statistics Canada CHMS Cycle 2. I also completed pilot studies of residential indoor environments using the same VOC sampling technology used by Statistics Canada in CHMS Cycle 2 in order to compare findings of VOCs where household cats were present in the home compared to those homes where household cats were not present. This has allowed me to suggest other VOCs that may be important to study in future investigations.

The CHMS data study involved an analysis of a subset of VOCs concentrations measured by Statistics Canada (benzene, ethylbenzene, toluene, *m,p*-xylenes, *o*-xylenes, chloroform, naphthalene, carbon tetrachloride, *alpha*-pinene, acetone and benzaldehyde) and VOC urine metabolites (*t,t*-mercapturic acid, phenol, *s*-phenylmercapturic acid, 1-hydroxynaphthalene, 2-hydroxynaphthalene) to compare exposures between two populations: children (3-11 years old) and youth-adults (12-79 years old) and the corresponding

measured VOCs in their residential indoor air environment. These VOCs were selected based upon those contaminants that were found to be higher than the limit of detection (LOD) in greater than 50% of the samples and upon those that had been previously reported in other studies.

Physical household characteristics of the CHMS data (age of dwelling, presence of adult smokers, cooking and heating sources, etc.) and geographic variations (urban/rural using the MIZ scores and CMA attributes) that may explain VOC exposure data variability were examined. I stratified the data by age group (3-11 and 12-79 years old) and age of the dwelling in separate analyses because I hypothesized that VOC concentrations will vary according to these variables. This approach will help to build a more comprehensive understanding of indoor air quality and exposures, as recommended by the US EPA (143).

My specific objectives were to:

1. Identify and compare the VOC profile differences in the indoor air in the residential dwellings of the two age groups and determine the extent to which the predictors of individual VOC exposures, urine metabolites and lead levels in children (3-11 years old) and youth-

adults (12-79 years old) explained these differences using a national

sample of data collected in CHMS Cycle 2.

2. Examine whether there are other VOCs that should be considered as

   potentially hazardous exposures in Canadian residential

   environments.

3. Examine the current sampling method used by Statistics Canada and

   others for levels of saturation of VOCs in residential indoor

   environments.

To address objective 1, I completed an analysis of VOC concentrations

(benzene, ethylbenzene, toluene, *m,p*-xylenes, *o*-xylenes, chloroform,

naphthalene, carbon tetrachloride, *alpha*-pinene, acetone and benzaldehyde)

and VOC urine metabolites (*t,t*-mercapturic acid, phenol, *s*-phenylmercapturic

acid, 1-hydroxynaphthalene and 2-hydroxynaphthalene) to compare exposures

between the two populations: children (3-11 years old) and youth-adults (12-79

years old) and the corresponding measured VOCs in their residential indoor air

environment using the CHMS Cycle 2 data available at the Atlantic Research

Data Centre. I am interested in physical household characteristics (age of

dwelling, presence of adult smokers, cooking and heating sources, etc.) and

geographic variations (urban/rural using the statistical area classification type)

that may explain VOC exposure data variability. I stratified the data by age group

(3-11 and 12-79 years old) and age of the dwelling in separate analyses because I hypothesized that VOC concentrations will vary according to these variables.

Objectives 2 and 3 were addressed through completion of a pilot study that collected indoor air samples on a convenience sample of nine residential dwellings and the analysis of lab samples using the automatic thermal desorber (ATD, PerkinElmer TurboMatrix 650) gas chromatograph (GC, PerkinElmer Clarus® 680)-mass spectrometer (MS, Perkin-Elmer Clarus® SQ 8).

CHAPTER 4. METHODS

4.1 Methodological considerations

4.1.1 VOC measurement methods

There are many ways to examine residential VOCs in indoor air. Samples can be collected using:

- Summa® canisters (19,21,137,138),

- SiloCan^{TM} canisters (Scientific Instrumention Specialist, Inc., Moscow, ID, USA) (137),

- 3 M organic vapour monitors (3 M, St. Paul, MN, USA) (18),

- TraceAir organic vapour monitors (K&M Environmental, Virginia Beach, VA, USA) (105,106,139),

- PerkinElmer Thermal Desorption Tube (PerkinElmer, Inc., Shelton, CT, USA) (16), and

- Gilian 5 personal samplers (Sensidyne, Florida) (44).

The Summa® canister and TD tube are commonly used methods and a comparison is presented in Table 10.

4.1.2 Questionnaires

Questionnaires were also used to obtain information about the dwelling and house management practices in recent results (16-19,21,44,106,138,140). Validation of questionnaires is important to obtain valid and reliable results (144,145); the Statistics Canada CHMS questionnaire has been extensively validated (146). Questionnaires are particularly important to obtain information on dwelling characteristics and household behaviours that may affect the exposure to VOCs (140). Loo et al. (140) determined self-reported responses to questions on the age of the dwelling, presence of a gas stove, cat, mice (pest), and musty odours predicted levels of pollutants that may be associated with adverse health outcomes. The authors concluded that questionnaires are a useful tool to assess a large population's exposures to residential indoor air pollutants (140); however, conclusions cannot be made about personal exposure in children because these associations have not yet been characterized.

Finally, an additional method to study VOC exposures is through biomonitoring methods. VOCs and their metabolites can be measured in urine, breath and blood, as humans release VOCs via their breath, skin, urine, feces, etc. (for a review on the human volatilome see Amann et al. (141). These biomonitoring tools have not been utilized in animals to study their exposures to VOCs.

4.1.3 Multi-receptor-based approach

The multi-receptor approach, as described by the United States Environmental Protective Agency (US EPA) methodology, includes evaluation of exposure to toxicants in a holistic manner, and the employment of these methods to create bridges between research and policy (142). The multi-receptor approach has been utilized by the US EPA in addition to a multimedia and multi-pathway exposure and risk assessment model (142).

The multi-receptor approach is relevant to this research as by design it includes of evaluation of residential indoor air as well as multiple types of residents. VOCs are measured in the indoor air, and personal VOC exposures are captured for an adult and child that share the same environment. An indoor-only pet, such as the cat, can be used as an additional receptor , to try to capture a comprehensive sample of VOCs in the residential indoor environment.

4.1.4 Canadian Health Measures Survey

The Canadian Health Measures Survey (CHMS) is the most extensive nation-wide survey that includes extensive biological and environmental data for the last two decades. The CHMS was developed because of the "growing demands for the surveillance of public health indicators and to address long-

standing limitations in Canada's health information system" (147). The objectives of the CHMS include estimating disease prevalence and distribution across time, and identifying risk factors and "protective behaviours" (147).

The CHMS occurs in two-year cycles and started in the spring of 2007. There have been five cycles to date; Cycle 5 data collection concluded in December 2017. Statistics Canada and Health Canada plan to continue the CHMS survey until the conclusion of Cycle 8 in 2023. (148) For a review of the development, trial and performance of the CHMS, see Tremblay (149).

4.1.4.1 Study design, sampling methods and VOC air quality technology

The CHMS has a two-stage sampling design with selection of residences near cities from selected provinces. Statistics Canada provided sampling weights to account for design effects and bootstrap standard errors. Therefore, the results presented herein are population weighted results and standard errors used are bootstrap standard errors provided by Statistics Canada. Those standard errors were incorporated into confidence interval calculations as mean plus 1.96 times the standard error.

Giroux et al. (150) described the sampling strategy overview for the CHMS. The survey methodology and procedures were initially developed and assessed

during a survey pre-test prior to Cycle 1. The pre-test included 120 volunteers

between the ages of 6 to 79 years old between October and December of 2004

in the Calgary Health Region, Calgary, Alberta. (147)

The study population for my research was the Canadians surveyed in the

CHMS Cycle 2. CHMS Cycle 2 involved a two-stage cluster sampling design and

included participants from these regions:

- British Columbia:
  - Richmond
  - Central and East Kootenay
  - Coquitlam
- Alberta:
  - Edmonton
  - Calgary
  - Manitoba
  - Winnipeg
- Ontario:
  - Central and East Ottawa
  - Oakville
  - South of Brantford
  - Southwest Toronto

- East Toronto

- Kingston

o Quebec:

  - Laval

  - South Monteregie

  - Gaspesie

  - North Shore Montreal

o Nova Scotia:

  - Colchester and Pictou counties

o Newfoundland:

  - St. John's

The CHMS first selected collection sites based on the Canadian Labour Force Survey sampling frame and the 2006 Census to obtain a sample of 5,000 Canadians with 500 males and females in each of 6 age groups (6-11, 12-19, 20-39, 40-59 and 60-79 years old). Fifteen collection sites were selected to obtain a sample of 10,000 participants each within 100 km of the site (mobile examination clinic (MEC)). Dwellings were then selected using a stratified random sampling strategy; the strata were devised from the age of dwelling inhabitants from the 2006 Census and other administrative files. The CHMS excluded dwellings that were non-residential, vacant or demolished and in which all persons living in the dwelling were under 3 years or over 79 years old. Canadian Forces members

and persons living on reserves were excluded. The dataset utilized extensive exclusion criteria that were updated with each cycle. (147,151)

The CHMS dataset has a sample between the ages of 3 and 79 years old. In residences with a child of 3-11 years old, one child and one youth-adult (age 12 to 79 years old) were randomly selected. Participant age groups were broken down by gender with the exception of the 3-5 year old group. (152). The CHMS aimed to randomly recruit 5,700 participants per Cycle to be able to make inferences about the Canadian population (152). The survey had 7,830 respondents in Cycle 2, 7,339 respondents in Cycle 3 and 7,503 in Cycle 4 for a total of 22,672 respondents. Approximately 79.3 % of respondents visited the clinic for physical examination, blood and urine collection: 6,395, 5,785 and 5,794 participants per Cycle, respectively. The survey has information on pairs of adults and children of the age group 3 to 5 years old (Cycles 2 and 3: 881) and 6 to 11 years old (Cycles 2 and 3: 1,235). However, the information for pairs of adults and children was not available for me to carry out the analysis. During the survey, participants were recruited into the study, completed the questionnaire and were forwarded to the Mobile Examination Centre that was within 50 to 75 km of their residence (153). Clinical tests had exclusion lists based on medications and diseases, e.g. tuberculosis medications, which meant that the person was excluded from spirometry testing. (146)

Part of the CHMS was an extensive questionnaire on nutrition, smoking habits, alcohol use, medical history, current health status, sexual behaviour, lifestyle and physical activity, the environment and housing characteristics (Cycle 2 only), as well as demographic and socioeconomic variables (Cycles 2-5). The questionnaire was reviewed multiple times by experts and tested qualitatively. The questionnaire was relayed with computer-assisted personal interviewing. A proxy was allowed to answer questions for a child or adult that needed assistance. (148)

The indoor air measurements for the CHMS were collected using PerkinElmer TD tubes (PerkinElmer, Inc., Shelton CT, USA) (154) for a week following the participant's visit to the Mobile Examination Centre (MEC) (148). See Patry-Parisien (154) for additional information on the methods of sampling, shipping and quality control. A selected sample from the MEC were sent home with the dwelling sampling tubes. People were instructed to place the TD tubes in their dwelling for a week then mail the tubes to specialized laboratories for analysis. The CHMS performed VOC measurements on a total of 118 compounds over Cycles 2, 3 and 4 (155).

The CHMS bootstrap weights created by Statistics Canada from a bootstrap sample of 500 respondents were used for calculation of standard errors (152).

4.1.5 US Air Toxics

The US EPA Air Toxics are air pollutants that can adversely affect the health of humans (24). Some of these indoor air pollutants exist at very low concentrations, however the effects of mixed pollutants and chronic low-dose exposure are important for public health (24). The relationship between toxicity and exposure is complex to study due to the low-level long term exposures to VOCs and the paucity of toxicological profiles for most of the VOCs.

During the short descriptive studies performed as part of this thesis, additional VOCs of interest were identified: 1,1,1,2-tetrachloroethane ($C_2H_2Cl_4$, CAS no. 630-20-6), 1,1,2-trichlorotrifluoroethane ($C_2Cl_3F_3$, CAS no. 76-13-1), 1,2,3-trichloropropane ($C_3H_5Cl_3$, CAS no.98-18-4), 1,2,4-trichlorobenzene ($C_6H_3Cl_3$, CAS no. 120-82-1), 1,2-dibromoethane ($C_2H_4Br_2$, CAS no. 106-93-4), 2-chlorotoluene (C_7H_7Cl, CAS no. 95-49-8), dibromochloromethane ($CHBr_2Cl$, CAS no. 124-48-1), hexachloro-1,3-butadiene (C_4Cl_6, CAS no. 87-68-3), *p*-cumene ($C_{10}H_{14}$, CAS no. 99-87-6), *sec*-butylbenzene ($C_{10}H_{14}$, CAS no. 135-98-8). 1,2,4-trichlorobenzene, hexachloro-1,3-butadiene and *p*-cumene are listed by the US EPA under the US Air Toxics list (156). The effects of some of these VOCs can be found in in their respective Agency for Toxic Substances & Disease Registry toxicological profiles (57).

4.2 Part 1: CHMS data analysis

4.2.1 Access to CHMS files and ethics review

Access to CHMS data involved preparation of a proposal with specific direction toward files and variables necessary for analysis. Once the proposal was accepted by Statistics Canada, I was granted access to the data at the Atlantic Research Data Centre (ARDC) in the Killam Library at the Dalhousie University, Halifax, Nova Scotia, Canada.

Ethics review for the use of CHMS data was not required for this research as Statistics Canada and Health Canada have obtained Research Ethics Board (REB) consent for all parts of the survey including statistical analysis. Statistics Canada and the Public Health Agency of Canada refer to the Health Canada REB and Office of the Privacy Commissioner of Canada (OPC) for policies and procedures regarding privacy and consent (157). I have been granted access to the master dataset under Statistics Canada supervision. Exporting my findings from the Dalhousie RDC site was subject to an accuracy and quality review by Statistics Canada staff.

4.2.3 Data Management

Table 1 contains a listing of the variables used in this study and how they were derived. Upon review of the contents of the available CHMS Cycles, I opted to work solely with Cycle 2 because this Cycle was the only one that provided complete questionnaire data on participants' residential characteristics and home management behaviours.

Air quality variables are continuous and are measured in micrograms per metre cubed ($\mu g/m^3$). I selected the BTEX compounds as known VOCs of interest, and *alpha*-pinene, carbon tetrachloride, chloroform, naphthalene, acetone, benzaldehyde and acetone as emerging indoor air compounds of concern after a literature review. Benzenepropanol was another emerging VOC of interest but there were too few observations above the limit of detection for that compound to be included in the analysis. Urine 1-hydroxynaphthalene, 2-hydroxynaphthalene, *t,t*-mercapturic acid, *s*-phenylmercapturic acid and phenol were selected as metabolites of naphthalene and benzene, respectively, to confirm exposure to these VOCs. Formaldehyde, acetaldehyde and acrolein were also of interest, but they were not captured using the TD tubes in the CHMS Cycle 2. Blood lead and urine free cotinine were selected as proxies for age of the dwelling and smoking, respectively.

I selected the following variables for analysis from the CHMS dataset: province of residence, postal code, CLINICID (unique identifier), age, sex, country of birth, total household income, dwelling characteristics including area and age of the dwelling, blood lead and urine free cotinine, smoking and VOCs (air and urine biomarkers) (Table 1). There were too few dwellings built before 1945 to reliably report the proportion of dwellings in this category.

I selected two main age groups: children (3-11 years old) and youth-adults (12-79 years old) based on the objective to compare the exposure in these two groups. Unfortunately, the CHMS does not have a linking variable between children and youth-adult pairs that live in the same dwelling. Bushnik et al. (158) published on the children and youth-adults pairs, but these were assigned by unpublished variables.

Dwelling age is a categorical variable that presents the year quintile that the dwelling was built and was derived from the dwelling variable provided by Statistics Canada regarding how long ago the home was built. To analyse the dwelling locations by urbanicity (urban, surburban and rural), I utilized the postal codes provided in conjunction with the Postal Code[OM] Conversion File Plus (PCCF+) by Canada Post (159) to determine the statistical area classification type (SAC type).

4.3.4 Preliminary analyses and validation of CHMS data

I performed data management and statistical analysis at the ARDC using SAS/STAT®[1] edition 14.2 (SAS Institute Inc.) (160).

I adapted a few variables from the available data. As per the instructions for use of the CHMS data, I imputed half the limit of detection (LOD) for the chemical compounds of interest that were below the LOD. I utilized the creatinine-adjusted variables of metabolites in the urine. I performed a natural log transformation of the VOC concentrations, urine metabolites and blood lead after examining the skewed distribution of each variable. The natural log transformed variables were utilized for descriptive analyses using normal methods and for model fitting. I generated a categorical variable for the age of the dwelling as per the Halifax Indoor Air Quality Study: 1945 and earlier, 1946-1960, 1961-1980, 1981-2000, and 2001 and later. I created a dichotomous variable for the age of dwelling as before and after 1980 for the regression analysis. I also generated a threshold value "below poverty," meaning having a total annual household income of less than $30,000. Finally, I created a total log indoor air BTEX variable that

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[1] SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc. in the USA and other countries. ® indicates USA registration.

combined the log transformed concentrations of benzene, toluene, ethylbenzene and the xylenes.

I also utilized the SAC type variable, which classifies residences as rural or urban using the PCCF+. The following SAC types are based on the census agglomerations (CA) and areas outside of CA (rural or small town Canada):

- 1. Census subdivision within census metropolitan area
- 2. Census subdivision within census agglomeration with a least one census tract
- 3. Census subdivision within census agglomeration having no census tracts
- 4. Census subdivision outside of census metropolitan area and census agglomeration area having strong metropolitan influence
- 5. Census subdivision outside of census metropolitan area and census agglomeration area having moderate metropolitan influence
- 6. Census subdivision outside of census metropolitan area and census agglomeration area having weak metropolitan influence
- 7. Census subdivision outside of census metropolitan area and census agglomeration area having no metropolitan influence
- 8. Census subdivision within the territories, outside of census agglomeration (161)

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There were too few observations in each of the SAC type categories to allow for these data to be released by Statistics Canada. Therefore, I collapsed the SAC type variable into three categories: urban (types 1-3), suburban (types 4-5) and rural (types 6-8).

The areas outside of the census agglomerations are further defined by the Metropolitan Influence Zones (MIZ) (162). The CA is defined as an urban core with 100,000 residents or more and includes the surrounding municipalities that have at least 50 % of their work force commuting to the urban core daily. The MIZ also defines integration with the urban economy:

- Strong MIZ: 30-49 % commute to the urban centre, strongly integrated

- Moderate MIZ: at least 5 % but less than 30 % commute, moderately integrated

- Weak MIZ: more than 0 % but less than 5 % commute, weakly integrated

- No MIZ: 0 % commute to the urban core, communities with less than 40 people employed in the labour force, not at all integrated in the urban core economy. (163)

I attempted to define adult and child pairs using combinations of variables including proxy (questionnaire answered for another person, yes/no), total household income, province, date of MEC visit and postal code. I found that there were multiple repetitions of pairs despite attempts to tease out pairs using these variables. Therefore, the unpaired child and youth-adult analyses were completed.

4.4.5 Statistical analysis methods

Though I performed weighted and unweighted descriptive analysis, Statistics Canada does not permit public release of unweighted statistical analyses of their data. Descriptive statistics such as the proportion distributions and sources of variability of housing and community characteristics for study variables of interest are included in the tables 2-7. This enabled identification of potentially important covariates of interest for the multiple regression analyses.

I summarized the associations of the following variables by sex and age (children vs. youth-adults), region and urbanicity: the dwelling age, heating type (electric, oil or gas, wood, or other), water source (municipal vs. other), drinking water source (municipal vs. other), finished high school, feelings of belonging to community (good vs. poor), self-perceived health (good vs. poor), self-perceived quality of life (good vs. poor), smoking, smoking more than 100 cigarettes, total

area of the dwelling, number of bedrooms in the dwelling, imputed total annual income under $30,000, and chemicals (BTEX, chloroform, naphthalene, carbon tetrachloride, *alpha*-pinene, acetone and benzaldehyde, urine *t,t*-mercapturic acid, urine *s*-phenylmercapturic acid, urine phenol, urine 1-hydroxynaphthalene, urine 2-hydroxynaphthalene, blood lead, urine free cotinine) (see Table 1 for variable list). I performed a correlation matrix to assess for interdependency, and it occurred between the agent and its metabolites and between the BTEX compounds.

I performed an unpaired Student's t-test of differences of mean concentrations of the VOCs between the sexes and the two age groups (children 3-11 years old and youth-adult 12 to 79 years old). I utilized a Chi-square test to compare unpaired frequencies of dwelling characteristics and self-reported lifestyle and health participant characteristics by sex and age groups.

I generated simple linear regression models of the dichotomous variable of participant age (children 3-11 years and youth-adults 12-79 years old) as the main exposure of interest and residential indoor air chemical concentrations as outcomes. I selected the simple linear regression models that were significant at an alpha = 0.1 level and then created multiple linear regression models for four logarithmically transformed VOCs as dependent variables that were significant in the univariable analyses: total BTEX, chloroform, naphthalene and *alpha*-pinene.

I built the multiple linear regression models using a hypothesis testing approach and forced the independent variables in the model using the change-in-estimate methods (1). The full model is listed as formula 1. I forced the exposure variable (children vs. youth-adults) and other independent variables grouped as follows: 1) age, 2) smoking, 3) dwelling characteristics (type of dwelling and age of the dwelling) and 4) socioeconomic factors (income under $30,000 and mortgage) and 5) urbanicity. I examined income as a confounding variable in all final models. I also evaluated the simple linear relationships of the urine benzene metabolites and urine naphthalene metabolites against their precursors.

