University of Alberta

Edmonton Indoor Air Quality Study (EIAQS): Determinants of Residential Benzene

By

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Abstract

Inhalation of benzene is associated with increased risk of leukemia. Edmonton Indoor Air Quality Study (EIAQS) investigated what factors were related to higher or lower levels of benzene in Edmonton homes. Factors examined were: season (winter, summer), environment (indoor, outdoor), traffic volume, proximity to downtown, socioeconomic status, garage type, number of occupants, and air exchange rate/age strata.

Neighborhoods were age stratified and ten dwellings were randomly sampled from each stratum. Fifty dwellings were sampled with SUMMA™ canisters for 7 consecutive 24-hour periods in winter and summer of 2010. Benzene samples were analyzed by GC/MS. Data on daily activity patterns and house characteristics were collected using questionnaires and analyzed using SAS v9.2.

A stepwise selection regression model predicted that 28% of the indoor benzene variability can be explained by season and presence of attached garage with connecting door as significant predictors ($p<0.05$).

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List of Abbreviations (in alphabetical order)

$\mu g/m^3$	Microgram per meters cubed
AAQ	Ambient air quality
ACH	Air changes per hour
AEP	Alberta Environmental Protection
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ATSDR	Agency for Toxic Substances and Disease Registry
ACH	Air changes per hour
AER	Air Exchange Rate
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEN	Benzene Emissions Number
CO	Carbon monoxide
CAT	Capillary absorption tube
CCINFO	a bi-weekly email newsletter produced by the Canadian Cochrane Centre
cfm	Cubic feet per meter
CHAPS	Canadian Human Activity Pattern Survey
CLT	Central limit theorem
CO_2	Carbon dioxide
DDT	Dichlorodiphenyltrichloroethane
ECD	Electron capture detector
EIAQS	Edmonton Indoor Air Quality Study
ELCR	Excess lifetime cancer risk

FH	Falconer Heights
GB	Gold Bar
GC	Gas chromatograph
GerES IV	German Environmental Survey for Children
H_2	Molecular hydrogen
HVAC	Heating, ventilation, and air conditioning
IAQ	Indoor air quality
IARC	International Agency for Research on Cancer
IQR	Interquartile range
IUR	Inhalation unit risk
LCR	Lifetime cancer risk
LLR	Lifetime leukemia risk
MLR	Multiple linear regression
MPO	Myeloperoxidase
MSD	Mass-selective detectors
MSDS	Material Safety Data Sheet
MW	Molecular weight
N_2	Nitrogen
NAAQS	National Ambient Air Quality Standards
NAPS	National Air Pollution Surveillance
NESHAPs	National Emission Standards for Hazardous Air Pollutants
NHAPS	National Human Activity Pattern Survey
NO_2	Nitrogen dioxide

NOAEL	No-observed-adverse-effect level
NOEL	No-observed-effect level
NRC	National Research Council
NSPS	New Source Performance Standards
O_3	Ozone
OSHA	Occupational Safety and Health Administration
OT	Ottewell
OX	Oxford
PD	Parkdale
PEL	Permissible exposure limit
PFT	Perfluorocarbon tracer
$PM_{2.5}$	Particulate matter less than 2.5 microns in diameter
PM_5	Particulate matter less than 5 microns in diameter
PM_{10}	Particulate matter less than 10 microns in diameter
ppb	Parts-per-billion
ppm	Parts-per-million
REB	Research Ethics Board
RF	Richford
SA	Spruce Avenue
SAS	Statistical Analysis Software
SIPs	State Implementation Plans
SO_2	Sulfur dioxide
SiO_2	Silicone dioxide

ST	Strathearn
TC	Thorncliff
TEAM	Total Exposure Assessment Methodology
TS	Terwillegar South
TT	Terwillegar Towne
TWA	Time-weighted average
U.S. EPA	United States Environmental Protection Agency
U.S. FDA	United States Food and Drug Administration
VOCs	Volatile organic compounds
VPD	Vehicle per day
WHO	World Health Organization
WM	Westmount

1.0 Introduction

1.1 Theme and Scope

This study investigated concentrations of benzene in ambient and indoor air of residential communities to estimate benzene exposure within households in the City of Edmonton and determine which external factors had significant influences on benzene exposures. Issues regarding both ambient and indoor air qualities (AAQ and IAQ, respectively) were addressed. Neighborhoods chosen for the study were selected from the City of Edmonton, Alberta, Canada.

Under the Clean Air Agenda, Health Canada is conducting exposure studies to provide measurements, data, and models that describe the impact of air pollution sources on the environment and Canadians (Heroux et al., 2009). To collect quantitative and qualitative data on indoor air pollution, Health Canada has to identify priority indoor air contaminants and their sources to develop evidence-based air quality guidelines and source product regulations to improve and maintain IAQ (Heroux et al., 2009). Health Canada has undertaken similar IAQ studies in Quebec City, Regina, Windsor, and Halifax to investigate air pollutant exposure levels and sources in homes of larger Canadian urban centers (Heroux et al., 2009).

Indoor and outdoor measurements of formaldehyde, naphthalene, particulate matter (PM_{10}, PM_5, and $PM_{2.5}$), CO, CO_2, NO_2, O_3, SO_2, and volatile organic compounds (VOCs), plus additional data regarding household occupants' activities and household activities, were recorded from 50 dwellings in the winter and summer seasons in Edmonton in 2010. With this expansive dataset, the

Edmonton Indoor Air Quality Study (EIAQS) could reveal the impacts of indoor and outdoor determinants on air pollutant levels in homes in the City of Edmonton. Moreover, this study could enable comparisons of air pollutant concentrations of urban centres across Canada and establish Edmonton's baseline air quality data for future comparisons.

The scope of this research project was to use selected results from the EIAQS to determine the significance and influence of indoor and outdoor variables on residential benzene concentrations. In addition, excess lifetime leukemia risk rate from inferred indoor benzene exposure was estimated for the Edmonton adult population and then compared to the age-accumulated, baseline leukemia risk rate in Alberta.

1.2 Problem Statement

Despite continual declines in ambient benzene concentrations in the U.S. (U.S. EPA, 2010a), Canada (Canadian Council of the Ministers of the Environment, 2009), and the City of Edmonton (Alberta Environment, 2011), emissions of VOCs continue to be an issue of concern in public health because there is a general misunderstanding regarding how much far-field sources contribute to personal exposures (Wallace, 1989). In the 1950s, many epidemiological studies blamed ambient air pollution as a root cause of the lung cancer epidemic in North America (Stocks, 1966; Stocks and Campbell, 1955; Waller, 1959). These studies focused on environmental pollutant concentrations near the source (rather than monitoring people), which inevitably exaggerated the "dangers" of ambient pollution and its contribution to personal exposure. Even though researchers quickly realized that near-field sources like smoking and ETS were the main culprits (rather than exposure from far-field, industrial sources of carcinogens in ambient air) (Buell and Dunn, 1967; Lawther, 1966; Mills and Porter, 1957), the "causal link" fallacy between cancer and air pollution was already planted into people's minds (Ames and Gold, 1997).

Before developing the fundamental principle of studying human exposure: "Measure where the people are" (Wallace, 2001), government agencies focused on developing policies to control atmospheric emissions from industries to protect public health. The efficacy of which were, however, nominal and questionable. When the U.S. Environmental Protection Agency (EPA) was established in 1970, public's exposure to pollutants was estimated from measurements of pollutants from their sources such as the smoke stack or discharge pipes (Wallace, 2001). In 1977, however, a publication from National Academy of Sciences criticized the lack of monitoring among human receptors (as cited in Wallace, 2001). Indeed, when looking at carcinogenicity data and toxicity models of U.S. EPA and U.S. Food and Drug Administration (FDA), Gough (1990) calculated that the proportion of cancer in the U.S. preventable by regulation is merely 0.25% and 1.3% of the annual cancer mortality of 485,000 deaths, based on U.S. EPA and U.S. FDA data, respectively. The estimated limitations of these regulations is not surprising since ambient exposure to contaminants in air, water, and soil only

Heeding advice from the National Science Academy, the U.S. EPA reassessed its exposure models (Wallace, 2001). Personal air quality monitors were developed and the Agency undertook a series of pioneering exposure studies to directly measuring thousands of people in numerous U.S. cities, including Beaumont, TX (Wallace et al., 1982); Research Triangle Park, NC (Wallace et al., 1982); Bayonne-Elizabeth, NJ (Wallace et al., 1984); Antioch-Pittsburg, CA (Wallace, 1987; Wallace et al., 1988); Los Angeles, CA (Wallace, 1987; Wallace et al., 1988; Wallace et al., 1991); Greensboro, NC (Wallace, 1987); Devils Lake, ND (Wallace, 1987); Baltimore, MD (Nelson et al., 1988); Elizabeth, NJ (Lioy et al., 1995); Washington, DC (Akland et al., 1985); Denver, CO (Akland et al., 1985); Springfield, MA (Immerman and Schaum, 1990); Jacksonville, FL (Immerman and Schaum, 1990); and Valdez, AK (Goldstein et al., 1992). These series of studies were called Total Exposure Assessment Methodology (TEAM) studies and as a result of conducting them, the Agency was able to develop and demonstrate sounds methods to measure human exposure to toxic substances in air and water (Wallace, 2001). This established evidence-based air quality exposure information for average Americans that was lacking in the past (Jia et al., 2007; Sheldon et al., 1992; Wallace et al., 1987).

Results from the TEAM studies established the importance of measuring personal exposure instead of emissions sources to determine human exposure. An example of this was highlighted with benzene (Wallace, 2001). Northern New Jersey has heavy petroleum refining and petrochemical areas with high volumes of benzene emitted into ambient air. Naturally, benzene exposures were assumed to be high for people living close to that area. Instead, when personal air quality monitors were used on participants, researchers found no difference in exposures between 150 people who resided near heavy petroleum refining and petrochemical areas and 150 people who resided far away (Wallace et al., 1985).

TEAM studies results also showed that people typically spend close to 90% of their times indoor and as such, individuals' exposures were actually most impacted by their indoor activities, indoor-sourced pollutants, and the unique combinations of micro-environments (Wallace et al., 1987). Concentrations from personal and indoor air pollutant monitors were consistently higher than those found outdoors, without obvious correlations among personal, indoor and outdoor exposure levels (Wallace et al., 1987). Personal exposure concentrations were typically 50% higher than those measured indoors because people walked around in their own personal clouds of particles and substances, otherwise known as the "Pigpen effect," named after the character Pigpen in the Peanuts© comics by Charles Schultz (Wallace, 1993). Nevertheless, indoor benzene concentrations can largely predict personal exposures to benzene (Stocco et al., 2008). Hence, from regulatory agencies' and public health researchers' perspectives, it is more pertinent to examine IAQ to model human exposures of air pollutants (Heroux et al., 2009).

In a national initiative by Health Canada, IAQ studies were conducted in major cities in Eastern and Western Canadian provinces to determine the air pollutant composition in typical Canadian dwellings (Heroux et al., 2009). By doing so, Health Canada could create regional IAQ profiles and develop up-to-date residential IAQ guidelines relevant to Canadians, which currently had not been established. The protocol for the EIAQS called for age stratification of all

Edmonton neighborhoods and randomly sampling ten dwellings from two neighborhoods that come from the same stratum in 2010. In total, fifty dwellings from ten neighborhoods and five age strata were randomly selected and sampled (with owners' consents) for 24-hour periods over 7 consecutive days in the winter (January to April) and summer (June to September) phases of the study (Appendix 1). Air sampling instruments were placed inside the homes and outside in the backyards. A wide range of parameters were measured: NO_2, SO_2, O_3, formaldehyde, CO, CO_2, particulate matter (PM_{10}, PM_5, and $PM_{2.5}$), naphthalene, and VOCs. Among the numerous compounds sampled, of particular interest for this study was one of the VOCs, benzene.

According to the International Agency for Research on Cancer (IARC), benzene is classified under Group 1 human carcinogens and considered by both the IARC and U.S. EPA as a causal agent of leukemia, especially for people exposed at high levels for prolonged periods (Chang et al., 2006; U.S. EPA, 1998; IARC, 1982; Mucci et al., 2004; Thomas and Chelghoum, 2004), like shoe tanners and shoemakers (Merler et al., 1986), automotive mechanics (Egeghy et al., 2002; Javelaud et al., 1998), and petrochemical workers (Garte et al., 2005; Rinsky et al., 1981). Major sources of non-occupational benzene exposures include automotive exhaust and environmental tobacco smoke (ETS) through inhalation (Wallace, 1989).

An abundance of scientific evidence strongly indicated that benzene is a leukemogen (Bergsagel et al., 1999; Chang et al., 2006; U.S. EPA, 1998; Heath, 1982; IARC, 1982; Jarvholm et al., 1997; Linet, 1985; Mucci et al., 2004; Paci et al., 1989; Thomas and Chelghoum, 2004; Wong and Raabe, 1989) with supporting evidence from toxicological studies (McMichael, 1988) and a mechanism of benzene-induced leukemia based on evidence (Smith, 1996). However, there is dispute over the subtype of leukemia that is associated with benzene exposure (Austin et al., 1988; Bergsagel et al., 1999; Infante, 1993) and the causal relationship between benzene and leukemia (Brondum et al., 2000; Infante-Rivard et al., 2000; Kabat et al., 1988). To err on the side of caution, this report will address all subtypes of leukemia risk under the umbrella term "leukemia." This author acknowledges that statistics related to leukemia from this study may be inflated.

Cheng et al. (1997) collected 24-hour ambient air samples every six days with 6-LSUMMA™ canisters in the downtown core and one to the east, in an industrial site about 9 km away. The median concentration of benzene measured in the downtown core and the industrial site were 3.38 $\mu g/m^3$ and 2.60 $\mu g/m^3$, respectively (Cheng et al, 1997). The authors calculated the total lifetime VOC-related cancer risk in Edmonton, using the U.S. EPA unit risk factors, to be 2-$3x10^{-5}$ (Cheng et al, 1997).

Currently, no studies have taken daily measured indoor benzene concentration to infer the lifetime risk of leukemia for residents in Edmonton by calculation, using the U.S. EPA unit risk factors. By doing so in this report, it will give insight into whether routine (e.g., daily), low dosage exposures to indoor benzene will lead to increased risks of leukemia for residents in Edmonton.

1.3 Objectives

This report is guided by two objectives. The first is to measure the levels of benzene in Edmonton homes. The second is to estimate the inferred excess lifetime cancer risk for leukemia based on assumed lifetime exposure to indoor residential level of benzene measured in the EIAQS.

1.4 Hypothesis

The residential concentrations of ambient and indoor benzene in Edmonton residences are estimated to be low because the study specifically did not include dwellings where smokers reside (which is the main source of benzene exposure for individuals), therefore exposure to benzene for the adult population living in dwellings in Edmonton, Alberta should be low.

2.0 Background Information

2.1 Air Quality

Air quality, which is determined by the level of pollution in the air, can be used to describe the health and safety of the atmosphere and create an environmental strategy to abate pollution to protect public health (Salvato et al., 2003). The quality of air tends to suffer as technology advances to satisfy the societal need for convenience, comforts, and ever growing demands and expectations as the population grows (Salvato et al., 2003). For example, the Industrial Revolution in the mid-1700's in England created smog because coal was burned on a massive scale to support increased mechanization (Kasa, 1973). In modern times, motor vehicles are the main contributors to man-made air pollution, about 85% (Wallace, 1996). In particular, urban centres have become bigger and more densely populated with increasing reliance on fuel-powered motor vehicles. As a result, human health and welfare are endangered as air quality degrades. The term "air pollution" was most appropriately defined as (Canter, 1996):

> "… [the] presence in the outdoor atmosphere of one or more pollutants in such quantities and of such duration as may be injurious to human, plant, or animal life, or to property, or which may be unreasonably interfere with the comfortable enjoyment of life or property, or the conduct of business."

More precisely, an air pollutant is a foreign contaminant added to the natural composition of the atmosphere that is present at a concentration that can assault the health of human, environment, and economy (U.S. EPA, 2011). Air pollutants can originate from natural (e.g. plants) or anthropogenic (e.g. internal combustion) sources and take various forms, such as particulates, aerosols, gases, and micro-organisms (Salvato et al., 2003). An air toxic substance is defined by the Alberta Environmental Protection as (AEP, 1998):

> "[a] substance is an air toxic substance if it enters or may enter the atmospheric environment in a quantity or concentration or under conditions (a) having or that may have an immediate or long-term effect on the environment; (b) constituting or that may constitute a danger to the environment on which human life depends; or (c) constituting or that may constitute a danger in Alberta to human life or health."

Air quality management is a major environmental issue because potentially toxic substances can travel through the atmosphere to locations distant from their sources and subjugate people to long-term, low-level exposure and contribute to negative effects on human health and environment. A substance is considered 'toxic' if: it enters (or may enter) the environment in a dosage that can pose a risk to human health, wildlife and the environment; humans are exposed to the substance at a toxic dose through inhalation, ingestion, or skin contact; and exposed humans are susceptible to the adverse effects of the toxic substance (*Canadian Environmental Protection Act,* 1999). There are five chemical classes of toxics: metals and metalloids; respirable mineral fibers; inorganic gases; non-halogenated organic compounds; and halogenated organic compounds.

Through monitoring and regulations, researchers and policy makers attempt to strike a balance between air quality and modernization. The ultimate goal for clean air, as established by the World Health Organization (WHO), is to attain "levels of air quality that do not give rise to significant negative impacts on and risks to human health and the environment" (WHO, 2004).

2.2 The Science and History of Studying Air Quality

From as early on as 377 B.C., ancient Greeks and Romans were aware of the negative effects of pollution, especially from mining and crowded cities (Sundell, 2004). Environmental health issues related to ventilation and sensory impacts of pollution were studied prior to 1950's (Hill, 1914; Sundell, 2004; von Pettenkofer, 1873; von Pettenkofer, 1941). As industrialization thrived, ambient air pollution became increasingly visible and ushered in the establishment of a federal air pollutant abatement initiative, the Clean Air Legislation of 1955 (Brooks and Davis, 1992). The emergence in awareness of AAQ caught steam when "Silent Spring" (Carson, 1962) was published. Carson's book argued that the unrestricted usage of pesticides, especially dichlorodiphenyltrichloroethane or DDT, were not only killing pests but also birds, hence the imagery depicted by the book's title. Heavy pollution and its effects on wildlife were major forces behind the birth of the Clean Air Act and the U.S. EPA in 1970 (Lewis, 1985). To implement the requirements of the Clean Air Act (1970), U.S. EPA created the National Emission Standards for Hazardous Air Pollutants (NESHAPs), National Ambient Air Quality Standards (NAAQS), State Implementation Plans (SIPs), and New Source Performance Standards (NSPS) (U.S. EPA, 2010b). Exposure models were employed and coupled with conservative assumptions (Viscusi and Gayer, 1995). An example of U.S. EPA making conservative assumptions is that negative studies are typically discounted by the agency. In contrast, European countries tend to give fair weight to such studies and are thus, less conservative.

Since the 1980's, an increasing amount of evidence showed that U.S. EPA's conservative modeling approaches regarding exposure and health impacts lacked adequate scientific basis (Abelson, 1993; Akland et al., 1985; Goldstein et al., 1992; Immerman and Schaum, 1990; Lioy et al., 1995; Nelson et al., 1988; Nichols and Zeckhauser, 1988; Viscusi and Gayer, 2005; Wallace et al., 1982; Wallace et al., 1984; Wallace et al., 1986; Wallace, 1987; Wallace et al., 1987; Wallace et al., 1988; Wallace et al., 1991). An unintended result was unnecessarily restrictive emission constraints implemented on industries. Some of the most notable studies that redefined environmental risk assessment modeling approaches were the Total Exposure Assessment Methodology (TEAM) studies led by U.S. EPA, which conducted large-scale, personal monitoring of participants in several major cities in the U.S. (Wallace, 2001). Through the TEAM studies, researchers found that indoor sources of air pollutants were more relevant to personal exposures than outdoor ones because people tend to spend over 90% of their times indoor (Wallace, 2001). Moreover, indoor concentrations of some pollutants (such as benzene) were higher indoors than outdoors (Wallace, 2001).

The indiscriminate application of no-observed-adverse-effect level (NOAEL) or no-observed-effect-level (NOEL) criterion by environmental risk assessors to all chemicals was unsound when insufficient amount of evidence was collected to prove that carcinogens acted through, or even had a threshold, and whether the threshold value could be accurately determined (Viscusi and Gayer, 2005). To address the growing body of criticism and knowledge, the National Research Council (NRC) and U.S. EPA developed their own guidelines, called "Risk Assessment in the Federal Government: Managing the Process" (NRC, 1983) and "The Risk Assessment Guidelines of 1986" (51 FR 33992, Sept. 24, 1986), respectively. Their goal was to "strengthen the reliability and objectivity of scientific assessment that forms the basis for federal regulatory policies applicable to carcinogens and other public health hazards" (NRC, 1983). These guidelines ensured that environmental risk assessments were done in a consistent manner to uphold technical quality and that cancer risks from chemicals in the environment were assessed according to guidelines, and the public are kept informed of any risks (Viscusi and Gayer, 2005). Public awareness increased when IAQ issues with radon, formaldehyde, sick building syndrome, cancer and allergies arose (Brooks and Davis, 1992; Sundell, 2004). All the while, scientific technology was improving so that instruments (such as gas chromatography and mass spectrometry) were becoming more sensitive to lower concentrations of chemicals to give researchers a better understanding of their effects over a wider and lower range of exposure concentrations closer to realistic exposures (Brooks and Davis, 1992).

Examination of the inter-relationship between IAQ and AAQ is crucial to understanding the effects of individuals' exposures to air pollutants. Broadly speaking, AAQ focuses on the environment, since outdoor-sourced pollutants could impact the atmosphere, vegetation, freshwater, and soil (Guidotti, 1995). IAQ, on the other hand, focuses more on indoor-sourced pollutants and indoor environment (Otson and Fellin, 1992). Because majority of the time is spent indoors (Wallace, 2001), AAQ tends to affect the population indirectly (Guidotti, 1995) while IAQ does so directly (Otson and Fellin, 1992). The relationship between AAQ and IAQ is very complex due to the multitude of variables involved, such as the extent of penetration of outdoor-sourced air pollutants into the indoor environments, air exchange rates inside the homes, and individual activity patterns, to name a few (Johnson et al., 2004; Wallace et al., 1986; Wallace et al., 1987).

Even though outdoor exposure is not directly related to personal exposure, studies have shown that a place with high ambient concentrations of pollutants will result in higher personal exposures, and vice versa (Lacasana et al., 2005; Rotko et al., 2002). This means that differences between regions can be identified using long-term data from central-site air pollutant monitors, like the NAPS stations that have been set up in Edmonton to monitor ambient air (AEP, 1998). It is also advantageous to monitor the outdoor air just outside of residential homes to look at traffic-related pollutants, including benzene (WHO, 2004).

2.3 Health Risk Assessment

Health risk assessment has become an integral part of policy development since its inception, and it is defined as (Paustenbach, 2000):

"the process wherein toxicology data from animal studies and human epidemiology are evaluated, a mathematical formula is applied to predict the response at low doses, and then information about the degree of exposure is used to predict quantitatively the likelihood that a particular adverse response will be seen in a specific human population."

There are four components to risk assessment: hazard identification, dose-response assessment, exposure assessment, and risk characterization (Appendix 2). Hazard identification involves finding the adverse health effects (enHealth, 2002); dose-response assessment is determining 'the incidence of adverse effects occurring in humans at different exposure levels' with consideration of qualitative and quantitative toxicology data (U.S. EPA, 1989); exposure assessment is finding the duration, frequency and type of exposure in a certain time period, as well as finding the at-risk population (enHealth, 2002); and lastly, risk characterization integrates the information from the last two components to estimate the likelihood, severity and sort of health risks, as well as describing the uncertainties related to each component (enHealth, 2002). Risk assessments can be combined with legislative, economic, technical, and political concerns to devise cost-effective strategies for controlling population exposure; this process is known as risk management (Viscusi and Gayer, 2005).

2.3.1 Concepts

Following are some concepts that are pertinent to risk assessment and the contents of this report:

- Ambient measurement — A measurement (usually of the concentration of a chemical or pollutant) taken in an ambient medium, normally with the intent of relating the measured value to the exposure of an organism that contacts that medium (Paustenbach, 2000).

- Background level (environmental) — The concentration of a substance in a defined control area during a fixed period of time before, during, or after a data-gathering operation (Paustenbach, 2000).
- Concentration (of air pollutant) — "[T]he amount of the material contained in a specified volume of air…expressed in mass per volume units… (or) parts per million by volume" (Ryan and Lambert, 1991).
- Exposure — "Contact of a chemical, physical, or biological agent with the outer boundary of an organism. Exposure is quantified as the concentration of the agent in the duration of that contact" (Paustenbach, 2000).
- Background exposure — Exposure that is not related to a specific site or activity. For example, exposure to chemicals at a different time or from locations other than the exposure unit of concern. Background sources may be either naturally occurring or anthropogenic (Paustenbach, 2000).
- Excess Lifetime Cancer Risk — The additional or extra risk of developing cancer due to exposure to a toxic substance incurred over the lifetime of an individual (U.S. EPA, 2011).

2.4 Exposure Assessment Model

Exposure assessment is a step in risk assessment that quantifies exposure to an agent, from the past, present, or future, by a specified population through contact with various environment media, such as water, air, soil, and food (enHealth, 2002; Paustenbach, 2000). There are two approaches to measure exposure: direct and indirect methods (Figure 1). Direct methods include personal monitoring and using biological markers and indirect methods include environmental monitoring, models, questionnaires, and diaries (enHealth, 2002).