I assessed the models constructed using the SAS regression diagnostics procedure, which included a graphical display of the residuals vs. predicted values, studentized residuals vs. predicted values, studentized residuals vs. leverage, normal quantile-quantile plot of the residuals, dependent variable values vs. predicted values, Cook's D vs. observation, histogram of the residuals, and "Residual fit" (164). This allowed for evaluation of model assumptions (linearity and homoscedasticity) and highly influential observations. Suspected outliers were examined individually, and the model was rerun without the outliers to evaluate their influence.

The results are presented using analytical weighting and after exponentiation of the coefficients for the regression models of the VOCs of interest. Cluster

selection in the sampling design was controlled by incorporating bootstrap weights in the analysis. The pairing variable or algorithm between a child and youth-adult that share a residence was not made available for these analyses. The results represent population weighted estimates. Effects of clustering at the home level due to pairing were not incorporated into the analysis due to data unavailability.

Formula 1: Full model for each of air total BTEX, chloroform, naphthalene and *alpha*-pinene (µg/m^3):

$$\log(VOC_{1-4}) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \beta_{10} x_{10} + \beta_{11} x_{11} + \varepsilon$$

x_1: age: 0 = youth to adults, 1= children

x_2: smoking inside the dwelling: 0 = no, 1 = yes

Dwelling characteristics:

x_3: type of dwelling: single detached: 0 = no, 1 = yes

x_4: type of dwelling: attached: 0 = no, 1 = yes

x_5: type of dwelling: apartment: 0 = no, 1 = yes

x_6: age of dwelling: 0 = >1980, 1 = <1980

x_7: number of persons in dwelling

Socioeconomic factors:

x_8: total annual household income: 0 = >\$30,000, 1 = <\$30,000

x_9: mortgage: 0= no, 1 = yes

Urbanicity:

x_{10}: urban: 0 = no, 1 = yes

x_{11}: suburban: 0 = no, 1 = yes

4.3 Part 2: Indoor air sampling and lab analysis – descriptive studies

I aimed to identify VOCs in the residential indoor air environment in Halifax, Nova Scotia and validate the currently used method for measuring VOCs in that environment. I selected thermal desorption (TD) tubes as an inexpensive and reliable technology to measure concentrations of VOCs. I also examined the possibility of utilizing a multi-receptor approach to VOC exposures in the residential indoor environment.

Residential indoor air samples from the volunteers' dwellings were collected using TD tubes (Tenax® TA: Markes International, California. U.S.A. and Millipore Sigma, Darmstadt, Germany) with passive (diffusive) sampling because of the ease and relatively inexpensive method as compared to sampling with a canister (Table 10). TD tubes were deployed with a Swagelok® cap on one end and a diffusive cap on the other (Figure 1). I deployed two TD tubes per dwelling (one field blank and one sampling tube) in the living room. The two tubes were suspended from the ceiling on a string using a thumbtack at a height of 1.2 to 1.5 m from the floor (36) and at least 1 m from the wall (Figure 2). I asked

participants to keep all the windows in the dwelling closed during the sampling period and 2 hours prior to the start of the experiment to mimic worst-case scenario of air ventilation. Otherwise, participants acted normally and performed regular behaviours, such as cleaning, cooking and hobbies during the sampling period.

After sampling, I extracted VOCs from the TD tubes using the automatic thermal desorber (ATD, PerkinElmer TurboMatrix 650) and measured the concentrations of VOCs using a gas chromatograph (GC; PerkinElmer Clarus® 680)-mass spectrometer (MS; PerkinElmer Clarus® SQ 8). I employed the U.S. EPA method TO-17 (3) for TD analysis on GC-MS using the instrumentation parameters listed in Table 11. I performed this analysis at the Health and Environments Research Centre (HERC) laboratory within 1-2 days of obtaining the samples. I analyzed the samples with a standard mixture containing 76 VOCs (Calibration Mix#1, Restek, Pennsylvania, USA). Then, I used TurboMass[TM] GC/MS Software (PerkinElmer, Massachusetts, USA) (165) and Chromeleon[TM] 7.2 Chromatography Data System Software (Thermo Fisher Scientific[TM], Massachusetts, USA) (166) for identification of the VOCs in the samples and quantification of the VOC concentrations. VOCs were identified by comparing the main ion, then two secondary ions for every compound in the standard mixture.

I utilized Stata 14 (StataCorp, Texas, USA) (167) to perform data management and descriptive analysis for these descriptive studies. Briefly, the calculated mass reflects the percentage of the contents of the TD tube that were passed through the GC-MS; therefore, the calculated mass was back-calculated from the measured mass and percent injection. I converted the measured VOCs to concentration using known (1995 MDHS 80 Volatile Organic Compounds in Air Methods (168)) or estimated passive diffusion rates (1 cm^3 per minute) that differ per compound (Formulas 2 and 3). The formulas utilized assume constant air exchange rate and require consideration of the volume of the room (indoor air quality questionnaire), relative humidity and temperature (mean of measured variables) because all of these variables affect the rate at which VOCs are adsorbed into the TD tubes. I also converted parts per million (ppm) to $\mu g/m^3$ (Formula 4).

Formula 2: Concentration of organic vapour in air (ppm) = $\frac{1000(m-m_{blank})}{U'xt}$

Formula 3: $U'\left(cm^3min^{-1}\right) = U(ng\ ppm^{-1}min^{-1}) \times \frac{24.5}{MW} \times \frac{T}{298} \times \frac{101}{P}$

Where:

U = uptake rate (ng $ppm^{-1}min^{-1}$)

U' = uptake rate (cm^3min^{-1})

24.5 = molar volume (litres) at 298K and 101 kPa

MW = molecular weight of volatile organic compound

T = temperature of sampled air in Kelvin

P = pressure of sampled air in kPa

m = mass (ng)

(168)

Formula 3: Concentration $\left(\text{ug}/\text{m}^3\right) = \frac{\text{molecular mass } (\text{g}/\text{mol})}{\text{molar volume (L)}} \times$ Concentration (ppm) $\times$

1000

(169)

During the first descriptive study, in March 2016, ten HERC laboratory members voluntarily deployed the two tubes (blank and sampling) in their living room for 48 hours, according to the methods described above. These participants also answered the Halifax Indoor Air Quality Study (IAQ) questionnaire (133).

Based on the initial findings from the first descriptive study, the second study was performed in August 2016 to answer the following questions:

1. What is the optimal sampling time frame?
2. What is the optimal height for TD tube sampling?
3. What VOCs are released by litter?

To evaluate the sampling time frame, I deployed 20 TD tubes in August 2016 for 10 days. Every 24 hours, I removed a pair of TD tubes (1 blank and 1 sampling). To evaluate height, I set 6 tubes at three heights in the living room (35 cm, 94 cm and 190 cm) for 48 hours. To evaluate if litter or the litterbox release any VOCs, two TD tubes were hung at the entrance/exit of the litterbox for 48 hours in August 2016 (Scepter Canada Inc. 170 L storage container made of polyethylene material that contains a large volume of litter (QualiCat Scoopable Cat Litter, A.C.L., Montreal, Quebec: 99 % dust-free scent-free agglomerating clay and blue zeolite litter)). The room with the litterbox also housed thermoplastic polyurethane bubble soccer suits and bonding adhesive (X-15 Bonding Adhesive, Datey®).

To test VOC exposures in multiple receptors that share the same environment (residential indoor air, stay-at-home adult, child and indoor-only companion cat), a multi-receptor approach was employed in the final descriptive study. To test the feasibility of the methods developed for the TD tubes worn on an adult and cat during 48 hours in December 2016. The adult and cat spent the majority of their time in the living room, and two TD tubes were hung in the room (1 blank and 1 sampler). The TD tube was attached to a harness that the cat was trained to wear prior to this study (Figure 3). I instructed the adult participant to wear the sampling device attached to their shirt/jacket collar, but not covered by clothing. At night, the passive sampling device was set in the living room. For

sampling, the Swagelok® cap was removed at one end, but the diffusive cap was not applied because it is not firmly attached to the TD tube and may have posed a risk of ingestion to the cat.

CHAPTER 5. RESULTS

5.1 Part 1: CHMS data analysis

The descriptive results and summary of model analyses are presented in Tables 2 to 9. The findings provided in the summary tables are representative of the Canadian population as the sampling weights have been incorporated in order to adjust for the entire Canadian population and control any clustering effects.

In what follows, where an estimate is presented as "child" there is also a youth-adult present in the same dwelling. However, when a youth-adult estimate is presented there is no indication whether there is a child or not in the same dwelling. This is a limitation of the data due to the lack of availability of a pairing indicator variable for these analyses. This was requested to Statistics Canada but denied.

There were 6,395 respondents to the CHMS Cycle 2 (2009-2011) thereby exceeding the sampling goal of 5,700 respondents (151). The total sample available for this investigation was reduced due to non-response for certain variables and incomplete chemical analyses for a subset of the respondents. The response rate had an adequate sample size for the exposures of interest for the

regression analysis (total BTEX n = 4085; chloroform, naphthalene and *alpha*-pinene n = 4087). The majority of samples were obtained from urban areas (n = 4776), which accounts for 74.68 % of the VOCs measured. In comparison, suburban areas contributed 16.51 % (n = 1056) and rural areas just 8.80 % (n = 563) of samples. The study sample had different sample sizes per region of Canada: in ascending order, the Atlantic Provinces, Prairie Provinces, British Columbia, Quebec and Ontario. The study sample had slightly more females (51.90 %) than males (48.10 %). Dwellings with children had on average 1.42 children less than 6 years old, 2.05 children less than 12 years old and 2.31 children less than 15 years old.

    BTEX, chloroform, naphthalene, carbon tetrachloride, *alpha*-pinene, acetone and benzaldehyde were selected for descriptive analysis. Prior to proceeding with modeling, I confirmed that each of the VOCs of interest exhibited a log normal distribution. Therefore, the estimates presented in tables are in original units ($\mu g/m^3$) as the estimates (ln transformed) were exponentiated. Total BTEX concentrations were large, and converted to mg/m^3 in Table 8a. Total BTEX, chloroform, naphthalene and *alpha*-pinene were selected for the development of multivariable regression modelling after confirming significant (alpha < 0.1) univariable linear regression results related to age group (Formula 1).

The final regression models explained less than 15% ($R^2 < 15$ %) of the overall variation in the total BTEX, chloroform, naphthalene and *alpha*-pinene concentrations.

5.1.1 VOC profile differences in the two populations: comparison between children (3-11 years old) and youth-adults (12-79 years old), and residential indoor air characteristics

There were significant differences of the type of dwelling, smoking in the residential dwelling, mortgage, self-perceived health, categorical age of the residential dwelling, number of persons in the residential dwelling, approximate area of the residential dwelling and heating source between dwellings with and without children. More adult participants (dwellings without children under the age of 12 years old) had mortgages (88.76 %) compared to dwellings with children (64.04 %). The total annual household income was under $30,000 for 13.42 % of the dwellings where children lived and 18.05 % where adults lived. Three quarters of the sampled Canadian population owned their dwelling between 2009 and 2011. (Table 2a)

Respondents that had an income under $30,000 had naphthalene concentrations (β = 1.30 µg/m^3, p < 0.0001; Table 8c) and *alpha*-pinene concentrations (β = 1.43 µg/m^3, p < 0.0001; Table 8d) in their exposures. Income

under \$30,000 was a non-significant predictor for total BTEX (β = 190.14 mg/m^3, p = 0.6192; Table 8a) and chloroform (β = 0.92 µg/m^3, p = 0.1194; Table 8b).

There is a significantly (p = 0.0036) higher percentage of dwellings with at least one smoker where youth-adults live compared to where children live (8.99 %). Of the 8.99 % of dwellings with a person that smoked and with children under 12, 12.08 % of those respondents were male and 8.18 % were female. There was no significant difference between the sexes of the respondents that lived where at least one person smoked inside the dwelling, but males did smoke over 100 cigarettes per day more frequently (47.94 % males compared to 41.42 % females, p = 0.0027). (Table 2a)

The indoor air concentration of total BTEX did not increase significantly with the presence of smoking in the dwelling (β = 4.12E+05 mg/m^3, p = 0.2606; Table 8a). Smoking in the dwelling was not a significant predictor for chloroform concentration variation in the air (β = 1.08 µg/m^3, p = 0.3179; Table 8b). Smoking in the dwelling contributed toward increased naphthalene concentration (β = 1.19 µg/m^3, p = 0.0087; Table 8c). A*lpha*-pinene concentration had an inverse association with smoking (β = 0.74 µg/m^3, p < 0.0001; Table 8d).

There were significant differences between the mean concentrations of VOCs between males and females, and children and youth-adults with some exceptions (Tables 5a-c). There were no significant differences ($p > 0.05$) for benzene and naphthalene concentrations. There was a borderline insignificant difference, at alpha = 0.05, between children and youth-adults for 1-hydroxynaphthalene concentration ($p = 0.0564$).

Dwellings with and without children under 12 years old being was not a significant predictor in the models for BTEX and chloroform ($p > 0.3000$; Tables 8a-b), but this variable was significant for naphthalene and *alpha*-pinene ($p < 0.0100$; Tables 8c-d). Children had exposures to naphthalene on average 0.79 µg/m^3 greater than adults ($p = 0.0002$). Being a dwelling with children under 12 years old increased the *alpha*-pinene exposure by 1.17 µg/m^3 compared to dwellings without children under the age of 12 ($p = 0.0066$).

Dwellings included in the sample population were heated by oil or gas, electricity, wood and other methods. There were no significant differences in the proportions of heating sources between residential dwellings with and without children. On average, the size of the dwelling was between 56 and 280 m^2. (Table 3a)

5.1.2 VOC profiles differences by the age of the dwelling

There were significant differences between dwellings with and without children during examination of the age categories of the dwellings. Dwellings built between 1961 and 1980 were less likely to have children under the age of 12 years (p = 0.0104), whereas dwellings built between 1981 and 2000 were more likely to have children under the age of 12 years living in them (p = 0.0209). Regional differences in the ages of residential dwellings were also observed. The majority of dwellings in BC and the Prairies were built between 1961 and 1980, while central and Eastern Canada dwellings were more likely to have been built between 1981 and 2000 (Table 3a). Furthermore, urban and suburban area dwellings were generally built more recently than rural dwellings (Table 4a).

The age of the dwelling (before and after 1980) was a significant predictor for total BTEX, chloroform and *alpha*-pinene (p < 0.05; Tables 8a-b,d). Dwellings built before 1980 had an increased total air BTEX concentration on average by 14.70 µg/m^3 (p < 0.0001) compared to dwellings built after 1980 when the other variables were kept constant. The mean concentration of chloroform increased by 0.25 µg/m^3 (p < 0.0001) in dwellings built before 1980. The mean concentration of *alpha*-pinene was also increased in older dwellings (β = 0.52 µg/m^3, p < 0.0001). The age of the dwelling before and after 1980 was not a significant predictor of the mean concentration change of naphthalene in the air (β = 1.05 µg/m^3, p = 0.2073; Table 8c).

5.1.3 VOC profile differences by the region (British Columbia, the Prairies, Ontario, Quebec, and the Atlantic Provinces) and urbanicity (urban, suburban and rural).

In all regions and urbanicity categories, single detached dwellings were the most frequent (Table 4a). Total BTEX was increased in single detached dwellings (β = 8.41E+15 mg/m^3, p < 0.0001) compared to other housing types (attached dwellings and apartments were not significant in the model; Table 8a). *Alpha*-pinene concentration increased significantly in single detached dwellings compared to other types (β = 1.63 µg/m^3, p < 0.0001; attached: β = 1.21 µg/m^3, p = 0.0802; apartment: β = 0.79 µg/m^3, p < 0.0756; Table 8d). The dwelling type also had an association with naphthalene, and the detached and attached dwelling types had an increased concentration of naphthalene compared to other types of residences (β = 1.42 µg/m^3, p = 0.0008 and β =1.27 µg/m^3, p = 0.0339, respectively; Table 8c).

In Atlantic Canada, 77.83 % of the respondents owned their dwelling, and 67.48 % were paying a mortgage (Table 4a). The other regions had similar frequencies of owning a dwelling and having a mortgage. In terms of income, households with a total annual income under $30,000 made up 21.75 % of the BC respondents, 13.88 % in the Prairies, 13.29 % in Ontario, 23.82 % in Quebec and 21.96 % in the Atlantic Provinces. There was a significantly higher frequency of total household annual income under $30,000 in rural areas (36.59 %)

compared to urban (15.96 %; p < 0.0001) and suburban areas (14.36 %; p < 0.0001) (Table 5a). Income and mortgage were significant predictors in the regressions for total BTEX, naphthalene and *alpha*-pinene concentrations (Tables 8a,c-d). The mortgage predictor had a significant interaction with smoking and urban areas in the model for total BTEX (p < 0.0001).

Respondents that completed high school were most frequent in the Atlantic Provinces, the Prairies, Ontario, Quebec and BC, in ascending order (Table 3a). More people graduated from high school in urban areas (94.00 %) than suburban (89.11 %; p < 0.0001) or rural areas (88.50 %; p = 0.0010; Table 4a).

Smoking inside the dwelling was least frequent in BC (2.50 %) and most frequent in Quebec (25.50 %; p = 0.0052; Table 3a). Of the smokers, 52.21 % of Quebecers smoked 100 or more cigarettes per day while the other regions had averages between 34.55 % and 49.39 %. A larger percentage of rural and suburban respondents smoked inside the dwelling compared to urban dwellers (Table 4a). There was the same trend in terms of frequency of persons that smoked over 100 cigarettes per day.

The most common heating sources for dwellings were oil or gas in BC, the Prairies and Ontario (Table 3a). Respondents from both Quebec and the Atlantic Provinces relied more heavily on electricity to heat their dwellings. The main heating sources were oil or gas in urban and suburban areas, while participants

in rural areas were more likely to report they used wood and electricity (38.48 %

and 41.00 %, respectively).

Although not evaluated in the current model, the average area of the

residential dwelling may have an effect on the residential indoor air. Dwellings in

BC and Ontario were on average 96 to 280 m^2 (Table 2b). In the three other

regions, the average area of the dwellings were between 56 to 185 m^2. Dwellings

were also larger on average in urban areas. Ontario typically had 3.46 persons

per dwelling and other provinces had fewer.

Respondents that lived in an urban centre had an increased (β = 1.25 µg/m^3,

p < 0.0001; Table 8b) chloroform exposure compared to suburban and rural

areas; however, in suburban areas there were higher chloroform concentrations

(β = 0.68 µg/m^3, p < 0.0001). In the model for naphthalene concentrations, urban

centres were not significant, but suburban centres were (β = 1.28 µg/m^3, p <

0.0001).

The mean concentrations of the VOCs were similar between BC and the

Prairie Provinces with the exception of *t,t*-mercapturic acid (p < 0.0001; Table 6).

Ontario, the Atlantic Provinces and BC had lower concentrations of benzene

compared to the Prairies and Quebec. Quebec had the highest average total air

BTEX (29.13 $\mu g/m^3$, 95 %, CI: 21.04-40.33 $\mu g/m^3$) compared to other regions.

The second highest total air BTEX was in Ontario with an average concentration

of 17.52 $\mu g/m^3$ (95 % CI: 11.25-27.30 $\mu g/m^3$; $p < 0.0001$). Residential dwellings

in rural areas had lower mean concentrations of air benzene, but had higher total

BTEX (Table 7). Quebec respondents also had the highest mean concentrations

of naphthalene and *alpha*-pinene compared to the other regions. *Alpha*-pinene

concentration was lowest in rural areas (4.86 $\mu g/m^3$, 95 % CI: 2.88-8.21 $\mu g/m^3$;

Table 7). The Prairie Provinces had the highest mean concentration of

chloroform. There was a trend of decreasing air carbon tetrachloride

concentrations when moving from urban to rural centres. Benzaldehyde was

highest in suburban areas (6.76 $\mu g/m^3$, 95 % CI: 3.60-12.71 $\mu g/m^3$) compared to

urban (2.90 $\mu g/m^3$, 95% CI; 4.63-9.73 $\mu g/m^3$; $p < 0.0001$) and rural areas (4.86

$\mu g/m^3$, 95 % CI: 2.27-4.39 $\mu g/m3$; $p < 0.0001$).

For every additional person in the dwelling, the total BTEX increased by 0.01

$\mu g/m^3$ ($p < 0.0001$), chloroform increased by 1.11 $\mu g/m^3$ ($p < 0.0001$),

naphthalene increased by 1.09 $\mu g/m^3$ ($p < 0.0001$) and *alpha*-pinene increased

by 1.06 $\mu g/m^3$ ($p < 0.0001$; Tables 8a-d).

Water sources in the sampled Canadian dwellings were mostly supplied by

the municipality and most respondents drank tap water. In urban centres, 95.34

% of dwellings were supplied by the municipality compared to 56.70 % of

suburban (p < 0.0001) and 61.75 % of rural centres (p < 0.0001; Table 3a).

5.1.4 Biomonitoring profiles: blood lead and urinary metabolites from indoor air contaminants

5.1.4.1 Benzene and naphthalene

The urine metabolite *t,t*-mercapturic acid had the highest mean concentration

in the Atlantic Provinces compared to other regions (Table 9), but this did not

coincide with a larger mean concentration of air benzene. Both urine 1-

hydroxynaphthalene and 2-hydroxynaphthalene were lowest in BC compared to

other regions; but BC did not have the lowest mean concentration of

naphthalene.

Simple linear regressions with the air precursor benzene for *t,t*-mercapturic

acid (n = 2020, β = 1.12 $\mu g/m^3$, p < 0.0001) and *s*-phenylmercapturic acid (n =

1569, β = 1.31 $\mu g/m^3$, p < 0.0001) demonstrated significant associations. The

urine metabolite phenol was not significantly predicted by its precursor benzene

(n = 2039, β = 1.02 $\mu g/m^3$, p = 0.3189). The hydroxynaphthalenes were

significantly explained by the precursor air naphthalene (1-hydroxynaphthalene:

n = 2056, β = 1.40 $\mu g/m^3$, p < 0.0001; 2-hydroxynaphthalene: n = 2003, β = 1.13

$\mu g/m^3$, p < 0.0001).