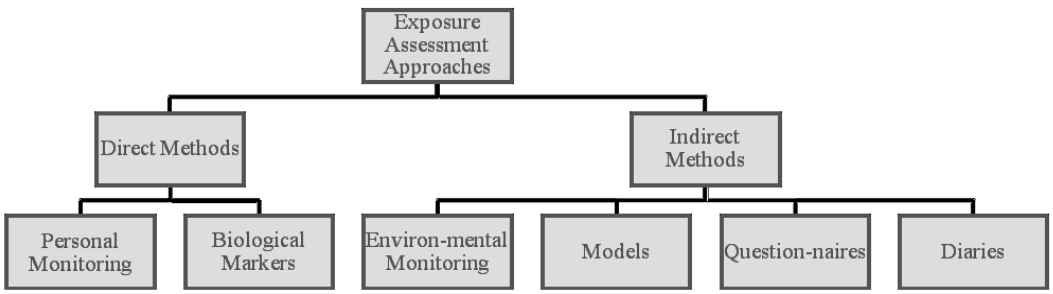

Figure 1 – Exposure assessment approaches (adapted from enHealth, 2002).

Direct methods can provide the most accurate and relevant exposure data, but they are inherently difficult to implement because of high cost and impracticality, especially if the sampling population is large (enHealth, 2002). Indirect methods are preferred in community-based studies, like the EIAQS. If important factors (e.g. scenario-specific factors) were considered carefully and U.S. EPA default assumptions were applied after careful discrimination, then the results retrieved using indirect methods could be valid (Paustenbach et al., 1997).

The emergence of the total human exposure (THE) approach and the results of the TEAM study changed the conventional view of exposure. They introduced a more scientifically accurate receptor-oriented approach to replace the sourceoriented approach that had been in use since the 1950s that was prone to overestimation of exposure (Ott, 1985; Wallace et al., 1986). Moreover, risk assessors realized that individual exposures were heavily influenced by the personal cloud created by individuals' unique combinations of micro-environments and activities as well as their indoor environments (Ott, 1990; Paustenbach, 2000; Wallace, 1996; Wallace et al., 1986; Wallace et al., 1987) because people usually spend 90% of their times indoor and 65-70% of their times at home (Klepeis et al., 1996; Leech et al., 1996). This study employed the receptor-oriented approach, using environmental monitors, diaries, and questionnaires to determine the average level and pattern of benzene exposure of Edmonton residents.

2.4.1 Time-Activity Patterns of North Americans

Canadian and U.S. federal agencies conducted studies to understand time-activity patterns of North Americans through the Canadian Human Activity Pattern Survey (CHAPS) and National Human Activity Pattern Survey (NHAPS), respectively (Klepeis et al., 1996; Leech et al., 1996). Notably, Edmonton, AB was one of the four Canadian cities, besides Toronto, ON, Vancouver, BC, and St. John, NB, surveyed in CHAPS allowing for meaningful application of the results from the CHAPS study to this study. An understanding of how people spend their time is critical for risk assessments to make accurate estimates of exposure distribution based on their locations (or rather, their micro-environments) and their activities during certain periods (Leech et al., 1996).

Both CHAPS and NHAPS found consistent evidence that North Americans tend to spend close to 90% of their times indoors (all locations except outdoor) (Klepeis et al., 1996; Leech et al., 1996). They also found that Canadians and Americans spend the majority of their times indoors at home, 64% and 69%, respectively (Klepeis et al., 1996; Leech et al., 1996). About 5% to 7% of the times were spent in vehicles and outdoors, respectively. These comparable results strongly suggested significant similarity of activity patterns among North Americans (Leech et al., 1996). The NHAPS study also did a breakdown of where people spend their time during a 24-hour time period: majority of the day was spent indoors at home, especially between the hours of 22:00 to 06:00, as those were typical sleeping hours. From 06:00 to 21:00, people were less likely to be at home, as they were at work/school, other indoor environments, or outdoors (Klepeis et al., 1996).

2.5 Benzene

2.5.1 Sources and Properties

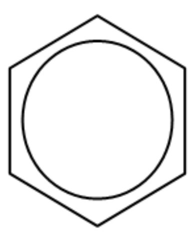

Figure 2– Structure of benzene ring.

Benzene (C_6H_6), also known as benzol or benzine, is an aromatic, non-polar air toxicant (MSDS, 2005) (Figure 2). It is a clear, colorless liquid with a strong yet sweet gasoline-like odor. It has a MW of 78.11 g/mol, odor threshold of 4.68 ppm, boiling point of 80.1ºC, and vapor pressure of 10 kPa at 20ºC. The octanol-water, air-water, and octanol-air partition coefficients of benzene are 135, 0.22, and 613.64, respectively. This means that benzene preferable partitions to airborne particles over air and water. The solubility of benzene in water and air increases when temperature decreases. Benzene is very volatile, thus, air is the main medium of human exposure (MSDS, 2005). Though, it should be noted that benzene can enter the body through all exposure routes (U.S. EPA, 1998). It is organic and non-polar (Dougherty, 1996). Benzene is highly flammable and naturally found in crude oil and gas emissions from forest fires and volcanoes (ATSDR, 2007). Currently, benzene is predominately made from petroleum and used by industries to make chemicals (e.g. styrene, cumene, and cyclohexane), rubbers, lubricants, dyes, detergents, drugs, and pesticides, to name a few household items (ATSDR, 2007). Because of its versatility, benzene is one of the top 20 chemicals manufactured in volume in the U.S. (ATSDR, 2007).

2.5.2 Benzene in the Ambient Environment

Benzene is a significant aromatic hydrocarbon as it has been used for over a century and is a precursor to many industrial and agricultural products (Yu, 2005). It is therefore ubiquitous in the environment. A predominant amount of benzene in ambient air is from automotive exhaust (80%), followed by industry (15%) and cigarette smoke (0.1%) (Figure 3).

There are benzene and over 70 of its derivatives present in the atmosphere (Yu, 2005). The derivation and presence of these compounds are from fossil fuel combustions and industrial emissions (Yu, 2005). The OH· radicals in the atmosphere are the main chain reactors of benzene and its derivatives (Yu, 2005).

As a result, aromatic rings may be added or hydrogen atoms may be abstracted, producing aromatic aldehydes, alcohols, nitrates, and products of ring cleavage (Yu, 2005). These products are readily deposited on aerosol particles due to their moderately high molecular weight and solubility in water (Yu, 2005).

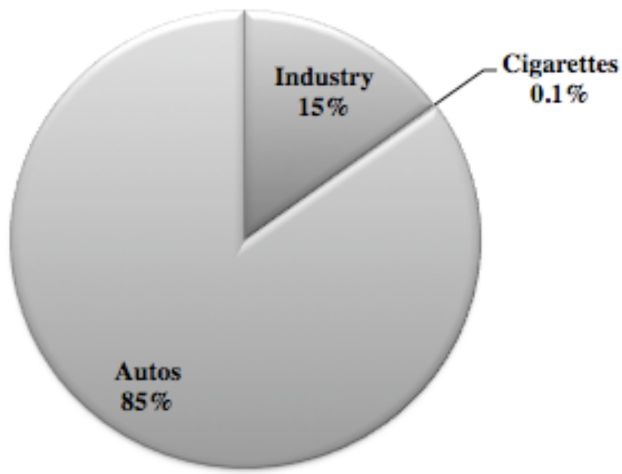

Figure 3 – Sources of benzene emission into the environment (adopted from Wallace, 1996).

2.5.3 Emission Regulations

Currently in Canada, there are no regulations to limit benzene concentrations allowable in residential homes. Government efforts to curb benzene emission are primarily emphasized on outdoor sources. Industries release the second greatest amount of benzene (greatest emission of benzene is originated from automobiles), yet their influence on personal exposure is estimated to be only 6% (Wallace, 1996). In Alberta, benzene emission standards were developed by Alberta Environmental Protection and Alberta Energy and Utilities Board for glycol dehydrators. The standard lists that less than 9.0 tonnes per year by January 1999 for existing facilities and 3.0 tonnes per year for new facilities, 3.0 tonnes per year within 0.75 km of permanent residents, and 5.0 tonnes per year for others by January 2001 (AEP, 1998). The main outdoor source of benzene in urban areas is automotive exhaust (Wallace, 1996). With the implementation of Benzene in Gasoline Regulations in 1999, the amount of benzene in gasoline was restricted; it was prohibited to supply gasoline that exceeded 1.0% benzene concentration by volume; it was also prohibited to sell or offer to sell gasoline that exceeded 1.5% benzene concentration in Canada. These restrictions are in place to limit benzene emissions from automobiles to ambient air (Canadian Environmental Protection Act, 1999).

2.5.4 Indoor Concentrations of Benzene

Potential indoor sources that have been found inside homes include: automobiles (evaporative emissions and start-up/shut-down emissions), paints, oil, gasoline, lacquers, and yard and garden supplies in garage (Batterman et al., 2006; Mendell, 2006; Schwartz, 2004; Wallace, 1989). Presence of indoor source materials compounded with decreased ventilation rates in newer energy efficient houses resulted in the concentration and predominance of exposure to indoor pollutants (Diamond, 2000).

Non-smokers living in urban areas are typically exposed to 16 $\mu g/m^3$ of benzene, a value well below the occupational standard (Wallace, 1996). However, as most people spend about 90% of their time indoors and concentrations indoor were much higher than outdoor (Wallace, 1989), it is important to review the concentrations of benzene in indoor air. Measurements of benzene concentration are typically in log normal distribution (U.S. EPA, 1992).

In a review by the Australian government, researchers looked at overseas research using two online databases (Medline, Toxline), two CD-ROMs (CCINFO - Canadian Centre for Occupational Health and Safety, OSH-ROM - Silver Platter Information Inc), proceedings of major conferences, and sixteen research/regulatory bodies (Brown et al., 1994). Comparing geometric means from different countries, indoor benzene concentrations range from as low as 1.9 $\mu g/m^3$ in the U.S. to 30.0 $\mu g/m^3$ in Italy, but the weighted geometric means of all the countries was 8.3 $\mu g/m^3$ (Brown et al., 1994). All of these values were at least 5 times lower than the OSHA permissible exposure limit (PEL) for general industry, which states that the time-weighted average (TWA) was 3 mg/m^3 over 8-hour work shift, short-term exposure limit is 16 mg/m^3 in a 15-minute sampling period, and action level is 1.5 mg/m^3 (OSHA, 2010).

In the same literature review by Brown et al. (1994), they used geometric means of assumed log-normal data from other studies to determine the ratios of indoor to outdoor concentrations and averaged them. Brown et al. (1994) found that the indoor/outdoor concentration ratio of benzene was 3. This was the consistent with the Boston Exposure Assessment in Microenvironments (BEAM) Study, which measured 2.6 $\mu g/m^3$ and 0.88 $\mu g/m^3$ arithmetic means of indoor and outdoor benzene concentrations, respectively, in fifty-five dwellings (homes and apartments) sampled over the summer of 2004 and winter of 2005 (Dodson et al., 2008). Arithmetic means of benzene concentration were also measured from non-living spaces of the house: garage had 58 $\mu g/m^3$; basement had 3.2 $\mu g/m^3$; and hallway had 2.8 $\mu g/m^3$ (Dodson et al., 2008). Homes with attached garages had 2 to 6 times higher benzene concentrations than those without (Batterman et al., 2007; Dodson et al., 2008; Isbell et al., 2005; Thomas et al., 1993).

Studies conducted in Poland (Zabiegala et al., 2010), Korea (Baek et al., 1997; Son et al., 2003) and North America (Wallace, 1993) showed that concentrations of benzene in the winter were usually higher than summer's because of limited ventilation and cars being started in attached garages before driving. Despite low levels of indoor benzene concentrations consistently measured in multiple studies, it still valuable to conduct the EIAQS because there is still limited amount of data in Western provinces regarding indoor benzene concentration and its contribution to the risk of leukemia in Edmonton, AB.

2.5.5 Human Exposure to Benzene

Despite tedious efforts to restrict benzene emissions to the ambient environment, outdoor air is not the primary source of benzene exposure for many individuals (Wallace, 1996). The U.S. EPS TEAM studies conducted a series of studies and summarized the sources of benzene exposures for smokers and non-smokers in the U.S. Figure 4 illustrated that typical American smokers who smoke about 32 cigarettes a day (about 55μg/cigarette) were mostly exposed to benzene from smoking (89%), and the rest is from ETS, outdoor air, personal activities/indoor air, and driving car (11%) (Wallace, 1996).

In contrast, typical American non-smokers had a greater exposure to benzene in outdoor air (40%), personal activities/indoor air (31%) and driving car (19%) (Figure 5). Not surprisingly, non-smokers are not exposed to any benzene from smoking; however, 10% of their benzene was still attributed to environmental tobacco smoke (Wallace, 1996).

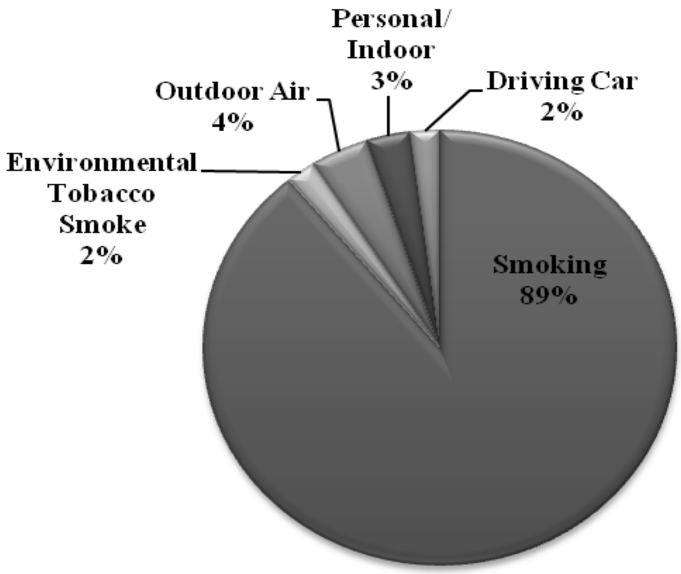

Figure 4 – Sources of benzene exposure for a typical American smoker. About 2 mg of benzene is inhaled by a smoker everyday, of which, 1.8 mg is from mainstream smoke (Wallace, 2001).

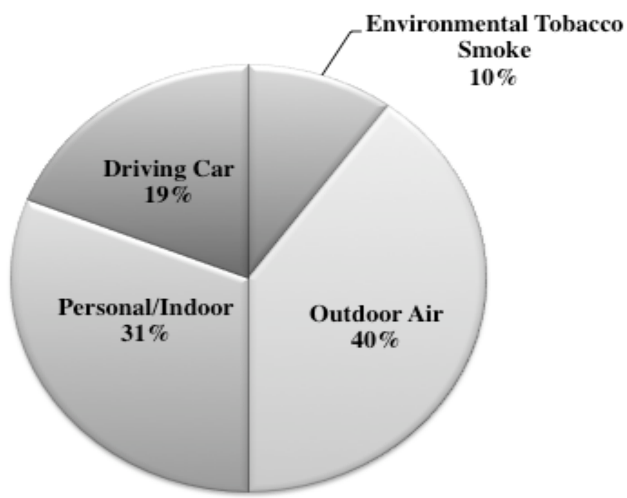

Figure 5 – Sources of benzene exposures for a typical American non-smoker. About 0.2 mg of benzene is inhaled by a non-smoker everyday with the assumption that an average exposure is 15 µg/m^3 and alveolar respiration rate is 14 m^3/day. The average outdoor level is 6 µg/m^3 and the remaining 9 µg/m^3 is from driving (100 minute at 30 to 40

μg/m^3), indoor sources and environmental tobacco smoke (Wallace, 1996).

2.5.6 Toxicology of Benzene and Related Health Effects

Benzene is a carcinogen associated with hematotoxicity and abnormal hematopoiesis in humans and mice (Yoon et al., 2003). Benzene and its metabolites are classified as genotoxic carcinogens (IARC, 1982; Rinsky, 1989; Rinsky et al., 1981; U.S. EPA, 1998; Whysner et al., 2004) that target multiple organs and glandular tissues (Low et al., 1995). This section will focus on benzene's effect on bone marrow cells leading to leukemia.

Although the mechanism of benzene-induced leukemia has been studied extensively, it is not completely understood (Smith, 1996). A number of events have been identified as key to benzene's mode of action to induce leukemia, listed below in chronological order (Smith, 1996; Yoon et al., 2003; Yu, 2005; Meek and Klaunig, 2010):

1. Metabolism of benzene in the liver by CYP2E1 enzymes produces proximate toxic metabolites such as benzene oxide/benzene oxepin metabolites and phenolic metabolites (Figure 6).
2. Benzene metabolites travel to the bone marrow and interact with myeloperoxidases (MPOs) to produce ultimate toxic metabolites: quinones, semi-quinones, and free radicals (Figure 6).
3. Quinones and free radicals damage bone marrow stem cells or hematopoietic progenitor cells through oxidation and adduct formation.

4. Machineries of cell cycle arrest sustain damages. Molecular targets affected include: tubulin, topoisomerase II, and histones.
5. DNA becomes damaged because DNA strand breaks, and abnormal mitotic recombination, chromosome translocations, and aneuploidy occur.
6. Changes to DNA can create changes in the stem cells and progenitor cells, including activation of proto-oncogene (e.g., c-Ha-*ras*-1 and c-ets) (Boulukos et al., 1988; Hiraku and Kawanishi, 1996), fusion of genes (e.g., MLL gene with partner genes) (Alexander et al., 2001), and inactivation suppressor gene (e.g., *p53* gene) (Boley et al., 2000). These changes give rise to leukemic clones that have selective growth advantage.
7. DNA repair genes cannot be properly activated, thus increasing cell mutation frequencies at DNA loci associated with benzene-induced carcinogenesis. Also, damaged cells continue to cycle.
8. Overtime, damages to cellular machinery and changes to genes can result in the development of leukemia.

Liver is the primary site of benzene metabolism where cytochrome P450-2E1 (CYP2E1) enzymes metabolize benzene to produce reactive, toxic metabolites such as hydroquinone, phenol, catechol, and *trans-trans* muconic acid (Barale et al., 1990; Ross, 2000; Yoon et al., 2003). These active metabolites undergo further activations by MPOs in bone marrow cells to produce quinones and radical oxygen species (e.g., *trans*-benzene-1,2-oxide) that can damage hemopoietic cells (Kolachana et al., 1993) and bone marrow stromal cells (Garnett et al., 1983). Quinones may undergo reductions to form semiquinone radicals to damage proteins and DNA. Oxygen free radicals, hydrogen peroxide, and hydroxyl radicals are formed as byproducts of this reduction. They cause lipid peroxidation, and damages to proteins and DNA.

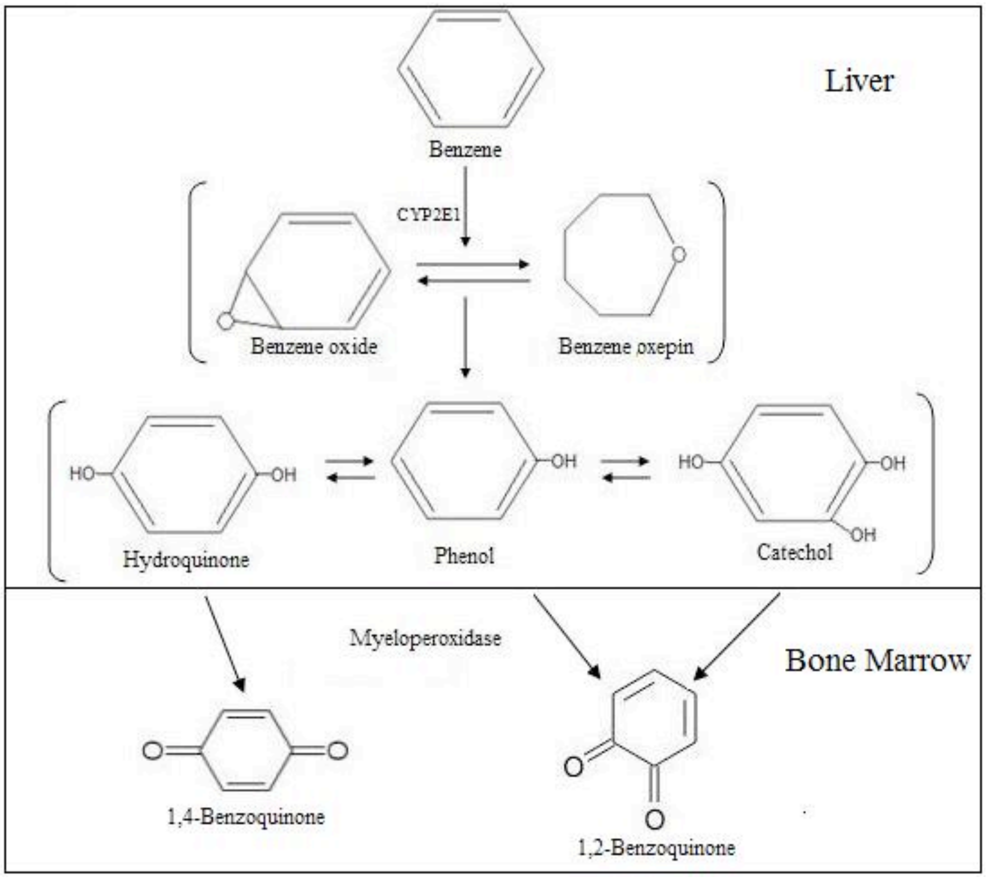

FIgure 6 – Mechanism of benzene metabolism in the liver and bone marrow.

Damages to protein targets, such as histones, tubulin, topoisomerase II, by benzene metabolites can increase the chances of DNA strand breakage, mitotic recombination, chromosome translocations and aneuploidy during anaphase (Smith, 1996). Such damages in stem cells or early progenitor cells can give rise to other genetic mutations (such as inactivation of suppressor-gene and activation of proto-oncogene) to leukemic clones that have selective advantage to grow and multiply (Smith, 1996).

The *p53* tumor suppressor gene has been studied extensively and is identified as an important factor in benzene-induced carcinogen (Yoon et al., 2003). A study by Boley et al. (2001) showed that the *p53* tumor suppressor gene in the bone marrow of mice is important to the control of cell cycle and apoptosis during genotoxic stress. In their study, they exposed C57BL/6 Trp53 homozygous (*p53+/+)* and heterozygous (*p53+/–*) mice to 15 weeks of benzene at 100 ppm (Boley et al., 2001) and measured the mRNA levels of *p53*-regulated genes involved in cell cycle control (*p21, gadd45,* and *cyclin G*) and apoptosis (*bax* and *bcl-2*) in both groups for comparison (Boley et al., 2001). They found that *p53+/+* mice had higher levels of mRNA of *p53*-regulated genes than *p53+/-* mice (Boley et al., 2001). Examples of pathways associated with benzene-induced hematotoxicity and leukemogenicity in bone marrow cells include metabolism, growth factor regulation, production of oxidative stress, DNA damage and repair, cell cycle regulation and apoptosis inhibition (Yoon et al., 2003).

To gain a deeper understanding of the mechanisms of benzene toxicity in the bone marrow, Yoon et al. (2003) conducted cDNA microassay analyses of wildtype C57BL/6 (WT; *P53+)* and p53-knock-out (*p53*-KO; *p53-)* mice during and after inhalation of 300 ppm of benzene for 6 hours/day, 5 days/week and two weeks. Results showed that even though *p53*-KO and WT mice were exposed to similar levels of benzene and its metabolites on the molecular level (similar expression levels of genes involved in benzene biotransformation), *p53*-KO mice had lower expression levels of DNA damage repair genes and cell cycle-regulating genes while WT mice had higher expressions levels in both (Yoon et al., 2003). Furthermore, expression levels of apoptosis genes were up-regulated only in the WT mice and not in the *p53*-KO mice (Yoon et al., 2003). The absence of *p53* tumor suppressor gene in mice can cause: 1. cellular damage by benzene and its metabolites; 2. continuous cycling of damaged cells without DNA repair; 3. inhibition of apoptosis; and 4. suppression of DNA damage repair genes (Yoon et al., 2003).

Benzene exerts different effects when humans are exposed at high or low concentrations. At high air concentrations, narcosis is the main mode of toxicological action, particularly in the CNS (Yu, 2005). Inhalation air with 64 g/m^3 of benzene can be fatal in minutes, while a tenth of that concentration can cause acute poisoning in one hour (Yu, 2005). Since benzene can enter into the body through various routes, exposure to benzene can also cause skin irritation, edema in the lungs, excitation, depression, and if the exposed dose and duration are great enough, it can lead to respiratory failure and death (Yu, 2005). Exposures to lower concentrations of benzene can suppress the number of hematopoietic progenitor cells (Lan et al., 2004), white blood cells (Rozen et al., 1984), bone marrow cells (Farris et al., 1997), and increase the risk of leukemia in both children and adults (Yu, 2005).

Manifestation of leukemia occurs when hematopoietic and progenitor cells in the bone marrow are mutated to produce leukemia cells (Canadian Cancer

Society, 2009). This disease is categorized by the types of stem cells they developed from: abnormal myeloid and lymphoid stem cells will develop into myelogenous and lymphocytic leukemia, respectively (Canadian Cancer Society, 2009). Leukemia is further grouped according to onset: those that develop within days or weeks are known as acute while those that takes months and years are chronic (Canadian Cancer Society, 2009).

Overall, there are four main types of leukemia: acute lymphocytic leukemia (ALL), acute myeloid leukemia (AML), chronic lymphocytic leukemia (CLL), and chronic myeloid leukemia (CML) (Canadian Cancer Society, 2009). ALL is the most common type of childhood leukemia with the peak age of development at 2 and 3 years of age (Sommers, 2011). In children, AML is most common in the first 2 years of life and also prevalent in the teens and elders (Sommers, 2011). The average age of a patient with AML is 65 (Sommers, 2011). Males are more susceptible to AML than females (Sommers, 2011). Americans with European ancestry are most susceptible to AML (Sommers, 2011).

Patients with chronic leukemia are typically adults over the age of 50; only 2% are children (Sommers, 2011). Males are twice as likely as females to develop chronic leukemia (Sommers, 2011). Race and ethnicity are not risk factors in CML. CLL, on the other hand, is more prevalent in Americans from European descents than those from African descents. CLL is also rare in Asian countries (Sommers, 2011).

Currently, there is no definitive evidence proving that benzene causes all types of leukemia (Austin et al., 1988; Bergsagel et al., 1999; Glass et al., 2003; Infante, 1993; Infante and White, 1983; Lamm et al., 1989; Vigliani and Forni, 1976; Wong, 1995), thus, to avoid underestimating the effect of benzene on any type of leukemia this study will define them under the umbrella term, 'leukemia.' Signs and symptoms commonly found in patients with leukemia include: anemia, neutropenia, fever, fatigue, weight loss, drenching night sweats, bone or joint pains, swollen lymph nodes, and weight loss (Canadian Cancer Society, 2009). Examples of diagnosis techniques are blood tests, imaging studies, and bone marrow biopsies (Canadian Cancer Society, 2009). A wide range of treatments are available for leukemia patients, such as chemotherapy, stem cell transplant, radiation, biological therapy, medications, and surgery (Canadian Cancer Society, 2009). The current five-year survival rate is 50% (Jemal et al., 2008).

2.6 Benzene and Leukemia in Alberta

2.6.1 Statistics

Leukemia is one of the cancers that causes the highest number of deaths in adolescents and young adults between the ages 15 to 29 in Canada at about 20% (Canadian Cancer Society, 2011). From 2002 to 2006, childhood leukemia was responsible for 28% of deaths. In 2011, an estimated 5,000 new cases of leukemia will be reported in Canada with 340 males and 230 females from Alberta (Canadian Cancer Society, 2011). Alberta has the fourth highest number of new cases across all Canadian provinces, after Ontario, Quebec, and British Columbia (Canadian Cancer Society, 2011). The estimated age-standardized annual incidence rates for Albertan males and females were at 18 and 11 cases per 100,000 cases, respectively (Canadian Cancer Society, 2011). Incidence rate is the number of new cases of disease in a candidate population within a certain period time (Aschengrau and Seage, 2008). The estimated age-standardized annual mortality rates for males and females in Alberta are 7 deaths per 100,000 cases of leukemia and 4 per 100,000 cases of leukemia, respectively (Canadian Cancer Society, 2011). Over 200 deaths are estimated to be attributable to leukemia in Canada in 2011 (Canadian Cancer Society, 2011).

Chronic Disease Surveillance and Monitoring Division, Centre for Chronic Disease Prevention and Control, Public Health Agency of Canada analyzed the data from Canadian Cancer Registry and Canadian Vital Statistics Death databases at Statistics Canada to calculate the lifetime probability of developing leukemia based on age- and sex-specific leukemia incidence and mortality rates for Canada in 2006. According to the Canadian Cancer Society (2011), Canadian males have a lifetime probability of 1 in 56.9 for developing leukemia, and 1 in 95.7 chance of dying from leukemia; females are less likely with 1 in 75.4 developing leukemia but 1 in 125.4 will die from leukemia.

To make the data more relevant to the adult population in Alberta (the Canadian Cancer Society only published the lifetime leukemia risks for both sexes), the lifetime cancer risk for the total population in Alberta was calculated. First, the lifetime leukemia risk rate of males was multiplied with the proportion of males in Alberta (using the population of 2006 to keep consistency since the risk rate was calculated using 2006 data). The same was done for the females.

Next, the products were summed and multiplied by 10^5 to derive the age-accumulated lifetime leukemia risk rate in Alberta per 100,000 people. According to Statistics Canada (2007), the Alberta's total population was 3,290,350, the proportions of male and female were 0.5005 (1,646,800 people) and 0.4995 (1,643,500), respectively (Statistics Canada, 2007). To determine the background age-accumulated lifetime risk rate for leukemia (regardless of the suspected cause), the following Equation 1 was used:

$$\text{Age-accumulated LLR} = (LCR_M{*}P_M + LCR_F{*}P_F) * 10^5 \text{ cases} \qquad \textbf{(Eq. 1)}$$

$$= (1/56.9{*}0.500494 + 1/75.4{*}0.4995) * 10^5$$

$$= \text{approximately 1,540 cases per 100,000 people over lifetime}$$

where:
LLR = is the lifetime leukemia risk rate in Alberta
P = the proportion in a population
M = male
F = female

The resultant LLR in Alberta (including risk from benzene exposure) is about 1,540 cases per 100,000 people over lifetime. This risk rate will be used to compare with the calculated excess lifetime cancer risk of leukemia based on data from EIAQS to estimate the number of cancers attributable to indoor exposure of benzene.

2.6.2 Excess Lifetime Cancer Risks

The U.S. EPA used animal toxicological and human epidemiological studies to develop mathematical models to calculate the cancer risk from exposure to a set concentration of a carcinogen, in this case benzene, through inhalation (U.S. EPA, 1992). To calculate the excess lifetime cancer risk (ELCR) when the concentration of benzene is not 1 μg/m^3, an average concentration is used instead because carcinogenic toxicity criteria are based on lifetime average exposures and it would provide best representation of the concentration over time (U.S. EPA, 1992). The formula for calculating the excess lifetime cancer risk is as follows (U.S. EPA, 1992):

$$ELCR = IUR\ (\mu g/m^3)^{-1} \times CA\ (\mu g/m^3) \qquad \textbf{(Eq. 2)}$$

Where:
IUR is the inhalation unit risk
CA is the contaminant concentration in the air

Inhalation unit risk is defined here as the upper-bound lifetime cancer risk from continuous exposure to benzene at a concentration of 1 $\mu g/m^3$ in air. For example, the IUR range for benzene is 2.2×10^{-6} to 7.8×10^{-6} per $\mu g/m^3$, which means that 2.2 to 7.8 excess tumors are expected to develop per 1 million people based on a daily, lifetime exposure to benzene at 1 µg of the chemical per cubic meter of air (U.S. EPA, 2010b). It should be noted that the actual risk of leukemia is lower since there is a tendency for conservative calculations (U.S. EPA, 2002).

When the mean and median of indoor benzene concentrations are estimated from analyzing data from the EIAQS, two ELCR ranges will be calculated for the City of Edmonton. Using the mean as CA and the lower and upper range of IUR, lower and upper ELCR values will be calculated. The same procedures will be repeated when median is the contaminant concentration in the air, or CA.

3.0 Description of Edmonton, Alberta

The EIAQS was conducted in the capital city of the province of Alberta, Edmonton, which is located on the prairies along the North Saskatchewan River in Western Canada. It is a metropolitan city with a population of 752,412 (City of Edmonton, 2008) and a land area of 9,418 km^2 (Statistics Canada, 2007). Out of a total of 245 residential neighborhoods in Edmonton (Statistics Canada, 2007a), twelve neighborhoods were sampled. In Canada, the baseline data of pollutant concentrations are more focused on the Eastern provinces, thus, the Western provinces are under-represented. This study tried to develop some baseline data for Edmonton to allow for meaningful comparisons between different Canadian cities in the future. Furthermore, exposure results from this study would be able to provide key information to Health Canada for the review and update of the Residential Indoor Air Quality Guidelines (Heroux et al., 2009).

4.0 Research Approval by Health Research Ethics Board

For students and research groups connected to the University of Alberta, the protocol for research undertaken must be reviewed and approved by a Research Ethics Board (REB) (University of Alberta, 2011). The purposes of an ethic review, as well as the REB, are to "ensure the highest standards of practice and ethical conduct; and ensure human research participants are treated safely and with respect" (University of Alberta, 2011). To this end, the REB will provide support and administration for all aspects of an ethics review and the approval process for research involving human participants (University of Alberta, 2011).

This study is a part of a series of IAQ studies conducted by Health Canada to determine the levels of air toxics across major Canadian cities. Methodology employed in Edmonton, AB were similar to those in Ottawa, ON (Zhu et al., 2005), Windsor, ON (Wheeler et al., 2008), Halifax, NS (Health Canada, 2010a), Quebec City, QB (Heroux et al., 2008), and Regina, SK (Heroux et al., 2010), thus, the research design had already been previously approved by Health Canada. Approval from the REB was received before data sampling began.

5.0 Methods and Materials

The importance of carrying out environmental field research in air quality monitoring are best summarized by Goldstein (1995) and Krzyzanowski (1997): “[f]rom the viewpoint of public health, it is...crucial to move exposure assessment away from “one size fits all” mathematical models to actual measurements of exposure in the affected population” (Goldstein, 1995) to fill in the gaps of scientific knowledge and uncertainties in risk assessment as well as establish quality criteria for future research (Goldstein, 1995; Krzyzanowski, 1997). However, applications of generalizations and inferences cannot always be avoided (for example, extrapolating results from one population to another). Even though extrapolations are criticized and their appropriatenessis difficult to test, “[t]he approximate result based on impact assessment from the best available knowledge is more systematic and clearer than a subjective judgment based on emotions or arbitrary assumptions” (Krzyzanowski, 1997).

5.1 Spatial Sampling Design

5.1.1 Selection of Target Neighborhoods

Homes were sampled from randomly selected and stratified neighborhoods to test the hypothesis. Only residential dwellings with non-smoking owners and residents were chosen because the study was interested in finding out major sources of VOCs/benzene other than tobacco smoke and ETS, which were already established as major sources of benzene in dwellings resided by smokers in U.S. EPA TEAM Studies (Wallace, 2001). Thus, the associated risk from benzene determined through the EIAQS will be biased low because cigarette smoke and smokers are excluded.

Data for neighborhood stratification was taken from the Edmonton Community Profile 2006 of Canadian Census data from 2006 obtained through the Data Library at the University of Alberta. Neighborhoods were divided into 5 strata based on their construction years: before 1946 (stratum 1), from 1946-1960 (stratum 2), from 1961 to 1980 (stratum 3), from 1981 to 2000 (stratum 4) and from 2001 onward (stratum 5). A table was constructed to determine the percentage of homes from each stratum in every neighborhood, and all the neighborhoods were assigned to the stratum where the majority of the homes in the neighborhood fell into that stratum. After stratification, ten homes would be sampled from each stratum to make up the targeted sample size of 50 participants. The recruitment design is depicted in Figure 7.

To minimize bias, it was important to randomize the selection of neighborhoods and homes/participants. To select sampling neighborhoods, every neighborhood in a stratum was assigned a random number and the two neighborhoods with the lowest assigned numbers were chosen for sampling. This selection process was repeated for every stratum. There was also an added benefit of minimizing field travel costs by limiting the number of neighborhoods sampled. Ideally, five homes were recruited from each neighborhood. However, in strata where recruiting ten homes were problematic, an alternative neighborhood from the same strata with the third lowest random number would be sampled to meet the target sample size.

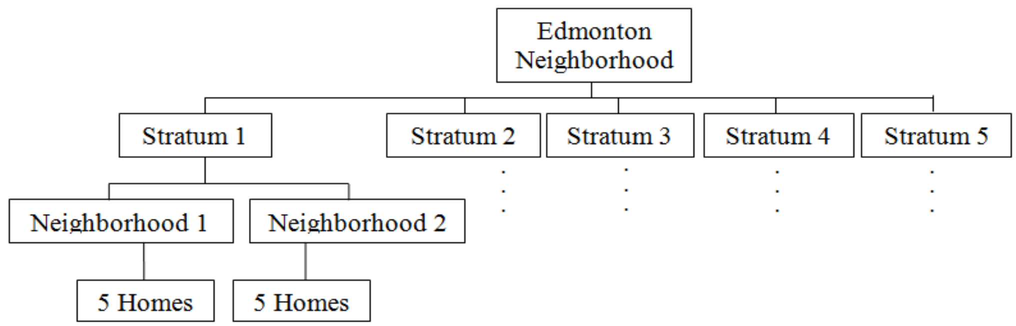

Figure 7 – Framework of recruitment design.

5.1.2 Selection of Dwelling Units

This study employed the stratified sampling approach, which is a type of probabilistic sampling. The same approach was also used by the U.S. EPA in their TEAM studies to monitor personal exposures to and indoor levels of VOCs (Wallace et al., 1986). In stratified sampling, the population of interest is divided into homogenous and non-overlapping subgroups (Sarndal et al., 2003; Albright et al., 2009). For the EIAQS, neighborhoods were separated into strata based on the construction year of the majority of the dwellings in each neighborhood then samples in each stratum were selected randomly and independently from other strata (see Section 5.1.1).

Adoption of the stratified sampling approach was both necessary and advantageous. By stratifying the neighborhoods by house age rather than taking random samples from the entire population, the samples could either be compared and characterized or studied as one pooled sample population. This approach would also further randomize the selection process and increase the accuracy of estimates of population parameters when budget is limited (Albright et al., 2009). The defined strata, however, must be relatively homogenous within their own groups and heterogeneous among the strata (Albright et al., 2009) (see Section 6.1).

This study had 2 stages of stratified sampling: first, stratification of neighborhoods based on construction years of the majority of houses in each neighborhood. Using the most recent census data available in 2010 (2006 Canadian Census Survey Data) from the University of Alberta library, the study team was able to categorize each neighborhood to a stratum. This ensured that every neighborhood was assigned to the appropriate and only one stratum. The second stage involved random sampling of dwellings from selected neighborhoods. To represent all strata equally, the same number of samples had to be taken from each stratum. After the decision was made concerning the quantity of samples and days sampled, steps were taken to recruit homes. All the streets in each neighborhood were listed and randomly ranked using Microsoft Excel® to determine the order the streets were to be visited during recruitment. To identify eligible dwelling units for recruitment and sampling, the City of Edmonton website (http://maps.edmonton.ca/) provided delineation of each neighborhood and estimates of all residential properties, including the year of construction, type of dwelling, and assessed house value. Hence, eligible homes could be pre-selected before door-to-door recruitment and homes that were not eligible would not be accidentally recruited. Ideally, recruitments would be done in two neighborhoods from each stratum (ten neighborhoods in total) and five homes would be recruited from each neighborhood to have a total sample size of fifty participants. This sample size ensured that central limit theorem would apply to carry out parametric methods during statistical analyses because they were more powerful (Asante-Duah, 2008) and robust against departures from normality, independence and differing stand deviations (Ramsey and Schafer, 1997).

Health Canada used analytical results from a similar air quality study conducted in Windsor, Canada to determine the highest within-subject and between-subject concentration variance estimates for six types of pollutants sampled (benzene, toluene, NO_2, ethylbenzene, xylene, and $PM_{2.5}$) to determine the number of sampling days and participants necessary to achieve maximum statistical power (Heroux et al., 2009). The highest variance estimates measured was 2.5 for NO_2 during summer sampling. A simulation graph was done using this variance value and it showed that the observed powers for 5 and 7 sampling days were around 0.90 ($\alpha = 0.05$) when the sample size (of participants) is 10 (Figure 8). As a result, this study sampled ten homes per stratum, each for seven consecutive days to ensure that variations within the age strata due to chance were minimized and that any "weekend effect" would be captured (Heroux et al., 2009).

In Edmonton, 32% of the dwellings were apartments, second to single-detached houses, which were 51% (City of Edmonton, 2008). Although significant, apartments were excluded from this study due to confounders that could not be controlled for, such as diffusions of VOCs between suites (Probert, 2000) and higher exposure of mobile-sourced VOCs by lower-leveled (first and second floors) suites due to proximity to apartment parking lots and roadways (Jo et al., 2003). In spite of this exclusion, the research objectives should not be affected since single-detached houses were the majority in every sampled neighborhood (City of Edmonton, 2008).

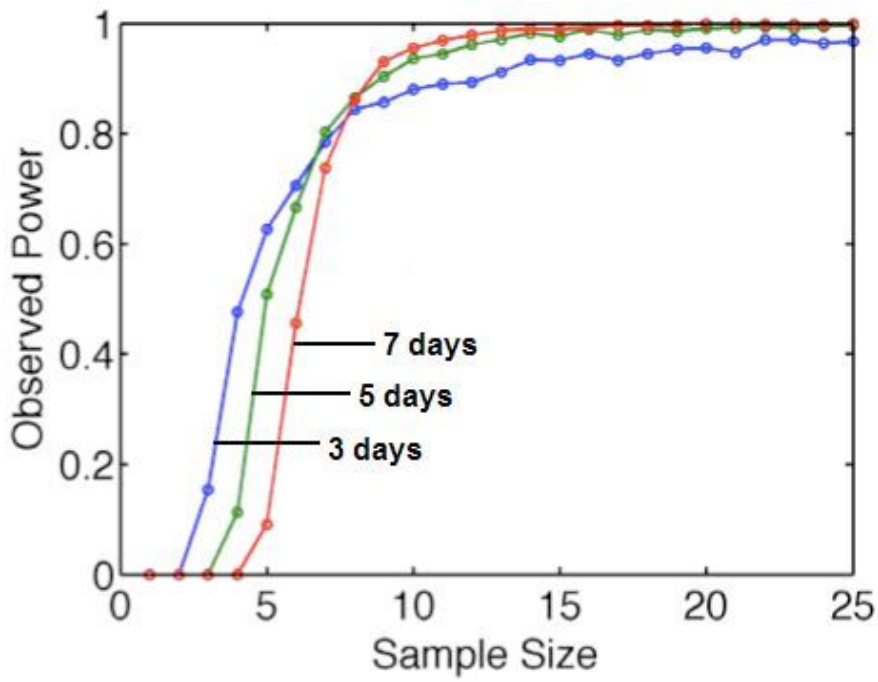

Figure 8 - Various samples sizes and observed powers for 3, 5 and 7 sampling days (adapted from Heroux et al., 2009).

5.1.3 Participant Recruitment

Systematic recruitment procedures were developed and implemented to maintain consistency among all neighborhoods and other Health Canada IAQ studies:

1. Maps of randomly selected neighborhood were provided by the City of Edmonton to identify and list the street names. Street names were then ordered with randomly generated numbers were visited in numerically ascending order.

2. Eligible homes were identified by the City of Edmonton website and recorded on these maps.
3. Recruitment was done between 15:00 to 19:30 during the weekdays and between 10:00 to 16:00 on the weekends.
4. Pairs of two field technicians were sent out with the following documents and forms prior to the recruitment:
    a. Neighborhood map showing eligible house numbers and street names;
    b. List showing the streets ranked in the order that they are to be visited;
    c. A cover letter with general information for visited homes (Appendix 3);

       Recruitment Tracking Sheet to record the streets and homes visited and recruitment results; and
    d. Screening Questionnaire to determine eligibility of participants (Appendix 4).
5. At the beginning of each street (as indicated by the lowest home number on the street), the second eligible home on the right hand side of the street was first approached for recruitment.
    a. If the homeowner refused to participate or were not eligible according to the Screening Questionnaire, the field technicians would proceed to the next home, which was the second home.

6. The field technicians would go to the next street if two homes were recruited from a single street, or if all the homes were visited but not enough participants had been recruited yet.

In the wintertime, participants were recruited using the procedure described above. In anticipation of drop-outs before the first visit, the number of homes recruited was greater than the actual number of homes sampled. Also, reminder phone calls were made to participants within one week of their scheduled first visit. Monthly scheduling templates were developed by Health Canada and followed during the study (Appendix 5).

In the summertime, it was highly desirable to retain as many homes from the wintertime as possible to control for biases; however, not all the homes from wintertime returned for summertime. Recruiting in summer followed the steps below:

1. Recruit by phone the homes that participated in the winter;
2. If not enough winter participants returned for the summer sampling period, eligible homes that expressed interest but could not participate in the wintertime were recruited over the phone;
3. If there were still not enough participants after steps 1 and 2, new participants would be recruited using the same procedure as in the winter with the same randomized street list from winter:
    a. Field technicians would begin recruiting from the street following the last visited street in winter; otherwise,

b. If every street from the neighborhood had been visited, then the field technicians would follow the randomized street list and revisit homes that had no replies previously.

4. The recruitment of a neighborhood ended when the target sample size (5 participants) was reached.

The three most common reasons why some winter participants from the winter sampling period did not return for the summer sampling period were: 1) the study team was unable to reach them after three tries, 2) participants were not able to meet the time requirements due to traveling, vacation, or busy schedules, and 3) participants thought the study was too time-consuming and could not commit again.

5.1.4 Participant Eligibility

During door-to-door recruitment, if a resident expresses interest in participating in the study, the field technicians will administer the Screening Questionnaire (Appendix 4). The participant has to meet the following criteria:

- The dwelling must be occupied by the owner(s) and his/her family;
- The dwelling must be either a single-detached house, duplex/triplex, mini or mobile home, or row house;
- The dwelling must not be occupied by smokers (before or during the study);
- The dwelling must have a backyard;
- The construction year of the dwelling must be within the age stratum of its designated stratum;

- The resident must be available during the sampling period;
- Is the owner of the home and at least 18 year of age;
- No one living in the home dwelling, including the homeowner, is a smoker;
- Is physically and mentally capable of participation;
- Does not have language barriers; and
- Preferably available to participate in both winter and summer sampling periods.

Due to potential liability issues and difficulty with obtaining landlord's permission to gain entry into the property, tenants of rental properties were excluded from the study. This was a selection bias that could limit the results from the study from extrapolating to the general population.

5.1.5 Participant Consent

The resident of the dwelling was asked to consent once they were deemed eligible and agreed to take part in the study. During recruitment, participants provided their names and phone numbers so that they could be contacted later to schedule for appointments. At the first scheduled visit, participants had to sign 2 copies of the Consent Form (Appendix 6) so that they could keep a copy and the other the study could keep the other.

Three main purposes for obtaining the participant Consent Forms were: 1) to attain official participant consent along with their contact information (i.e. name, address, phone number) and assigning participant identification (e.g. "EDM-###") for each household; 2) to ensure that the participants understand: the details and purposes of the study, potential risks and benefits, confidentiality of data and anonymity of personal information, and that they were free to withdraw from the study at any point without consequences (but they would not receive $20 compensational cheque from the electricity used during the study nor a Summary report regarding the indoor air quality of their home), and that the data collected could be used for other scientific analyses other than the current study; and 3) to satisfy the requirements of the Research Ethics Board of the University of Alberta (University of Alberta, 2011). Because this study is a collaborative project between University of Alberta and Health Canada, the study also needed to be approved by Health Canada's Research Ethics Board and to be in compliance with the Canadian Access to Information Act and Privacy Act.

5.2 Temporal Sampling Design

5.2.1 Temporal Variation of VOC/Benzene

Indoor and outdoor VOC levels were demonstrated to differ significantly in several large-scale studies in the past (Wallace et al., 1986; Wallace et al., 1987; Otson and Fellin, 1992; Wallace 1993; Wallace 1996). Furthermore, VOC levels were higher in the colder seasons compared to the warmer seasons due to greater ventilation (air exchange rate or AER) in the summer months (Seifert et al., 1989; Otson and Fellin, 1992; Heroux et al., 2008). To test the seasonal and indoor/outdoor variations, summer and winter seasons were selected. Since Canada is a horizontal country that contains six primary time zones at one-hour intervals, (except for Newfoundland, which is thirty minutes ahead of the Atlantic

Time), the provinces share similar latitudes and all have two distinctive seasons: winter (January to April) and summer (June to early September).

5.2.2 Participant Scheduling in Each Season

Nine scheduled visits per participant were needed for data collection to collect seven consecutive 24-hour samples and a dust sample. Homeowners were contacted on the phone to schedule the nine visits based on availability. The dust visits were scheduled to be before or at least one week after the sampling period because it would be disruptive to their normal routine if scheduled during sampling visits, which was undesirable. They were told not to vacuum or dust a 2m by 2m area for hardwood floors or 1m by 2m area for carpeted floors in the main living area (i.e. the living room) so that the field technicians could collect 4 g of dust necessary for analysis. In each season, fifty age-stratified randomly chosen homes were sampled over a period of nine sampling periods. Each week, the study group tried to schedule six participants (which is the maximum number of appointments) so that there would be four extra appointment spots in week 9 to meet the target sample size. The following is a basic summary of the tasks carried out during each visit (the dust visit is arbitrarily assumed to be visit 9) in both seasons:

Visit 1: Prior to setting up the equipment, a field technician would go through the general information sheet with a homeowner or an adult occupant in plain-language. The field technicians would answer any questions that may raise and have. The homeowner or the adult occupant would be asked to sign the Consent Form. After signing, the field technicians would deploy the samplers indoors (in the living room, and if applicable, the second floor and basement) and outdoors (in the backyards).

Visits 2-7: Pairs of field technicians returned to their assigned participants' homes on a daily basis at approximately the same time as the day before. They administered new 24-hour period samples and Daily Questionnaires after they collected the old ones. A quick review of the Daily Questionnaires would be done to ensure proper completion and that the participants did not have problems answering the question or regarding the monitoring equipment. Devices were calibrated and filters were replaced.

Visit 8: All questionnaires and sampling devices were collected and removed from the owners' homes.

Visit 9 (Dust Visit): A pair of field technicians would visit a participant's home on an appointed date and time. If the dust visits were prior to the sampling visits, then the field technicians would need to administer Consent Form as described previously in Visit 1. One technician would collect dust while the other administers a Baseline Questionnaire (Appendix 7).

5.3 Air Sampling and Monitoring

5.3.1 Selection of Air Sampling Methodology

The atmospheric concentration of a chemical is typically low but it is highly variable due to wind, temperature, humidity, and spatial variables, such as traffic hours in the morning. Because of these complications, the choice of sampling method is key to getting accurate and reliable results since errors made in this step cannot be corrected later in the analysis (Kumar and Viden, 2007). The two most widely used VOC sampling methods are whole air sampling and sorbent sampling, and in some cases, chemisorptions (Rudolph et al., 1990).