5.1.4.2 Blood lead

The highest concentration of blood lead was in Quebec (0.43 µg/L; Table 3b). The higher concentration of blood lead did not coincide with older dwellings in that province as most dwellings were built between 1981 and 2000 (37.11 %; Table 3a). The average concentration of blood lead was highest in rural areas (0.44 µg/L) compared to urban and suburban areas (both 0.29 µg/L).

5.2 Part 2: Indoor air sampling and lab analysis – descriptive studies

The VOCs of interest were selected from the descriptive studies and a literature review. I identified ten VOCs (1,1,1,2-tetrachloroethane ($C_2H_2Cl_4$), 1,1,2-trichlorotrifluoroethane ($C_2Cl_3F_3$), 1,2,3-trichloropropane ($C_3H_5Cl_3$), 1,2,4-trichlorobenzene ($C_6H_3Cl_3$), 1,2-dibromoethane ($C_2H_4Br_2$), 2-chlorotoluene (C_7H_7Cl), dibromochloromethane ($CHBr_2Cl$), hexachloro-1,3-butadiene (C_4Cl_6), *p*-cumene ($C_{10}H_{14}$), *sec*-butylbenzene ($C_{10}H_{14}$)) that had the highest median concentrations (in alphabetical order) during the first two descriptive studies (Tables 12 and 13).

5.2.1 Descriptive study 1

TD tubes from 9 of 10 participants were returned to the laboratory for analysis. Approximately half of the 76 VOCs in the standard were detected (47.4 %, 36/76) in the samples. Hexachloro-1,3-butadiene (C_4Cl_6), dibromochloromethane ($CHBr_2Cl$), 1,2-dibromoethane ($C_2H_4Br_2$), 1,1,2-trichlorotrifluoroethane ($C_2Cl_3F_3$), 1,2,3-trichlorobenzene and 1,2,4-trichlorobenzene ($C_6H_3Cl_3$; tied for 5th) had the highest median concentrations (in descending order) measured in the nine residences (Table 12). The maximum measured concentrations of VOCs identified were below the eight hour time-weighted average set by the Occupational Safety and Health Administration (170). All VOCs measured demonstrated a lognormal distribution.

Eight of the nine (88.9 %) participants completed the questionnaire. The participants volunteered that the questionnaire was time-consuming and extensive. The major recommendation was to produce a one to two-page questionnaire (Appendices G and H). Later, two two-page questionnaires were produced to capture information about the dwelling (baseline questionnaire) and about habits during the sampling period (diary questionnaire, e.g. cleaning products utilized).

The VOCs measured in the nine dwellings had levels below the limit of detection for the BTEX compounds, chloroform and carbon tetrachloride. *Alpha*-pinene, acetone and benzaldehyde are not part of the standard used for analysis of the samples in this descriptive study. Naphthalene was the only compound analyzed in Cycle 2 of the CHMS that was detected (above the LOD) in this descriptive study. The geometric mean concentration of naphthalene was higher in the 9 Halifax dwellings (93.84 µg/m^3, minimum 84.11 µg/m^3, maximum 96.13 µg/m^3) compared to the mean concentration in Atlantic Canada (0.66 µg/m^3, 95 % CI 0.57-0.76 µg/m^3). No direct comparisons between these values (Part 1: CHMS and Part 2: descriptive studies) can be made due to differences in sampling techniques used in the lab data analysis.

I determined the need to clarify the location of TD tube placement in the home after discussion with the volunteers. Some placed the TD tube on a surface such as a table, while others hung the tube from a string attached to the wall.

5.2.2 Descriptive study 2

Based on the findings from the first study, I optimized the collection process of VOCs in the residence. The number of identified VOCs increased from 0 to 5 compounds over the 10-day sampling period, but only 10/76 (13.2 %) of the

VOCs on the standards were detected: 1,1,1,2-tetrachloroethane ($C_2H_2Cl_4$),

1,2,3-trichloropropane ($C_3H_5Cl_3$), *sec*-butylbenzene ($C_{10}H_{14}$), *p*-cumene ($C_{10}H_{14}$),

2-chlorotoluene (C_7H_7Cl) (in descending order of median concentrations

measured over the 10 days, Table 13; Figure 4). Again, all maximum measured

concentrations were below the recommended eight-hour time-weighted average

(170).

The adsorption of VOCs on the Tenax® TA TD tubes over 10 days

demonstrated an exponentially decaying function (Figure 5). These results are

consistent with the findings of a previous study; a non-linear relationship in

diffusion (passive) sampling over time (171). Maddalena et al. (172)

demonstrated the passive sampling uptake curve has a power function

distribution. The linear uptake curve can be obtained by plotting the "cumulative

volume sampled over time" (172). The raw data and time average data for the

VOC groups alkanes, halogenated, terpene, aromatic and alkoxy demonstrated

steady state of the concentration trend lines at approximately 100 hours or a little

over 4 days (172). The CHMS validated VOC uptake over 4 to 10 days (173).

n-Propylbenzene (C_6H_{12}) and chlorobenzene (C_6H_5Cl) were identified at 0.35

m over 48 hours in August 2016. No other VOCs were detected at a sampling

height of 0.35, 0.94 and 1.90 m that were not also present on the blank sample.

This preliminary test result suggests sampling at a low height is more appropriate

for detection of VOCs in indoor settings. However, due to the small sample size and short period of passive sampling, the association between height and VOCs captured on the Tenax® TA TD tube needs to be further examined.

Tetrahydrofuran (C_4H_8O) and dibromochloromethane ($CHBr_2Cl$) were identified in the room with the litterbox and/or released by the litter and/or litterbox. An examination of PubMed literature revealed that no studies have been reported regarding concentrations of VOCs emanating from cat litter. The X-15 adhesive label indicates it contains tetrahydrofuran, polyester resin and acetone. The litter may be a source of dibromochloromethane and tetrahydrofuran. I recommend a diffusion cap on further studies testing VOCs released by cat litter; despite the 99 % dust-free guarantee, it still produces a lot of dust that can affect the adsorption onto TD tubes and may contaminate the GC-MS.

The CHMS used sampling in the middle of the room at adult breathing height (148). In this lab analysis, I found lower sampling (at coffee table height) provides different VOC profiles.

5.2.3 Descriptive study 3

This descriptive study was designed to test the feasibility of the sampling methods developed for assessing VOC exposures of multiple receptors (including household pets) in the residential indoor environment. During the day, the cat and volunteer adult wore the TD tube on the harness and a pocket clip on the front of the shirt, respectively. At night, TD tubes were removed and placed in the living room where both the cat and volunteer spent over 90 % of their time. I also removed the halter from the cat overnight. I observed the cat scratching at the harness occasionally; however he did not change his habits during the sampling period. The volunteer (person) did not see any inconveniences to wearing the tube during the 48 hours.

I trained my pet cat early as a kitten using low stress handling techniques to wear a halter (Appendix D). He was habituated to wearing the TD tube on the halter during 2 sessions of approximately 30-60 minutes. He performed normal behaviours of sleeping, grooming and eating while wearing the halter and device during the 48 hours of sampling performed for the third study. Not all companion cats will adapt as readily when wearing the halter.

Multiple VOC peaks were shown on the chromatogram, but the compounds were not quantified due to high background noise in the TD tubes collected by

the three receptors (living room, adult and pet cat). I could not detect the VOCs

sampled due to experimental and instrumentation condition, but validation of this

technique would be a useful tool in the residential indoor environment utilizing the

multi-receptor approach. Despite the limited data in this part of the analysis, I

found that the cats had similar behaviour to the adult volunteer and therefore cats

could be used as a surrogate for humans in future studies.

CHAPTER 6. DISCUSSION

This is the first investigation to report a comparison of child and adult exposures to key VOCs (total BTEX, chloroform, naphthalene and *alpha*-pinene) from a national sample (CHMS cycle 2) and link these exposures to corresponding biomonitoring data in residential indoor environments. This study contributes new evidence regarding differences in VOC exposures in the residential indoor air of dwellings that do and do not have children under the age of 12 years.

This study also made some advances in air monitoring methods of VOCs in indoor environments with the application of TD tubes in nine Halifax, NS, residential dwellings without children. This multiple receptor method is different from the method used in the CHMS. This study also presents findings from a pilot study measuring the impacts of indoor air quality testing methods on household pets. The presence of animal-related variables was not included in the CHMS household survey questionnaire. Further research is necessary, as I postulate that using pets as a surrogate species, such as the indoor-only companion cat, may be a valuable tool for the monitoring of 'toddler relevant' VOC exposures in future CHMS data collection.

The VOCs measured during the laboratory and CHMS analysis were all below the limits set by the regulating agencies, such as the Occupational Safety and Health Administration (170).

6.1 Part 1: CHMS data analysis

An important finding of this study is that average concentrations of total BTEX, chloroform, naphthalene and *alpha*-pinene were higher in dwellings where children less than 12 years of age live compared to dwellings without children. This association was observed to be significant in the final models for naphthalene and *alpha*-pinene, but not for BTEX and chloroform. The differences between dwellings with and without children under 12 years old is hypothesized to be due to differences in the presence of children's toys and cleaning products and home management practices in the dwellings. Toys can release scents (174) and fragrances (175) that are effectively emitting VOCs into the indoor air environment. There are regulations in Canada for certain chemicals in toys and on the surface of toys (176): for example, benzene, carbon tetrachloride, lead and organic solvents on balloons.

Stönner et al. (177) evaluated environments with and without children by measuring VOCs in movie theatres. This study found differences in the indoor air

of the movie theatres when there was a greater proportion of children than adults watching a movie (177).

The Cycle 2 model developed for total indoor air BTEX explains the variation in the CHMS data poorly (R^2 = 0.0307). In comparison, other models, e.g. Harrison et al. (24), had 9.2-49.5 % of the variance explained by the models for source apportionment in exposures to VOCs outdoors. For improved regression modelling for exposures to total BTEX, naphthalene, chloroform and *alpha*-pinene, an additional risk factor that should be evaluated is the presence of a garage attached to the dwelling. Recently, Cycle 4 descriptive data was released (178) and there was a higher concentration of benzene in the residential indoor air when the dwelling had an attached garage with direct entry to the dwelling. Stocco et al. (21) produced mixed effects models that predicted adult personal exposure to VOCs correlated to exposure of VOCs in indoor air (CEPA VOCs R^2 = 58.4-87.2 %, other common VOCs R^2 = 41.7-90.1 %).

I did not have the opportunity to utilize the multi-receptor approach in this study of the CHMS Cycle 2 data. The benefits of a multi-receptor approach, as described by the United States Environmental Protective Agency (US EPA) methodology, includes evaluation of exposure to toxicants in a holistic manner, and the employment of these methods to create bridges between research and policy (143). The multi-receptor approach has been utilized by the US EPA in

addition to a multimedia and multi-pathway exposure and risk assessment model (143). In this analysis, I was unable to match children to their parent/guardian in the same dwelling for a direct comparison of their exposures. Bushnik et al. (158) created a variable in the CHMS dataset, within Statistics Canada, to identify pairs of children and a parent/guardian that share the same dwelling. This linking variable or algorithm was not released to us. Nevertheless, the presented data do suggest that there is variability of VOC exposures and metabolites experienced by children and adults within Canadian residential environments.

BTEX was higher in dwellings with smokers, as expected because studies have shown that BTEX are released into the air during the combustion of cigarettes (25). BTEX compounds were lower than the maximum health limit as determined by the Occupational Safety and Health Administration (OSHA) (170). The measured concentration of toluene was much lower than the 24 hour exposure limit (2.3 mg/m^3) (126). Naphthalene mean concentrations were also lower than the 24 hour exposure limit of 10 µg/m^3. Acetone, carbon chloride, ethylbenzene and the xylenes were below the Indoor Air Reference Levels as set by Health Canada (57,127). Statistics Canada (178) published its summary of Cycle 4; concentrations of benzene, o-xylene and toluene concentrations increased, while ethylbenzene and m,p-xylenes decreased compared to Cycle 2. However, it should be noted that these guidelines do not take into account the differences in the respiratory system of the child versus the adult (179).

The province of Quebec had the highest mean concentrations of total BTEX and naphthalene. The highest concentrations of chloroform were noted in the Prairie Provinces. I recommend further regression analysis by region to determine the risk factors resulting in higher concentrations of the identified VOCs in these regions of Canada. The total BTEX concentration may be elevated in Quebec compared to other regions because it has a larger urban centre with high vehicle traffic; further analysis is necessary to determine if that is the cause as other city centres would have similar trends of higher total BTEX. Differences of outdoor air total BTEX have been determined to be secondary to traffic and point source (e.g. industrial area) emissions (180).

Urine *t,t*-mercapturic acid, *s*-phenylmercapturic acid, phenol, 1-hydroxynaphthalene and 2-hydroxynaphthalene are considered biomarkers for exposure to benzene and naphthalene, respectively. However, the captured concentrations of these metabolites do not match with the higher concentration of the precursors, suggesting individual metabolism and other factors affect the concentration of urine metabolites. Phenol is the least specific biomarker for benzene exposure at low concentrations (181). Phenol is also present in our environment as it is utilized as a disinfectant, and it is present naturally in foods (182).

Although not a primary objective, I evaluated the blood lead concentration of respondents in CHMS Cycle 2. The most recent report about lead in the Canadian population (183) described the state of lead exposure in Canada. The document outlines the possible sources of lead exposure, such as lead paint degradation, renovations and hobbies, which may account for the variations in lead concentrations observed. In Quebec, where the majority of dwellings were built between 1981 and 2000, lead paint may not have been the major contributor to the blood lead concentration. The high mean concentration of blood lead could be due to other sources of exposure as described in the final report for lead (183).

6.2 Part 2: Indoor air sampling and lab analysis – descriptive studies

The descriptive studies provided the opportunity for the use of the TD tubes and GC-MS technologies in VOC exposure assessment. From the findings of this work and the literature review of VOCs in the residential indoor environment, the common VOCs detected in the residential indoor environment were identified and selected for the CHMS analysis. The TD tube with Tenax® TA adsorbent (184) was an easy and inexpensive sampling tool to measure multiple VOCs.

Twenty-four VOCs were shared between the descriptive analysis and the CHMS: 1,1,2-trichloroethane, 1,1-dichloroethane, 1,2,3-trichlorobenzene, 1,2,3-

trichloropropane, 1,2,4-trichlorobenzene, 1,2,4-trimethylbenzene, 1,2-dichlorobenzene, 1,2-dichloroethane, 1,2-dichloropropane, 1,4-dichlorobenzene, 1,4-dioxane, benzene, bromodichloromethane, carbon tetrachloride, chlorobenzene, ethylbenzene, *m,p*-xylenes, *o*-xylene, pentachloroethane, naphthalene, styrene, tetrahydrofuran and toluene.

The studies can also inform future CHMS research by demonstrating companion animals should be included in the questionnaire at a minimum, and at best included as part of the sampling plan. I demonstrated that a cat can comfortably and safely wear a TD tube attached to a halter for 48 hours. Other methods such as those employed by Holderman and others (117-119,185) could be adapted toward felines for measurement of their volatilome. However, the techniques are poor for assessing the environmental exposure because they suction VOCs from the skin and fur of the animal. The TD tube method has the added benefit of ease of use and provides a sample of the feline exposure to VOCs in the residential indoor environment.

6.3 Strengths of this research project

The CHMS dataset is comprehensive and representative of a national sample of the Canadian population from age 3 to 79 years. It included all types of dwellings during residential indoor air VOC analysis: detached, semi-detached,

apartment and townhouses. The CHMS was also comprised of biomonitoring information of VOCs in the blood and urine. I was able to describe exposures to multiple VOCs in Canadian populations, stratified by the age and sex of respondents, region (BC, Prairies, Ontario, Quebec and Atlantic Canada), age of the dwelling and urbanicity. This study contributes information about childhood exposures to VOCs and household conditions that have not been previously published.

The laboratory pilot studies demonstrated that a wide range of VOCs, especially air toxics, should be investigated in the CHMS. The CHMS has an extensive list of VOCs measured, but further statistical analysis must be performed to better understand associations between the air toxics and exposures in children and adults.

The descriptive studies also helped refine protocols for TD tube sampling in indoor settings. Based on the results from the descriptive studies, I planned and developed a pilot study evaluating the associations of the child (under 3 years old), adult and pet cat personal exposures to VOCs and residential indoor air VOCs (Appendices A to H). REB approval of this pilot study was not obtained. It remains that the results of the current study and the proposed study can be utilized to further develop holistic methods to evaluate multiple members of a same household.

6.4 Limitations of the CHMS

Results from the available CHMS Cycle 2 analysis and the descriptive studies can inform potential adaptations of the CHMS that could improve outcome analysis. However, Statistics Canada and Health Canada have already planned CHMS data collection until Cycle 8 (2022-2023). I would strongly recommend that the CHMS utilize the household questionnaire during each Cycle to obtain details about the environmental characteristics of the dwelling and household activities than can increase exposure to VOCs.

The CHMS locations were carefully selected for appropriate sample size and representativeness of the general population. This means that there is an oversampling of the urban environment compared to suburban and rural areas. Determination of differences between the regions would be improved if a greater proportion of the sample were obtained from suburban and rural areas.

I identified the need to have a linking variable for pairs of children (3-11 years old) and youth-adults (12-79 years old) in the same households. A unique dwelling identifier can serve this purpose and reduce the error introduced by secondary identification of pairs from the current data.

A method to circumvent the challenge of personal exposure sampling in children using TD tubes is to do biomonitoring analysis of blood and urine for the presence of VOCs and their metabolites. Regretfully, even though these samples were collected from children, the CHMS has not included children's (3 to 11 years old) urine and blood samples in their VOCs analyses.

6.5 Limitations of the descriptive studies

The main limitation of the descriptive laboratory studies was a limited number of samples and VOC concentrations measured. The use of TD tubes during the descriptive studies did not allow for the inclusion of carbon dioxide, formaldehyde and other aldehydes in the analysis. Carbon dioxide can be measured using a sensor/monitor, and formaldehyde is most easily measured using the Summa® canister.

These descriptive studies were originally for the purpose of methods optimization for a larger study evaluating the dwellings of 20 volunteer adults, their children (6 months to 3 years old) and pet cats; however, obtaining REB approval proved difficult. It remains that this proposed project could have a large impact on understanding the VOCs in the residential indoor environments in Halifax, Nova Scotia, and the relationship between multiple members of the same household (multi-receptor approach (143)). One of the options suggested

by the REB to comply with safety concerns was to remove children from the study completely. I believe this would severely limit the performance of this proposed study because sampling of dwellings without children will introduce bias and we would not be able to make any suggestions or associations regarding dwellings with children. As supported by the analysis of Cycle 2 CHMS data, there are differences in the indoor air in dwellings with and without children.

CHAPTER 7. CONCLUSION

This project aimed to improve the knowledge of VOC exposures in the residential indoor environments of children under 12 years old in Canada. Research on residential environmental exposures of young children have poorly described VOC exposures because of the difficulty and ethical challenges of recruiting children into such studies.

This research presents a summary of CHMS Cycle 2 VOC analysis and optimization of thermal desorption tube analysis. The analysis of the CHMS data supported the hypothesis that there are differences in VOC profiles in dwellings that have children. Dwellings with children between the ages of 3 and 11 years had higher mean concentrations of VOCs compared to the dwellings with youth and adults, with few exceptions (benzene and naphthalene). Children also had higher mean concentrations of the measured urine metabolites compared to adults, with the exception of 1-hydroxynaphthalene. This information strongly suggests that more research is needed to assess VOC exposures in children under the age of 12 years. This evidence also supports the proposed study plan to evaluate the VOCs in dwellings with young children. Further research is necessary to determine how the VOC concentrations vary in the residential indoor environment when there are varying ages of children present (infants vs. toddlers vs. children under 12 years old).

This study also highlights the differences between dwellings that are in urban, suburban and rural areas. The urban and suburban areas were significant predictors for high chloroform and naphthalene concentrations after adjusting for household characteristics. Chloroform and naphthalene may vary in these areas due to dwelling quality differences and household habits. Further research into the factors influencing chloroform and naphthalene concentrations in the residential environments of these different areas is recommended. Outcomes from further studies can help inform housing policy and guidelines for VOC exposures in the residential indoor environment.

The regression analyses demonstrated different significant predictors for total BTEX, chloroform, naphthalene and *alpha*-pinene, which confirm the different sources of these VOC exposures in the dwelling environments. BTEX are released from cigarette smoke and car exhaust. Chloroform is evaporated from chlorinated water. Naphthalene is released from mothballs and cigarette smoke. *Alpha*-pinene is released by cleaning products and turpentine (for more on the possible sources of these VOCs, see Sections 1.2.1 and 1.2.2). Education of the public about the sources of these residential indoor VOCs can help mitigate exposure. For example, people can be advised that pine-scented cleaning products release *alpha*-pinene into the environment and may be a concern for susceptible populations.

Persons concerned about residential indoor air quality can inform themselves further. The public can inform themselves through information from the important regulating agencies: Environment and Climate Change Canada and Health Canada (126), the World Health Organization (83) and the US OSHA (186). One of the tools available to the general public is the ambient Air Quality Health Index, which is a value on the scale of 0 to 10 plus to help the public make informed decisions about their health and the environment (187). Other programs in place to monitor and address air quality in Canada can be found on the Government of Canada website (188).

Filters can be purchased for dwellings that will aid in improving indoor air quality by decreasing dust and particulate matter, and other air pollutants, but the filters will not affect VOCs due to their small size. Opening windows is also a solution to improve ventilation in the dwelling, but this is not necessarily the solution to VOC exposures as many VOCs can move from outdoors to indoors (116,189). The Government of Canada has identified three main targets for the general public to help decrease air pollution outdoors, and to a minor degree, indoors: 1) avoid travel as a single person in motor vehicles, instead carpool/bus/bike/walk, 2) avoid using a woodstove or fireplace, and 3) save energy and support renewable energy (190).