Whole air sampling, as the name suggests, is the collection of whole air samples in set-volume containers, such as glass bulbs or bottles, plastic bags, and stainless steel canisters (Kumar and Viden, 2007; LeBouf et al., 2010). This method is very sensitive and can measure trace amounts of VOCs as low as parts-per-trillion, or ppt (Wang and Austin, 2006). Glass bulbs and bottles are relatively inexpensive and can generate reproducible results, making them ideal for studies that require large numbers of samples either for a big sampling population or to improve the strength of the results (LeBouf et al., 2010). Since they are made out of glass, they are prone to damage (LeBouf et al., 2010). Therefore, glass samplers will not be suitable for this study because of the large amount of transporting during shipping between laboratories and transporting into the field.

Plastic bags are inexpensive, easy to use and clean, and they come in various sizes depending on what each study needs. They are also preferable when large volumes of samples are needed and the concentrations of sampling VOCs are known to be high. The major down side is that contamination can happen in several ways: 1) when the bags are not cleaned properly (cleaning is done by repeatedly filling the bags with pure nitrogen or ultra-high purity zero air); 2) leakage, either due to unintentional perforations or the plastic's permeability to certain chemicals; and 3) when samples are pumped into the bag (Zielinska and Faujita, 1994; Kumar and Viden, 2007). Damages to plastic bags will likely happen during this study due to the extent of transportation between the analytical lab, the Edmonton lab, and the field.

The third kind of containers used is the 6-litre stainless steel canister. Prior to sample collection, the canisters must be carefully cleaned and evacuated. To minimize unwanted physical adsorption or chemical reaction to the internal surface of the canister, canisters will undergo passivation (canister preparation will be further discussed in Section 5.4.1). Samples can be collected under different modes: through grab or time-integrated sampling on sub-atmospheric/passive pressure or pressurized/active pressure with a pump (Kumar and Viden, 2007). Whole air samples need to pass through a cryogenic trap for pre-concentration prior to analysis then into a gas chromatography column by thermal desorption (Camel and Caude, 1995; U.S. EPA, 1999; Kumar and Viden, 2007). Gas chromatography and mass spectrometry will be discussed in more detail in Section 5.4.2. There are considerations that need to be taken into account prior to canister sampling. Firstly, there are two types of canisters, SUMMA™ polished and fused-silica lined (FSL) canister, the former has a smooth, nickel-chromium oxide surface and the latter has a silica surface. In a study by Ochiai et al. (2002), they compared SUMMA™ and FSL canisters and found that the two types have similar and excellent recovery percentages under a wide range of relative humidity (1.6, 8, 27, 39, 53, and 99 %) for benzene (SUMMA™: 90, 99, 100, 103, 96, and 102%; FSL: 102, 102, 99, 105, 96, and 97%). Ochiai et al. (2002) also compared benzene percent recovery between SUMMA™ and FSL canisters after 0, 3,7,14, and 28 days of storage period (under different conditions of +relative humidity), the percent recoveries typically ranged from 89 to 105% and the values from the two varieties were within 15% of each other. Ultimately, there were no statistical differences between the percentages (Ochiai et al., 2002). Secondly, the degree of relative humidity could be problematic for polar or unstable compounds, but since benzene is both non-polar and stable, it can be recovered at very high percentages (Ochiai et al., 2002). Lastly, there is another type of canister that is sorbent-lined. In a study conducted by Daughtrey et al. (2001), they found clear correlations and insignificant statistical differences between the data collected by the sorbent-lined canister and the FSL and SUMMA™ canister. At the time of this study, the SUMMA™ canister approach was taken because it is the only method recognized by the U.S. EPA to determine VOC levels in ambient air, in accordance with Compendium method TO-15 (U.S. EPA, 1999).

5.3.2 VOC Sampling Apparatus

5.3.2.1 Description

Two types of sampling techniques commonly used to collect VOCs in ambient air are active and passive sampling. Active sampling involves the use of a battery-powered pump to actively draw samples into the canister. Passive sampling, on the other hand, draws in air samples because there is a negative pressure inside the canister. To avoid complications of maintaining battery-powered pumps, passive sampling was used in this study. The apparatus to sample VOCs was comprised of five fundamental components: an in-line Swagelok™ filter with a 2 μm stainless steel sintered filter to eliminate particulate, a restrictor at the inlet, a Veriflow SC423XL back-pressure flow regulator and a vacuum gauge. Twenty-four-hour (± 3 hours) samples were collected for seven consecutive days in order to capture time-weighted average (TWA) samples reported in μg/m^3 to reflect the mean conditions of the ambient air in the environment. By restricting the flow to a steady rate (3.5 mL/min), sample collection could be spread over 24 hours (Wang, 2011). Field blanks were not collected for VOCs because it would mean to bring a SUMMA™ canister out into the field without opening the valve. Since it is a vacuum inside an evacuated SUMMA™ canister, there would be no air to sample (van Ryswyk, 2012).

5.3.2.2 Advantages and Disadvantages

Aside from being the standard validated method for capturing ambient VOCs (U.S. EPA, 1999), there are many advantages to sampling with SUMMA™ canisters: 1) over 150 applicable VOCs can be collected (Wang and Austin, 2006); 2) concentrations from ppt to parts-per-million (ppm) can be measured, which is suitable for residential exposures (Wang and Austin, 2006); 3) duplicate sample analyses can be done from the same sample because the sample volume is large (Kumar and Viden, 2007); 4) grab sampling is suitable for C_2-C_{10} hydrocarbons, including benzene (which has minimal risk of compound loss or adsorption because it is non-polar and volatile); 5) compared to sorbent-based methods, canister sampling is less fastidious and can collect whole air samples

(Brymer et al., 1996; Ochiai et al., 2002); and 6) SUMMA™ canisters are sturdy and able to perform normally over a wide range of temperature (Ochiai et al., 2002).

The disadvantages are (Kumar and Viden, 2007): 1) strict clean-up regiment of canisters between sampling; and 2) decreased flow rate of the gauges towards the end of sampling due to equalization between ambient and canister pressure. For the EIAQS, measures were taken to target the shortcomings of canister-sampling, including: proper training of the field technicians in handling and inspecting the canisters and gauges, sending used canisters for laboratory analyses and cleaning in a timely manner, and limiting the sampling period to only 24 hours to avoid internal and external pressures equalization. Another potential issue specific to this study was the extreme conditions that the samplers were placed in this study (-30ºC or lower in the winter and over 20ºC in the summer). Canisters are able to work over a wide range of conditions without interrupting their performance or suffer damages.

5.3.2.3 Field Procedures

Laboratory-evacuated and cleaned canisters were sent in boxes to the Edmonton lab from the Environment Canada Laboratory in Ottawa, ON prior to the sampling visits. Before leaving the Edmonton lab, identification numbers on the SUMMA™ canisters were recorded onto Tracking Sheets to keep physical record of the date when canisters were used by which group of field technicians. In addition, each field technician group had an alternative canister gauge in case the one out in the field was broken. The field technicians had to bring two canisters for each participant's home (one indoor and one outdoor). The canisters were installed during data collecting visits (visit 1 to visit 7) for seven consecutive 24-hour samples. Field technicians had to assemble the VOC sampler in the field and open the valve to begin sampling. When installing the air gauge onto an unused canister, the field technicians had to check whether the starting pressure on the air gauge was below zero, otherwise, the alternative gauge was used.

Every field technician was trained by Health Canada to implement VOC sampling the same way in the field so that data collected would be validated, consistent, and accurate. Two VOC samplers, one each in indoor and outdoor, were set up per household. Due to the differences between the indoor and outdoor environments, canisters had to use different dedicated flow controllers with different flow rates, as indicated by labels. Assembly of the VOC sampling apparatus was done in the field, otherwise, unwanted contaminants may enter into the flow controllers and canisters. The procedure to deploy SUMMA™ canisters follows (Health Canada, 2010b):

1. Make sure the green valve on the canister is closed by turning the valve to the indicated close position;
2. Remove the brass caps at each end of the flow controller and from the canister valve;
3. Install the flow controller on top of the canister valve. First tighten by hand and then with a wrench, turn only a ¼ turn with the wrench;
4. Open the valve;

5. Record the reading on the gauge at the beginning of the sampling, the flow controller ID#, date, location and starting time of sampling on the logsheet (the initial reading should be about -29 mmHg);
6. If the reading on the gauge is moving, close the valve immediately and reattach the flow controller;
7. If the initial reading is not between -30 to -25 mmHg, use another canister.

To ensure that the VOC samples reflected the air the participants were breathing in, the VOC canister was set up at the average adult breathing height of 1.5 m. On the days of follow-up, the field technicians had to (Health Canada, 2010b):

1. Record the reading of the gauge as well as the end time on the logsheet. The final reading should be around -5 to -10 inches of Hg (Note: if the reading was 0 mmHg for two days in a row, then different flow controller was used.);
2. Close the valve and remove the flow controller from the canister. Replace the brass cap on the canister;
3. When the flow controller is not in use, always cap the inlet and outlet to avoid dirt getting into the flow controller; and
4. Use the same flow controller and attach it to a new canister, following the deployment procedures described above.

There were dedicated spaces on the Indoor (Appendix 8) and Outdoor Daily Logsheets (Appendix 9) for field technicians to take note of any unusual observations or incidents, like a crack in the gauge's reading glass or changing gauges. (Note: only winter versions of the daily logsheets are available in the Appendix, but they are identical in both seasons.) A new logsheet was inserted into each team's field binder prior to field technicians dispatching so that the field technician could record the new information every visit. The used canisters dispatched on the previous day were brought back to the lab and a field technician would check that all the VOC canisters dispatched were returned to avoid accidentally reusing the same canister 2 days in a row. This was a crucial step to allow for future cross-referencing and as a means to check if the canisters dispatched the day before were returned to the lab and whether the canisters were accidentally used two days in a row. Canisters were rarely mistakenly used twice in this study, and those that did were not analyzed.

5.3.2.4 Quality Assurance and Quality Control

To ensure results were validated, it was essential to have components of quality assurance and quality control (QA/QC) in all aspects of the study by developing and using the chain-of-custody Tracking Sheet, logsheets, and standardized procedures. Before every dispatch, a pair of field technicians must record the I.D. on the canisters (each canister had a unique I.D.) and indicate which canisters were going to be utilized by which team on the Chain of Custody Tracking Sheet (Appendix 10). When the field technicians were setting up the instruments at participants' homes, they recorded the I.D.'s of the canisters and gauges onto daily Indoor and Outdoor Logsheets (Appendices 7-8). Upon their return to the laboratory after visiting the participants' homes, the field technicians who recorded the canister I.D.'s previously would cross off the used canisters from the previous day (except of the day of the set-up) to make sure that all the used ones were not used again. Furthermore, the field technicians adhered closely to the field procedures in Section 5.3.2.3 to increase validity and accuracy of the samples captured in the micro-environments, moreover, decrease bias of the results.

Another important aspect was the storage of the VOC canisters before and after dispatch. The canisters were kept in cardboard boxes before their dispatches into the field and were used in the order that they were shipped to Edmonton, AB from Ottawa, ON. After they returned from the field sampling, canisters were stored into boxes (separate and away from unused canisters to avoid confusion). Between 1 to 4 days, the used canisters were shipped back to the Environment Canada Laboratory in Ottawa, ON for analysis. A short storage period ensured minimal loss of VOC samples caused by physical adsorption of VOCs onto the canister walls, dissolution of VOCs by water condensed within the canisters, and the reaction of VOCs with ozone collected during sampling (U.S. EPA, 1999). Although there had been no models developed to estimate the amount of loss that could occur during storage, it was still undesirable and should be avoided by minimizing storage times (U.S. EPA, 1999).

5.4 Laboratory Preparation and Analysis

5.4.1 Preparation of SUMMA™ Canisters and Flow Controllers

In preparation for sub-atmospheric pressure sampling in canister (the passive sampling approach), the canisters must be evacuated to 20 psig or less with humidified, high purity air to reduce contaminants inside, this process is known as passivation (Wang, 2011). It is a complicated process that requires special equipment and many hours (U.S.EPA, 1999) and could only be done in the Environment Canada Laboratory in Ottawa, ON. This process involves polishing and deactivation procedures to create a coat of inert nickel-chromium oxide electropolished onto the inside walls of canisters and heating it at 80ºC for one hour (Wang, 2011). Evacuation and heating were repeated five to seven times to assure their cleanliness (Wang, 2011).

In addition, the flow controllers needed to be assembled, leak tested, and cleaned in the laboratory prior to use, which included setting the flow rate on the flow controllers using the following equation (U.S. EPA 1999):

$$F = (P \times V)/(T \times 60) \qquad \textbf{(Eq. 3)}$$

where:
F = flow rate (mL/min)
P = final canister pressure, atmosphere absolute (kPa)
V = volume of the canister (mL)
T = sampled period (hours)

For 24-hour sampling, the desired flow rate was 3.5 mL/min for the 6-L canisters (Wang, 2011). After assembly, the flow controllers were purged with humidified clean air for at least three days. According to the U.S. EPA Compendium Method TO-15, the flow controllers must be certified clean by passing humidified, high-purity air through the controllers into the evacuated canisters and analyzing the gas by GC/MS. The sampled VOCs must be less than 0.2 ppb to be certified clean. The canisters were then capped with Swagelok fittings and shipped off to sampling sites (U.S. EPA, 1999; Wang, 2011).

When the canisters were opened, the differential pressure between the canister and the environment would force samples into the canister through a flow controller. The controller was set at a certain flow rate to allow for slow intake for 24 hours, but as the pressures between the canister and environment equalize the flow rate would decrease, at which time, a new canister would be set up for the next sampling period.

5.4.2 Gas Chromatograph/Mass Spectrometry

VOC samples were analyzed using the GC/MS process. Two identical analytical systems for polar and non-polar VOCs were used (note: benzene is non-polar), the only difference was in their water removal methods from the sample and GC temperature program (Wang, 2011). Fused silica capillary columns, gas chromatograph, and linear quadruple mass-selective detectors (MSD) were used to detect compounds and achieve high temporal resolution of the VOCs (U.S. EPA, 1999). Air samples must be concentrated to increase the sample loading into a detectable range by the mass spectrometers. The two techniques available are: 1) passing air samples through a multi-sorbent packing tube kept at or above surrounding air temperature, and 2) passing the samples through a cryogenic pre-concentrator (cold trap) (U.S. EPA, 1999). The latter technique was employed for this study using the EnTech Model 7100 pre-concentrators with auto-sampler (EnTech Instruments, Inc., Simi Valley, CA) (Wang, 2011). The different VOCs were separated on a 60 metre, 0.32 I.D. fused silica capillary column with a 1.0 µm film thickness of J & W DB-1 bonded liquid phase then identified and quantified using Agilent 6890 gas chromatograph and Agilent 5973 MSD (Wang, 2011).

If water vapour and CO_2 were present at levels four to eight times greater than the VOCs of interest, they must be removed by the Entech 7100 prior to GC injection to avoid problems during GC/MS. The Entech 7100 can do so in three stages called the "Microsclae Purge and Trap" without losing any analytes. For non-polar VOCs, 500 mL of outdoor or 200 mL of indoor sample air was passed through a glass bead trap maintained at -170°C and mixed with 50 mL of a gaseous internal standard under mass flow control. This would concentrate the sample to around 0.5 cc in the trap. Next, the trap was heated to 10°C and held there while 40 to 50 cc of helium slowly passed through to transfer the organics to a secondary Tenax™ trap at -60°C. This would transfer all the VOCs with less than 1 µl of water remaining. The VOCs were heated to 180°C and back-flushed to be further focused on an open-tubular focusing trap at -180°C. This cryofocusing trap was ballistically heated to 100°C, resulting in rapid injection of VOCs onto the analytical column (Wang, 2011). The instruments and parameters used are detailed in Table 1.

Table 1. GC Parameters for Non-Polar VOCs.

Instrument	Parameters
GCMS inlet System: 7100 Preconcentrator and 7016 16 Position Autosampler (EnTech Instruments, Inc.)[1]	7100 Mode of Operation: Microscale Purge and Trap GCMS: Agilent 6890 GC/5973 MSD (Palo Alto, CA) Column: DB-1, 0.32 mm ID, 60 M, 1 um Temperature: -60°C (3 min) to 164 at 7°C/min, to 220°C at 14°C /min

[1] (Wang, 2011)

Detection and identification by GC/MSD is highly accurate, specific, and sensitive. The GC/MSD was operated in the selected ion monitoring (SIM) mode to identify target VOCs monitoring the retention time and abundance of two or three characteristics ions of the VOCs commonly found in the environment (Wang, 2011).

5.4.3 Quality Assurance and Quality Control

Canisters and flow controllers must be certified cleaned in accordance with the procedures outlined by the U.S. EPA Compendium Method TO-15 prior to use (U.S. EPA, 1999). The GC/MSD system had to be calibrated to ensure accuracy and precision of the results. Calibration standards were prepared using stock gas standards prepared at the University of Alberta laboratory from multi-component liquid mixtures and gas mixture cylinders, manufactured by Scott Environmental Technology Inc. The standards were then verified for accuracy against two certified reference standards, the Scotty TO-14 calibration mix (39 compounds) and the Spectra Gases Inc. certified 62 compounds standard. Quantification was done on a daily 6-point linear regression calibration curves obtained from analysis of these external standard mixtures. Samples were replicated and analyzed to test for precision, which had to be within 15% for the compounds at concentrations greater than 0.1 $\mu g/m^3$ (Wang, 2011).

5.5 Daily and Baseline Questionnaires

5.5.1 Purpose of Questionnaires

In environmental studies, retrospective questionnaires are often used to gather information regarding exposures to environmental hazards (Coggon, 1995). Administering questionnaire is usually the most cost-effective method to conduct environmental assessment when a study has a large sample population (Coggon, 1995). The statistical power of questionnaires can often be enhanced by a larger sample size (Coggon, 1995). When the exposure of interest is not a chemical agent but rather a situation or an activity, questionnaires may be the most appropriate data collection method (Coggon, 1995). To fulfill some objectives of the EIAQS, questionnaires were specially designed. This study utilized four questionnaires to screen households' eligibility - Screening Questionnaire (Appendix 4), record 24-hour household activities - Daily Diary Questionnaire (Appendices 11 and 12 for winter and summer, respectively), household characteristics and occupancy - Baseline Questionnaire (Appendix 7), and if winter participants returned in the summer, a Returning Baseline Questionnaire to update household characteristics and occupancy (Appendix 13). If a participant decided not to complete one of the questionnaires during the sampling period in either season, then that would represent their withdrawal from the study and another home would be recruited in its place from the same neighborhood with the aforementioned procedures. With quantitative and qualitative data, the research team was able to compile a relatively comprehensive dataset to understand the level of exposures to VOCs/benzene experienced by Edmonton homeowners living in residential dwellings in winter and summer in correlation to many important factors, including time-activity patterns, proximity to and frequency of exposures to wide range of VOC sources, products used/stored at home, and house characteristics.

5.5.2 Limitations of Questionnaires

The Daily Diary Questionnaires were self-administered with minimal supervision by the research team. This would avoid bias resulting from an interviewer's questioning format (Coggon, 1995). On the other hand, self-administration could pose potential issues. Firstly, the research team must rely on the participants' commitment to fill in the questionnaire accurately and diligently everyday. Otherwise, important activities related to benzene exposure would be missed, such as smoking multiple cigarettes inside the home. Hence, field technicians had to stress the importance of writing things down immediately and suggest ways to make it convenient for the participants, such as placing the questionnaire on the refrigerator where it is visible and easily accessible. Secondly, questionnaires may lack criterion validity if it were not designed to capture all aspects of benzene exposure (Seifert, 1995). This, however, was unlikely because Health Canada had meticulously developed these questionnaires and continuously improved on them based on comments, revisions, and experience (Zhu et al., 2005; Heroux et al., 2008; Wheeler et al., 2008; Heroux et al., 2009; Heroux et al., 2010).

Other limitations to collecting information using questionnaires relate to biases. Recall bias can occur under different circumstances. For example, participants may fail to report certain incidents regarding socially sensitive exposures (e.g., if a participant wanted to maintain a healthy and clean image, he/she may not report that guests were smoking inside the house). This type of differential recall bias can obscure the true measure of association between environmental factors and exposures (Aschengrau and Seage, 2008). Another type is the interview bias, in which case there is a systematic difference in ways interviewers solicit, record, or interpret information (Aschengrau and Seage, 2008). This was avoided by having the same interviewer administering all of the Baseline Questionnaires to every participant, using close-ended questions with straight-forward replies, and supplying reply options for ease of classification (Aschengrau and Seage, 2008). Same precautions were taken for the Returning Baseline Questionnaires.

5.5.3 Field Procedures for Questionnaires Administrations

Four questionnaires were administered during different parts of the study. The Screening Questionnaire was administered by the field technicians during door-to-door recruitment. It took about 5 to 10 minutes to complete, depending on their answers, and further explanations were provided by the field technicians when asked. The Daily Diary Questionnaire was self-administered. Field technicians would leave a new copy every visit (visits 1 to 7), except on visit 8 when the sampling ended. During visit 1, participants were told to skim over the Daily Diary Questionnaire and ask the field technicians if they had any questions. More questions could be posed in the later visits. To reduce errors of recalls of past 24-hour activities, participants were suggested to place the questionnaire in a convenient place (e.g. the refrigerator in the kitchen) so that they could record activities immediately post hoc. This questionnaire required about 30 minutes to complete in total. The Baseline Questionnaire was administered during visit 9, the dust visit, and took about 45 to 60 minutes to complete. Questions would be answered when posed by participants, and guidance would be provided if answers were incomplete or incorrect. The Returning Questionnaire was only administered in the summer to participants that returned from the winter sampling period. Field technicians could administer this during any visit (except visit 1 due to a lack of time), depending on the participants' availability. This was a shorter version of the third questionnaire and took about 20 minutes to complete.

6.0 Results and Discussion

6.1 Sample Population

Age distributions of people living in the five neighborhood strata were relatively similar (Figure 9). For age group 0-19 years old, between 19-27% of the residents were in that group, 11-20% were 20-29, and 34-41% for 30-54 years old. The range of proportion of people from the 5 strata was greatest in the over 55-year-old age group; between 16-42% were in that group. All strata were populated by residents aged 30 years and over.

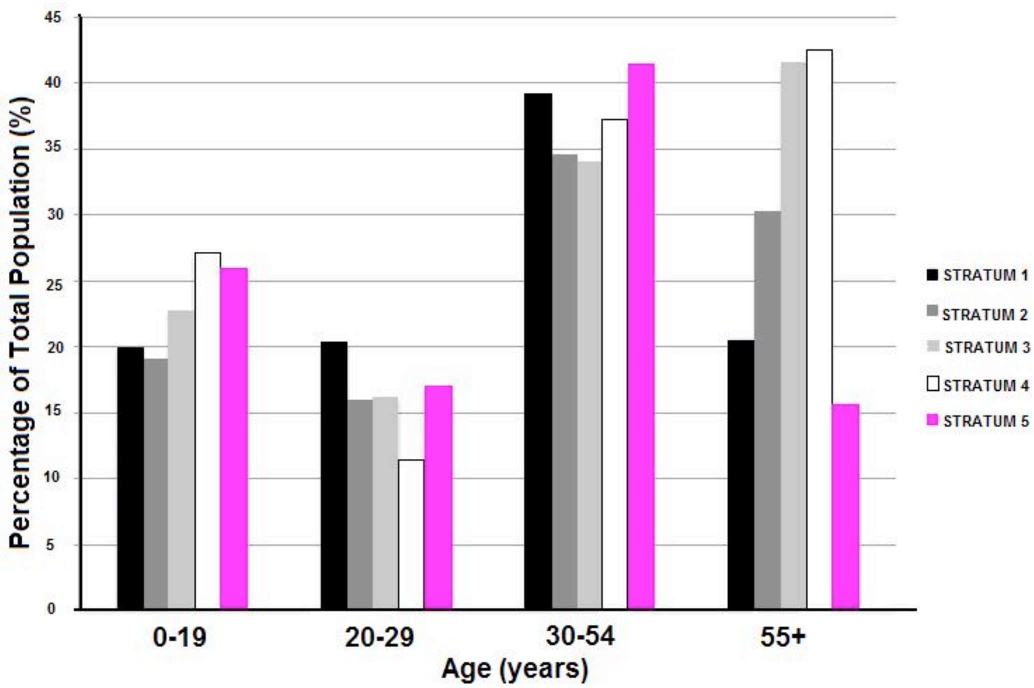

Figure 9 - Age distributions for residents in strata 1 to 5 for Edmonton, Alberta (Office of the City Clerk, 2008).

Strata 1, 3, and 5 had similar number of population (10627, 9440, and 9077, respectively), while strata 2 and 4 were more comparable (5373 and 5255, respectively) (Figure 10) (Office of the City Clerk, 2008). Stratum 1 had the most households, totaling to 6089, while the rest were comparative: stratum 2 to 5 had

2739, 4026, 2013, and 3914, respectively (Office of the City Clerk, 2008). The number of residence was approximately half of the number of total population in each corresponding stratum.

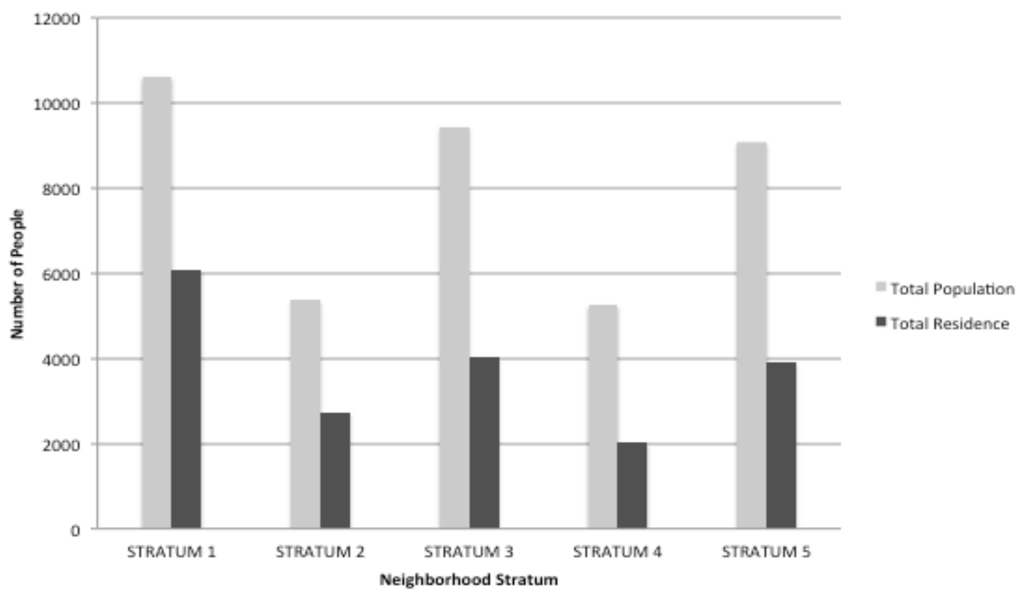

Figure 10 - Populations and residential distributions in each neighborhood stratum in Edmonton, Alberta (City of Edmonton, 2008).

Similar dwelling types were found among the strata (Figure 11). These neighborhoods mostly consisted of single detached houses, from 54% in stratum 3 to 63% in stratum 5 (Office of the City Clerk, 2008). Coincidentally for this study, only single-detached houses were recruited and thus, sampled.

The employment rates among all the neighborhood strata were similar (Figure 12). All the strata had about 70% of the residents employed with approximately 90% of which employed in full-time positions (over 30 hours each week) (Office of the City Clerk, 2008). Stratum ranking from highest to lowest percentages of full-time was 5, 1, 4, 3, and 2 (Office of the City Clerk, 2008).

Unfortunately, there were no available data on household income for each neighborhood to make inferences regarding socioeconomic status.

As a trend, neighborhoods further away from Downtown Edmonton had a lower number of rental properties. Dwellings closer to the Downtown Core in strata 1 and 2 had similar number of residences renting and owning their places of residence (Office of the City Clerk, 2008), as shown in Figure 13. There was a decline in the percentages of dwellings rented while the home ownership increased observed in Strata 3 to 5 (Office of the City Clerk, 2008).

Overall, the neighborhood strata had some demographic differences and should not be considered homogenous. They were similar in terms of proportion of residences, dwelling compositions, and socioeconomic status. On the other hand, the property ownership was much higher in strata 3 to 5 than strata 1 and 2. Even though the ages of the residents were similar over most of the strata, there were significantly more residents who were over 55 in strata 3 and 4. Finally, since all the strata are in Edmonton, they were exposed to comparable weather conditions all year long.

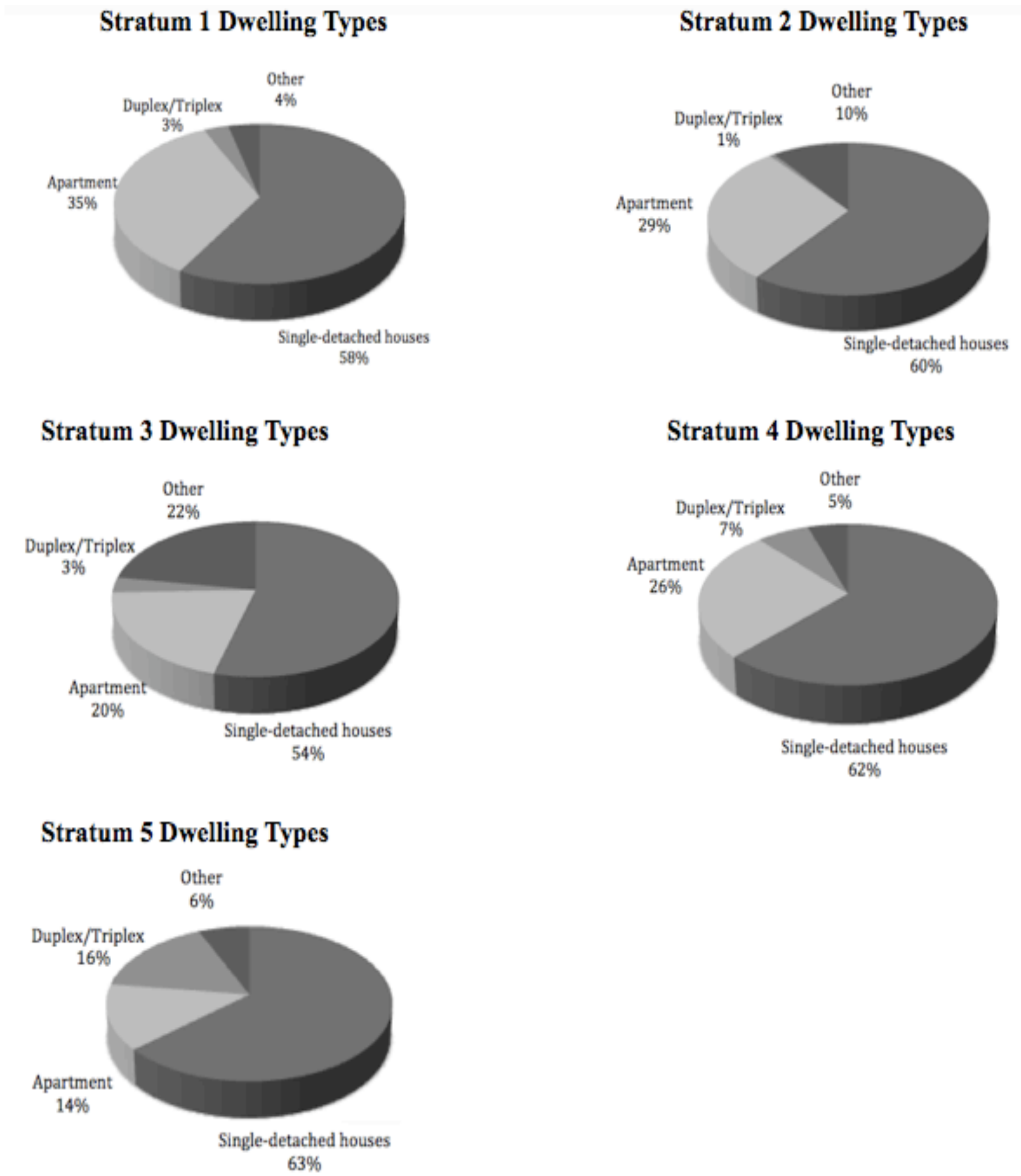

Figure 11 - Dwelling types in Stratum 1 to 5 in Edmonton, Alberta. Dwelling type "Other" includes hotel/motel, mobile homes, row houses, and other residential structures (Office of the City Clerk, 2008). Note: the percentages calculated were derived from averaging the same dwelling type percentages from the same stratum, thus, not all pie-charts (strata 3 and 5 had 99%) equaled to 100%.

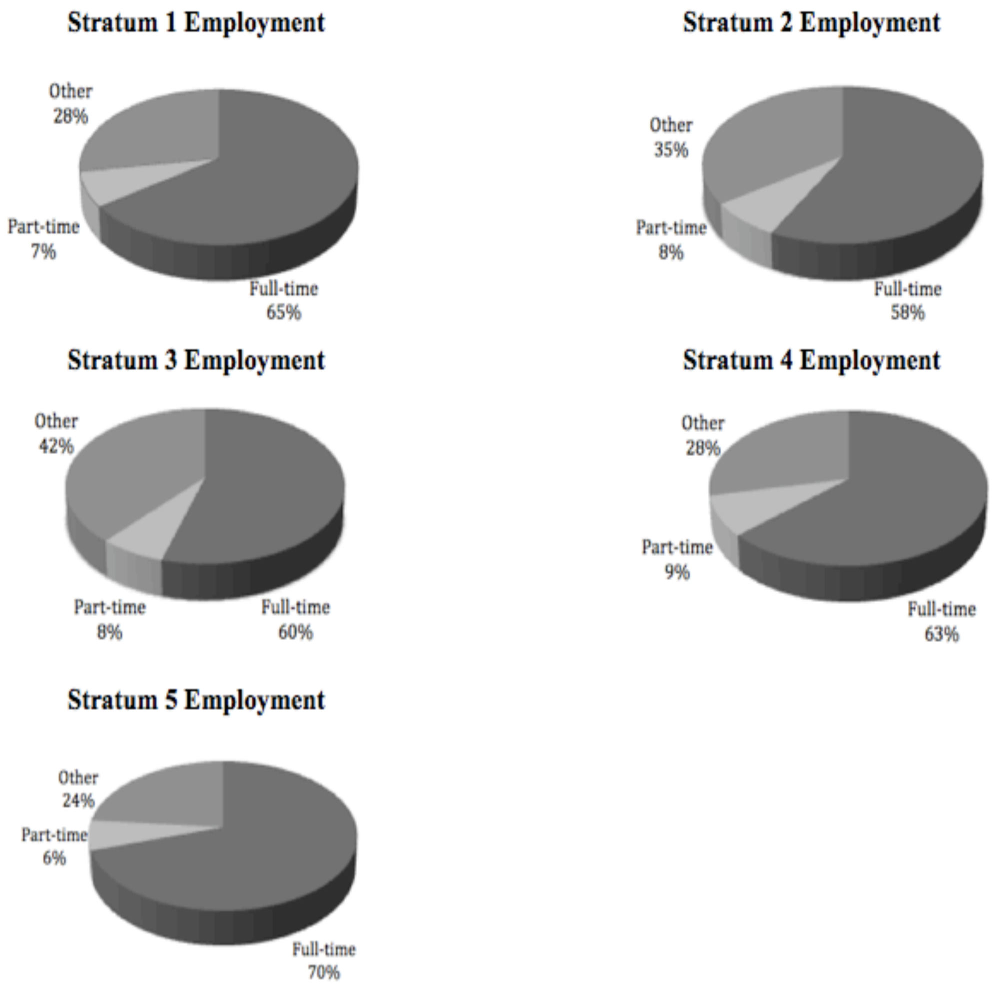

Figure 12 - Employment rates for strata 1 to 5. Full-time employment were those employed over 30 hours a week, part-time were less than 30 hours, and others included homemakers, unemployed, retired, permanently unable to work, and other (Office of the City Clerk, 2008). Note: the percentages calculated were derived from averaging the same dwelling type percentages from the same stratum, thus, not all pie-charts equaled to 100%.

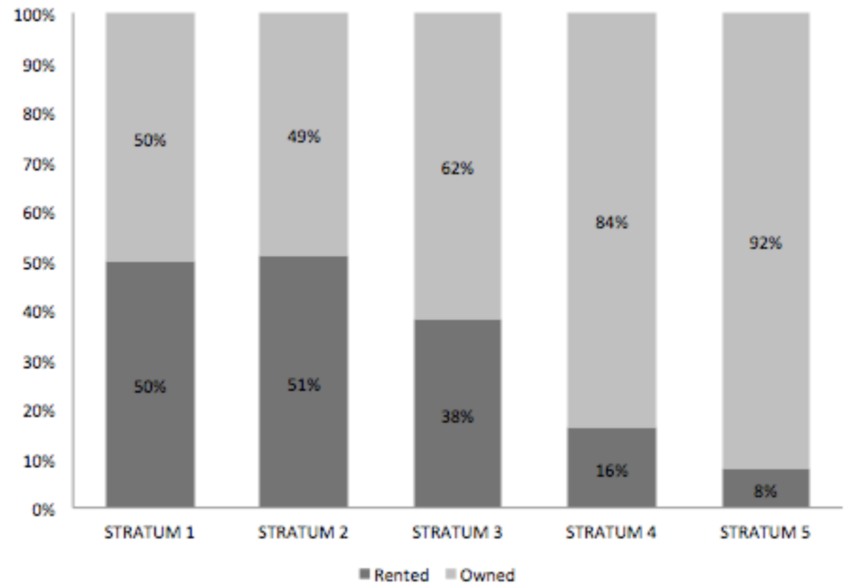

Figure 13 - Home ownership distributions from strata 1 to 5 (Office of the City Clerk, 2008).

6.2 Sampling Design

Response rate is defined as the number of qualified homes participating in the study over the total number of homes contacted or visited during recruitment. It did not take into account the number of times a home was contacted to obtain a consent or refusal. In the wintertime, the response rate was 3.5 % (50 homes recruited/1434 homes visited) and 15% in the summertime (50 homes recruited/341 homes visited). Similar VOC studies by Wallace et al. (1986), Wallace et al. (1987), and Otson et al. (1992) had response rates around 50%. The air quality study conducted by Health Canada in Quebec City had 23% (96 homes recruited/418 homes contacted). In comparison, this study had rather low response rates. Participant burden and eligibility criteria were deterring factors for a low response rate in the U.S. EPA study (Wallace et al., 1986) and same for this study. Reasons for refusal to participate as stated by homeowners during recruitment included:

- Unable to meet the time demands (seven consecutive days) for various reasons, such as busy schedules, kids, too old, health reasons, etc.;
- May be away on vacation during the sampling periods (in the summer);
- Unable to satisfy the requirement of not vacuuming for a week prior to dust visit; and
- Uncomfortable letting strangers (i.e. the field technicians) into their houses.

Some interested homeowners were not eligible based on the Screening Questionnaires (i.e., smokers, renters, renovations taking place during sampling, etc.), which further compromised the response rate. The most noteworthy reason for low response rate was that many of the homes visited during recruitment had no response (Tables 2 and 3).

The response rates in the winter from all the neighborhoods were between 2 to 15%, the lowest in Parkdale, and highest in Richford (Table 2). Field technicians were able to recruit the targeted number of homes from strata 2 to 4. Strata 1 and 5 both needed to recruit from three neighborhoods, rather than two, so that each stratum could be equally represented. Field technicians had a hard time recruiting five homes from the stratum 1 neighborhood Parkdale because it mostly consisted of smokers and renters. As a result, three homes were recruited from Spruce Avenue since only two homes were recruited from PD. The other problematic neighborhood was Richford from stratum 5. Richford is a very small neighborhood that had only twenty eligible homes. After three visits to RF, three homes were recruited but one of them later declined due to personal reasons. Three more homes had to be recruited from the next randomly chosen neighborhood from stratum 5, which was Terwillegar South.

The summer door-to-door recruitment results were displayed in Table 3. The response rates were between 5 to 27%, lowest in ST and SA and highest in TS. Door-to-door recruitment was unnecessary for PD (stratum 1), TC (stratum 3), OX (stratum 4), and RF (stratum 5). Since the research group had difficulty recruiting the targeted number of participants from PD and RF from the previous sampling season, it was decided that recruitment from those two would solely involve calling the qualified participants from previous season so that greater efforts could be put into participant recruitment in SA and ST. In TC, all winter participants returned for the summer period. The field technicians were able to recruit an excess number of qualified homes (six homes) so that if one participant did not want to participate in the summer time, the sixth eligible home was contacted and recruited.

It was highly desirable to have the same participants in both sampling periods because that would limit the number of confounders. All participants from the winter sampling period were invited to return for the summer sampling period but only twenty-six of the fifty (52%) winter participants returned (Table 4). None of the homes dropped out prior to the completion of their respective data collecting visits. Almost half (48%) of the winter participants decided not to return for the summer sampling seasons, which could have potential effects when comparing seasonal effects on benzene levels.

Table 2. Winter door-to-door recruitment and participation results of selected neighborhood from each age stratum.

Stratum	Neighborhood	Number of Homes Visited	Responses from Recruited Homes: Number of 'No' Response	Responses from Recruited Homes: Number of Homes Said 'No' or Disqualified	Responses from Recruited Homes: Number of Homes Said 'Yes' and Qualified	Response Rate (%)	Number of Homes Sampled
1	PD	219	153	61	5	2	2
	SA[a]	40	24	12	4	10	3
	WM	75	50	19	5	7	5
2	GB	116	38	70	8	7	5
	ST	91	52	34	5	5	5
3	OT	90	45	37	8	9	5
	TC	168	103	63	7	4	5
4	FH	174	99	62	13	7	5
	OX	200	114	78	6	3	5
5	RF	20	7	10	3	15	2
	TS[a]	66	35	28	3	5	3
	TT	175	110	58	7	4	5

[a]Neighborhood selected to fill the number of participants from each stratum

Appointment start times were between 3:30 p.m. to 6:30 p.m. Using similar time appointments in both seasons ensured that proper representations of winter and summer benzene levels would be consistent and captured.

Sampling periods began on Monday or Thursday until the same weekday in the following week and most participants had no preference for either starting days. However, the biggest scheduling difficulty was for sampling week 7 in winter which coincided with public holidays since many planned on leaving town when weather permitting. Also, during recruitment for summer participants, some winter participants and eligible homeowners explained that they could not be expected to stay in Edmonton whilst sampling is ongoing because they wanted to go on vacation or leave town when the weather was pleasant. These were limitations that could not be controlled.

Table 3. Summer door-to-door recruitment and participation results of selected neighborhood from each age stratum.

Stratum	Neighborhood	Number of Homes Visited	Responses from Recruited Homes			Response Rate (%)
			Number of 'No' Response	Number of Homes Said 'No' or Disqualified	Number of Homes Said 'Yes' and Qualified	
1	PD	-	-	-	-	No door-to-door recruitment[a]
	SA	78	61	13	4	5
	WM	42	28	11	3	7
2	GB	45	24	15	6	13
	ST	58	37	18	3	5
3	OT	58	32	21	5	9
	TC	-	-	-	-	No door-to-door recruitment[b]
4	FH	4	0	3	1	25
	OX	-	-	-	-	No door-to-door recruitment[c]
5	RF	-	-	-	-	No door-to-door recruitment[a]
	TS	11	6	2	3	27
	TT	45	34	8	3	7

[a] Recruitments were done by phone.
[b] All winter participants returned for the summer study phase.
[c] Number of qualified participants were recruited in excess during winter sampling period, so that even though not all winter participants returned, there were enough summer participants recruited by phone.

6.3 Air Monitoring

A consistent and verified method was utilized to allow for comparison of air quality and exposure levels of Canadians in major cities across the nation. Currently, the U.S. EPA's TO-15 is the most up-to-date and only verified method for ambient VOC sampling using SUMMA™ canisters at the time of this paper (U.S. EPA, 1999). SUMMA™ canisters were verified to work over a wide range of temperature: from -40 ºC to 204 ºC (Columbia Analytical Services, 2011). In 2010, the highest and lowest ambient temperatures around Edmonton

International Airport were 31.3 ºC and -31.0 ºC, respectively (Environment Canada, 2011). Indoor temperature range was within that of the ambient environment. Hence, the SUMMA™ canisters were sampling well within the verified temperature range and should be expected to sample without problems throughout the duration of the EIAQS.

Table 4. Breakdown of participation for each season, stratum and neighborhood.

Stratum	Neighborhood Age Range	Neighborhood	Winter	Summer	
			Recruited Participants	Returning Participants	New Participants
1	Homes constructed before 1946	Parkdale (PD)	2	1	0
		Spruce Avenue (SA)*	3	1	3
		Westmount (WM)	5	4	1
2	Homes constructed between 1946 to 1960	Gold Bar (GB)	5	2	3
		Strathearn (ST)	5	1	4
3	Homes constructed between 1961 to 1980	Ottewell (OT)	5	2	3
		Thorncliff (TC)	5	5	0
4	Homes constructed between 1981 to 2000	Falconer Heights (FH)	5	2	3
		Oxford (OX)	5	3	2
5	Homes constructed after 2001	Richford (RF)	2	1	0
		Terwillegar South (TS)+	5	2	3
		Terwillegar Towne (TT)	3	2	2
Total Number of Participants			50	26	24

*Spruce Avenue as alternative neighborhood to Parkdale
+Terwillegar South as alternative neighborhood to Richford

6.4 Treatment of Censored Data

None of the VOC samples measured had benzene values below the method detection limit (MDL) of 0.04 μg/m^3 (outdoor) and 0.00 μg/m^3 (indoor), which was estimated as three times the standard deviation of the laboratory blanks

(Heroux et al., 2010). In total, there were 87 "missing" values (6% of the 1313 of valid participant-days remained after laboratory analysis of the 1400 theoretical participant-days). Upon revisiting the hard copies of logsheets, the reasons why some participants had missing values included:

- Field technician errors (e.g., wrong dates on logsheets, wrong participant id);
- Family emergency in one household during the winter sampling period and the visit could not be carried out as usual; and
- Over or under 3 hours of the 24-hour sampling period.

Some of the technical errors were categorized as "invalid," based on the Air Pollution Exposure Data: Compilation Guideline compiled by van Ryswyk of Health Canada (van Ryswyk, 2010). The Guide (also used by Health Canada in air quality studies in Windsor, Halifax, Quebec City, and Regina to maintain consistency) outlines methods on cleaning the data, data coding, calculations and final compilation. Invalid values were taken out during compilation, resulting in "missing values."

Environmental sampling data are usually log-normal (Esmen and Hammad, 1997; Ott, 1995), skewing to the right and bounded on the left by zero (van Belle, 2008), or the detection limit. As Ott (1995) explained, "[this is because a] concentration undergoing a series of independent random dilutions tends to be log-normally distributed." Replacement of censored data with central tendency values based on Gaussian distribution would be inappropriate. Theoretically, there should be 1400 participant-days of VOC samples (indoor and outdoor for winter and summer seasons). After laboratory analysis, 1313 valid participant-days remain. Of the 87 missing values, 21 were from outdoor winter, 30 outdoor summer, 13 indoor winter, and 23 indoor summer.

Because there were only 7 benzene data points for the 50 participants, it was necessary to fill in censored data to maximize the number of data points for results with stronger statistical power. There were several approaches to filling in censored data (Jhangri, 2011). For example, if a value was missing for a participant day in outdoor winter, then the mean of the measured outdoor benzene values for that participant in winter would be used to substitute for a missing value. This method, however, would not be preferable since some participants had between 3 to 1 participant days missing, which meant that: 1) the average value would be drawn upon a very small pool (between 4 to 6 sample days); and 2) the average value was unlikely to be representative of the benzene exposure level for any one day in a week. Another method involved using the measured benzene values of the weekday that the missing value falls on to calculate the median and use that number to fill in. For example, if participant A was missing an outdoor winter benzene value on a Monday, then all the Monday values from the winter outdoor sample pool would be used to calculate a "Monday outdoor winter median." This method was preferred and employed because 1) the average value would be drawn upon a reasonably sized sample pool (between 40 to 49 samples) and have more statistical power; 2) since people usually have similar weekly activity patterns, fill-in values drawn from the same weekday in the same season from the same environment would be more representative; and 3) benzene values from each weekday in each season from each environment showed a characteristic, positively skewed distribution (Figures 14 and 15), as a result, median values were more appropriate than means, which would be more fitted for a Gaussian sample distribution.

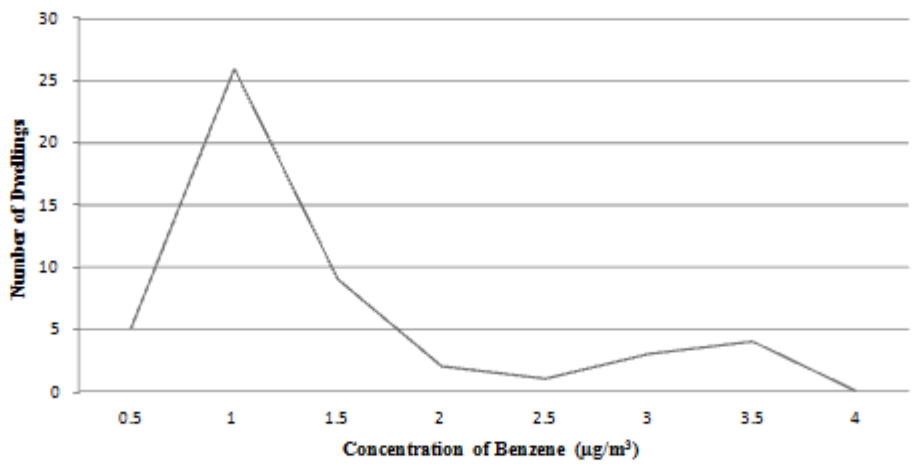

Figure 14 – Distribution of outdoor benzene concentrations measured on Wednesdays in winter. Data points have been categorized into bins based on concentration range. Other days of the weeks all have a similar characteristic, log-normal curve. This curve is characteristic of outdoor samples, even in summer.

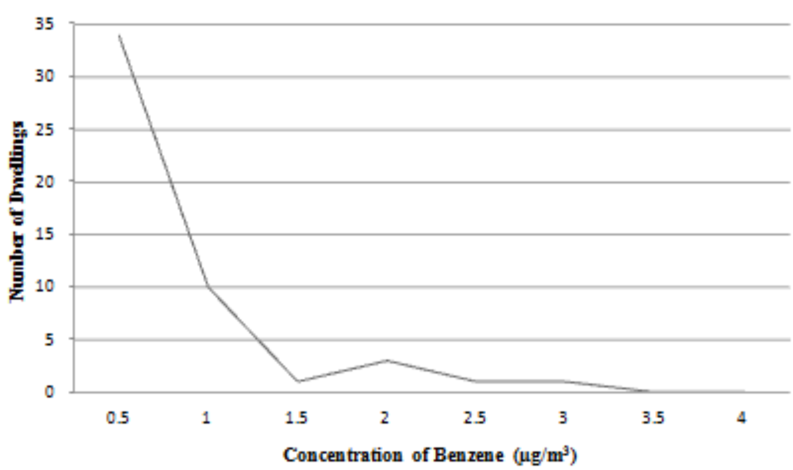

Figure 15 – Distribution of indoor benzene concentrations measured on Wednesdays in winter. Data points have been categorized into bins based on concentration range. Other days of the weeks all have a similar characteristic, log-normal curve. This curve is characteristic of outdoor samples, even in summer.