TABLES

Table 1. Canadian Health Measures Survey Cycle 2. Variables included in the investigation.

Variable	Type	Levels	Description
Air quality variables			
Air benzene	continuous		$\mu g/m^3$
Air ethylbenzene	continuous		$\mu g/m^3$
Air toluene	continuous		$\mu g/m^3$
Air *m,p*-xylene	continuous		$\mu g/m^3$
Air *o*-xylene	continuous		$\mu g/m^3$
Air *alpha*-pinene	continuous		$\mu g/m^3$
Air carbon tetrachloride	continuous		$\mu g/m^3$
Air naphthalene	continuous		$\mu g/m^3$
Air chloroform	continuous		$\mu g/m^3$
Air acetone	continuous		$\mu g/m^3$
Air benzaldehyde	continuous		$\mu g/m^3$
Urine 1-hydroxynaphthalene	continuous		Naphthalene metabolite ($\mu g/g$ creatinine)
Urine 2-hydroxynaphthalene	continuous		Naphthalene metabolite ($\mu g/g$ creatinine)
Urine *s*-phenylmercapturic acid	continuous		Benzene metabolite ($\mu g/g$ creatinine)
Urine *t,t*-mercapturic acid	continuous		Benzene metabolite ($\mu g/g$ creatinine)
Urine phenol	continuous		Benzene metabolite ($\mu g/g$ creatinine)
Dwelling characteristics			
		<1945	
		1946-1960	
		1961-1980	
		1981-2000	
Dwelling age	categorical	>2001	Derived from dwelling age category

Variable	Type	Levels	Description
Dwelling characteristics			
Dwelling type	categorical	detached attached apartment mobile or other	Derived from dwelling type
Approx. area of the dwelling	categorical	1 55 m^2 2 56-95 m^2 3 96-185 m^2 4 186-280 m^2 5 281-371 m^2 6 372 m^2	
Number of persons	continuous		
Number of persons less than 6 years old	continuous		
Number of persons less than 12 years old	continuous		
Number of persons less than 15 years old	continuous		
Number of bedrooms	continuous		
Total annual household income	categorical	<$30,000 >$30,000	Derived from the imputed total annual household income
Mortgage	categorical	yes no	
Dwelling is owned by resident	categorical	yes no	
Smoking inside the dwelling	categorical	yes no	
Number of cigarettes smoked per day	categorical	<100 >100	
Heating source	categorical	oil or gas electricity wood other	Derived from heating types: electric, oil, gas, wood, mixed, other

Variable	Type	Levels	Description
Dwelling characteristics			
Water source	categorical	municipal private well, surface source or other	Derived from water source: municipal, well, lake, other
Water source for drinking water	categorical	tap water bottled or other	Derived from water source for drinking water: municipal, bottled, other
Region	categorical	British Columbia Prairies Ontario Quebec Atlantic Prov.	
Urbanicity	categorical	urban suburban rural	Derived from PCCF+ and Postal Code
Blood lead	continuous		µg/L
Urine free cotinine	continuous		Marker for cigarette smoking (µg/g creatinine)
Participant characteristics			
Age	categorical	children: 3-11 years old youth-adults: 12-79 years old	Derived from age at questionnaire
Sex	categorical	male female	Derived from sex as announced on the questionnaire
Graduated from high school	categorical	yes no	Derived from highest level of education achieved
Self-perceived health	categorical	strong poor	Derived from self-perceived health: excellent or good = strong
Self-perceived quality of life	categorical	strong poor	Derived from self-perceived quality of life: excellent or good = strong
Sense of belonging to community	categorical	strong poor	Derived from sense of belonging to the community: excellent or good = strong

Table 2a. Canadian Health Measures Survey Cycle 2. Dwelling characteristics and self-reported lifestyle and health participant characteristics by sex and age (child 3-11 years old, adult 12-79 years old); n= 6395.

| Variable | Males | | | Females | | | Male vs. Females | Both sexes | | | Child vs. Adult |
	n	Child (%)	Adult (%)	n	Child (%)	Adult (%)	p value	n	Child (%)	Adult (%)	p value
Graduated from high school	1467	NA	92.56	1761	NA	93.36	0.5713	3227	NA	92.97	NA
Self-perceived excellent or very good health	1310	82.16	54.44	1534	87.46	50.00	0.1121	2840	84.73	52.21	**<0.0001**
Self-perceived high quality of life	1480	NA	67.39	1624	NA	66.11	0.5993	3106	NA	66.74	NA
Strong sense of belonging to the local community	1391	NA	63.48	1659	NA	67.74	0.3026	3045	NA	65.63	NA
Dwelling age											
1946-1960	322	7.18	11.33	330	10.57	10.43	0.7777	652	8.83	10.88	0.1886
1961-1980	1063	29.57	36.74	1070	28.44	34.46	0.3717	2135	29.02	35.59	**0.0104**
1981-2000	1110	44.23	36.75	1216	41.21	38.15	0.7285	2325	42.76	37.46	**0.0209**
>2001	461	19.02	15.18	545	19.78	16.95	0.3955	1004	19.39	16.07	0.1673
Dwelling type											
Single detached	2039	70.83	65.73	2111	70.06	62.87	0.3329	4153	70.46	64.29	**0.0184**

Table 2a. Continued

| Variable | Males | | | Females | | | Male vs. Females | Both sexes | | | Child vs. Adult |
	n	Child (%)	Adult (%)	n	Child (%)	Adult (%)	p value	n	Child (%)	Adult (%)	p value
Dwelling type											
Attached	387	15.12	12.29	599	18.50	17.98	**0.0029**	979	16.76	15.45	0.3765
Apartment	556	10.31	19.01	508	7.99	16.11	0.2580	1067	9.18	17.55	**0.0003**
Mobile or other	94	3.74	2.98	102	3.45	3.03	0.9819	196	3.60	3.01	0.5850
Total annual household income											
<$30,000	489	15.04	16.00	639	11.70	20.08	0.0644	1124	13.42	18.05	0.0773
Have mortgage on dwelling	1561	87.57	63.35	1684	90.12	64.04	0.8209	3246	88.76	63.70	**<0.0001**
Dwelling is owned by resident	2243	79.03	72.22	2485	73.99	74.95	0.5167	4725	76.58	73.59	0.3128
Smoking inside the dwelling	364	9.76	12.08	448	8.18	14.11	0.2329	810	8.99	13.10	**0.0036**
Respondent smoked 100 or more cigarettes per day	1067	NA	47.94	1027	NA	41.42	**0.0093**	2102	NA	44.66	NA
Heating source											
Oil or gas	1725	60.72	56.55	1762	61.17	53.23	0.1793	3490	60.94	54.87	**0.0042**
Electricity	911	25.75	30.64	1043	27.24	32.53	0.3329	1952	26.47	31.60	**0.0021**
Wood	234	9.56	7.53	269	8.87	8.19	0.7151	503	9.22	7.86	0.3406
Other	155	3.97	5.28	186	2.71	6.05	0.7478	341	3.36	5.67	**0.0072**

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Table 2a. Continued

Water source										
Municipal	2712	87.32	88.48	2838	87.81	85.41	0.2283	5554	87.55	86.93	0.5589
Other	358	12.68	11.52	476	12.19	14.59	0.2455	830	12.45	13.07	0.2367
Water source for drinking water										
Tap water	2024	70.21	66.68	2159	64.73	66.18	0.6923	4185	67.53	66.43	0.7056
Bottled or other	995	29.79	33.32	1111	35.27	33.82	0.4133	2104	32.47	33.57	0.8086

NA: Not applicable; results not available due to too few observations to be reliably reported

Table 2b. Canadian Health Measures Survey Cycle 2. Mean of the quantitative dwelling characteristics and geometric mean of blood lead and urine free cotinine categorized by self-reported sex and age (child 3-11 years old, adult 12-79 years old) - population weighted results; n= 6395.

Variable	Males			Females			Both sexes		
	n	Child Mean	Adult Mean	n	Child Mean	Adult Mean	n	Child Mean	Adult Mean
Blood lead	3076	**0.56**	0.38	3319	**0.62**	0.17	6395	**0.59**	0.27
Urine free cotinine	779	**2.1**	**4.58**	692	**2.07**	**5.12**	1491	**2.09**	**4.81**
Approx. area of the dwelling	2844	**3.15**	**2.95**	2904	**3.13**	**2.95**	5748	**3.14**	**2.95**
Number of persons	3076	**4.36**	**3.20**	3319	**4.53**	**2.93**	6395	**1.48**	**1.80**
Number of persons <6 years old	859	**1.36**	**1.40**	985	**1.50**	**1.28**	1844	**1.42**	**1.34**
Number of persons <12 years old	1637	**2.05**	**1.76**	1836	**2.04**	**1.52**	3473	**2.05**	**1.63**
Number of persons <15 years old	1859	**2.27**	**1.90**	2046	**2.37**	**1.66**	3905	**2.31**	**1.77**
Number of bedrooms	3071	**3.45**	**3.14**	3317	**3.46**	**3.05**	6388	**3.45**	**3.09**

Blood lead in air are measured in $\mu g/m^3$ and urine metabolites are measured in $\mu g/g$ creatinine.
Bold values indicate significant findings at $p < 0.05$ (Chi-square test) for adult vs. child (both sexes) and male vs. female (all ages).

Table 3a. Canadian Health Measures Survey Cycle 2. Dwelling characteristics and self-reported lifestyle and health participant characteristics by region - population weighted results; n= 6395.

Variable	BC		Prairies		Ontario		Quebec		Atl. Prov.	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
Graduated from high school	596	96.04	538	90.89	1112	93.10	624	94.05	354	88.26
Self-perceived excellent or very good health	623	54.58	570	53.54	1134	55.11	782	56.89	463	61.02
Self-perceived high quality of life	502	61.88	514	68.21	1041	67.65	661	66.28	383	69.05
Strong sense of belonging to the local community	581	**71.80**	404	**53.95**	1052	**68.49**	622	**62.74**	422	**76.09**
Dwelling age										
1946-1960	87	7.95	148	14.70	194	9.86	147	11.13	67	9.08
1961-1980	436	39.81	395	39.28	695	35.28	394	29.95	214	29.38
1981-2000	304	27.80	275	27.29	909	46.19	489	37.11	296	40.57
>2001	268	24.44	188	18.73	171	8.67	287	21.81	153	20.98
Dwelling type										
Single detached	739	64.77	702	66.00	1234	59.96	949	69.04	583	76.95
Attached	146	12.81	149	14.05	356	17.31	215	15.66	82	10.88
Apartment	196	17.18	159	14.91	423	20.55	188	13.67	64	8.45
Mobile or other	60	5.24	54	5.04	45	2.18	22	1.63	28	3.73
Total annual household income <$30,000	248	21.75	148	13.88	274	13.29	327	23.82	166	21.96
Have mortgage on dwelling	593	66.38	537	64.28	999	66.94	716	66.80	399	67.48
Dwelling is owned by resident	861	75.52	772	72.54	1469	71.39	1059	77.06	590	77.83
Smoking inside the dwelling	29	**2.50**	118	**11.07**	175	**8.53**	350	**25.50**	125	**16.50**
Respondent smoked 100 or more cigarettes per day	282	34.55	359	47.05	646	41.73	532	52.21	278	49.39
Heating source										
Oil or gas	682	**60.45**	895	**85.68**	1485	**74.72**	112	**8.16**	206	**27.24**
Electricity	298	**24.81**	83	**7.94**	275	**13.86**	1002	**73.22**	387	**51.16**
Wood	119	10.54	6	0.56	71	3.59	222	16.24	133	17.63

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Table 3a. Continued

Variable	BC		Prairies		Ontario		Quebec		Atl. Prov.	
	n	(%)	n	(%)	n	(%)	n	(%)	n	(%)
Heating source										
Other	47	4.20	61	5.82	156	7.83	33	2.38	30	3.98
Water source										
Municipal	1003	87.86	1037	97.53	1776	86.60	1161	84.70	503	68.69
Other	138	12.14	26	2.47	275	13.40	210	15.30	237	31.31
Water source for drinking water										
Tap water	830	**74.10**	717	**68.10**	1381	**67.92**	768	**57.46**	526	**70.35**
Bottled or other	290	**25.90**	336	**31.90**	652	**32.08**	568	**42.54**	222	**29.65**

Region is defined as British Columbia, Prairies: Alberta, Saskatchewan and Manitoba, Ontario, Quebec, Atlantic Provinces: New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland.

Bold values indicate significant findings at $p < 0.05$ (Chi-square test) for differences between regions.

Table 3b. Canadian Health Measures Survey Cycle 2. Mean of the quantitative dwelling characteristics and geometric mean of blood lead and urine free cotinine categorized by region - population weighted results; n= 6395.

Variable	BC		Prairies		Ontario		Quebec		Atl. Prov.	
	n	Mean	n	Mean	n	Mean	n	Mean	n	Mean
Blood lead	1141	**0.26**	1064	**0.14**	2058	**0.33**	1374	**0.43**	758	**0.29**
Urine free cotinine	152	**4.87**	232	**4.31**	436	**4.78**	460	**4.63**	211	**4.59**
Approx. area of the dwelling (categorical)	1053	**3.15**	1008	**2.83**	1884	**3.06**	1137	**2.81**	666	**2.94**
Number of persons	1141	**3.20**	1064	**2.99**	2058	**3.46**	1374	**3.06**	758	**2.84**
Number of persons <6 years old	342	**1.33**	329	**1.27**	590	**1.40**	402	**1.40**	181	**1.33**
Number of persons <12 years old	664	**1.85**	606	**1.67**	1063	**1.84**	741	**1.70**	399	**1.53**
Number of persons <15 years old	732	**1.96**	676	**1.79**	1202	**1.99**	845	**1.87**	450	**1.67**
Number of bedrooms	1139	**1.35**	1064	**1.04**	2057	**1.70**	1370	**1.16**	758	**0.98**

Blood lead in air are measured in $\mu g/m^3$ and urine metabolites are measured in $\mu g/g$ creatinine. Region is defined as British Columbia, Prairies: Alberta, Saskatchewan and Manitoba, Ontario, Quebec, Atlantic Provinces: New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland.

Bold values indicate significant findings at $p < 0.05$ (Chi-square test) for differences between regions.

Table 4a. Canadian Health Measures Survey Cycle 2. Dwelling characteristics and self-reported lifestyle and health participant characteristics by urban, suburban and rural designation; n= 6395.

Variable	Urban		Suburban		Rural	
	n	(%)	n	(%)	n	(%)
Graduated from high school	2503	94.00	482	89.11	236	88.50
Self-perceived excellent or very good health	2715	56.85	553	52.38	279	49.60
Self-perceived high quality of life	2330	67.20	489	63.71	283	67.45
Strong sense of belonging to the local community	2203	63.74	519	67.69	328	78.64
Dwelling age						
1946-1960	375	8.24	216	21.14	82	15.00
1961-1980	1576	34.67	339	33.11	217	39.65
1981-2000	1738	38.22	404	39.45	186	34.05
>2001	858	18.87	65	6.31	62	11.30
Dwelling type						
Single detached	2817	**58.98**	898	**85.07**	481	**85.48**
Attached	857	**17.95**	55	**5.23**	46	**8.10**
Apartment	948	**19.85**	67	**6.30**	29	**5.20**
Mobile or other	154	3.22	36	3.40	7	1.22
Total annual household income <$30,000	762	15.96	152	14.36	206	36.59
Have mortgage on dwelling	2433	68.68	590	66.42	230	50.51
Dwelling is owned by resident	3360	**70.38**	908	**85.98**	483	**85.80**
Smoking inside the dwelling	535	11.22	166	15.69	116	20.58
Respondent smoked 100 or more cigarettes per day	1497	42.65	354	45.66	255	60.51

Table 4a. Continued.

Variable	Urban		Suburban		Rural	
	n	(%)	n	(%)	n	(%)
Heating source						
Oil or gas	2811	60.19	576	54.69	98	17.38
Electricity	1466	31.38	240	22.77	231	41.00
Wood	114	2.44	197	18.68	217	38.48
Other	279	5.98	41	3.86	18	3.14
Water source						
Municipal	4545	**95.34**	599	**56.70**	346	**61.75**
Other	222	4.66	457	43.30	215	38.25
Water source for drinking water						
Tap water	3178	67.48	592	57.04	396	73.01
Bottled or other	1531	32.52	445	42.96	147	26.99

Urban, suburban and rural designation is defined as urban: census metropolitan area and within census agglomeration, suburban: census agglomeration with strong and moderate metropolitan influence and rural: census agglomeration with weak and metropolitan influence and outside of census agglomeration.

Bold values indicate significant findings at $p < 0.05$ (Chi-square test) for differences between urbanicity designations

Table 4b. Canadian Health Measures Survey Cycle 2. Mean of the quantitative dwelling characteristics and geometric mean of blood lead and urine free cotinine categorized by urban, suburban and rural designation - population weighted results; n= 6395.

Variable	Urban		Suburban		Rural	
	n	Mean	n	Mean	n	Mean
Blood lead	4776	**0.29**	1056	**0.29**	563	**0.44**
Urine free cotinine	993	**4.67**	285	**4.71**	213	**4.39**
Approx. area of the dwelling (categorical)	4313	**0.89**	955	**0.75**	480	**0.75**
Number of persons	4776	**3.25**	1506	**3.18**	563	**2.90**
Number of persons <6 years old	1390	**1.36**	293	**1.40**	161	**1.36**
Number of persons <12 years old	2617	**1.70**	569	**2.03**	287	**1.90**
Number of persons <15 years old	2933	**1.85**	649	**2.14**	323	**2.07**
Number of bedrooms	7442	**1.47**	1055	**1.03**	561	**1.14**

Blood lead in air are measured in $\mu g/m^3$ and urine metabolites are measured in $\mu g/g$ creatinine. Urban, suburban and rural designation is defined as urban: census metropolitan area and within census agglomeration, suburban: census agglomeration with strong and moderate metropolitan influence and rural: census agglomeration with weak and metropolitan influence and outside of census agglomeration.

Bold values indicate significant findings at $p < 0.05$ (Chi-square test) for differences between urbanicity designations.

Table 5a. Canadian Health Measures Cycle 2. Geometric mean (G.M.) concentrations and 95% confidence intervals of VOCs and certain urine metabolites for males by age (child 3-11 years old, adult 12-79 years old) ; n= 6395.

Variable Males	Child n	G.M.	95 % CI	Adult n	G.M.	95 % CI
Air benzene	687	1.10	0.88-1.36	1779	1.03	0.84-1.27
Air ethylbenzene	687	**1.50**	1.22-1.83	1777	**1.41**	1.15-1.74
Air toluene	680	**8.77**	7.27-10.57	1785	**8.24**	6.54-10.39
Air *m,p*-xylene	680	**5.25**	4.31-6.40	1786	**4.98**	4.07-6.08
Air *o*-xylene	680	**1.55**	1.27-1.90	1786	**1.46**	1.17-1.81
Air chloroform	680	**0.36**	0.25-0.51	1786	**0.32**	0.23-0.43
Air naphthalene	680	0.75	0.64-0.88	1786	0.89	0.73-1.08
Air carbon tetrachloride	680	**0.30**	0.27-0.33	1786	**0.29**	0.26-0.32
Air *alpha*-pinene	680	**10.03**	7.14-14.08	1786	**5.98**	4.26-8.38
Air acetone	680	**4.13**	3.21-5.31	1786	**3.82**	3.04-4.80
Air benzaldehyde	680	**3.41**	2.55-4.57	1786	**2.69**	2.02-3.59
Urine *t,t*-mercapturic acid	508	**106.27**	92.83-121.66	753	**57.18**	48.34-67.64
Urine *s*-phenylmercapturic acid	388	**0.23**	0.19-0.28	620	**0.25**	0.20-0.32
Urine phenol	520	**7.93**	6.86-9.16	757	**6.83**	6.12-7.61
Urine 1-hydroxynaphthalene	522	1.33	1.08-1.62	760	1.18	0.90-1.55
Urine 2-hydroxynaphthalene	503	**4.47**	3.89-5.14	744	**3.40**	2.76-4.20
Total air BTEX	680	**19.76**	16.44-23.76	1784	**18.86**	15.23-23.37

VOCs in air are measured in µg/m^3 and urine metabolites are measured in µg/g creatinine.
Male vs. female aggregate of adult and child significant at $p < 0.05$ (see Table 5b).

Table 5b. Canadian Health Measures Cycle 2. Geometric mean (G.M.) concentrations and 95% confidence intervals of VOCs and certain urine metabolites for females by age (child 3-11 years old, adult 12-79 years old) ; n= 6395.

Variable Females	Child n	G.M.	95 % CI	Adult n	G.M.	95 % CI
Air benzene	687	1.10	0.85-1.43	2038	1.10	0.91-1.33
Air ethylbenzene	687	**1.54**	1.24-1.90	2038	**1.48**	1.19-1.84
Air toluene	683	**9.69**	7.39-12.70	2041	**8.45**	7.03-10.17
Air *m,p*-xylene	683	**5.37**	4.34-6.64	2042	**5.35**	4.28-6.69
Air *o*-xylene	683	**1.58**	1.26-1.98	2042	**1.54**	1.24-1.92
Air chloroform	683	**0.38**	0.25-0.57	2042	**0.30**	0.21-0.41
Air naphthalene	683	0.80	0.64-1.00	2042	0.90	0.80-1.02
Air carbon tetrachloride	683	**0.30**	0.26-0.34	2042	**0.30**	0.27-0.33
Air *alpha*-pinene	683	**9.07**	6.69-12.29	2041	**6.51**	5.00-8.48
Air acetone	683	**4.78**	3.72-6.16	2042	**4.11**	3.31-5.09
Air benzaldehyde	683	**3.46**	2.58-4.64	2042	**2.94**	2.31-3.76
Urine *t,t*-mercapturic acid	504	**103.78**	90.52-118.98	747	**67.32**	57.99-78.16
Urine *s*-phenylmercapturic acid	396	**0.25**	0.23-0.28	557	**0.26**	0.22-0.32
Urine phenol	513	**6.88**	5.95-7.95	756	**6.54**	6.07-7.04
Urine 1-hydroxynaphthalene	518	1.34	1.00-1.81	763	1.25	1.01-1.54
Urine 2-hydroxynaphthalene	500	**4.48**	3.95-5.08	745	**4.06**	3.56-4.63
Total air BTEX	683	**21.10**	16.72-26.62	2041	**19.73**	16.04-24.27

VOCs in air are measured in μg/m^3 and urine metabolites are measured in μg/g creatinine.
Male vs. female aggregate of adult and child significant at p < 0.05 (see Table 5a).

Table 5c. Canadian Health Measures Cycle 2. Geometric mean concentrations and 95% confidence intervals of VOCs and certain urine metabolites for both sexes by age (child 3-11 years old, adult 12-79 years old) ; n= 6395.

Variable Both sexes	Child n	G.M.	95 % CI	Adult n	G.M.	95 % CI	p-value C v A
Air benzene	1374	1.10	0.89-1.36	3817	1.07	0.88-1.29	0.4709
Air ethylbenzene	1374	1.52	1.25-1.84	3815	1.44	1.18-1.77	**0.0022**
Air toluene	1374	9.19	7.51-11.24	3815	8.35	6.83-10.20	**<0.0001**
Air *m,p*-xylene	1374	5.31	4.40-6.40	3817	5.16	4.22-6.33	**<0.0001**
Air *o*-xylene	1374	1.57	1.29-1.90	3817	1.50	1.21-1.86	**0.0015**
Air chloroform	1374	0.37	0.26-0.52	3817	0.31	0.23-0.42	**<0.0001**
Air naphthalene	1374	0.77	0.65-0.92	3817	0.90	0.77-1.04	0.1292
Air carbon tetrachloride	1374	0.30	0.27-0.33	3817	0.29	0.27-0.32	**<0.0001**
Air *alpha*-pinene	1374	9.56	7.07-12.95	3816	6.24	4.66-8.36	**<0.0001**
Air acetone	1374	4.42	3.53-5.55	3816	3.96	3.23-4.86	**<0.0001**
Air benzaldehyde	1374	3.43	2.60-4.54	3816	2.82	2.17-3.67	**<0.0001**
Urine *t,t*-mercapturic acid	1018	105.02	95.92-114.99	1794	61.48	56.16-67.31	**<0.0001**
Urine *s*-phenylmercapturic acid	789	0.24	0.21-0.27	1172	0.26	0.22-0.31	**<0.0001**
Urine phenol	1039	7.38	6.68-8.16	1507	6.70	6.23-7.20	**<0.0001**
Urine 1-hydroxynaphthalene	1046	1.34	1.09-1.63	1517	1.21	0.99-1.47	0.0564
Urine 2-hydroxynaphthalene	1009	4.47	3.99-5.01	1483	3.68	3.17-4.27	**<0.0001**
Total air BTEX	1374	20.38	16.84-24.66	3814	19.30	15.74-23.67	**<0.0001**

VOCs in air are measured in µg/m^3 and urine metabolites are measured in µg/g creatinine.

Table 6. Canadian Health Measures Cycle 2. Geometric mean (G.M.) concentrations and 95% confidence intervals of VOCs and certain urine metabolites by region; n= 6395.

Variable	British Columbia			Prairie Provinces			Ontario		
	n	G.M.	95 % CI	n	G.M.	95 % CI	n	G.M.	95 % CI
Air benzene	961	0.99	0.58-1.66	900	1.20	0.99-1.45	1635	1.05	0.74-1.50
Air ethylbenzene	961	1.12	0.78-1.60	900	1.54	1.12-2.11	1633	1.25	0.82-1.92
Air toluene	961	7.11	4.85-10.41	900	8.78	6.12-12.58	1633	8.07	5.16-12.62
Air *m,p*-xylene	961	3.89	2.65-5.73	900	5.51	4.15-7.30	1635	4.30	2.78-6.63
Air *o*-xylene	961	1.24	0.86-1.78	900	1.74	1.30-2.34	1635	1.27	0.82-1.96
Air chloroform	961	0.36	0.31-0.43	900	0.51	0.30-0.86	1635	0.22	0.12-0.39
Air naphthalene	961	0.78	0.65-0.94	900	0.78	0.54-1.11	1635	0.87	0.62-1.23
Air carbon tetrachloride	961	0.31	0.25-0.38	900	0.31	0.26-0.38	1635	0.29	0.24-0.36
Air *alpha*-pinene	961	4.13	3.17-5.38	900	5.91	2.23-15.65	1635	7.64	4.63-12.63
Air acetone	961	2.94	2.07-4.18	900	4.64	3.54-6.08	1634	3.33	2.13-5.22
Air benzaldehyde	961	3.00	2.54-3.55	900	3.37	1.30-8.74	1635	2.55	1.56-4.19
Urine *t,t*-mercapturic acid	478	47.96	45.01-51.11	457	73.71	58.69-92.56	742	67.02	57.48-78.15
Urine *s*-phenylmercapturic acid	338	0.18	0.14-0.24	336	0.24	0.14-0.41	588	0.25	0.21-0.30
Urine phenol	485	6.97	5.81-8.35	465	7.24	6.57-7.99	749	6.98	6.33-7.68
Urine 1-hydroxynaphthalene	488	0.85	0.64-1.13	166	1.30	0.76-2.21	754	1.33	1.04-1.70
Urine 2-hydroxynaphthalene	473	2.49	2.26-2.75	456	4.03	2.31-7.02	734	3.48	2.99-4.05
Total air BTEX	961	15.31	10.12-23.17	900	20.10	14.72-27.44	1632	17.52	11.25-27.30
	Quebec			Atlantic Provinces					
Air benzene	1126	1.20	0.72-2.00	569	0.66	0.57-0.76			
Air ethylbenzene	1126	2.37	1.58-3.56	569	0.94	0.62-1.43			
Air toluene	1126	11.04	8.58-14.19	569	5.42	4.57-6.42			

Table 6. Continued

	Quebec			Atlantic Provinces		
	n	G.M.	95 % CI	n	G.M.	95 % CI
Air *m,p*-xylene	1126	9.01	6.41-12.65	569	3.52	2.03-6.10
Air *o*-xylene	1126	2.24	1.44-3.49	569	1.04	0.53-2.04
Air chloroform	1126	0.34	0.15-0.80	569	0.33	0.12-0.97
Air naphthalene	1126	1.18	1.05-1.33	569	0.63	0.47-0.84
Air carbon tetrachloride	1126	0.27	0.22-0.34	569	0.27	0.25-0.28
Air *alpha*-pinene	1126	8.20	5.25-12.80	569	4.07	2.20-7.55
Air acetone	1126	5.78	4.28-7.82	569	4.35	2.98-6.35
Air benzaldehyde	1126	3.11	2.63-3.68	569	2.55	2.41-2.71
Urine *t,t*-mercapturic acid	561	72.71	56.80-93.06	274	100.05	91.12-109.84
Urine *s*-phenylmercapturic acid	484	0.29	0.21-0.38	215	0.40	0.24-0.65
Urine phenol	569	6.40	5.54-7.40	278	6.18	4.42-8.65
Urine 1-hydroxynaphthalene	576	1.20	0.82-1.77	279	1.66	1.04-2.65
Urine 2-hydroxynaphthalene	557	5.06	4.18-6.12	272	5.02	3.82-6.60
Total air BTEX	1126	29.13	21.04-40.33	569	12.87	9.32-17.78

VOCs in air are measured in µg/m^3 and urine metabolites are measured in µg/g creatinine.
Region is defined as British Columbia, Prairies: Alberta, Saskatchewan and Manitoba, Ontario, Quebec, Atlantic Provinces: New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland.

Table 7. Canadian Health Measures Cycle 2. Geometric mean (G.M.) concentrations and 95% confidence intervals of VOCs and certain urine metabolites by urban, suburban and rural designation; n= 6395.

Variable	Urban			Suburban			Rural		
	n	G.M.	95 % CI	n	G.M.	95 % CI	n	G.M.	95 % CI
Air benzene	3851	1.09	0.89-1.33	864	1.19	0.80-1.77	476	0.77	0.34-1.73
Air ethylbenzene	3850	1.46	1.11-1.90	863	1.37	0.83-2.25	476	1.56	0.97-2.52
Air toluene	3850	8.43	6.52-10.90	863	8.53	5.90-12.33	476	8.31	4.96-13.93
Air m,p-xylene	3851	5.14	3.93-6.73	864	4.82	2.92-7.94	476	6.21	3.77-10.23
Air o-xylene	3851	1.53	1.17-2.00	864	1.39	0.85-2.28	476	1.49	0.93-2.38
Air chloroform	3851	0.37	0.27-0.51	864	0.20	0.08-0.53	476	0.14	0.05-0.38
Air naphthalene	3851	0.91	0.27-0.51	864	0.20	0.08-0.53	476	0.14	0.62-1.57
Air carbon tetrachloride	3851	0.29	0.27-0.51	864	0.20	0.08-0.53	476	0.14	0.17-0.37
Air alpha-pinene	3851	6.71	4.63-9.73	864	6.76	3.60-12.71	476	4.86	2.88-8.21
Air acetone	3850	4.38	3.58-5.37	864	2.82	1.36-5.83	476	3.28	2.43-4.43
Air benzaldehyde	3851	2.90	4.63-9.73	864	6.76	3.60-12.71	476	4.86	2.27-4.39
Urine t,t-mercapturic acid	1945	66.84	59.67-74.89	376	72.00	53.19-97.47	191	75.98	38.37-150.47
Urine s-phenylmercapturic acid	1474	0.26	0.21-0.31	340	0.22	0.11-0.44	147	0.33	0.23-0.46
Urine phenol	1969	6.96	6.46-7.49	381	6.26	5.22-7.51	196	6.63	5.14-8.54
Urine 1-hydroxynaphthalene	1981	1.23	0.99-1.53	382	1.26	0.66-2.43	200	1.20	0.56-2.58
Urine 2-hydroxynaphthalene	1932	3.83	3.16-4.65	372	3.38	1.93-5.92	188	4.74	3.35-6.72
Total air BTEX	3849	19.32	14.85-25.14	863	19.06	12.62-28.79	476	20.79	12.85-33.62

VOCs in air are measured in µg/m^3 and urine metabolites are measured in µg/g creatinine.

Urban, suburban and rural designation is defined as urban: census metropolitan area and within census agglomeration, suburban: census agglomeration with strong and moderate metropolitan influence and rural: census agglomeration with weak and metropolitan influence and outside of census agglomeration.

Table 8. Canadian Health Measures Survey Cycle 2. Beta coefficients and standard errors for linear models for continuous indoor air VOC outcomes in relation to age category of participants, presence of smoking in the home, other dwelling physical characteristics and sociodemographic factors using the change-in-estimates approach (1).

Table 8a. Canadian Health Measures Survey Cycle 2. Beta coefficients and standard errors for linear models for continuous indoor air total BTEX; n = 4085.

	Model 1		Model 2		Model 3		Model 4	
	β (SE)	p	β (SE)	p	β	p	β	p
Age (child)	38.77 (61559.24)	0.4300	48.80 (61559.24)	0.4642	105.40 (70105.41)	0.5964	8.31 (1.54E+05)	0.3422
Smoking in dwelling (yes)			4.19E+06 (53517.03)	0.0362	4.13E+08 (53517.03)	0.0012	4.12E+05 (2.11E+05)	0.2606
Dwelling type								
Single detached					1.24E+14 (1.44E+06)	0.0007	8.41E+15 (5.12E+06)	0.0005
Attached					8.10E+06 (2.34E+06)	0.2463	1.14E+09 (1.09E+07)	0.1337
Apartment					14.41 (2.39E+06)	0.5860	0.00 (9.68E+07)	0.1027
Dwelling built before 1980					2.00E+10 (12553.51)	<0.0001	3.33E+10 (23103.87)	<0.0001
No. persons					0.05 (2.41)	0.0007	7.75 (3064.85)	<0.0001
Mortgage (yes)							2.53E-08 (2.24E+05)	<0.0001
Total annual household income ≤ $30,000							190.14 (28502.73)	0.6192
Adjusted R^2	-0.0001		0.0006		0.0222		0.0219	

VOCs in air are measured in $\mu g/m^3$ and presented in mg/m^3. Change-in-estimates method (1).

Model 1: log(BTEX) = log(benzene + toluene + ethylbenzene + xylenes) = Age + ε
Model 2: log(BTEX) = Age + Smoking + ε
Model 3: log(BTEX) = Age + Smoking + Dwelling Characteristics + ε

Model 4: log(BTEX) = Age + Smoking + Dwelling Characteristics + Sociodemographic Factors + ε

Table 8b. Canadian Health Measures Survey Cycle 2. Beta coefficients and standard errors for linear models for continuous indoor air chloroform; n = 4087.

	Model 1 β (SE)	p	Model 2 β (SE)	p	Model 3 β	p	Model 4 β	p
Age (child)	1.20 (1.07)	0.0084	1.20 (1.07)	0.0076	1.07 (1.07)	0.3551	1.05 (1.08)	0.5101
Smoking in dwelling (yes)			1.07 (1.07)	0.2763	1.14 (1.07)	0.0511	1.08 (1.08)	0.3179
Dwelling type								
Single detached					0.37 (1.13)	0.4152	1.03 (1.14)	0.8341
Attached					0.93 (1.14)	0.5921	0.94 (1.15)	0.6960
Apartment					0.90 (1.14)	0.4398	0.98 (1.20)	0.9096
Dwelling built before 1980					1.32 (1.04)	<0.0001	1.39 (1.05)	<0.0001
No. persons							1.09 (1.02)	<0.0001
Mortgage (yes)							1.09 (1.08)	0.3036
Total annual household income ≤ $30,000							0.92 (1.05)	0.1194
Adjusted R^2	0.0011		0.0012		0.0147		0.0202	

VOCs in air are measured in $\mu g/m^3$. Change-in-estimates method (1).

Model 1:   log(chloroform) = Age + ε

Model 2:   log(chloroform) = Age + Smoking + ε

Model 3:   log(chloroform) = Age + Smoking + Dwelling Characteristics + ε

Model 4:   log(chloroform) = Age + Smoking + Dwelling Characteristics + Sociodemographic Factors + ε

Table 8c. Canadian Health Measures Survey Cycle 2. Beta coefficients and standard errors for linear models for continuous indoor air naphthalene; n = 4087.

	Model 1 β (SE)	p	Model 2 β (SE)	p	Model 3 β	p	Model 4 β	p
Age (child)	0.86 (1.05)	0.0067	0.87 (1.05)	0.0092	0.80 (1.06)	0.0001	0.79 (1.06)	0.0002
Smoking in dwelling (yes)			1.21 (1.05)	0.0003	1.25 (1.05)	<0.0001	1.19 (1.07)	0.0087
Dwelling type								
Single detached					1.22 (1.11)	0.0348	1.42 (1.11)	0.0007
Attached					1.12 (1.11)	0.2914	1.32 (1.12)	0.0128
Apartment					1.19 (1.11)	0.1017	1.31 (1.15)	0.0594
Dwelling built before 1980					1.01 (1.03)	0.7549	1.05 (1.04)	0.2073
No. persons					1.05	<0.0001	1.09 (1.01)	<0.0001
Mortgage (yes)							1.31 (1.07)	<0.0001
Total annual household income ≤ $30,000							0.76 (1.04)	<0.0001
Adjusted R^2	0.0012		0.0036		0.0089		0.0263	

VOCs in air are measured in µg/m^3. Change-in-estimates method (1).

Model 1:   log(naphthalene) = Age + ε

Model 2:   log(naphthalene) = Age + Smoking + ε

Model 3:   log(naphthalene) = Age + Smoking + Dwelling Characteristics + ε

Model 4:   log(naphthalene) = Age + Smoking + Dwelling Characteristics + Sociodemographic Factors + ε

Table 8d. Canadian Health Measures Survey Cycle 2. Beta coefficients and standard errors for linear models for continuous indoor air *alpha*-pinene; n = 4087.

	Model 1		Model 2		Model 3		Model 4	
	β (SE)	p	β (SE)	p	β	p	β	p
Age (child)	1.54 (1.06)	<0.0001	1.51 (1.06)	<0.0001	1.22 (1.05)	0.0002	1.17 (1.06)	0.0066
Smoking in dwelling (yes)			0.63 (1.05)	<0.0001	0.75 (1.05)	<0.0001	0.74 (1.06)	<0.0001
Dwelling type								
Single detached					1.65 (1.09)	<0.0001	1.63 (1.11)	<0.0001
Attached					1.26 (1.11)	0.0180	1.21 (1.12)	0.0802
Apartment					0.80 (1.11)	0.0290	0.79 (1.15)	0.0756
Dwelling built before 1980					1.75 (1.03)	<0.0001	1.68 (1.04)	<0.0001
No. persons					1.08 (1.11)	<0.0001	1.06 (1.01)	<0.0001
Mortgage (yes)							0.93 (1.06)	0.2478
Total annual household income ≤ $30,000							1.43 (1.04)	<0.0001
Adjusted R^2	0.0108		0.0253		0.1488		0.1256	

VOCs in air are measured in $\mu g/m^3$. Change-in-estimates method (1).

Model 1:   log(*alpha*-pinene) = Age + ε

Model 2:   log(*alpha*-pinene) = Age + Smoking + ε

Model 3:   log(*alpha*-pinene) = Age + Smoking + Dwelling Characteristics + ε

Model 4:   log(*alpha*-pinene) = Age + Smoking + Dwelling Characteristics + Sociodemographic Factors + ε

Table 9. Canadian Health Measures Survey Cycle 2. Beta coefficients and standard errors for simple linear regression models of selected urine metabolites of benzene and naphthalene.

Outcome		Air precursor		Intercept	
	n	β	SE	β	SE
Benzene metabolites					
t,t-mercapturic acid	2020	1.12[a]	1.02	65.37[a]	1.02
s-phenylmercapturic acid	1569	1.31[a]	1.03	0.23[a]	1.03
phenol	2039	1.02	1.02	6.62[a]	1.02
Naphthalene metabolites					
1-hydroxynaphthalene	2056	1.40[a]	1.03	1.31[a]	1.03
2-hydroxynaphthalene	2003	1.13[a]	1.02	3.74[a]	1.02

VOCs in air are measured in $\mu g/m^3$ and urine metabolites are measured in $\mu g/g$ creatinine

[a] significant at $p < 0.0001$.

Model 1:   *t,t*-mercapturic acid = benzene + ε
Model 2:   *s*-phenylmercapturic acid = benzene + ε
Model 3:   phenol = benzene + ε
Model 4:   1-hydroxynaphthalene = naphthalene + ε
Model 5:   2- hydroxynaphthalene = naphthalene + ε

Table 10. Comparison of the canister and thermal desorption tube according to Smith (2).

	Canister	Thermal desorption tube
VOCs	All, including sulfur and other reactive compounds	Dependent on adsorbent
Molecular weight	Low C_1-C_4	High $C_{5/6}$-C_{26}
Volume		Not dependent on size
Expense	More expensive than thermal desorption	Cheap
Ease of personal exposure monitoring	Limited by sampling pump	Easy
Re-analysis	Possible	Easy
Re-calibration	More difficult	Easy
Time	24 hours and longer	Short term

Table 11. Automatic desorption and gas chromatograph-mass spectrometer parameters. Methods were developed by the Health and Environmental Research Centre, Dalhousie, NS, according to the U.S. Environmental Protection Agency method TO-17 (3).

Sample Introduction	PerkinElmer TurboMatrix 650
Transfer Line Temperature	250 ^{o}C
Trap Low Temperature	10 ^{o}C
Trap High Temperature	275 ^{o}C
Dry Purge (Helium)	5 min
Trap Hold Time	8 min
Desorb Time	8 min
Outlet Split	16 mL/min
Column Flow	1.8 mL/min
Desorb Flow	60 mL/min
Transfer Line	Deactivated Fused Silica 5 m x 320 µm
Gas Chromatograph	PerkinElmer Clarus® 680
Column	Elite-5MS, 60m x 0.25 mm (PerkinElmer N9316287)
Run Time	52 min
Oven Program Initial Temperature	35 ^{o}C
Hold Time 1	4 min
Ramp 1	5.0 ^{o}C/min to 250 ^{o}C
Hold Time 2	5 min
Mass spectrometer	PerkinElmer Clarus SQ® 8 C
Mass Range	30-300 u
Ionization Mode	EI+
Solvent Delay Time	0 min
Dwell Time	0.02 sec
Inter-Channel Delay	0.001 sec

Table 12. Descriptive study results. Volatile organic compounds (VOCs) identified and measured using the automatic thermal desorber GC-MS at the Health and Environments Research Centre laboratory at Dalhousie University. The geometric mean (G.Mean) and geometric standard deviation (GSD) are presented for nine dwellings during 48 hours of passive sampling in March 2016 unto Tenax® TA thermal desorption tube.