Daily benzene averages were calculated utilizing samples from 7 consecutive days of VOC sampling for every participant for each season in each environment. Treatment of censored data ensured that missing values were filled-in. Participants with more than two "fill-ins" were excluded because over 30% of their benzene levels were contrived and analysis using these values may mask the true relationships between different factors and benzene concentrations. One participant was excluded in winter outdoor category, and in the summer 3 each for indoor and outdoor. Overall, less than 10% of participants were missing in any comparison combination, which was small and acceptable: indoor and outdoor environments were missing 3% and 4%, respectively; and winter and summer were missing 1% and 6%, respectively.

6.5 Selecting a Statistical Method to test the Null Hypothesis

As mentioned previously, environmental data tends to be log-normally distributed and positively skewed (Esmen and Hammad, 1977). The distributions of benzene concentrations from each season, either indoor or outdoor, are also positively skewed (Figure 16).

T-tests are used in most of the analyses even though the data or comparison groups are not always normal or have equal variances. There are many advantages of using t-tests over other non-parametric tests. For one, t-tests provide more statistical information (like 95% confidence level, standard error). Secondly, the central limit theorem (CLT) applies when there are over 30 data points in a comparison group (Ramsey and Schaffer, 1997). In that case, t-tests are appropriate because normality applies since CLT applies (Jhangri, 2011).

Thirdly, when done in SAS 9.2, t-tests provide two p-values; one when comparison groups have equal variances, the other when they have non-equal variances. Fourthly, t-tests are very robust, even when the dataset is not normal (Ramsey and Schaffer, 1997). As a result, most of the analytical results are from t-tests. When certain comparison groups are log-normal (because not all of them are despite being environmental data), the geometric means are used instead of arithmetic means.

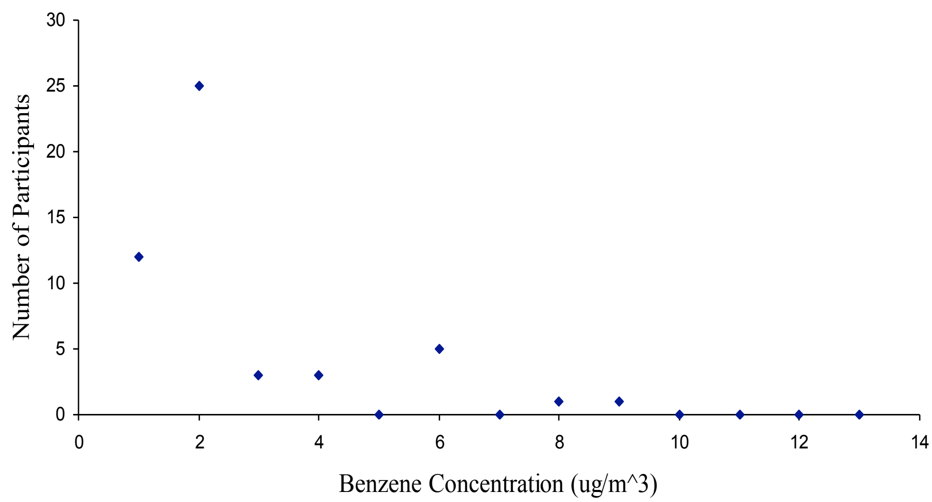

Figure 16 - The distribution of daily mean from 5-7-day samples measured in summer and indoor environment. The data points have been separated into bins, based on concentration range, to reduce cluttering of data points. Winter indoor, outdoor and summer outdoor also have a similar characteristic positive skew.

6.6 Defining Testable Variables for Analysis

The EIAQS studied a wide range of air pollutants in indoor and outdoor environments throughout the winter and summer seasons. The questionnaires captured much information regarding factors that could contribute to increased benzene levels in residential homes. Still, it was impossible to analyze all the factors due to resource limitations. After careful considerations, factors that were examined were: season (winter and summer), environment (indoor and outdoor), traffic volume in proximity to homes, home location relative to the downtown core, socioeconomic status (using house value as a proxy), garage type, number of occupants in dwellings, and air exchange rate relative to age stratum.

Both indoor and outdoor benzene concentrations were used for seasonal comparisons. Only ambient benzene concentrations were used for the analyses of traffic volume and proximity to downtown core, and indoor concentrations for the rest of the test variables. Participants were represented by their own daily mean benzene values for all the tests.

Analysis on traffic volume did not use a daily mean value based on the 7-day data, instead, daily mean benzene values derived from samples measured on Tuesdays, Wednesdays and Thursdays (three 24-hour periods) were used. These three weekdays were selected because traffic volume and benzene concentrations tend to peak mid-week and are comparatively higher on weekdays than weekends (Dann and Wang, 1995; Husch and Albeck, 2003).

Sampling period started in the afternoon, hence, the three 24-hour periods started from Tuesday afternoon to Friday late afternoon/early evening (Tuesday to Wednesday, Wednesday to Thursday, and Thursday to Friday). Dann and Wang (1995) in the nationwide Environment Canada study of benzene also used Tuesday to Friday samples to represent their urban weekday means (Dann and Wang, 1995). Mondays were not included because certain sampling weeks started on Mondays and the appointment times (i.e. those that started in the evening rather than in the afternoon) could affect the sample analysis. Weekends were also excluded because Iovino et al. (2007) found that weekend ambient benzene levels were 1.6 times lower compared to weekdays. Therefore, to capture the maximal effect of traffic volume on benzene, weekend benzene values were negated to avoid diluting weekday benzene levels. With three 24-hour samples per participant, only one-third of the values were allowed to be filled to ensure 67% was from actual data. Winter and summer analyses excluded 2 and 1 participant, respectively.

6.6.1 Seasons and Environments

Similar exposure studies in the U.S. (Wallace et al., 1986; Wallace et al., 1987; Wallace et al., 1988) and Canada (Otson and Fellin, 1992; Otson et al., 1992; Heroux et al., 2008) showed that seasonal and environmental effects had major implications on VOC levels. Particularly, levels in winter were several folds higher than in summer. Na and Kim (2001) measured benzene levels in Seoul, Korea from August 1998 to July 1999 collecting 24-hour air samples with 6-L SUMMA™ canisters every 6 days. They reported that the average winter (January 1999 to April 1999) and summer (June 1999, July 1999, and August 1998) benzene levels were 3.5 $\mu g/m^3$ and 2.6 $\mu g/m^3$, respectively (Na and Kim, 2001). Indoor levels were much higher than outdoor levels (Wallace et al., 1986; Wallace et al., 1987; Otson and Fellin, 1992; Otson et al., 1992; Na and Kim, 2001; Elbir et al., 2007; Heroux et al., 2008). For example, in Izmir, Turkey, benzene levels from urban samples were three times higher than in the summer (Elbir et al., 2007).

To test these hypotheses and accommodate for the fact that 26 participants returned for the summer sampling from the winter period (and 24 new ones recruited in the summer), the results had to be compared in three ways: 1) paired, 2) unpaired, and 3) all. Recruiting the same participants from winter for summer would minimize the number of confounders. Results from this group should be the most informative and powerful because most of the confounders would be controlled. Twenty-six homes were sampled in both seasons and tested as pairs. The remaining 24 were tested as unpaired samples. The third approach had all the homes from the two groups (winter vs. summer or indoor vs. outdoor) tested against each other as though they were all unpaired. This was justified because participants were all independently recruited and it would create a larger sample size for greater statistical power.

6.6.2 Ambient Benzene and Traffic Volume

Occupational exposure to high doses of benzene is known to cause leukemia, which raises health concerns regarding long-term, low-level benzene exposure from traffic. Studies regarding childhood leukemia and traffic volume have had mixed conclusions. On one hand, some studies showed no association between childhood acute leukemia and heavy-traffic roads within 460m of the homes (Langholz et al., 2002), 100m (Harrison et al., 1999), and 50m (Steffen et al., 2004; Visser et al., 2004). On the other hand, positive associations were established for homes within 230m from roads with greater than or equal to 20,000 vehicles per day (VPD) (Pearson et al., 2000) and those within 500m of heavy traffic roads (Amigou et al., 2011). Then, there were some that showed only little or no associations between leukemia and high vehicle density (Reynolds et al., 2002). Two hypotheses were tested regarding traffic volume: 1) did homes that were within 250 m of the roadways have higher ambient benzene concentrations? and 2) when homes were separated based on traffic volume exposure, were those in the third and fourth quartiles of traffic volume exposed to higher levels of benzene than those in the first quartile?

To determine the proximity of homes from heavy traffic roadways, Google Map was used to help pinpoint the location of homes and an Edmonton Transit Map (Edmonton Transit System, 2011), printed by the Edmonton Transit System, was used to indicate major roadways near the homes. An Edmonton Transit System map was preferred over a normal municipal map because instead of indicating all the roadways, it would show only those major roadways used by buses and other vehicles to help to weed out the roadways with insignificant traffic volumes.

Next, it was determined whether participants' homes were equal to or less than 250 m or over 300 m from major roadways using the scale available on the Edmonton Transit System map. In total, 10 homes out of 74 were over 300 m away and no traffic volumes could be determined for those homes. No further actions were taken to determine the traffic volumes based on the assumption that if roadways were major then they would appear on the map or the traffic reports; otherwise the traffic volume would be too low to be considered. Roadways selected from the Edmonton Transit System Map were then cross-referenced with the primary source "2007 Traffic Flow Map" and the secondary source "Traffic

Volumes Annual Weekday 2004 – 2009," both available on the City of Edmonton website as the most recent resources available for estimating traffic volumes at the time of this paper (City of Edmonton, 2011). The "2007 Traffic Flow Map" was considered the primary source because, like the Edmonton Transit System Map, it only showed major roadways and their reported average annual weekday VPD as recorded by automated traffic counters (City of Edmonton, 2011). To maintain consistency and validity, a procedure was designed and outlined as follows:

1. Find roads within 250 m of a participant home on the "2007 Traffic Flow Map" and sum up their traffic volumes;
    a. if a home was located between two value on the same road on the flow map, then the value closest to the one would take preference;
    b. but if the home was equidistance between the two values, then an average would be taken; or
    c. if the road did have a traffic volume indicated but its width changed (indicating a change in traffic volume) and a new value was not given, then the secondary source would be referenced.
2. If none of the roads on the flow map fell into that criteria, then refer to the "Traffic Volumes Annual Weekday 2004 - 2009" report to find street descriptions that were within 250 m and record the value;

3. If roads indicated on the Edmonton Transit System Map were not shown in the flow map, then traffic volumes would be taken from the report;
4. Homes that were not 250 m within any major roadways with traffic volumes reported were left blank; and
5. Repeat the above steps for all homes.

Participants were separated into quartiles based on their traffic volumes. Next, those from quartile 1 were compared to those from quartiles 3 and 4 within each season. In winter, homes with less than or equal to 3,550 VPD were compared to those with greater than or equal to 33,500 VPD. In summer, comparisons were made between those with less than or equal to 2,500 VPD and greater than or equal to 36,200 VPD.

6.6.3 Ambient Benzene and Proximity to Downtown Core

Exposure to ambient benzene was affected by home proximity in relation to the downtown core. Studies in different cities showed that ambient benzene levels were higher than that measured in the suburbs. In London, England, the downtown and suburbs benzene levels observed to be 8.1 $\mu g/m^3$ and 3.5 $\mu g/m^3$ in June 1991, respectively; approximately 2.3 times greater in downtown (Perry and Gee, 1993). Lei and Wang (2005) observed a range of 20 to 85 $\mu g/m^3$ in downtown in Beijing versus 9 to 50 $\mu g/m^3$ in Beijing suburbs. In Izmir, Turkey, benzene in areas with heavy traffic was four times greater than levels found in the suburban area (Elbir et al., 2007). The researchers used the receptor model to estimate the contribution of specific source types and found that there were six source factors from downtown (listed in descending order of significance for benzene): diesel vehicle exhaust & residential heating > undefined > dry cleaning > gasoline vehicle exhaust > degreasing > paint production/application; and three source factors in urban areas (also listed in descending order): gasoline vehicle exhaust, diesel vehicle exhaust, and paint production/application (Elbir et al., 2007). Cheng et al. (1997) measured the levels of ambient benzene in Edmonton, Canada from December 1991 to November 1993 and found that the downtown and east side industrial area (about 9 km east of the downtown core with manufacturing plants up to 2500 m away near the neighborhood of Gold Bar) had similar median levels of 3.4 $\mu g/m^3$ and 2.6 $\mu g/m^3$, respectively (Cheng et al., 1997).

The hypothesis tested here was that homes further away from the downtown core should have lower ambient benzene levels than those closer to the core. First, one had to define the location of the downtown core and then to group the homes by their locations. The Bay/Enterprise Square LRT Station (53°32′27″N 113°29′54″W) was arbitrarily designated as the downtown core and it is located on Jasper Avenue between 103 and 104 Street in downtown Edmonton.

Next, based on the locations of the homes, they were divided into three proximity groups: homes 0 m to less than 4000 m away from the downtown core (Group 0), 4000m to less than 8000 m away (Group 4000), and greater than 8000 m (Group 8000) (Appendix 1). It was not part of the study design to divide them based on proximity to downtown core. This test was decided upon after looking at the locations of the neighborhoods, thus, homes were not evenly distributed within the perimeters and the number of homes in each category is not equivalent. Also, the locations of the homes were not evenly distributed across Edmonton because the study design was not intended to compare benzene concentrations from different parts of the city, for example North vs. West vs. South vs. East vs. Central.

The numbers of homes between Groups 0 and 4000 were relatively the same, in each season, while the Group 8000 had the highest number of samples (Table 5). Daily averages based on seven 24-hour samples were used. However, only those participants with two or less missing days were included so that the average was based on over 70% of actual data. Based on this criterion, one participant and three participants were excluded in winter and summer, respectively.

Table 5. Number of participants in Group 0, 4000, and 8000.

Winter			Summer		
Group 0	Group 4000	Group 8000	Group 0	Group 4000	Group 8000
15	10	24	12	10	25
Total = 49			Total = 47		

Group 0 = Homes 0 to less than 4000 m away from the downtown core
Group 4000 = Homes 4000 to less than 8000m away (Group 4000), and greater than 8000m (Group 8000).

6.6.4 Indoor Benzene and Socioeconomic Status

Evans and Krantrowitz (2002) proposed that socioeconomic status (SES) can impact the environmental quality people are exposed to, and in turn, affects public health:

SES → Environmental Quality → Health

Figure 17 - Conceptual relationship of SES, Environmental Quality, and Health (adapted from Evans and Kantrowitz, 2002).

The model has not been proven due to limited amount of research on SES currently in the field of environmental health sciences. Studies regarding SES and environmental exposure were mostly examination of income (Forastiere et al., 2007; Voss, 2007) and/or ethnicity (Perlin et al., 1995; Gunier et al., 2003) as proxies as of SES. Low SES was strongly linked to increased exposure to environmental risks in homes (Braubach and Fairburn, 2010). But these findings were not consistent since those considered to have low SES (i.e. living below poverty line) did not always have the highest environmental exposures to pollutant. In Germany, the German Environmental Survey for Children (GerES IV) was carried out in 2003-2006 (Seiwert et al., 2008) where blood, urine, and indoor air samples were collected from 1,790 children and questionnaires regarding living conditions and exposure-relevant habits were administered to adults. They used the parents' incomes, education levels, and occupational statuses as SES indices. Researchers found that concerns of exposure to environmental pollutants were not exclusive to children from low SES families since several pollutants were more commonly found in high SES families (Seiwert et al., 2008). For example, exposure to tobacco smoke was highest for children from low SES families while DDT and PCB were highest for those from high SES families due to differences in breast-feeding habits in the different SES groups.

The EIAQS collected information regarding total household income for every participant home using the Baseline Questionnaires. But because of the broad ranges of income given as answer options ("less than $35,000", "$35,000 to $80,000", "more than $80,000", "I prefer not to say", and" Don't know"), most participants fell into the $35,000 to $80,000 and others chose "I prefer not to say" and "Don't know." To conduct analyses that included all the participants and data with distinctive separations among the groups, house value was used as a SES index and considered to be a reflection of a family's income. Current house values were available on the City of Edmonton website (http://maps.edmonton.ca) (City of Edmonton, 2010). Participants with house values greater than or equal to the third quartile (Q3) value were compared to those with less than or equal to the first quartile (Q1) house values, in both seasons. There were 13 participants in each comparison group. Correlations between house values and daily benzene levels (based on seven 24-hour samples) were calculated using SAS v9.2 (SAS Institute Inc, Cary, NC, USA).

6.6.5 Indoor Benzene and Garage Types

High concentrations of VOCs in garages could increase the benzene levels of attached residences (Thomas et al., 1993) because the highest levels of benzene were typically found in garages (Dodson et al., 2008) and pollutant migration through cracks in the foundation and/or opening and closing of the connecting door (Batterman et al., 2007). Multiple benzene sources present in the garage could explain the higher levels found in the garage compared to the rest of the home, such as vehicle emissions, gasoline (in the vehicles and/or lawnmowers), paints, solvents, and cleaners garage (Thomas et al., 1993; Wallace, 1996; Mann et al., 2001; Batterman et al., 2006; Batterman et al., 2007; Dodson et al., 2008; Jia et al., 2008a and 2008b). Batterman et al. (2007) sampled two-story houses with attached 2-car garages in Michigan and reported that 6.5% of the houses' overall air exchange was attributable to air flow from the garage into the house. More species of VOCs were detected in the garages compared to ambient air. Gasoline-related VOCs (like benzene) were found in very high levels (37 $\mu g/m^3$) in the garages and that most of the benzene inside the homes originated from the garage (Batterman et al., 2007). Thus, for non-smoking individuals, the large portion of their exposures to benzene may originate from living in homes with attached garages (Batterman et al., 2007). A recent study by Dodson et al. (2007) indicated that different garage types (e.g., attached or detached) could affect residential air flows and VOC concentrations (Dodson et al., 2007).

Extracted from the Daily Diary and Baseline Questionnaires, one was able to determine: whether a participant home had a garage; the type of garage (attached with connecting door, attached without connecting door, and detached); car ownership, and if so, how many, and whether the car was used. From these information, participants were divided into 9 groups (Table 6). In a similar study in Windsor, ON, Stocco et al. (2008) measured personal exposure levels of benzene and found that those living in houses with attached garages had higher levels of exposure than those that did not. In addition, benzene exposure levels were comparatively low for those living in houses with no garages, detached garages, and attached garages with no connecting doors (Stocco et al., 2008).

Table 6. Garage type and car usage.

Group	Garage Type	Owned a Car?	Car Used	# of Winter Participants	# of Summer Participants
1	None	No	Not Applicable	3	1
2	Attached Garage with Connecting Door	No	Not Applicable	-	1
3	Attached Garage with Connecting Door	Yes	No	1	1
4	Attached Garage with Connecting Door	Yes	Yes	16	15
5	Detached Garage	No	Not Applicable	3	-
6	Detached Garage	Yes	No	5	3
7	Detached Garage	Yes	Yes	21	25
8	Attached Garage without Connecting Door	No	Not Applicable	1	-
9	Attached Garage without Connecting Door	Yes	Yes	-	1

6.6.6 Indoor Benzene and Number of Occupants in Dwellings

There is a scarcity of quantitative studies directly examining the influence of number of occupants on the residential benzene levels. Seifert et al. (1989) studied twelve German homes and measured their VOC levels with passive samplers for twenty-six 2-week periods. They found that the total VOC emissions dropped by 50% when residents left their homes; a strong indicator that half of the VOC concentrations were generated by the occupants' activities (Seifert et al., 1989). A more recent study by Health Canada carried out in Regina, SK also found that 53% of indoor air pollutant variability was explained by occupants' activities (Heroux et al., 2010). These activities most likely involve the usage of household products that may contain benzene because it is present in a wide range of commonly used household products, such as rubbers, lubricants, dyes, detergents, drugs, and pesticides, to name a few (ATSDR, 2007). Hence, it was hypothesized that if more occupants resided in a household, then there would be higher levels of benzene because indoor benzene emissions were highly connected to occupants' activities within the homes and an increased number of occupants may increase activities that may increase benzene emissions. The Baseline Questionnaire collected information regarding the number of occupants in the household and divided the participants into 2 groups: dwellings with 2 occupants or less and dwellings with 4 occupants or more.

6.6.7 Indoor Benzene, Air Exchange Rate and Age Stratum

In the earlier part of the twentieth century, building ventilation standards required 15 cubic feet per meter (cfm) of outside air per occupant mainly for the dilution of body odors (U.S. EPA, 1991). During the oil embargo in 1973 when energy conservation became the national focus, ventilation standards were lowered to 5 cfm per occupant (U.S. EPA, 1991). Reports of acute health effects by building occupants began to arise. Since these signs and symptoms could not be traced to any specific disease or cases, they became collectively known as the "sick building syndrome," or SBS (U.S. EPA, 1991). Inadequate ventilation due to ineffective air distribution to individuals in a building by the heating, ventilation, and air conditioning (HVAC) system was one of the recognized causes of SBS (U.S. EPA, 1991). To balance health and comfort of building occupants on the one hand, and energy-efficiency on the other, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) required a minimum of 15 cfm (7.5 L/s) of outdoor air per person in the living areas, or 0.35 air changes per hour (ACH) (U.S. EPA, 1991). These standards have also been adopted by the Government of Alberta (Alberta Municipal Affairs, 2004).

Air exchange rates (AERs), expressed in air changes per hour (ACH), indicate the extent of pollutant removal by ventilation (Repace, 2004). The perfluorocarbon tracer (PFT) source is a small permeation device that contains PFT liquid and emits PFT vapor through a silicone plug at a constant rate (Dietz et al., 1986). Four sources of PFT gas and one capillary absorption tube (CAT) receptor were deployed in each participant's home on the main floor, while avoiding draft sources like the kitchen, windows, and doors (Stocco et al., 2008; Wang, 2011). The fully fluorinated family class of perfluoroalkylcycloalkane was chosen because it has a high electron capture detector (ECD) response, lower atmospheric background concentration, and harmless to the environment (Dietz et al., 1986). The PFT technique was used to calculate the home air infiltration rates (m^3/h) (Heroux et al., 2010; Wang, 2011). The CAT receptor absorbed PFT gas and needed to be collected and reinstalled every 24-hour for seven days of sampling (Stocco et al., 2008; Wang, 2011). The CATs were shipped to the Brookhaven National Laboratory (Upton, NY) and analyzed with the gas chromatograph system (Varian Instrument Corp., Floral Park, New Jersey, Model 3700 GC with a Model CDS-111 integrator-controller) modified at Brookhaven and ECD determination of amount of tracer recovered (Wang, 2011; Dietz et al., 1986). In Table 7, the parameters for GC analysis are indicated. Every column is made from a 3.2 mm stainless steel tubing (Dietz et al., 1986). This process involves thermal desorption, chemical and physical processing (Dietz et al., 1986). The method is explained in detail in a scientific article by Dietz et al. (1986). Air exchange rate was then calculated by dividing the infiltration rate captured by the PFT method derived from the estimated house volume, which was measured and recorded during the dust visits (Heroux et al., 2010; Wang, 2011). AERs were measured in both seasons.

Table 7. GC Parameters for CATs[1].

Instrument	Parameters
Main column	1.2 m long packed with 0.1% SP-1000 on Carbopack C (Supelco, Inc., Bellefonte, PA)
Pre-cut column	1.2 m long Porasil F followed by 0.3 m long of 0.1 % SP-1000 on Carbopack C
Column oven	140°C
Pre-cut catalyst	10.1cm long packed with palladium (1%) on polyethylenimine/SiO_2-Royer palladium catalyst (Strem Chemicals, Inc., Newburyport, MA); 200°C
Main catalyst	3.2 cm long packed with palladium (1%) on polyethylenimine/SiO_2-Royer palladium catalyst; 200°C
Carrier gas	5% H_2 in N_2 at 25 and 20 mL/min, respectively, through the pre-cut and main columns
Porapack QS trap	10.1 cm long packed with Porapack QS
Permeation dryer	1.2 m long Naflon dryer (PermapureProcuts Inc., Oceanpot, NJ, Model MD-125-48S) located in the top of GC (~35°C)
ECD	180°C

[1] (Dietz et al., 1986)

Older homes tend to have lower VOC levels than the newer, more energy efficient homes. A study carried out in Quebec City, QB by Health Canada measured 0.77 μg/m^3 and 1.94 μg/m^3 for houses constructed before 1953 and after

1978, respectively (Heroux et al., 2008). AER could also be reduced by closing the windows and doors, thus, trapping indoor emissions and elevating benzene levels (Jia et al., 2008a and 2008b). Winter AERs were usually lower than summer AERs because more windows were closed in the wintertime to retain heat (Sarnat et al., 2002; Sax et al., 2004). During wintertime in Regina, SK, AERs ranged from 0.02 to 3.09 ACH, with a mean ± SD of 0.39 ± 0.38 ACH (Heroux et al., 2010), which was just above the acceptable ventilation standard established by ASHRAE (U.S. EPA, 1991). Alternatively, opening windows and doors (typically in the summertime) would have the opposite effect. Air exchange rates could increase by 2-3/h when doors and windows were opened (Howard-Reed et al., 2002; Wallace et al., 2002). Higher AERs were correlated with lower personal exposures to VOCs (Heroux et al., 2008; Stocco et al., 2008). Sarnat et al. (2004) observed that spring/summer AER was 2.5-fold greater than the fall/winter AER in metropolitan Boston, MA.

Correlations between age stratum and AER were tested using SAS v9.2. The strata were split into two groups (strata 1-3 vs. 4-5) to capture inferred decrease in ventilation caused by the embargo in 1973. Houses from strata 1 to 3 should have the higher AERs because they were less energy-efficient and had greater ventilation.

6.7 Data Analysis

Censored environmental data are usually log-normally-distributed with a positive skew because most data points are close to zero (Ott, 1995). A small number of high concentration outliers can significantly bias the data and lead to distorted estimates of the mean and standard deviation (Singh and Nocerino, 2002). Consequently, NIOSH recommended the use of the geometric mean (an estimate of the median) and geometric standard deviation for analyzing data sets with lognormal distributions (Hornung and Reed, 1990). Therefore, the median and interquartile range (IQR) are generally regarded as more suitable measures of central tendency and variability, respectively, since they are not sensitive to extreme values in a dataset (Ott and Longnecker, 2008). Median, or the 50th percentile, is the middle number of a list of measurements arranged from lowest to highest, otherwise, if the halfway is between two integers, then the median is the mean between the two (Ott and Longnecker, 2008). The IQR is the difference between third and first quartiles of a set of measurements (Ott and Longnecker, 2008). To allow for meaningful comparisons, the median and IQR, as well as the mean and standard deviation were reported here. The data analyzed are shown in the Appendix. To satisfy the research objectives, the following data analyses were done:

1. creating scatter plots to illustrate trends;
2. determining descriptive statistics to summarize the data values;
3. using parametric and non-parametric statistics to test statistical differences; and
4. compiling a table to compare results with international benzene standards.

6.7.1 Indoor to Outdoor Comparison of Benzene Levels

In Section 6.6.1, studies discussing the differences between indoor and outdoor levels showed that indoor benzene concentrations were typically higher than outdoor ones. Benzene measurements in City of Edmonton showed the same patterns (Table 8). Paired t-tests (α=0.05) were done to figure out significant differences between indoor and outdoor levels. Daily benzene concentrations were used based on participants with five or more actual measurements in a sampling week, plus fill-ins. Results from the unpaired t- tests (Appendix 15) showed that the mean indoor benzene concentrations were statistically greater than outdoor concentrations in both sampling seasons. These statistical differences suggested that most residential benzene originated from indoor sources (since the opposite would suggest stronger outdoor sources entering into the homes).

Table 8. Edmonton residential benzene concentrations ($\mu g/m^3$) in winter and summer (α=0.05).

Season	N	Indoor				N	Outdoor			
		Median	Mean	IQR	Max		Median	Mean	IQR	Max
Winter	50	1.5	1.7	0.9	6.2	49	1.0	0.9	0.6	1.8
Summer	47	0.6	1.1	0.54	4.4	47	0.5	0.6	0.3	1.5

N = number of participants
IQR = interquartile range

6.7.2 Comparing Winter and Summer Levels of Benzene

Section 6.6.1 discussed studies that observed differences in benzene levels between winter and summer levels, which showed that winter benzene concentrations were higher than summer because of greater ventilation in the warmer months and in the winter cars needed to be warmed up in attached garages (Jia et al., 2008b). Benzene measurements in the City of Edmonton had similar results (Table 8). T-tests (α=0.05) were done using daily benzene concentrations for each participant. Method of calculating the daily benzene concentrations was discussed in Section 6.4. The number of excluded participants from winter outdoor, winter indoor, summer outdoor, and summer indoor were 1, 0, 3, and 3, respectively. Results from these tests (Appendix 16) showed that winter concentrations were statistically greater than summer concentrations in both indoor and outdoor environments.

6.6.3 Traffic Volume Comparison of Ambient Benzene Levels

Studies looking at traffic volume from high-volume roads had shown mixed results on the rates of childhood leukemia (Harrison et al., 1999; Langholz et al. 2002; Reynolds et al., 2002; Steffen et al., 2004; Amigou et al., 2011). Although the EIAQS did not collect personal medical records of the participants regarding leukemia (that would be beyond the scope and resources of this study), it examined concentrations of ambient benzene concentrations relative to traffic volume within 250 m away from participant homes. Participants were divided into quartiles based on traffic volume as described in Section 6.6.2. In the winter, homes from quartile 1 (those with less than or equal to 34,050 VPD) were compared to those from quartiles 3 and 4 (greater than or equal to 33,550 VPD) using t-tests (α=0.05) (Table 9). In the summer, quartile 1 (those with less than or equal to 2,500 VPD) was compared to those from quartiles 3 and 4 (greater than or equal to 36,200 VPD) using t-tests (α=0.05). Benzene concentrations were equivalent between the two groups in both seasons (Appendix 17), however, failure to reject the null hypothesis does not imply that it is true. The sample sizes in our comparisons (between 12 to 13 participants in each comparison group) were extremely small to be able to accept or reject the null hypothesis.

Table 9. Edmonton ambient benzene concentrations (μg/m^3) from different quartiles of traffic volume (α=0.05).

Season	N	Quartile 1[a]				N	Quartiles 3 and 4[b]			
		Median	Mean	IQR	Max		Median	Mean	IQR	Max
Winter	12	1.3	1.2	1.0	2.1	12	0.8	1.0	0.5	2.0
Summer	13	0.6	0.8	0.4	2.4	13	0.4	0.4	0.2	0.7

N = number of participants
IQR = interquartile range
[a] = Quartile 1 is less than 34, 050 VPD and 2,300 VPD in winter and summer, respectively.
[b]= Quartiles 3 and 4 are less than 33,550 VPD and 36,200 VPD in winter and summer, respectively.

6.7.4 Comparison of Proximity to Downtown Core

As described in Section 6.6.3, neighborhoods were divided into three groups based on their distance from the downtown core: 0 to 3999 m (Group 0), 4000 to 7999 m (Group 4000), and 8000 m and over (Group 8000). T-tests (α=0.05) were done to test the statistical differences between groups (Tables 10 and 11, and Appendix 18). The highest levels of ambient benzene were found in Group 4000 in both seasons. Group 0 was not statistically different from Group 8000 in winter. Though the t-tests showed that Group 0 was statistically greater than Group 8000 in the summer, a look at the actual central tendency values of both groups suggested that they were essentially the same (the means are both 0.5 μg/m^3) (Table 11). Other studies have shown that benzene concentrations in the air were typically higher in downtown areas than those measured in the suburbs (Perry and Gee, 1993; Cheng et al., 1997; Lei and Wang, 2005; Elbir et al., 2007) but results from our analyses did not exhibit the same trend. Group 0 (the homes nearest the downtown core) had similar levels as Group 8000 (homes in the suburbs furthest away from the downtown core), but Group 4000 (homes near and in Gold Bar) were always highest. In an air quality study examining ambient benzene levels in Edmonton, Cheng et al. (1997) found that the median concentrations of downtown (3.4 μg/m^3) was higher than that of Gold Bar (2.6 μg/m^3). Differences in our results could be attributed to bias in our measurements and limitations small sample sizes since neither would allow results from the null hypothesis tests to be interpreted in a meaningful manner.

Table 10. Edmonton ambient benzene concentrations (μg/m^3) relative to downtown core proximity in the winter (α=0.05).

Statistical Summary	Group		
	0	4000	8000
N	15	10	24
Median	0.8	1.3	0.9
Mean	0.9	1.3	0.8
IQR	0.6	0.3	0.6
Max	1.6	1.8	1.2

N = number of participants
IAQ = interquartile range

Table 11. Edmonton ambient benzene concentrations (μg/m^3) relative to downtown core proximity in the summer (α=0.05).

Statistical Summary	Group		
	0	4000	8000
N	12	10	25
Median	0.5	0.7	0.3
Mean	0.5	0.9	0.5
IQR	0.1	0.8	0.2
Max	0.8	1.5	1.5

N = number of participants
IQR = interquartile range

6.7.5 Socioeconomic Status Comparison

Socioeconomic status is not the most ideal predictor of indoor benzene concentrations because correlations to SES tend to be inconsistent across different pollutants, as discussed in Section 6.6.4. To help understand the true effects of SES on indoor benzene concentrations, more research should be done in this area. House value was used instead of household income, which is a typical measure of SES, so that accurate numbers were used and sample size would be bigger (since not every participant supplied their household income value).

First and third quartiles were calculated using the house values. In the winter, indoor benzene concentrations from quartile 1 (equal to or less than $341,500) and quartiles 3 and 4 (greater than or equal to $450,000) homes were not statically different (Table 12 and Appendix 19).

Table 12. Edmonton ambient benzene concentrations (μg/m^3) from different quartiles of house values (α=0.05).

Season	N	Quartile 1				N	Quartiles 3 and 4			
		Median	Mean	IQR	Max		Median	Mean	IQR	Max
Winter	13	1.5	1.8	1.3	4.1	13	2.1	2.5	1.2	6.2
Summer	13	0.6	0.8	0.2	1.6	13	1.0	1.8	2.2	4.4

N = number of participants
IQR = interquartile range

But during the summer months indoor benzene concentrations of homes from quartiles 3 and 4 (greater than or equal to $439,500) were greater than those from quartile 1 (equal to or less than $340,500). Homes with the highest levels of benzene were the most expensive homes while the least expensive homes had the lowest concentrations. Significance of SES' effect on indoor benzene cannot be concluded from our study because: 1. season should not have influenced our results on SES and indoor benzene if SES was truly an important variable; and 2. our sample sizes were too small (13 participants in each group) to present statistically powerful results.

6.7.6 Garage Type Comparison

Benzene levels were compared by dividing participant homes into different groups based on their characteristics (as described in Section 6.6.5). They were further regrouped into three general categories: no garage (group 1), attached garage (groups 3, 4, and 8), and detached garage (groups 5, 6, and 7) (Tables 13 and 14). T-tests (α=0.05) showed that indoor benzene levels were present in the following descending order, sorted by garage types: attached garage > detached garage = no garage (all summer participants owned a garage) (Appendix 20).

Table 13. Edmonton winter indoor benzene concentrations (µg/m^3) relative to garage type (α=0.05).

Statistical Summary	Garage Type		
	No Garage	Attached Garage	Detached Garage
N	3	18	29
Median	1.3	2.0	1.2
Mean	1.2	2.3	1.3
IQR	0.2	1.3	0.8
Max	1.3	6.2	4.1

N = number of participants
IQR = interquartile range

However, to study the difference between homes that had garages and used their cars, Group 4 (homes with attached garage, connecting door and had used their car during the sampling period) was compared to Group 7 (homes with detached garage and had used their car) (Table 15). The benzene levels in homes were still statistically greater in those with attached garages compared to those with detached ones (Appendix 20). These results are similar to studies discussed in Section 6.6.5, which reinforces the idea that benzene sources from the garage (paints, oil, vehicles, and others) could migrate into the homes by way of the connecting door of an attached garage.

Table 14. Edmonton summer indoor benzene concentrations (μg/m^3) relative to garage type (α=0.05).

Statistical Summary	Garage Type	
	Attached Garage	Detached Garage
N	18	28
Median	0.8	0.6
Mean	1.6	0.7
IQR	2.1	0.3
Max	4.4	1.6

N = number of participants
IQR = interquartile range

Table 15. Edmonton indoor benzene concentrations (μg/m^3) relative to homes with attached garages and detached garages that had used their cars during sampling period (α=0.05).

Statistical Summary	Winter		Summer	
	Attached garage with connecting door and car was used (Group 4)	Detached garage and car was used (Group 7)	Attached garage with connecting door and car was used (Group 4)	Detached garage and car was used (Group 7)
N	16	21	15	25
Median	2.0	1.2	1.0	0.6
Mean	2.3	1.2	1.8	0.7
IQR	1.2	0.8	2.2	0.3
Max	6.2	1.9	4.4	1.6

N = number of participants
IQR = interquartile range

6.7.7 Number of Occupancy Comparison

Indoor benzene levels are highly correlated with human activity patterns, thus, the number of occupants could be positively associated with benzene concentrations (as discussed in Section 6.6.6). Participant homes were divided based on the number of participants living in their households and then those from two or less occupants were tested against those with four or more (Table 16). Results from t-tests (α=0.05) using winter data were as expected: homes with higher number of occupants had significantly greater benzene levels than those with less (Appendix 21). Yet, in the summer the groups were statistically similar. The significance of occupants on indoor benzene cannot be concluded from our results because season should not be influential in our comparisons if the number of occupants were a significant factor; and sample sizes were not big enough to produce meaningful analytical results.

Table 16. Edmonton indoor benzene concentrations ($\mu g/m^3$) between two occupants or less and four occupants or more (α=0.05).

Season	N	Two Occupants or Less				N	Four Occupants or More			
		Median	Mean	IQR	Max		Median	Mean	IQR	Max
Winter	22	1.0	1.2	0.8	3.0	22	1.7	2.0	1.0	6.2
Summer	22	0.6	0.9	0.2	2.8	17	0.6	1.2	1.2	4.4

N = number of participants
IQR = interquartile range

6.7.8 AER and Stratum Age Comparison

Changes in regulatory household AER standards, house construction year and building materials all contributed to indoor benzene levels (see Section 6.6.7). Correlations (α=0.05) between benzene levels, house age, and AER were determined using scatter plots (Figures 18 and 19) and Pearson correlation coefficient derived from SAS v.9.2 (see Appendix 22). For Figure 18, the x and y-axes for scatter plots A, B and C are: year of construction X benzene concentration ($\mu g/m^3$); AER (ACH) X benzene concentration ($\mu g/m^3$); and AER (ACH) X year of construction, respectively. For Figure 19, the x and y-axes for scatter plots D, E and F are: year of construction X benzene concentration ($\mu g/m^3$); AER (ACH) X benzene concentration ($\mu g/m^3$); and AER (ACH) X year of construction, respectively. Each point represents a home.

In scatter plots A (Figure 18) and D (Figure 19), the relationship between indoor benzene concentration and year of construction were examined. Both scatter plots showed a positive trend: as the year of construction increase, measurements of indoor benzene concentration increases as well. This pattern was especially noticeable in the summer. Pearson correlation coefficients (α=0.05) for winter and summer were consistent with the plots, 0.30 and 0.40, respectively. However, both correlations were not statistically significant at α=0.05 (Appendix 22), suggesting that alternative factor(s) maybe in play in winter and summer that is effecting the appearance of positive correlations.

In scatter plots B (Figure 18) and E (Figure 19), the relationship between indoor benzene concentration and AER were examined. Pearson correlation coefficients (α=0.05) for winter and summer (-0.06 and -0.24, respectively) inferred negative correlations, though summer correlation was 4 times stronger. Both correlations were statistically significant at α=0.05 (Appendix 22). It is speculated that the presence of newer building materials and more energy efficient designs in more recently built homes could contribute to the greater benzene concentrations sampled indoors, and vice versa.

In scatter plots C (Figure 18) and F (Figure 19), the relationship between year of construction and AER were examined. In scatter plot C, houses built before 1940 had the highest AER values observed; after 1940, the levels were more consistent and ranged between 0.4 and 0.1 ACH. In summer (see scatter plot F), majority of the points appeared to be relatively equally distributed between 0 to 1.5 ACH. Pearson correlation coefficients (α=0.05) for winter and summer (-0.52 and -0.17, respectively) suggested negative, albeit weak, correlations. Winter correlation was statistically significant at α=0.05 while summer's was not (Appendix 22). It is speculated that this discrepancy in correlation may be attributable to greater ventilation in the warmer months (windows and doors are opened more often) causing AER values to increase.

Next, benzene levels from strata 1,2, and 3 ("Old") dwellings were compared to strata 4 and 5 ("New") dwellings using t-tests (α=0.05) (Appendix 23 and Table 17). The winter groups were log-normally distributed while the summer groups were neither normal nor lognormal. Despite the differences in data distribution, t-tests were employed since they are generally robust against normality. New homes showed statistically higher benzene concentrations than Old homes in winter and summer. These results were consistent with findings regarding building materials and energy efficiency as discussed in Section 6.6.7.

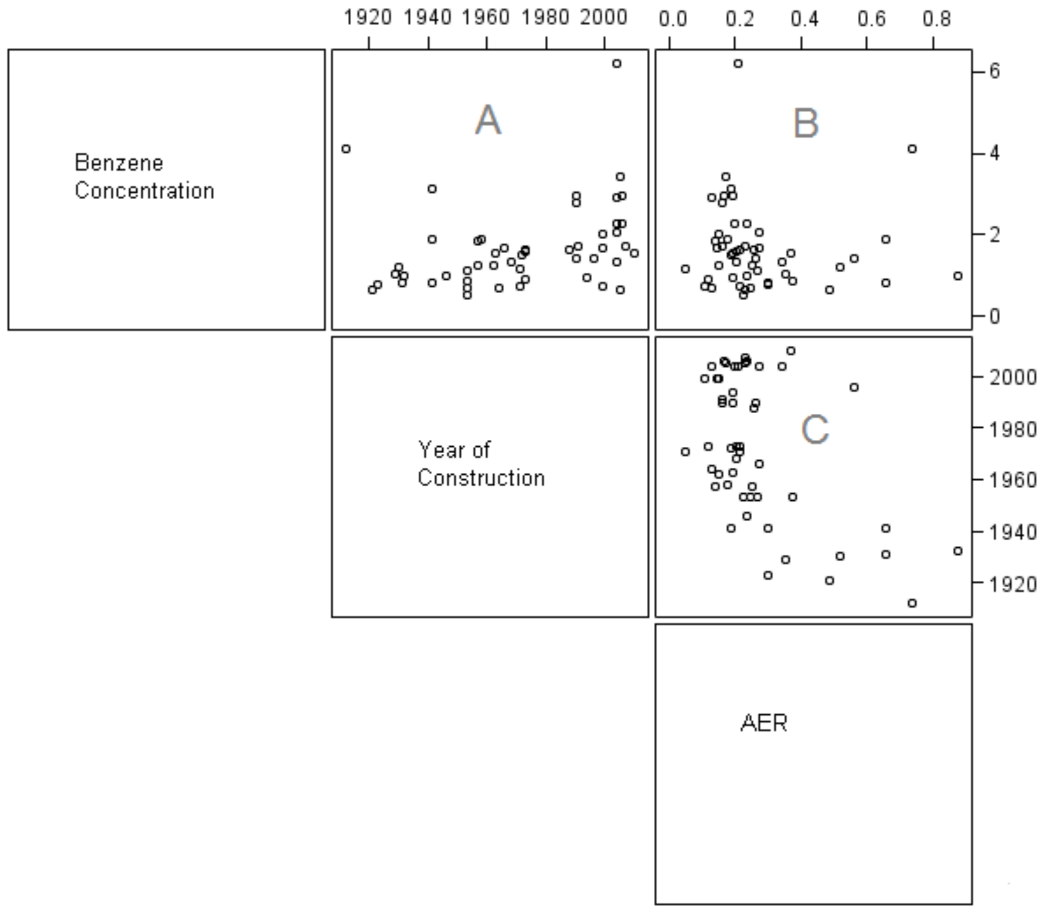

Figure 18 – Scatter plots showing trends among winter Edmonton indoor benzene levels, house construction year, and AER. The x and y-axes for scatter plots A, B and C are: year of construction X benzene concentration (μg/m^3); AER (ACH) X benzene concentration (μg/m^3); and AER (ACH) X year of construction, respectively.

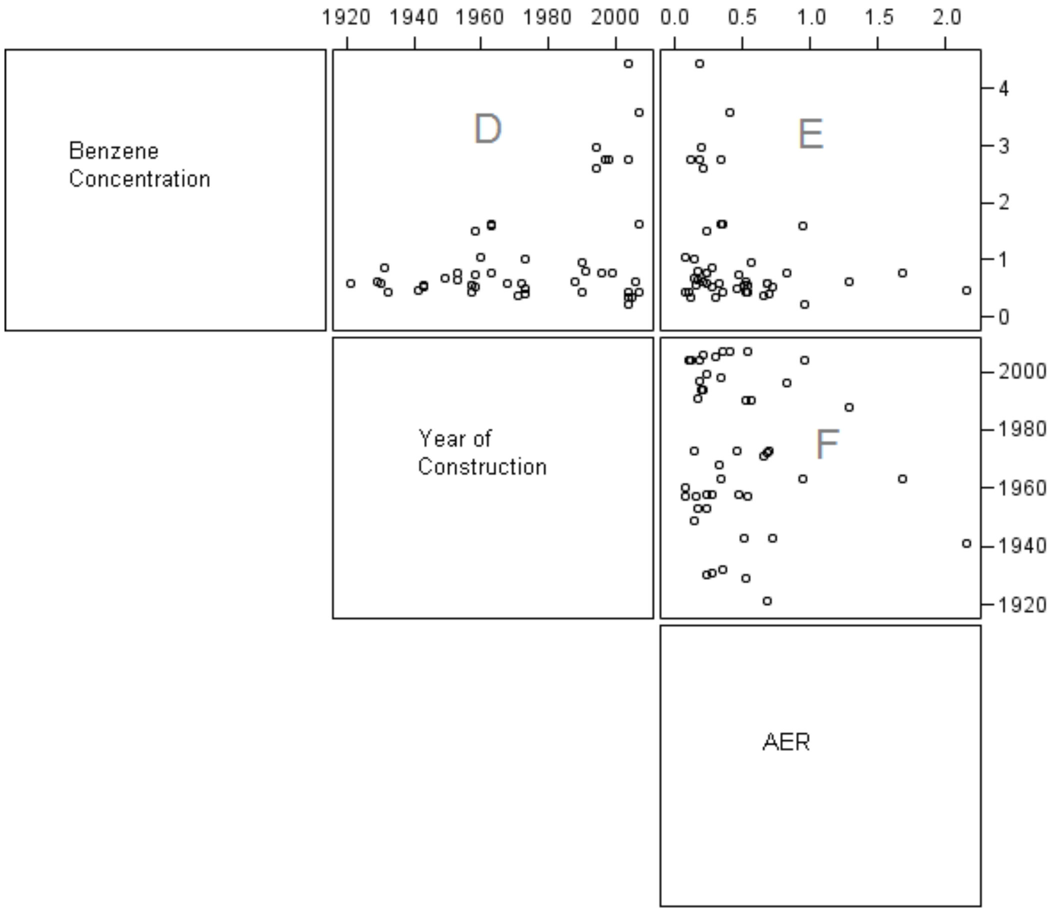

Figure 19 – Scatter plots showing trends among summer Edmonton indoor benzene levels, house construction year, and AER. The x and y-axes for scatter plots D, E, and F are: year of construction X benzene concentration (μg/m^3); AER (ACH) X benzene concentration (μg/m^3); and AER (ACH) X year of construction, respectively.

Table 17. Edmonton residential benzene concentrations (μg/m^3) between old and new homes (α=0.05).

Season	N	Old[1]				N	New[2]			
		Median	Mean	IQR	Max		Median	Mean	IQR	Max
Winter	30	1.2	1.3	0.5	4.1	20	1.9	2.2	1.4	6.2
Summer	27	0.6	0.7	0.3	1.6	20	0.8	1.5	2.3	4.4

N = number of participants
IQR = interquartile range
[1] Homes from Strata 1 to 3
[2] Participants from Strata 4 to 5

6.7.9 Multivariate Analysis

To gain a better understanding of the relationships between indoor residential benzene (dependent variable, y) and variables that are associated with benzene (independent, explanatory, or predictor variables, x_n), multiple linear regression (MLR) was done using SAS v.9.2. Based on the results from parametric and non-parametric tests done in Sections 6.6.1 to 6.6.8, the most pertinent indicator variables for indoor benzene were included into the MLR model.

Two factors that are associated with benzene concentration were excluded: Traffic volume and proximity to downtown core. This is because people are mostly affected by near-field sources rather than far-field ones (Wallace et al., 1985). The TEAM Studies in New Jersey demonstrated that pollutants in people's indoor microenvironments contributed more to their benzene exposures that from industrial petroleum refineries located near their homes (Wallace et al., 1985). Thus, irrespective of where measurements were made in Edmonton, indoor benzene concentration should not be significantly influenced by sources outside of individual's microenvironments. In addition, both traffic volume and distances from downtown core were not actually measured in this study but inferred from available sources (City of Edmonton website and ETS Map, respectively). Therefore, their true influences on benzene would not be as accurate as those that were measured with samplers, questionnaires, or taken from government house value assessment. Lastly, actual outdoor benzene concentrations from the outdoor VOC samples would be a more reliable, preferred measure of the influence of outdoor sources of benzene on indoor benzene concentration than inferred values of traffic volumes nearby and distances from downtown cores.

All other variables were included because studies have shown their significance in influencing indoor benzene concentrations (see Section 6.6). In addition, the values or categories of these factors were not estimated or inferred, but based on government statistical information and results from sampling and questionnaires. The variables selected for multivariate analysis were: season (winter and summer), mean daily outdoor benzene concentration from over 5 days of sampling, house value, house age (calculated as the year 2010, when the sampling was done, subtracted by the actual year the house was built), AER, garage type, and occupancy. Using SAS v.9.2, a model was created using step-wise selection.

For the numerically continuous variables like house values, AER, outdoor benzene concentration, house age, and occupancy, their raw values were used. Season was labeled as season_type (winter is coded as 1 and summer is coded as 0). Three variables were created to categorize garage types: GT1, which included those with no car and no garage and those with detached garage (types 1, 5 to 7 in Table 6); GT2, which included those with attached garage but no connecting door (types 8, 9 in Table 6); and GT3, which included those with attached garage and connecting door (types 2 to 4 in Table 6). To avoid co-linearity and instability in the model, only the GT variables were tested at a time, GT1 & GT2, as suggested by the biostatistician (Wang, 2012). Although house age was stratified as part of the design of the study and in the univariate analysis (Table 4), it was a better representation of the house age variable if it were analysed as continuous values. Thus, the house age was determined as 2010 (the year the samples were measured) minus the actual construction year of the home.