Compound	Molecular formula	CAS no.	MW (g/mol)	BP (°C)	n	G.Mean (µg/m³)	G.S.D. (µg/m³)	Min. (µg/m³)	Max. (µg/m³)	Ref. value (µg/m³)	% total
1,1,1,2-Tetrachloroethane	$C_2H_2Cl_4$	630-20-6	167.85	130.4		b.d.l.					
1,1,1-Trichloroethane	$C_2H_3Cl_3$	71-55-6	133.4	74		b.d.l.				2.08E+06	
1,1,2,2-Tetrachloroethane	$C_{14}H_8Cl_6$	79-34-5	167.85	146		b.d.l.				3.75E+04	
1,1,2-Trichloroethane	$C_2H_3Cl_3$	79-00-5	133.4	110		b.d.l.				5.96E+04	
1,1,2-Trichlorotrifluoroethane	$C_2Cl_3F_3$	76-13-1	187.38	48	9	201.6	192.4	179.01	204.95	8.37E+06	5.50
1,1-Dichloroethane	$C_2H_4Cl_2$	75-34-3	98.96	57		b.d.l.				4.42E+05	
1,1-Dichloroethene	$C_2H_4Cl_2$	75-35-4	96.94	32	9	54.96	52.8	48.9	56.26		1.50
1,1-Dichloropropene	$C_2H_4Cl_2$	563-58-6	110.97	78.12		b.d.l.					
1,2,3-Trichlorobenzene	$C_6H_3Cl_3$	87-61-6	181.45	218.5	9	188.74	180.64	167.68	192.79	4.05E+05	5.15
1,2,3-Trichloropropane	$C_3H_5Cl_3$	96-18-4	147.43	156.5		b.d.l.				3.29E+05	
1,2,4-Trichlorobenzene	$C_6H_3Cl_3$	120-82-1	181.45	213	9	188.74	180.64	167.68	192.79		5.15
1,2,4-Trimethylbenzene	C_9H_{12}	95-63-6	120.19	169	9	83.17	78.87	73.51	84.24		2.27
1,2-Dibromo-3-chloropropane	$C_3H_5Br_2Cl$	96-12-8	236.33	164.5		b.d.l.				1.06E+01	
1,2-Dibromoethane	$C_2H_4Br_2$	106-93-4	187.86	131	9	202.96	193.73	180.31	206.31	1.68E+05	5.53
1,2-Dichlorobenzene	C_6H_4Cl	95-50-1	147	180.1	9	124.03	118.78	110.25	126.66		3.38
1,2-Dichloroethane	$C_2H_3Cl_2$	107-06-2	98.96	83.5	5	56.11	53.9	49.92	57.43	2.21E+05	1.53
1,2-Dichloropropane	$C_3H_6Cl_2$	78-87-5	112.99	96	9	73.14	70.11	65.07	74.65	3.78E+05	1.99
1,3,5-Trimethylbenzene	C_9H_{12}	108-67-8	120.19	165	9	113.75	108.39	100.87	115.9		3.10
1,3-Dichlorobenzene	$C_6H_4Cl_2$	541-73-1	147	173		b.d.l.					
1,3-Dichloropropane	$C_3H_6Cl_2$	142-28-9	112.99	120.4		b.d.l.					
1,4-Dichlorobenzene	$C_6H_4Cl_2$	106-46-7	147	174	9	124.03	358.97	110.25	607.69	4.92E+05	3.38
1,4-Dioxane	$C_4H_8O_2$	123-91-1	88.11	101	9	44.45	42.48	39.73	45.24	3.93E+05	1.21
2,2-Dichloropropane	$C_3H_6Cl_2$	594-20-7	112.99	68.53		b.d.l.					
2-Chloroethanol	C_2H_5ClO	107-07-3	80.51	129		b.d.l.				1.80E+04	

Compound	Molecular formula	CAS no.	MW (g/mol)	BP (°C)	n	G.Mean (µg/m³)	G.S.D. (µg/m³)	Min. (µg/m³)	Max. (µg/m³)	Ref. value (µg/m³)	% total
2-Chlorotoluene	C_7H_7Cl	95-49-8	126.58	159	9	92.11	88.15	81.94	93.8		2.51
2-Nitropropane	$C_3H_7NO_2$	79-46-9	89.09	120	9	45.74	43.75	40.57	46.53	9.94E+04	1.25
4-Chlorotoluene	C_7H_7Cl	106-43-4	126.58	162	9	92.11	88.15	81.94	93.8		2.51
4-Isopropyl toluene	$C_{10}H_{14}$	99-87-6	134.22	177	9	103.66	98.87	91.68	105.46		2.83
Acetonitrile	C_2H_3N	75-05-8	41.05	82	9	9.71	9.35	8.61	9.9	7.33E+04	0.26
Acrylonitrile	C_3H_3N	107-13-1	52.06	77	9	15.8	15.34	14.18	16.27		0.43
Allyl chloride	C_3H_5Cl	107-05-1	76.52	45		b.d.l.				3.42E+03	
Benzene	C_6H_6	71-43-2	78.11	80		b.d.l.				3.49E+04	
Bromobenzene	C_6H_5Br	108-86-1	157.01	156.2		b.d.l.					
Bromochloromethane	CH_2BrCl	74-97-5	129.38	68		b.d.l.				1.16E+06	
Bromodichloromethane	$CHBrCl_2$	75-27-4	163.83	90		b.d.l.					
Bromoform	$CHBr_3$	75-25-2	252.73	149		b.d.l.[1]				5.64E+03	
Carbon disulfide	CS_2	75-15-0	74.14	46	9	32.44	31.11	28.8	33.1	6.62E+04	0.88
Carbon tetrachloride	CCl_4	56-23-5	153.82	76.8		b.d.l.				6.87E+04	
Chlorobenzene	C_6H_5Cl	108-90-7	112.56	132		b.d.l.				3.77E+05	
Chloroform	$CHCl_3$	67-66-3	119.38	61.6		b.d.l.					
Chloroprene	C_4H_5Cl	126-99-8	88.54	59.4		b.d.l.				2.50E+01	
cis-1,2-dichloroethene	$C_2H_2Cl_2$	156-59-2	96.94	57.6		b.d.l.					
cis-1,3-dichloropropene	$C_3H_4Cl_2$	10061-01-5	110.97	104.3		b.d.l.					
cis-1,4-dichloro-2-butene	$C_4H_6Cl_{12}$	764-41-0	125	313		b.d.l.					
Dibromochloromethane	$CHBr_2Cl$	124-48-1	208.28	121	7	249.19	238.03	221.3	253.84	1.86E+06	6.79
Dibromomethane	CH_2Br_2	74-95-3	173.83	97	3	173.83	165.29	154.43	176.16		4.74
Diethyl ether	$C_4H_{10}O$	60-29-7	74.12	35	6	31.43	30.11	28.13	32.1	1.32E+06	0.86
Ethyl methacrylate	$C_6H_{10}O_2$	100-41-4	100.12	100							0.00
Ethyl methacrylate	$C_6H_{10}O_2$	87-68-3	100.12	100		b.d.l.					
Ethylbenzene	C_8H_{10}	74-88-4	106.16	136		b.d.l.				4.74E+05	
Hexachloro-1,3-butadiene	C_4Cl_6	78-83-1	260.76	213.5	9	389.98	372.51	346.9	398.12		10.63
Iodomethane	CH_3I	98-82-8	141.94	42.5	7	115.96	110.26	102.65	117.86	3.17E+04	3.16
Isobutyl alcohol	$C_4H_{10}O$	126-98-7	74.12	108		b.d.l.				3.31E+05	
Isopropylbenzene	C_9H_{12}	96-33-3	120.19	152	9	83.17	78.87	73.51	84.24	2.68E+05	2.27

Compound	Molecular formula	CAS no.	MW (g/mol)	BP (°C)	n	G.Mean (µg/m³)	G.S.D. (µg/m³)	Min. (µg/m³)	Max. (µg/m³)	Ref. value (µg/m³)	% total
Methacrylonitrile	C_4H_5N	80-62-6	67.09	90.3	9	25.76	24.86	23.06	26.36		0.70
Methyl acrylate	$C_4H_6O_2$	96-33-6	86.09	80.6		b.d.l.				3.84E+04	
Methyl methacrylate	$C_5H_8O_2$	108-38-3	100.12	100.5	9	57.66	54.98	50.95	58.55	4.47E+05	1.57
Methylene chloride	CH_2Cl_2	91-20-3	84.93	40	4	41.33	39.43	36.78	42.09	9.48E+04	1.13
m-xylene	C_8H_{10}	104-51-8	106.16	139		b.d.l.					
Naphthalene	$C_{10}H_8$	98-95-3	128.17	218	9	93.84	90.41	84.11	96.13	5.72E+04	2.56
n-butylbenzene	$C_{10}H_{14}$	103-65-1	134.22	183.3	9	103.06	98.87	91.68	105.46		2.81
Nitrobenzene	$C_6H_5NO_2$	95-47-6	123.11	211	9	86.84	82.99	77.49	88.49	5.50E+03	2.37
n-propylbenzene	C_9H_{12}	75-09-2	120.19	159.2	9	77.8	78.87	73.51	84.24		2.12
o-xylene	C_8H_{10}	107-12-0	106.16	144.5		b.d.l.					
Pentachloroethane	C_2HCl_5	106-42-3	202.29	162		b.d.l.					
Propionitrile	C_3H_5N	135-98-8	55.08	97		b.d.l.					
p-xylene	C_8H_{10}	100-42-5	106.16	138		b.d.l.					
sec-butylbenzene	$C_{10}H_{14}$	98-06-6	134.22	173.5		b.d.l.					
Styrene	C_8H_8	127-18-4	104.15	145	9	31.15	29.76	27.9	31.62	4.65E+05	0.85
tert-butylbenzene	$C_{10}H_{14}$	109-99-9	134.22	169.1	9	103.66	98.87	91.68	105.46		2.83
Tetrachloroethene	C_2Cl_4	108-88-3	165.83	121	9	57	54.78	51.08	57.74	7.40E+05	1.55
Tetrahydrofuran	C_4H_8O	156-60-5	72.11	65.5		b.d.l.				6.44E+05	
Toluene	C_7H_8	10061-02-6	92.14	111		b.d.l.				8.23E+05	
trans-1,2-dichloroethene	$C_2H_2Cl_2$	10061-02-6	96.94	51.2		b.d.l.					
trans-1,3-dichloropropene	$C_3H_4Cl_2$	110-57-6	110.97	108		b.d.l.					
trans-1,4-dichloro-2-butene	$C_4H_6Cl_{12}$	630-20-6	125	155.3		b.d.l.					
Trichloroethene	C_2HCl_3	71-55-6	131.39	87	9	99.13	94.44	87.98	100.89	5.87E+05	2.70

[1]b.d.l. below detection limit

[2]http://www.worldofchemicals.com/chemicals/chemical-properties/11-dichloropropene.html

[3]http://www.chemspider.com/Chemical-Structure.11170.html

Molecular formula, CAS number, molecular weight and boiling point from PubChem (191).

Ref value (OSHAEL). (170)

Table 13. Descriptive study results. Volatile organic compounds (VOCs) identified and measured using the automatic thermal desorber GC-MS at the Health and Environments Research Centre laboratory at Dalhousie University. The geometric mean (G.Mean) and geometric standard deviation (GSD) are presented for a single dwelling during one to ten days of passive sampling in August 2016 unto Tenax® TA thermal desorption tube.

Compound	Molecular formula	CAS no.	MW (g/mol)	BP (°C)	n	G.Mean ($\mu g/m^3$)	G.S.D. ($\mu g/m^3$)	Min. ($\mu g/m^3$)	Max. ($\mu g/m^3$)	Ref. value ($\mu g/m^3$)	% total
1,1,1,2-Tetrachloroethane	$C_2H_2Cl_4$	630-20-6	167.85	130.4	2	71.6	77.43	25.61	256.14		9.06
1,1,1-Trichloroethane	$C_2H_3Cl_3$	71-55-6	133.4	74		b.d.l.				1.16E+06	
1,1,2,2-Tetrachloroethane	$C_{14}H_8Cl_6$	79-34-5	167.85	146		b.d.l.				3.26E+04	
1,1,2-Trichloroethane	$C_2H_3Cl_3$	79-00-5	133.4	110		b.d.l.				4.91E+04	
1,1,2-Trichlorotrifluoroethane	$C_2Cl_3F_3$	76-13-1	187.38	48		b.d.l.					
1,1-Dichloroethane	$C_2H_4Cl_2$	75-34-3	98.96	57		b.d.l.					
1,1-Dichloroethene	$C_2H_4Cl_2$	75-35-4	96.94	32		b.d.l.					
1,1-Dichloropropene	$C_2H_4Cl_2$	563-58-6	110.97	78.12		b.d.l.					
1,2,3-Trichlorobenzene	$C_6H_3Cl_3$	87-61-6	181.45	218.5		b.d.l.				4.88E+05	
1,2,3-Trichloropropane	$C_3H_5Cl_3$	96-18-4	147.43	156.5	7	75.46	81.74	27.25	269.68	3.49E+05	9.55
1,2,4-Trichlorobenzene	$C_6H_3Cl_3$	120-82-1	181.45	213		b.d.l.					
1,2,4-Trimethylbenzene	C_9H_{12}	95-63-6	120.19	169		b.d.l.					
1,2-Dibromo-3-chloropropane	$C_3H_5Br_2Cl$	96-12-8	236.33	164.5		b.d.l.				7.34E+00	
1,2-Dibromoethane	$C_2H_4Br_2$	106-93-4	187.86	131		b.d.l.				1.17E+05	
1,2-Dichlorobenzene	C_6H_4Cl	95-50-1	147	180.1		b.d.l.					
1,2-Dichloroethane	$C_2H_3Cl_2$	107-06-2	98.96	83.5		b.d.l.				1.86E+05	
1,2-Dichloropropane	$C_3H_6Cl_2$	78-87-5	112.99	96		b.d.l.				3.21E+05	
1,3,5-Trimethylbenzene	C_9H_{12}	108-67-8	120.19	165		b.d.l.					
1,3-Dichlorobenzene	$C_6H_4Cl_2$	541-73-1	147	173	2	82.64	90.36	29.35	297.34		10.46
1,3-Dichloropropane	$C_3H_6Cl_2$	142-28-9	112.99	120.4		b.d.l.					
1,4-Dichlorobenzene	$C_6H_4Cl_2$	106-46-7	147	174	2	83.12	90.88	29.52	299.06	5.83E+05	10.52
1,4-Dioxane	$C_4H_8O_2$	123-91-1	88.11	101	4	28.86	31.56	10.37	104.16	4.51E+05	3.65
2,2-Dichloropropane	$C_3H_6Cl_2$	594-20-7	112.99	68.53		b.d.l.					
2-Chloroethanol	C_2H_5ClO	107-07-3	80.51	129	3	33.98	36.86	12.09	121.51	2.88E+04	4.30

Compound	Molecular formula	CAS no.	MW (g/mol)	BP (°C)	n	G.Mean (µg/m³)	G.S.D. (µg/m³)	Min. (µg/m³)	Max. (µg/m³)	Ref. value (µg/m³)	% total
2-Chlorotoluene	C_7H_7Cl	95-49-8	126.58	159	1	65.3	71.69	23.42	235.66		8.26
2-Nitropropane	$C_3H_7NO_2$	79-46-9	89.09	120		b.d.l.				1.34E+05	
4-Chlorotoluene	C_7H_7Cl	106-43-4	126.58	162		b.d.l.					
4-Isopropyl toluene	$C_{10}H_{14}$	99-87-6	134.22	177	6	77.44	84.55	27.66	278.14		9.80
Acetonitrile	C_2H_3N	75-05-8	41.05	82		b.d.l.				1.46E+05	
Acrylonitrile	C_3H_3N	107-13-1	52.06	77		b.d.l.					
Allyl chloride	C_3H_5Cl	107-05-1	76.52	45		b.d.l.				2.01E+03	
Benzene	C_6H_6	71-43-2	78.11	80		b.d.l.				3.57E+04	
Bromobenzene	C_6H_5Br	108-86-1	157.01	156.2		b.d.l.					
Bromochloromethane	CH_2BrCl	74-97-5	129.38	68		b.d.l.				6.07E+05	
Bromodichloromethane	$CHBrCl_2$	75-27-4	163.83	90		b.d.l.					
Bromoform	$CHBr_3$	75-25-2	252.73	149		b.d.l.					
Carbon disulfide	CS_2	75-15-0	74.14	46		b.d.l.				4.11E+04	
Carbon tetrachloride	CCl_4	56-23-5	153.82	76.8		b.d.l.				3.43E+04	
Chlorobenzene	C_6H_5Cl	108-90-7	112.56	132	1	48.32	52.45	17.09	173.84	4.42E+05	6.11
Chloroform	$CHCl_3$	67-66-3	119.38	61.6		b.d.l.					
Chloroprene	C_4H_5Cl	126-99-8	88.54	59.4		b.d.l.				6.63E+04	
cis-1,2-dichloroethene	$C_2H_2Cl_2$	156-59-2	96.94	57.6		b.d.l.					
cis-1,3-dichloropropene	$C_3H_4Cl_2$	10061-01-5	110.97	104.3		b.d.l.					
cis-1,4-dichloro-2-butene	$C_4H_6Cl_{12}$	764-41-0	125	313		b.d.l.					
Dibromochloromethane	$CHBr_2Cl$	124-48-1	208.28	121		b.d.l.					
Dibromomethane	CH_2Br_2	74-95-3	173.83	97		b.d.l.					
Diethyl ether	$C_4H_{10}O$	60-29-7	74.12	35		b.d.l.				6.25E+05	
Ethylbenzene	C_8H_{10}	100-41-4	106.16	136		b.d.l.					
Hexachloro-1,3-butadiene	C_4Cl_6	87-68-3	260.76	213.5		b.d.l.					
Iodomethane	CH_3I	74-88-4	141.94	42.5		b.d.l.				9.49E+03	
Isobutyl alcohol	$C_4H_{10}O$	78-83-1	74.12	108		b.d.l.				4.82E+05	
Isopropylbenzene	C_9H_{12}	98-82-8	120.19	152		b.d.l.				3.39E+05	
Methacrylonitrile	C_4H_5N	126-98-7	67.09	90.3		b.d.l.					
Methyl acrylate	$C_4H_6O_2$	96-33-3	86.09	80.6		b.d.l.				3.60E+04	

Compound	Molecular formula	CAS no.	MW (g/mol)	BP (°C)	n	G.Mean (µg/m³)	G.S.D. (µg/m³)	Min. (µg/m³)	Max. (µg/m³)	Ref. value (µg/m³)	% total
Methyl methacrylate	$C_5H_8O_2$	80-62-6	100.12	100.5		b.d.l.				4.49E+05	
Methylene chloride	CH_2Cl_2	75-09-2	84.93	40	4	11.07	12.14	3.93	39.64	4.46E+04	1.40
m-xylene	C_8H_{10}	108-38-3	106.16	139		b.d.l.					
Naphthalene	$C_{10}H_8$	91-20-3	128.17	218		b.d.l.				9.73E+04	
n-butylbenzene	$C_{10}H_{14}$	104-51-8	134.22	183.3		b.d.l.					
Nitrobenzene	$C_6H_5NO_2$	98-95-3	123.11	211		b.d.l.				9.42E+03	
n-propylbenzene	C_9H_{12}	103-65-1	120.19	159.2	8	62.54	68.23	22.03	223.88		7.91
o-xylene	C_8H_{10}	95-47-6	106.16	144.5		b.d.l.					
Pentachloroethane	C_2HCl_5	75-09-2	202.29	162		b.d.l.					
Propionitrile	C_3H_5N	107-12-0	55.08	97		b.d.l.					
p-xylene	C_8H_{10}	106-42-3	106.16	138		b.d.l.					
sec-butylbenzene	$C_{10}H_{14}$	135-98-8	134.22	173.5	1	75.91	82.88	27.11	272.64		9.61
Styrene	C_8H_8	100-42-5	104.15	145		b.d.l.				6.47E+05	
tert-butylbenzene	$C_{10}H_{14}$	98-06-6	134.22	169.1	1	73.98	80.78	26.42	265.73		9.36
Tetrachloroethene	C_2Cl_4	127-18-4	165.83	121		b.d.l.				5.40E+05	
Tetrahydrofuran	C_4H_8O	109-99-9	72.11	65.5		b.d.l.				5.85E+05	
Toluene	C_7H_8	108-88-3	92.14	111		b.d.l.					
trans-1,2-dichloroethene	$C_2H_2Cl_2$	156-60-5	96.94	51.2		b.d.l.					
trans-1,3-dichloropropene	$C_3H_4Cl_2$	10061-02-6	110.97	108		b.d.l.					
trans-1,3-dichloropropene	$C_3H_4Cl_2$	10061-02-6	110.97	108		b.d.l.					
trans-1,4-dichloro-2-butene	$C_4H_6Cl_{12}$	110-57-6	125	155.3		b.d.l.					
Trichloroethene	C_2HCl_3	71-55-6	131.39	87		b.d.l.				3.88E+05	

[1]b.d.l. below detection limit

[2]http://www.worldofchemicals.com/chemicals/chemical-properties/11-dichloropropene.html

[3]http://www.chemspider.com/Chemical-Structure.11170.html

Molecular formula, CAS number, molecular weight and boiling point from PubChem (191).

Ref value (OSHAEL). (170)

FIGURES

Figure 1.Thermal desorption sampling tools: A) Swagelok® caps to seal the tube airtight during transportation, 21g weight, B) white caps for use during short-term storage and chemical analysis, C) thermal desorption tube: metal cylinder 8.9cm by 0.5cm, 9g weight, D) metal clasp, E) sampling setup with filter on the left end, 32g total weight, F) wearing the tube at the back of the shirt.
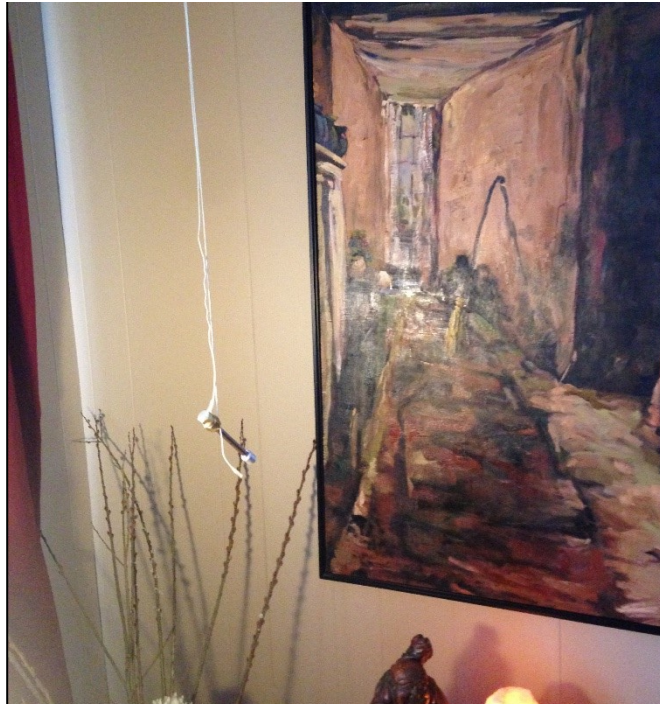
Figure 2. Tenax® TA thermal desorption tube is hung on a string from the ceiling during descriptive study 1 in March 2016. The thermal desorption tube is capped on one end with a diffusion cap and then other end with a Swagelok® cap.
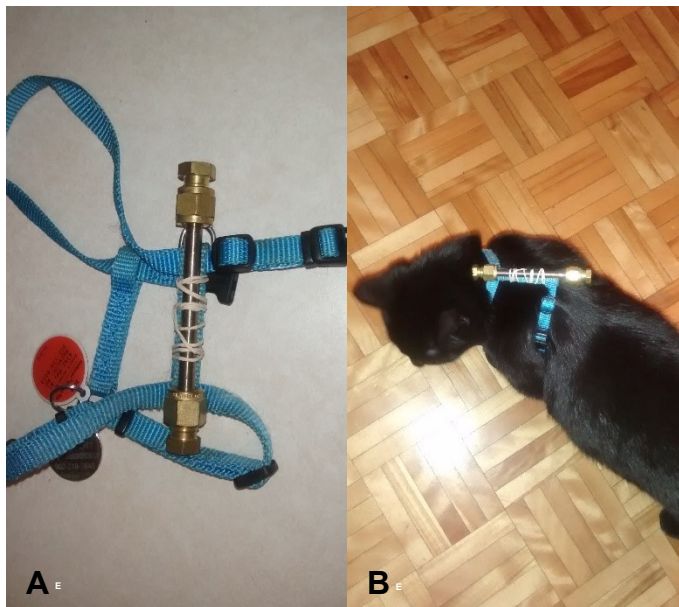
Figure 3. A) Thermal desorption tube attached to a feline halter, B) cat trained to wear a halter comfortably walking around the house.
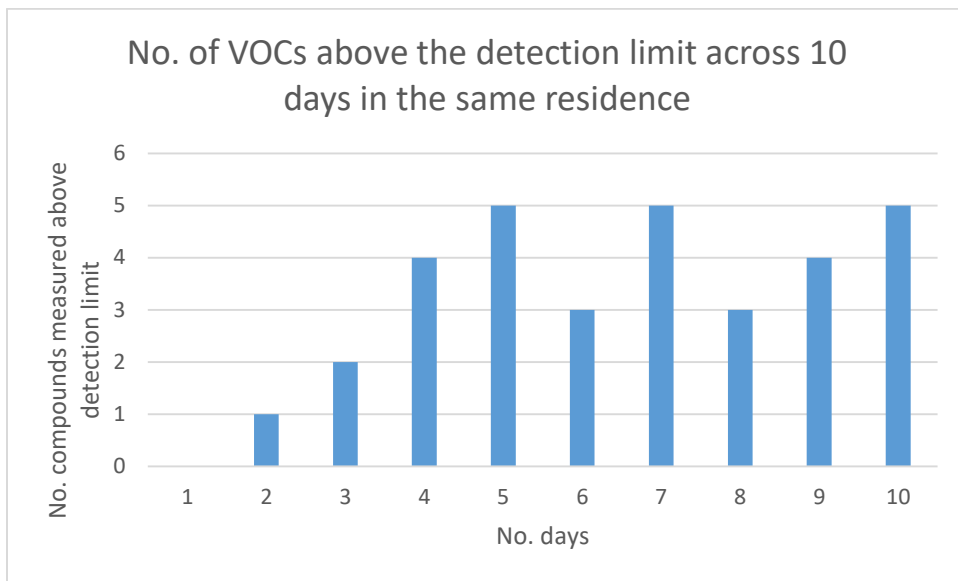
Figure 4. Frequency of VOCs detected in the same dwelling in Halifax over 10 days.
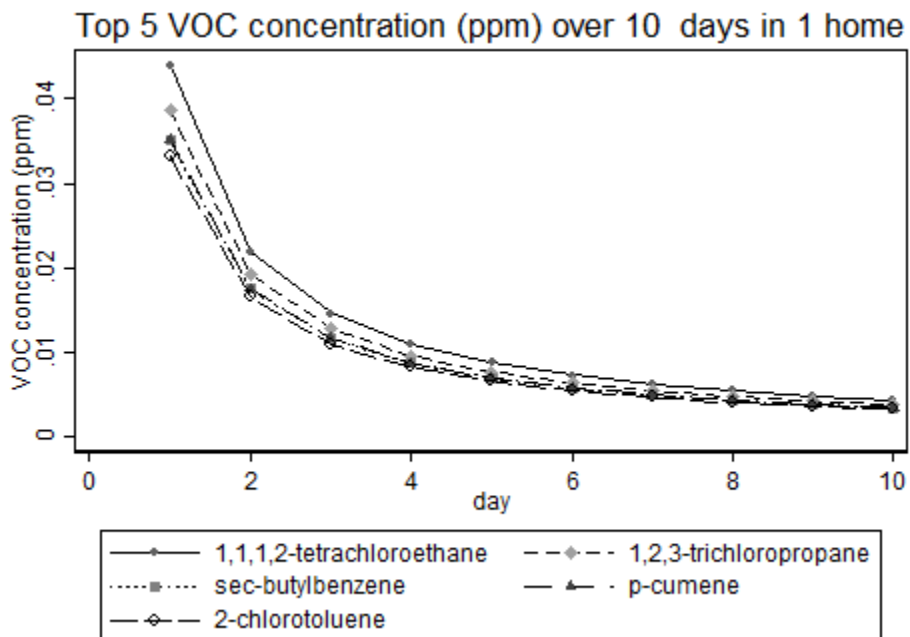
Figure 5. The concentration of 1,1,1,2-tetrachloroethane, 1,2,3-trichloropropane, *sec*-butylbenzene, *p*-cumene and 2-chlorotoluene during 10 days in the same residence in August 2016.

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APPENDICES

Appendix A

March 2017

Veterinary hospital address
Halifax NS

Re: Recruiting for project on indoor air quality in Halifax

Dear Dr. _____,

My name is Marianne Parent and I am a practicing companion animal veterinarian in the province of Nova Scotia. I am also completing a Master's degree in Community Health & Epidemiology. My project is focused on indoor air quality in Halifax dwellings: "**A pilot exposure assessment study of volatile organic compounds (VOCs) in residential indoor environment using a multi-receptor approach.**"
The purpose of this letter is to request permission to recruit from families that attend your veterinary hospital. We need veterinary hospitals in the Halifax Regional Municipality to advertise the study with a poster and handouts of the study details and consent forms to interested clients by way of the front desk personnel. The consenting veterinary hospitals will also host Dr. Parent in your reception area for a period of approximately 2 hours to talk with interested participants and answer any questions and concerns. Dr. Parent will not actively approach clients in the area, but will be available to discuss the study with interested people that approach her.

Volatile organic compounds (VOCs) are ubiquitous air pollutants, and although there is some information available on the exposure of VOCs in adult Canadians, there is a lack of information in children and in pets. We will assess the relationship between the child and indoor-only cat expecting that the cat can be a representative exposure receptor for the child. Therefore, if the indoor-only cat is a possible receptor for exposure in the child we can decrease the need to sample VOCs personal exposure in the child.
We are looking to recruit 20 families with young children (6 to 24 months old) that own indoor-only cats. In the dwellings, one adult and one cat will wear a thermal desorption tube (small lightweight metal tube) for 7 days, as well as placing one of the tubes in the living room. The parent will also be asked to fill out a questionnaire. We do not require access to the pet's health records and

information received from the recruitment process will remain completely confidential.

Sincerely,

Dr. Marianne Parent

Graduate student, Master's candidate

Supervisors:
Dr. Jong Sung Kim
Dr. Judith Read Guernsey
Community Health and Epidemiology
Dalhousie University Faculty of Medicine
5790 University Avenue
Halifax, NS B3H 1V7

![Dalhousie University logo] **DALHOUSIE UNIVERSITY**

CONSENT FORM

Project title

A pilot exposure assessment study of volatile organic compounds (VOCs) in residential indoor environment using a multi-receptor approach

Project Investigator
Dr. Marianne Parent, MSc. Candidate, Community Health & Epidemiology, Dalhousie University, Halifax, NS, marianne.i.parent@dal.ca

Dr. Parent's Master Thesis Supervisory Committee:
Dr. Judith Guernsey (Lead Co-supervisor), Professor, Community Health & Epidemiology, Dalhousie University, (jrg@dal.ca)
Dr. Jong Sung Kim (Co-supervisor), Assistant professor, Community Health & Epidemiology, Dalhousie University, (jskim@dal.ca)

Committee Members:
Dr. Swarna Weerasinghe, Associate Professor, Community Health & Epidemiology, Dalhousie University, Halifax, NS
Dr. Erin Leonard, Staff Epidemiologist, Nova Scotia Health Authority, Public Health - Central Zone, Halifax, NS

Introduction and Purpose
We invite you to support Dr. Marianne Parent master's thesis research study about volatile organic compounds in the dwelling environment. Dr. Parent is currently a veterinarian and is enrolled as a graduate student at Dalhousie University's Department of Community Health & Epidemiology. The purpose of her investigation is to build better understanding of exposures to volatile organic compounds (VOCs) in residential dwelling environments. VOCs are inhalable compounds that are released most commonly from household cleaning agents, cooking, candles, personal care products and other sources. Exposures to VOCs have been associated with irritation of the throat, nose, eyes and skin. They have also been associated with asthma. Some VOCs have also been linked with the subsequent development of heart disease and cancer.

Dr. Parent is interested in studying indoor environments because Canadians spend approximately 90 % of their time indoors. Specifically, her focus is on how exposures to VOCs vary according to adults, young children, and indoor cats in the dwelling. While young children are believed to be at greatest risk for potential health effects from VOCs (given their rate of growth from forming new cells and higher rates of metabolism), they are a population that are amongst the least studied because of difficulties in obtaining consent from this group. Hence the hypothesis that household pets, particularly indoor cats, may represent a valid exposure surrogate population because they also spend most of the day inside the dwelling and because their breathing zone is also only a short distance from the floor. In order to complete this analysis, 7 days passive samples from an adult and an indoor cat using a lightweight portable yet durable sampler that will be attached to clothing or to a specially designed cat harness. Third and fourth samplers will be placed in the living room of the dwelling as a background marker (4 samples in total). We will assess the relationship of four measurements with the room sampler providing a background comparator.

Who Can Take Part in the Research Study?
You can take part in this research study if you meet the following criteria:
- You are an adult of 18 years or older
- Yourself or another adult is a stay at dwelling parent
- Have a child between the ages of 6 months and 2 years old
- Live in a single-detached or duplex dwelling
- You are non-smoker
- You have at least one indoor-only cat
- You do not have a dog

What You Will Be Asked to Do?
Meeting 1
We will meet at your dwelling at a previously agreed upon time and review the purpose and process of the research study and provide you with the opportunity to ask any questions. We will then ask for your consent to participate. If allowed to proceed, we will then set up the exposure samplers in your dwelling and show you how and when to wear the tubes. We will also ask you questions using the standardized questionnaire about features of your dwelling (size of dwelling, heating source, humidification, windows, etc.) and possible sources of VOCs (paints, etc.). The total amount of time needed to complete these activities is about 1 to 2 hours.

Sampling in your dwelling
The air samplers will passively collect VOCs using thermal desorption tubes over 7 days. The living room testing tube will be set up in an inconspicuous place at 1 meter height from the floor. We ask that you do not touch these tubes. We will also take

temperature and humidity measurements at the beginning and end of the sampling period.

Pet cat individual exposure sampling
Your cat should wear the sampling tube attached to their collar or harness (Figure 2). It may be necessary to train your pet to wear the tube comfortably. Dr. Parent will demonstrate how to do this. She will assess how comfortable your cat is wearing the harness before the study begins and can go through a short training period so that your cat gets accustomed to wearing the collar or harness.

Personal exposure sampling
You will be fitted with a pencil-sized, brass sampling tube that will be attached to your shirt or jacket collar at the back of the neck (Figure 1). The tube should not be covered by clothing while you are wearing it and you should not touch the tube without gloves (we will provide). Wear the device when awake, except when showering, bathing or swimming, at which time it is to be left outside the door. At night, the testing tube needs to be set next to your bed. The sampling period will last 7 days. At the end of this period, we will collect the tubes from you.

Meeting 2
Meeting 2 will take place two days after the meeting 1 and will allow Dr. Parent to interview you about household activities and events that might have contributed to VOCs in the dwelling environment in the previous two days. The total amount of time needed to complete these activities is estimated to be about 1 hour.

Confidentiality
You will be assigned a participant identification number at the start of the study (roster file) and this identification number will be used on all subsequent forms and data results from your samples. Your responses to the questionnaire and the results of the VOCs that we measure in your dwelling will be maintained in confidential files and separately from identifying information. We will not share any personal identifying information with third parties (including name, employment, address, etc.).

Information that you provide to us will be kept private. Only the research team at Dalhousie University will have access to this information. We will describe and share our findings in a thesis, presentations and journal articles. We will be careful to only talk about total study findings and not present individual findings such that the source will be identifiable. All electronic records will be kept secure in an encrypted file on the researcher's password-protected computer.

Data retention
Data files and original questionnaires will be stored in locked filing cabinets as required by the University Research Ethics Board in locked filing cabinets until the

information is fully transferred into electronic format. The electronic data will then be stored in the department for 5 years after which it will be destroyed.

If You Decide to Stop Participating
If you decide to stop participating at any point in the study, you can also decide whether you want any of the information that you have contributed up to that point to be removed or if you will allow us to use that information. You can retract your participation up to the day we analyze the samples.
There will be no negative effects of withdrawal from the research study, but we request that you contact us immediately so we may retrieve the sampling equipment from your dwelling.

Possible Risks and Discomforts
Risks to the adult
Wearing the TD tube for 7 days may cause some mild discomfort similar to what would be experienced if you wore a pen in your pocket or on your collar for a day. The questionnaire has been pretested to collect information about your dwelling in the shortest time possible and to avoid collecting sensitive or personal information about your dwelling. All data from the study will be kept in confidential, password protected data files and will list your findings by your participant ID. These files will be kept separate from the roster file that contains your personal contact information.

Risks to the pets
Wearing the TD tube for 7 days may cause some mild discomfort so your pet should be supervised to prevent any unusual handling or event from occurring. The diffusion cap will not be used when the tubes are placed on pets because this piece may pose as a choking hazard. Moreover, the tube that is setup in the living room will be placed out of reach of children and cats.

Benefits
Each participant will receive a final, personalized report that provides a brief description of the overall study and their own dwelling's VOC findings at the end of the study. The results of this study will also serve as a contribution to the understanding of VOCs exposures in residential indoor environments and what contributes to these levels. It may also provide a new surrogate for measuring exposures that are relevant for investigations of young children.

Questions
We are happy to talk with you about any questions or concerns you may have about your participation in this research study. Please contact Dr. Judy Guernsey at 902-494-1767, or jrg@dal.ca at any time with questions, comments, or concerns about the research study (if you are calling long distance, please call collect). You may also contact her supervisor, Dr. Guernsey at 902-494-1767 or jrg@dal.ca. If you have any

ethical concerns about your participation in this research, you may also contact Research Ethics, Dalhousie University at (902) 494-1462, or email: ethics@dal.ca (reference REB file # 2016-3910)."

We thank you for your interest and support of this research.

Sincerely,

Marianne Parent, DVM   Judith Read Guernsey, MSc, PhD
MSc Candidate   Professor

Jong Sung Kim, MSc, PhD
Assistant professor

Definitions

Sampling: technique to collect data for the research study

Thermal desorption tube: small tube used to collect volatile organic compounds from the air

Volatile organic compounds (VOCs): inhalable hazardous air pollutants, released from cigarette smoke, oil-based paints, floor and wall materials, automobile exhaust, and industrial combustion.

Figure 1.Thermal desorption sampling tools: A) Swagelok® caps to seal the tube airtight during transportation, 21g weight, B) white caps for use during short-term storage and chemical analysis, C) thermal desorption tube: metal cylinder 8.9cm by 0.5cm, 9g weight, D) metal clasp, E) sampling setup with filter on the left end, 32g total weight, F) wearing the tube at the back of the shirt.

Figure 2. A) Thermal desorption tube attached to a feline halter, B) cat trained to wear a halter comfortably walking around the house.
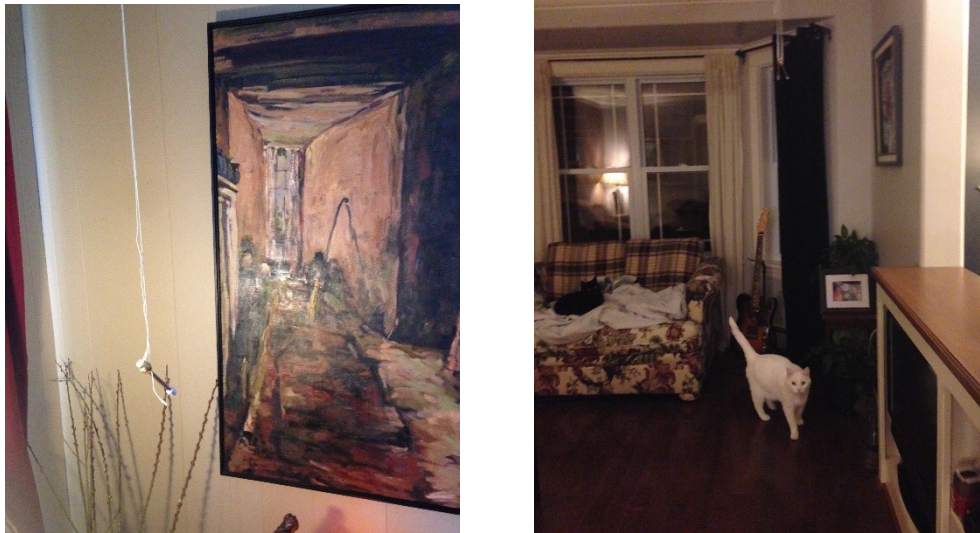
Figure 3. Thermal desorption tube hanging from the ceiling by a string to measure the VOCs in the residential indoor air.

Signature Page

Project Title: A Pilot Exposure Assessment Study of Volatile Organic Compounds (VOCs) in Residential indoor Environment using a Multi-receptor Approach

Lead Researcher: Dr. Marianne Parent, MSc Candidate, Community Health & Epidemiology, Dalhousie University, Halifax, NS, marianne.i.parent@dal.ca

Consent for yourself
I, _____, have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction. I understand that I have been asked to participate in personal exposure sampling to VOCs and sampling in my dwelling. My participation is voluntary and I understand that I am free to withdraw from the study at any time, until 3 months after my second interview is completed.

_____   _____   _____
Name   Signature   Date

Consent for your pet cat:
I, _____, have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction. I understand that I have been asked to consent to the participation of my pet, _____, in personal exposure sampling to VOCs and sampling in my dwelling. My participation and consent is voluntary and I understand that I am free to withdraw from the study at any time, until 3 months after my second interview is completed.

_____
Cat's name

_____   _____   _____
Name   Signature   Date

I, Dr. Marianne Parent, have discussed the research study in detail with _____.

_____   _____
Signature   Date

Appendix C

List of materials for each dwelling

1. Questionnaire
    a. 3 page baseline
    b. 3 page daily diary
2. 5 thermal desorption tubes
3. 10 Swagelok caps
    a. 5 will be removed at the start of sampling and brought back to the lack for storage until the end of the sampling period
4. 8 pairs of gloves
    a. Small, medium or large
5. String
    a. Excess brought back to the lab after setup of the thermal desorption tube in the living room
6. Scissors
    a. Brought back to the lab after setup of the thermal desorption tube in the living room
7. Q-Trak for measurement of relative humidity and temperature
    a. Collect relative data and remove to the lab for storage until the end of the sampling period
8. 1 small hygrometer and thermometer
9. 1 thumbtack to attach the string to the ceiling when setting up the living room thermal desorption tubes

Harness or halter training protocol prior to sampling

Time: Sessions should be approximately 5 minutes in length and can be repeated 2-3X per day. It will take approximately 3-4 days to learn this new behaviour.

Goal: Train your cat to wear a halter or harness with an attached thermal desorption monitoring device for a period of 5 days without being distressed about the event.

Training tips:
- Yes, cats can be trained!
- Be patient!
- Your timing is key! Be sure to reward the good behaviour at the exact time that you see it.
- Use smooth motions. Avoid jerky rapid reactions.
- Works best when the cat is a little bit hungry. For best results, feed twice a day and withhold the next meal until after the training session. To avoid overfeeding, use kibble or canned food as treats and/or reduce the normal amount of food received daily during training days.
- Get the whole family involved!
- This can easily be combined with trained behaviours such as sit!

Step 1. Identify the appropriate source of positive reinforcement for the individual. Can be a treat, piece of food from the regular diet, tuna juice (from a can), etc. Avoid foods that are high in salt, oil and dairy as they can result in diarrhea and dehydration.
2. Have a harness or halter that is loose enough to fit on your cat. Do not force the harness or halter on your cat to try to fit it properly. This can result in a negative experience and require longer training time.
3. Lay the harness on the ground near the cat and provide a few treats next to the harness. Let him/her approach the harness/halter.
4. Hold up the harness in front of the cat and fit your hand through the harness (up to the middle of the palm of the hand). Offer the cat a treat from that hand at the cat's level and about 5cm/2 inches from the cat's nose. Let the cat approach and take the treat. **Remove the treat and the harness at the same time.** Repeat 5-10X.
- This makes it clear that no harness/halter equals no treat.
5. Hold up the harness in front of the cat and fit your hand through the harness (up to the webs of the fingers). Offer the cat a treat from that hand. Let the cat approach and take the treat. Remove the treat and the harness at the same time. Repeat 5-10X.

6. Hold up the harness in front of the cat and fit the fingertips through the harness. Offer the cat a treat from that hand. Let the cat approach and take the treat. Remove the treat and the harness at the same time. Repeat 5-10X.

7. Hold up the harness and hold the treat 1cm/<1/2inch away so that the cat has to push his/her head through the harness to get the treat. Let the cat approach and take the treat. Do not force the harness on as that may elicit a fearful response. Remove the treat and the harness at the same time. Repeat 5-10X.

- Some cats will try to go around the harness to get the treat. Yes, this is smart, but not the behaviour that we want so he/she does not get the treat. Hold the harness up and open with one hand and the treat in the other near the opening in front of the cat.

8. Hold up the harness and hold the treat 5cm/2 inches away so that the cat pushed his/her head through the harness. Once the cat pushes through comfortable, we can clip on the harness. Unclip and remove the harness. Repeat 5-10X.

9. Let the cat pull through the harness and offer a treat. Clip on the harness. **Offer more treats. The harness should remain on for as long as the cat is focused on the food. Slowly increase the time between treats.**

10. Once the cat is comfortable wearing the harness for approximately 10 minutes. Introduce the metal cylinder (tube). Lay the tube on the ground and place treats around it so that he/she can explore the object.

11. Hold your hands side by side at the cat's level about 5cm/2 inches from the cat's nose. In one hand hold the tube and in the other a treat. Repeat 5-10X.

12. Clip on the tube to the harness and repeat steps 1 to 9. Continue to provide treats and increasing intervals of time. Make your intervals of time less predictable (e.g. 2 min, then 30 sec then 5 minutes, then 1 minute). Provide different treats and toys to continue improving the cat's comfort in wearing the harness/halter.

Refer to Dr. Sophia Yin's Kitten Socialization: Training a Kitten to Wear a Harness. https://drsophiayin.com/blog/entry/kittensocializationtrainingakittentowearaharness/

Behaviours indicating mild stress
Stay within Score 1 to 3
1. Fully relaxed posture:
- Laid out on side or on back with slow ventilation,
- Legs fully extended
- Tail extended or loosely wrapped
- Head on the surface
- Eyes closed or half open, maybe slow blinking, normal pupil size
- Normal ear position (half back)
- Lateral whiskers
- No vocalization or soft purr
- Sleeping or resting

3. Weakly tense:
- Laid ventrally or sitting/standing or moving
- Back horizontal
- Belly not exposed
- Normal ventilation rate (16-40 breaths per minute)
- Bent legs when lying/extended when standing
- Tail on the body or curved backward, may be twitching/tail may be up or tense during activity
- Head over the body
- Eyes opened normally, normal pupil size
- Normal ear position or erect and moved to front or back and forward
- Whiskers are lateral or forward with small amount of tension
- Meowing or quiet
- Resting or actively exploring

Training situations that elicit a score of 4 (very tense) are to be avoid. Signs of increased stress indicate lack of desensitization and counterconditioning for the situation that elicited the response; requires a step back in the training ladder.
Adapted from (192)

Appendix E

Troubleshooting during sampling

Cat constantly rubbing on the floor or other surfaces trying to remove the tube
- Take a break. Remove the harness and tube. Lay the tube on a surface where the cat is present. If the cat moves to another room, place it near the cat. Try to replace the harness and tube on the cat.
- Practice your training skills to increase comfort of wearing the harness and tubes
- Distract your cat with toys that dispense food, toys and other games

Tube or clip rubbing against the skin causing discomfort
- Wear an undershirt that prevents contact of the sampling device with the skin
- Remove the tube. Collect information for the participant until removal of the tube

Exposure Assessment Study of VOCs
in Indoor Residences
Household Practices Baseline Questionnaire
Participant ID: _____
Date: _____
    MM-DD-YYYY

Baseline QUESTIONNAIRE

The purpose of this questionnaire is to obtain information about you and your residence in order to understand which factors contribute to higher VOC levels. We are asking the same questions of each participant in the study. All the information will be kept confidential.

1. How many of the following live in the dwelling?
    Adults   _____   Cats _____
    Children <24 months _____   Other (explain)_____
    Children >24 months _____

2. Select one. What type is your dwelling?
    ☐ Detached house   ☐ Row house   ☐Duplex/triplex   ☐
    Apartment
    ☐ Other, describe: _____

3. How many stories do you have in your dwelling? _____ stories

4. Select one. How old is your dwelling?
    ☐ 1945 and earlier   ☐1946-1960   ☐1961-1980
    ☐ 1981-2000   ☐ 2001 and later   ☐ Don't know

5. What is the area of your dwelling? _____ total square footage (measure)

6. What is the area of the following rooms (measure)?
    Living room?   _____ square feet
    Adult bedroom?   _____ square feet
    Child bedroom?   _____ square feet

7. How many bedrooms are in your dwelling? _____ bedrooms

8. How many rooms are in your dwelling, including the kitchen but excluding bathrooms? _____ number of rooms

9. Does your dwelling have a garage?
   ☐ Yes   ☐ No   ☐ Don't know
   If yes, select one.
   ☐ Attached garage   ☐ Detached garage

10. Select all that apply. Do you store any of the following in your garage?
    ☐ Motorized equipment (other than cars)   ☐ Car(s)   ☐ Gasoline   ☐ Firewood
    ☐ Paint   ☐ Other, describe: _____

11. Select one. What is the primary source of heating for your dwelling?
    ☐ Wood   ☐ Electricity   ☐ Natural gas   ☐ Oil   ☐ Mixed
    ☐ Other, describe: _____   ☐ Don't know
12. Select one. What is the primary heat distribution system for your dwelling?
    ☐ Radiators   ☐ Baseboards   ☐ Forced air furnace
    ☐ Radiant floor or ceiling panels   ☐ Other, describe: _____
    ☐ Don't know

13. Select all that apply. Which of the following have you used within the last 6 months in your dwelling?
    ☐ Room Humidifier   ☐ Dehumidifier   ☐ Gas fireplace   ☐ Woodstove
    ☐ Wood fireplace ☐ Open sump pump ☐ Washing machine
    ☐ Vented clothes dryer ☐ Unvented clothes dryer

14. At what temperature do you generally set the thermostat?
    Daytime   _____ Nighttime _____

15. Do you use supplemental heating in your dwelling?
    ☐ Yes   ☐ No   ☐ Don't know
    If yes, describe: _____

16. Do you have a stand-alone air cleaner or filtration unit?
    ☐ Yes   ☐ No   ☐ Don't know
    If yes, what kind? _____

17. Do you have carpets in the following rooms?
    Living room?   ☐ Yes ☐ No
    Adult bedroom?   ☐ Yes ☐ No
    Child bedroom?   ☐ Yes ☐ No

18. Have you done significant renovations and painting to the interior of your dwelling during the past year?
    ☐ Yes   ☐ No   ☐ Don't know
    If yes, have these renovations or painting been done in the following rooms?

Living room? □ Yes □ No
Adult bedroom? □ Yes □ No
Child bedroom? □ Yes □ No

19. Have you bought new furniture or rugs for your dwelling in the last 6 months?
    □ Yes   □ No   □ Don't know

20. In the past months, have you or anyone else used any pesticides (e.g. bug sprays or rodent poison) inside your dwelling?
    □Yes   □ No   □ Don't know

21. In the past month, have you cleaned your oven using a chemical cleaner?
    □Yes   □ No   □ Don't know

22. In the past month, have you or anyone else cleaned the heating ducts in your dwelling?
    □Yes   □ No   □ Don't know

23. If you have a vacuum cleaner, does it have a HEPA filter?
    □Yes   □ No   □ Don't know

24. How often do you clean your dwelling (vacuuming and dusting)?
    □Everyday   □2-3 times per week   □Once per week
    □Less than once per week

25. Do you have any other exposures in dwelling that you believe might contribute to indoor air quality?
    □Yes   □ No   □ Don't know

 Thank you for your time today!

Exposure Assessment Study of VOCs
in Indoor Residences
Household Practices Questionnaire
Participant ID: _____
Date: _____
   MM-DD-YYYY

Household Practices QUESTIONNAIRE

The purpose of this questionnaire is to obtain information about activities in your residence that may have contributed to levels of VOCs in your dwelling environment over the past two days. We are asking the same questions of each participant in the study. All the information will be kept completely confidential.

Please answer these questions in regards to household practices <u>during the last 7 days.</u>

Part 1. Participants
1. Did anyone in the dwelling use any of the following personal care products?
Perfume or cologne	☐ Yes ☐ No	☐ Don't know
Spray deodorant	☐ Yes ☐ No	☐ Don't know
Hairspray	☐ Yes ☐ No	☐ Don't know
Nail polish or remover	☐ Yes ☐ No	☐ Don't know
Mouthwash	☐ Yes ☐ No	☐ Don't know

   Other, describe: _____

2. Did anyone bring dwelling dry cleaning? ☐ Yes   ☐ No   ☐ Don't know

3. Did anyone smoke (tobacco or other product) inside the dwelling?
   ☐ Yes   ☐ No   ☐ Don't know
4. Did anyone smoke (tobacco or other product) outside before entering the dwelling?
   ☐ Yes   ☐ No   ☐ Don't know

Part 2. Cooking
5. Did anyone use the following appliances to prepare food?
Stovetop burner/cooker	☐ Yes ☐ No	☐ Don't know
Oven	☐ Yes ☐ No	☐ Don't know
Broiler	☐ Yes ☐ No	☐ Don't know
Toaster oven	☐ Yes ☐ No	☐ Don't know
Toaster	☐ Yes ☐ No	☐ Don't know
Exhaust fan	☐ Yes ☐ No	☐ Don't know

6. Did anyone burn food (e.g. toast) in the past 7 days?
   ☐ Yes   ☐ No   ☐ Don't know

Part 3. Cleaning & chemicals
7. Did anyone actively clean your dwelling?

Vacuum   ☐ Yes ☐ No   ☐ Don't know
Dust   ☐ Yes ☐ No   ☐ Don't know
Sweep   ☐ Yes ☐ No   ☐ Don't know
Polish glass or other surface using chemical agent ☐ Yes ☐ No   ☐ Don't know
Clean litterbox   ☐ Yes ☐ No   ☐ Don't know
Other, describe: _____

8. Did anyone use commercial cleaning products?
 Bleach   ☐ Yes ☐ No   ☐ Don't know
 Citrus-scented   ☐ Yes ☐ No   ☐ Don't know
 Pine-scented   ☐ Yes ☐ No   ☐ Don't know
 Vinegar   ☐ Yes ☐ No   ☐ Don't know
 Foaming agent   ☐ Yes ☐ No   ☐ Don't know
 Other, describe: _____

Part 4. The dwelling

9. Did anyone use the following scented products in the dwelling?
 Scented candles ☐ Yes ☐ No   ☐ Don't know
 Candles   ☐ Yes ☐ No   ☐ Don't know
 Incense   ☐ Yes ☐ No   ☐ Don't know
 Scented oil   ☐ Yes ☐ No   ☐ Don't know
 Air fresheners   ☐ Yes ☐ No   ☐ Don't know
 Other, describe: _____

10. If you have an air filtration unit or air cleaner, was it used?
 ☐ Does not apply ☐ Yes ☐ No   ☐ Don't known

11. If you have a laser printer, was it used?
 ☐ Does not apply ☐ Yes ☐ No   ☐ Don't known

12. Were any of the windows opened in the past 7 days?
 Living room?   ☐ Yes ☐ No   ☐ Don't known
 Adult bedroom?   ☐ Yes ☐ No   ☐ Don't known
 Child bedroom?   ☐ Yes ☐ No   ☐ Don't known

13. Did anyone use supplemental heating inside the dwelling?
 Open stove   ☐ Yes ☐ No   ☐ Don't know
 Electric space heater ☐ Yes ☐ No   ☐ Don't know
 Kerosene space heater ☐ Yes ☐ No   ☐ Don't know
 Gas fireplace   ☐ Yes ☐ No   ☐ Don't know
 Decorative fireplace ☐ Yes ☐ No   ☐ Don't know
 Gas space heater   ☐ Yes ☐ No   ☐ Don't know
 Wood burning stove ☐ Yes ☐ No   ☐ Don't know
 Pellet stove   ☐ Yes ☐ No   ☐ Don't know
 Other, describe: _____

Part 5. Cat activities

14. Do(es) your cat(s) spend the majority of its time in the living room?
    ☐ Yes   ☐ No   ☐ Don't know

15. Where is(are) the litterbox(es) located? (List all:_____)

16. What proportion of time does(do) did the cat(s) spend in the same room as the child in the past 7 days?
    ☐ 0-25 %   ☐ 26-50 %   ☐ 51-75 %   ☐ 76-100 %

17. What proportion of time do(es) the cat(s) spend in the same room as you in the past 7 days?
    ☐ 0-25 %   ☐ 26-50 %   ☐ 51-75 %   ☐ 76-100 %

Thank you very much for your time today!

Interviewer comments: _____

Appendix H

DALHOUSIE UNIVERSITY

Project title

Personal exposure to VOCs in matched adults, children and companion animals in the same household in Halifax, NS

Lead researcher

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Other researchers

Dr. Jong Sung Kim (co-supervisor), Assistant professor, Community Health & Epidemiology, Dalhousie University, Halifax, NS. jskim@dal.ca
Dr. Judith Guernsey (co-supervisor), Professor, Community Health & Epidemiology, Dalhousie University, Halifax, NS
Dr. Swarna Weerasinghe, Associate professor, Community Health & Epidemiology, Dalhousie University, Halifax, NS
Dr. Erin Leonard, Staff Epidemiologist, Nova Scotia Health Authority, Public Health - Central Zone, Halifax, NS

Introduction

Volatile organic compounds are everywhere, including dwelling indoor air. VOCs are released from cigarette smoke, oil-based paints, floor and wall materials, automobile exhaust, and industrial combustion. Exposure to VOCs has been associated with irritation of the throat, nose, eyes and skin. It has also been associated with asthma, and chronic obstructive pulmonary disease (COPD). VOCs have also been associated with heart disease and cancer.
We measured VOCs in your dwelling and on tubes that you wore. Below we present to you a snapshot of the VOCs in your environment. Please note that the measured VOCs exist at very low levels and may not affect the health of your child, your cat and yourself.

Results

Compound	Living room (µg/m^3)		Individual exposure		Ref. value (µg/m^3)
	Height 1 m	Height 30 cm	Adult	Cat	
1,1,1,2-Tetrachloroethane					
1,1,1-Trichloroethane					2.08E+06
1,1,2,2-Tetrachloroethane					3.75E+04
1,1,2-Trichloroethane					5.96E+04
1,1,2-Trichlorotrifluoroethane					8.37E+06
1,1-Dichloroethane					4.42E+05
1,1-Dichloroethene					
1,1-Dichloropropene					
1,2,3-Trichlorobenzene					4.05E+05
1,2,3-Trichloropropane					3.29E+05
1,2,4-Trichlorobenzene					
1,2,4-Trimethylbenzene					
1,2-Dibromo-3-chloropropane					1.06E+01
1,2-Dibromoethane					1.68E+05
1,2-Dichlorobenzene					
1,2-Dichloroethane					2.21E+05
1,2-Dichloropropane					3.78E+05
1,3,5-Trimethylbenzene					
1,3-Dichlorobenzene					
1,3-Dichloropropane					
1,4-Dichlorobenzene					4.92E+05
1,4-Dioxane					3.93E+05
2,2-Dichloropropane					
2-Chloroethanol					1.80E+04
2-Chlorotoluene					
2-Nitropropane					9.94E+04
4-Chlorotoluene					
4-Isopropyl toluene					
Acetonitrile					7.33E+04
Acrylonitrile					
Allyl chloride					3.42E+03
Benzene					3.49E+04
Bromobenzene					
Bromochloromethane					1.16E+06
Bromodichloromethane					
Bromoform					5.64E+03
Carbon disulfide					6.62E+04
Carbon tetrachloride					6.87E+04
Chlorobenzene					3.77E+05
Chloroform					

Chloroprene	2.50E+01
cis-1,2-Dichloroethene	
cis-1,3-Dichloropropene	
cis-1,4-Dichloro-2-butene	
Dibromochloromethane	1.86E+06
Dibromomethane	
Diethyl ether	1.32E+06
Ethyl methacrylate	
Ethyl methacrylate	
Ethylbenzene	4.74E+05
Hexachloro-1,3-butadiene	
Iodomethane	3.17E+04
Isobutyl alcohol	3.31E+05
Isopropylbenzene	2.68E+05
Methacrylonitrile	
Methyl acrylate	3.84E+04
Methyl methacrylate	4.47E+05
Methylene chloride	9.48E+04
m-Xylene	
Naphthalene	5.72E+04
n-Butylbenzene	
Nitrobenzene	5.50E+03
n-Propylbenzene	
o-Xylene	
Pentachloroethane	
Propionitrile	
p-Xylene	
sec-Butylbenzene	
Styrene	4.65E+05
tert-Butylbenzene	
Tetrachloroethene	7.40E+05
Tetrahydrofuran	6.44E+05
Toluene	8.23E+05
trans-1,2-Dichloroethene	
trans-1,3-Dichloropropene	
trans-1,4-Dichloro-2-butene	
Trichloroethene	5.87E+05

How to interpret these results

Please understand that the VOCs that were measured in your dwelling are a snapshot in time and does not reflect on your total indoor air quality. You can improve your indoor air quality by taking the following precautions:
-   Using low or no VOC paints, varnishes, and glues
-   Don't let the car idle in the garage
-   Clean any leaks rapidly to prevent mould growth

- Clean the furnace and stove filters as required by the manufacturer
- Open windows to improve air circulation
- Visit the Government of Canada website on air quality (http://healthycanadians.gc.ca/healthy-living-vie-saine/environment-environnement/air/index-eng.php)

If you are concerned about the VOCs that we measured in your living room or the tube you were wearing, we ask that you contact an occupational health specialist in the area.

We cannot make any conclusions regarding your health and that of your children and pets. Please see a physician for consultation for yourself and your child if you are concerned. Please see a veterinarian for consultation of your pet's health if you are concerned.

What's next?

The next step is the statistical analysis of the information collected from your dwelling and the dwellings of the other participants. We can forward a copy of any ensuing publication if you make the request.

If you decide to stop participating

We ask that you let us know within 3 months of the end of the sampling period if you want to retract your participation in this study. If you do, there are no consequences, but we will remove you from the statistical analyses. Just a remainder that the information you provided us is kept confidential and it will not be shared with third parties.

We are extremely appreciative of your participation in this study.

Summary of results for 20 dwellings

Compound	Living room (µg/m^3)		Individual exposure		Ref. value (µg/m^3)
	Height 1 m	Height 30 cm	Adult	Cat	
1,1,1,2-Tetrachloroethane					
1,1,1-Trichloroethane					2.08E+06
1,1,2,2-Tetrachloroethane					3.75E+04
1,1,2-Trichloroethane					5.96E+04
1,1,2-Trichlorotrifluoroethane					8.37E+06
1,1-Dichloroethane					4.42E+05
1,1-Dichloroethene					
1,1-Dichloropropene					
1,2,3-Trichlorobenzene					4.05E+05
1,2,3-Trichloropropane					3.29E+05
1,2,4-Trichlorobenzene					
1,2,4-Trimethylbenzene					
1,2-Dibromo-3-chloropropane					1.06E+01
1,2-Dibromoethane					1.68E+05
1,2-Dichlorobenzene					
1,2-Dichloroethane					2.21E+05
1,2-Dichloropropane					3.78E+05
1,3,5-Trimethylbenzene					
1,3-Dichlorobenzene					
1,3-Dichloropropane					
1,4-Dichlorobenzene					4.92E+05
1,4-Dioxane					3.93E+05
2,2-Dichloropropane					
2-Chloroethanol					1.80E+04
2-Chlorotoluene					
2-Nitropropane					9.94E+04
4-Chlorotoluene					
4-Isopropyl toluene					
Acetonitrile					7.33E+04
Acrylonitrile					
Allyl chloride					3.42E+03
Benzene					3.49E+04
Bromobenzene					
Bromochloromethane					1.16E+06
Bromodichloromethane					
Bromoform					5.64E+03
Carbon disulfide					6.62E+04
Carbon tetrachloride					6.87E+04
Chlorobenzene					3.77E+05
Chloroform					

Chloroprene	2.50E+01
cis-1,2-Dichloroethene	
cis-1,3-Dichloropropene	
cis-1,4-Dichloro-2-butene	
Dibromochloromethane	1.86E+06
Dibromomethane	
Diethyl ether	1.32E+06
Ethyl methacrylate	
Ethyl methacrylate	
Ethylbenzene	4.74E+05
Hexachloro-1,3-butadiene	
Iodomethane	3.17E+04
Isobutyl alcohol	3.31E+05
Isopropylbenzene	2.68E+05
Methacrylonitrile	
Methyl acrylate	3.84E+04
Methyl methacrylate	4.47E+05
Methylene chloride	9.48E+04
m-Xylene	
Naphthalene	5.72E+04
n-Butylbenzene	
Nitrobenzene	5.50E+03
n-Propylbenzene	
o-Xylene	
Pentachloroethane	
Propionitrile	
p-Xylene	
sec-Butylbenzene	
Styrene	4.65E+05
tert-Butylbenzene	
Tetrachloroethene	7.40E+05
Tetrahydrofuran	6.44E+05
Toluene	8.23E+05
trans-1,2-Dichloroethene	
trans-1,3-Dichloropropene	
trans-1,4-Dichloro-2-butene	
Trichloroethene	5.87E+05