The exclusion criterion was $p < 0.05$ and of those selected in the step-wise analysis, only variables with p-values less than 0.05 were considered significant. The MLR model predicted that 37% of the indoor benzene concentration variability was explained by two significant predictors ($p < 0.05$): season and garage type (Appendix 24). This was based on the 99 participants that were sampled in the entire study (one was excluded because the AER data for thtat participant was invalid). Season (specifically winter, according to the univariate results in Section 6.7.2) is positively correlated with indoor benzene correlation while garage type 1 is negatively correlated.

7.0. Calculations of the ELCR for leukemia in Edmonton

The ELCR of leukemia in the City of Edmonton for homes with non-smoking residents was calculated using Eq. 2, as shown in below:

$$ELCR = IUR\ (\mu g/m^3)^{-1} \times CA\ (\mu g/m^3) \qquad \textbf{(Eq. 2)}$$

A ELCR range was calculated using the lower and upper-bound IUR estimates of 2.2×10^{-6} to 7.8×10^{-6}, respectively, for an adult constantly exposed to 1 $\mu g/m^3$ of benzene in the air over their lifetime (default lifetime duration is 70 years) (U.S. EPA, 2002). The CA is the indoor benzene measurements deduced from the EIAQS. Calculations of the ELCR range were done using indoor mean and median benzene concentrations.

From Table 19, the mean indoor benzene concentration was 1.4 $\mu g/m^3$ and the resultant ELCR range was calculated as follows:

$$\text{Lower-bound estimate of ELCR} = IUR\ (\mu g/m^3)^{-1} \times CA\ (\mu g/m^3)$$

$$= 2.2 \times 10^{-6} \text{ per } \mu g/m^3 \times 1.4\ \mu g/m^3$$

$$= 3.1 \times 10^{-6}$$

$$\text{Upper-bound estimate of ELCR} = IUR\ (\mu g/m^3)^{-1} \times CA\ (\mu g/m^3)$$

$$= 7.8 \times 10^{-6} \text{ per } \mu g/m^3 \times 1.4\ \mu g/m^3$$

$$= 10.9 \times 10^{-6}$$

From Table 19, the median indoor benzene concentration was 1.1 $\mu g/m^3$ and the resultant ELCR range was calculated as follows:

$$\text{Lower-bound estimate of ELCR} = IUR\ (\mu g/m^3)^{-1} \times CA\ (\mu g/m^3)$$

$$= 2.2 \times 10^{-6} \text{ per } \mu g/m^3 \times 1.1\ \mu g/m^3$$

$$= 2.4 \times 10^{-6}$$

$$\text{Upper-bound estimate of ELCR} = \text{IUR } (\mu g/m^3)^{-1} \text{ x CA } (\mu g/m^3)$$

$$= 7.8 \times 10^{-6} \text{ per } \mu g/m^3 \times 1.1\ \mu g/m^3$$

$$= 8.6 \times 10^{-6}$$

7.1 Alberta Leukemia Risk Rate and Edmonton ELCR from Indoor Benzene Exposure

The LCR of leukemia in Alberta is about 1,540 cases per 100,000 people (Canadian Cancer Society, 2011). The ELCR ranges of leukemia in Edmonton calculated with the mean and median indoor benzene concentrations were 3.1 x 10^{-6} to 1.1 x 10^{-5} and 2.4 x 10^{-6} to 0.9 x 10^{-5}, respectively. As a conservative estimate, the upper value of the ELCR range was used and it was inferred that approximately 1 case of leukemia per 100,000 people in their lifetimes could be attributed to indoor residential benzene exposure for person living in a single-detached dwelling in the City of Edmonton out the of 1,540 expected cases of leukemia in 100,000 Albertans. This is an extremely small risk relative to the background.

Aside from benzene exposure, other environmental risk factors for leukemia identified include high-dose radiation (Noschenko et al., 2010; Kaldor et al., 1990), pesticides (Infante-Rivard et al., 1999), smoking (Chang, 2009), deficiency in micronutrients such as zinc (Sandstead et al., 2008) and magnesium (Slahin et al., 2000), and certain cancer treatment agents such as alkylating agents (e.g. mechlorethamine) (van Leeuwen et al., 1994) and chemotherapeutic agents (e.g., cyclophosphamide and chlorambucil) (Kaldor et al., 1990).

People who are genetically more susceptible to leukemia include those with Down's Syndrome (Hasle et al., 2000), Fanconi anemia (Rosenberg et al., 2003), and ataxia telangiectasia (Taylor et al., 1996).

8.0 Conclusions

The purpose of this study was to determine which factors were correlated to higher and lower concentrations of benzene in Edmonton residential homes. The study was done in winter and summer of 2011. Numerous air pollutants were measured but in-depth analysis focused solely on benzene due to its potential carcinogenicity and prevalence in the environment. Multiple objectives were established to fulfill the primary purpose of this study.

First, seasonal indoor and outdoor residential benzene levels were determined and presented in Tables 9, 18, and 19 to compare winter-summer, indoor-outdoor, and international ambient and indoor benzene levels. Paired and independent t-tests supported that there were statistical differences between winter-summer and indoor-outdoor benzene levels.

Secondly, ambient residential benzene levels were not statistically different between houses with highest and lowest inferred traffic volumes that were within 250 m of roadways. This indicates that vehicular benzene emissions from nearby traffic roadways may not be important contributors to backyard ambient residential benzene exposure. Analyzing household proximity from Edmonton downtown core showed that Group 4000 had the highest levels in both seasons, while Group 0 was equivalent to and greater than Group 8000 in winter and summer, respectively. These findings were contrary to the hypothesis and other studies (Perry and Gee, 1993; Cheng et al., 1997; Lei and Wang, 2005; Elbir et al., 2007) that found greater levels of benzene in high-volume traffic urban cores. This may be explained by Group 4000's close proximity to heavy industrial areas concentrated in the Edmonton East, such as the Sherwood Park Industrial Corridor. Results from the EIAQS were incongruent with other scientific literature and of limited scientific value because of possible confounding from small sample sizes, such as biased observations.

The remainder of the analyses was focused on indoor residential benzene concentrations. Socioeconomic status was approximated using house values found on the City of Edmonton website. Households with the highest and lowest house values had equivalent indoor benzene levels in wintertime. However, benzene levels were two-fold greater from the highest valued homes than the lowest valued homes (Table 13). By inference, families with higher SES living in higher valued homes may be exposed to greater levels of indoor benzene than those from families with lower SES. But the limitation of small sample sizes truly reduced the value of the analysis.

Another objective was to determine whether the type of garage led to differences in benzene levels. Results showed that houses with attached garages had statistically higher levels than houses with attached garages but no connecting door or detached garages, which were consistent with results from other similar studies. Results also demonstrated that homes with a greater number of occupants resulted in higher benzene levels in the winter; but number of occupants were not significant in the summer. This inconsistency implicated the importance of seasonal influences. Finally, correlations among AER, strata and benzene were investigated. Benzene and construction year were not correlated; AER and construction year was only significant correlated in the winter but not in the summer; and AER and benzene were significantly correlated in both seasons. Although house age showed no correlations to benzene levels, indoor benzene levels were higher in the households from strata 4 and 5 than those from 1 to 3. As mentioned before, these analyses (garage type, number of occupants, AER, stratum, and house age) are of limited value because of confounding from small sample sizes.

A MLR model using step-wise selection regression was created using SAS v.9.2 with an exclusion criterion of $p < 0.05$. It predicted that 37% of indoor benzene variability was predicted by garage type and season. Those without garages and with detached garages were negatively correlated to indoor benzene concentration. This was consistent with the univariate analysis results (Section 6.7.6), which showed that homes with attached garages had higher levels of benzene than those detached or no garages. The significance of benzene concentrations from attached garages with connecting doors was consistent with the results from Stocco et al. (2008) where they found that people who lived in homes with attached garages had higher levels of VOC exposure than those living in homes that did not have attached garages. This was likely explained by findings that showed garages had high levels of benzene (37 $\mu g/m^3$) and that most of the benzene inside the homes were originated from the garage since 6.5% of the house's airflow originated from the garage (Batterman et al., 2007). Season was the second most influential variable to indoor benzene concentration. There was a positive correlation (Appendix 24) to winter, as indicated by the univariate analysis results in Section 6.7.2. This was also consistent to findings from the

TEAM Studies (Wallace et al., 1986; Wallace et al., 1987; Wallace et al., 1988) and Canadian air quality studies (Otson and Fellin, 1992; Otson et al., 1992; Heroux et al., 2008). They found that winter levels of benzene were statistically higher than summer levels. Results from EIAQS indicated a positive correlation as a result of how the seasons were coded (summer = 0, winter =1).

Part of this study was to estimate the lifetime leukemia risk of the non-smoking adult population residing in single-detached homes in Edmonton. Benzene exposure was hypothesized to be low since smoking is a known major contributor of benzene (Wallace, 1996) and the smoking population was not included as part of the sampling population. However small the risk may be, it was valuable to estimate the inferred lifetime leukemia risk for those that do not smoke to understand the relevance of indoor residential benzene has on the non-smoking sub-population's health. Furthermore, since the risk from exposure to residential indoor benzene appears to be small, research focus may be shifted to other areas to determine what the major contributors to benzene exposure are for non-smoking individuals.

Out of an estimated 1,540 lifetime risk of leukemia per 100,000 people in Edmonton, ≤ 1 case would be attributed to residential indoor benzene levels from single-detached dwellings of non-smoking residents, based on the findings of this study. Despite the low risk of leukemia attributable to exposure from indoor benzene, it should be reminded that this study did not include personal monitoring (which traditionally would yield sampling values greater than from indoor sampling) nor the smoking population in Edmonton (who would have a significantly greater lifetime risk of leukemia).

9.0 Recommendations

This study employed a wide range of approaches to collect exposure data, including air samplers, questionnaires, and diaries. Although the method was meticulously designed by Health Canada, the data could not be considered comprehensive for analysis of benzene exposure. Below are three recommendations to improve data quality:

1. Traffic volume near homes may affect residential benzene levels yet this information was not acquired during the sampling period. To determine the number of vehicles passing by a house, car counters could be set up in front of homes. This would be more accurate then estimating traffic volumes using maps.
2. Even though the questionnaire included questions regarding household income, the data were still incomplete because some people did not want to divulge the information or they may have inflated the data during the interview. Thus, a more accurate way to determine one's SES was to find his/her household value, which should not be difficult to research since house values were collected annually by the municipal government for tax purposes. In addition, the income ranges given in the questionnaires were not adjusted to the City of Edmonton but designed to be applicable across Canada. As a result, the majority of EIAQS participants belonged to the intermediate salary range on the Baseline Questionnaire ($35,000-$80,000) because the division was not distinct enough to test the differences of incomes (or SESs) on benzene exposures. The ranges

should be designed to match the average income of the citizens based on the province.

3. There could be more questions regarding occupancy to obtain more information, such as the age groups of residents in the homes. By finding out the number of children, adults, and seniors in a household, exposure assessment could be more comprehensive because different age groups usually have different activity patterns that could affect the importance of certain microenvironments and ultimately, benzene exposures.

Community-based environmental research encompasses many different approaches and it could pose obstacles for researchers when deciding on the most appropriate approach to conducting air quality study. The following are three recommendations for possible future research:

1. Conduct a similar study with similar selection criteria except participants or a resident in the household must be a smoker. The results from such a study could lead to a comparisons of benzene concentrations and lifetime leukemia risks for the smoking and non-smoking populations in Edmonton.
2. An investigation of air pollution model regarding residential ambient benzene levels in the City of Edmonton to explain why Edmonton East had much higher levels of benzene than the downtown core.
3. A similar study in different settings (i.e. in vehicles, offices, schools, and restaurants) examining the same multitude of air pollutants in the City of

Edmonton to obtain a comprehensive exposure assessment of residents in Edmonton in order to effectively improve air quality.

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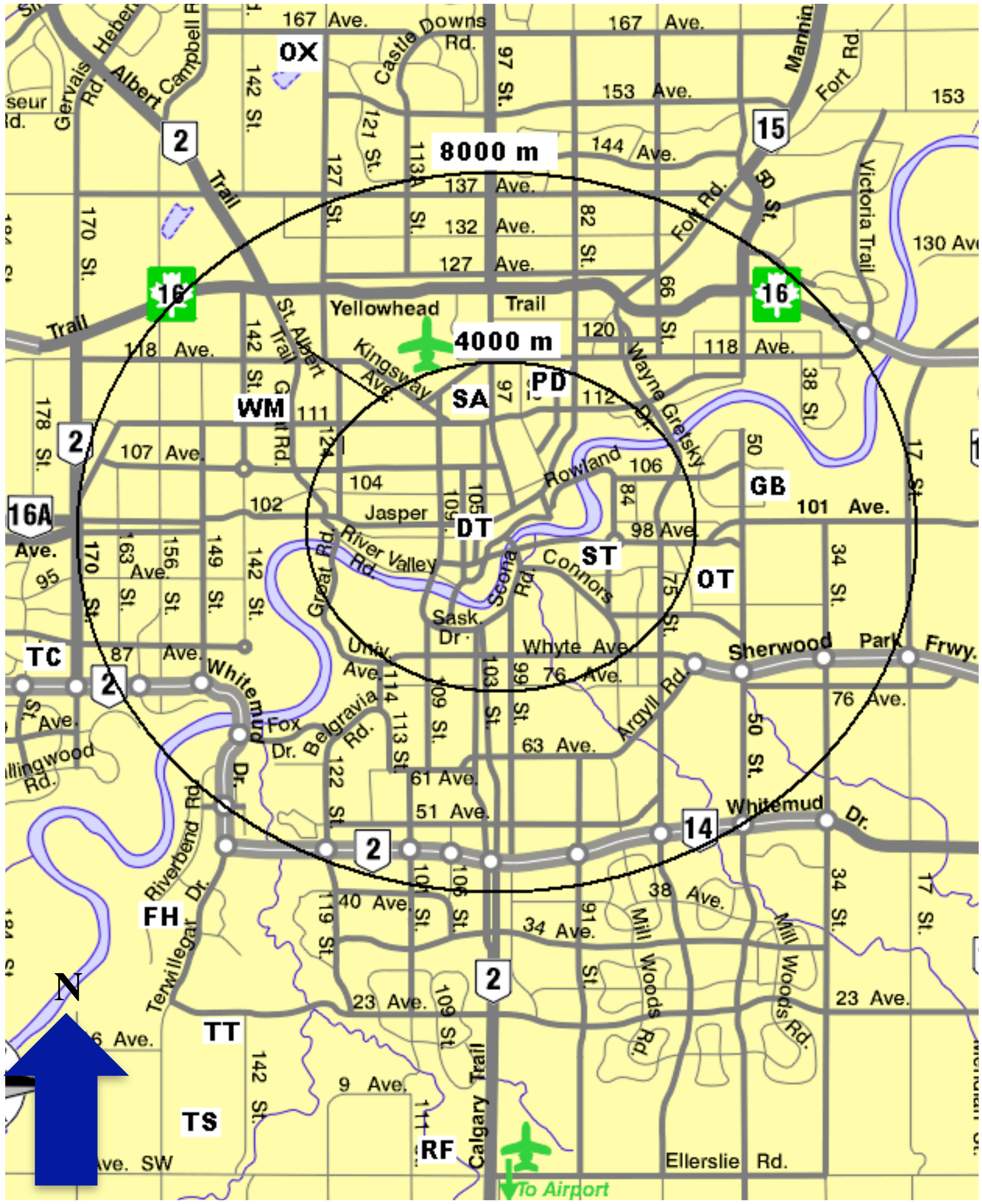
11.0 Appendices

Appendix 1 – Map of Edmonton, Alberta with approximate locations of downtown core, neighbourhoods and 4000 m perimeter from downtown core and 8000 m perimeter from downtown core (adopted from Public Works and Government Services Canada, 2010).

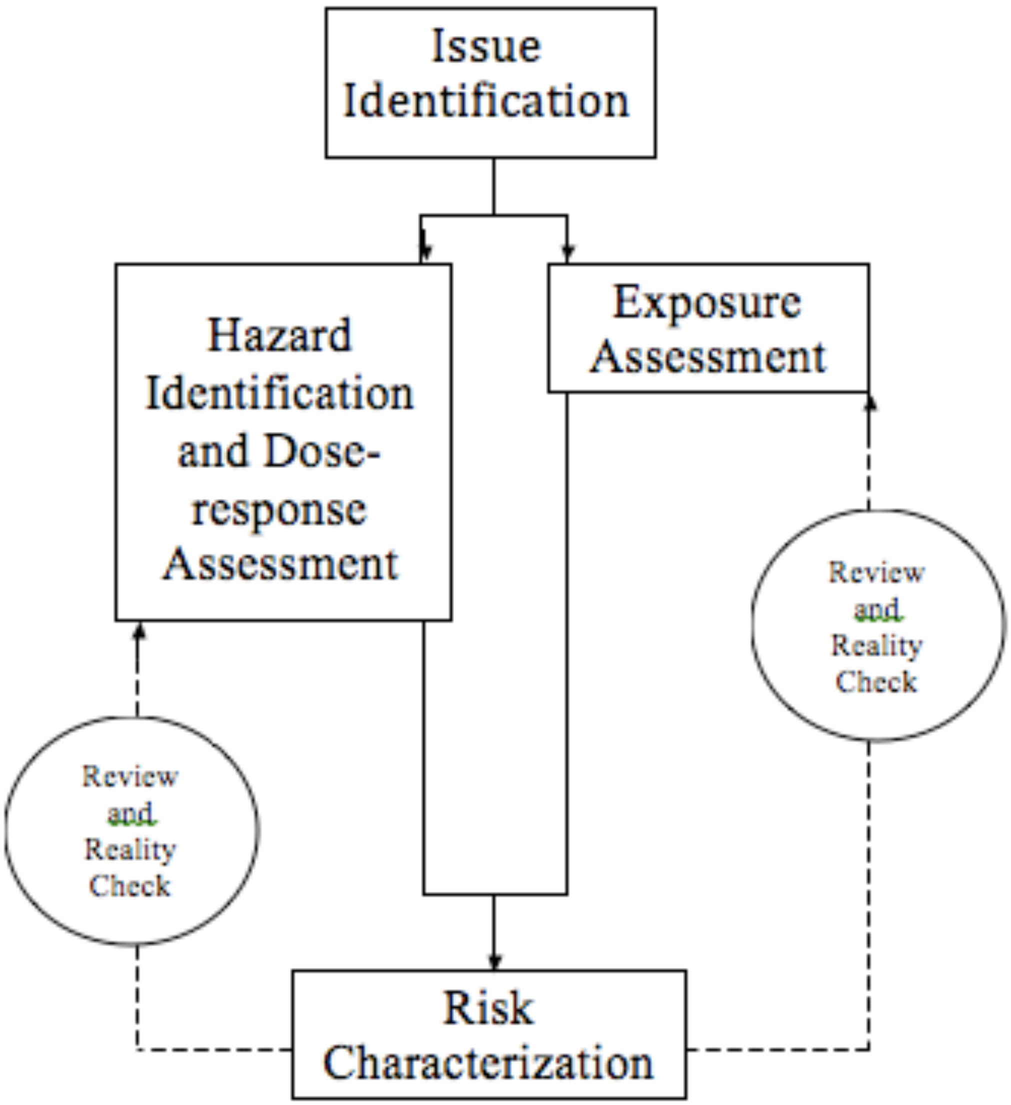
Abbreviations:

DT	Downtown Core (Bay/Enterprise Square LRT Station)
PD	Parkdale
SA	Spruce Avenue
ST	Strathearn
WM	Westmount
OT	Ottewell
GB	Gold Bar
RF	Richford
TT	Terwillegar Towne
TS	Terwillegar South
TC	Thorncliff
OX	Oxford



8000 m
4000 m
OX
WM
SA
PD
DT
ST
OT
GB
TC
FH
TT
TS
RF
N
167 Ave.
153 Ave.
144 Ave.
137 Ave.
132 Ave.
127 Ave.
118 Ave.
107 Ave.
101 Ave.
98 Ave.
87 Ave.
76 Ave.
63 Ave.
61 Ave.
51 Ave.
40 Ave.
38 Ave.
34 Ave.
23 Ave.
9 Ave.
Castle Downs Rd.
St. Albert Trail
Yellowhead Trail
Kingsway Ave.
Wayne Gretzky Dr.
Fort Rd.
Victoria Trail
Rowland
Jasper
River Valley Rd.
Connors
Sask. Dr.
Whyte Ave.
Sherwood Park Frwy.
Whitemud Dr.
Argyll Rd.
Fox Dr.
Belgravia Rd.
Riverbend Rd.
Terwillegar Dr.
Mill Woods Rd.
Calgary Trail
Ellerslie Rd.
To Airport
97 St.
142 St.
170 St.
178 St.
149 St.
156 St.
50 St.
34 St.
17 St.
75 St.
82 St.
91 St.
109 St.
119 St.
122 St.

Appendix 2 - Environmental risk assessment model (adapted from enHealth, 2002)



Appendix 3 – Cover Letter with general information

Health Canada Santé Canada

SCHOOL OF PUBLIC HEALTH UNIVERSITY OF ALBERTA

March 23, 2010

Dear Homeowner,

Would you be interested in participating in a Residential Indoor Air Quality Study funded by the federal government? This is a joint project between Health Canada and University of Alberta to study the air quality inside people's homes in Edmonton to develop and update Health Canada's Residential Indoor Air Quality Guidelines. Similar studies have been completed in other cities in Canada. Homeowners would benefit by receiving individualized reports in regards to the air pollutant concentrations within their homes. More general information about this study can be found on the following page.

Your participation is greatly appreciated.

Sincerely,

Fayanna Li, Ph.D.
Project Coordinator
School of Public Health
University of Alberta
10-126B Clinical Sciences Building
11350 - 83 Avenue
Edmonton, AB T6G 2G3
Phone: (780) 248-2053

Health Canada Santé Canada

SCHOOL OF PUBLIC HEALTH UNIVERSITY OF ALBERTA

GENERAL INFORMATION – WINTER 2010

Residential Indoor Air Quality Study in Edmonton, Alberta

Who is conducting this study?

This study is a project of Health Canada, conducted in collaboration with the Department of Public Health Sciences of University of Alberta.

What is the study about? –

The focus is on understanding air quality inside people's homes in Edmonton, and how the local external and residential environments influence levels of indoor air pollutants. Tenants of rental properties will be excluded from participating in this study due to liability issues. The study involves measuring concentrations of various pollutants inside and outside houses, and noting the characteristics of these houses by means of questionnaires administered to one of the adult occupants. Air concentrations will be measured in winter 2010. If they agree, participants will be contacted again to have the same parameters measured in their homes during summer 2010.

In total, the study involves nine visits to the residence (see attached calendar):

- pollutants will be measured continuously inside and outside the home each day across an eight-day sampling period (or 7 consecutive periods of 24-hours);
- house dust will be collected on a visit scheduled separately.

On the first visit, the participant will be asked to sign the consent form, while the technicians will install the monitors. This visit will last approximately 2 hours.

On the next 7 visits, the participant will be asked to fill in a daily diary questionnaire. This short questionnaire will collect information on events that occurred during the measurement period and could influence the results (e.g. use of a fireplace, cooking activities, using household cleansers, doing housework or absences from the home). Each visit will last around 30 minutes.

On a separate visit, house dust will be collected. In order to sample enough dust, the participant will be asked not to vacuum the home for one week prior to the sampling. Also, a baseline questionnaire will be administered by an interviewer. Through this questionnaire, information on the characteristics of the house and certain habits of the occupants that are likely to affect air quality will be collected. No personal identifying information will be collected.

The air quality monitors will be installed out of reach of young children. These devices make a small amount of noise, similar to having a fan operating in the room. Participants are asked not to touch them at all during the entire sampling period.

Why are we doing this study?

This study is being done in order to gather information on exposure to indoor air pollutants in homes. This information will be used to develop and update Health Canada's Residential Indoor Air Quality Guidelines.

How will my participation in the study benefit me?

All participants in the study will receive an individual report describing concentrations of pollutants measured in their home at the end of the study. If some of these measurements exceed the levels recommended by Health Canada, the participants will be informed of this; the notice will also contain practical advice for reducing exposure to residential indoor airborne pollutants.

Compensation

Upon completion of the study, the participants will receive $25.00 per season for which they have participated, to cover the power supply used by the monitoring devices.

Will I be able to withdraw from the study while it is under way?

Yes. You need only notify the project coordinator (information on how to contact the project coordinator is given at the bottom of this document). If you decide to withdraw during sampling, samples collected at your home will not be analyzed. As such, any results from your home will not be reported to you, and you will not be entitled to the compensation.

Will my name be made public?

No. The information identifying you will be kept only for the purpose of contacting you, if necessary. For example, if a situation appears to present an immediate danger, the research team will take the necessary measures to advise the homeowner and anyone who might be present in the home as soon as possible. Moreover, the principal investigator at University of Alberta will be required to notify the Alberta Health Services Medical Officer of Health for Capital Region who will take corrective action.

The reports that will be published at the end of the study will contain no information that could be used to identify the participants; the reports will only contain statistics on the participants as a whole.

The participants' names and contact information will be kept strictly confidential and will be retained at the Department of Public Health Sciences of University of Alberta for a period of 2 years, after which it will be shredded.

Who are the research team members?

Warren Kindzierski, Ph.D.
University of Alberta, Department of Public Health Sciences
Tel.: 780-492-0382; Email: warren.kindzierski@ualberta.ca;

Marie-Ève Héroux
Health Canada, Air Quality Programs Division
Tel.: 613 957-3490; Email: marie-eve_heroux@hc-sc.gc.ca

Amanda Wheeler
Health Canada, Exposure Assessment Section
Tel.: 613-948-3686; Email: amanda_wheeler@hc-sc.gc.ca

Who can provide me with more information?

Fayanna Li, the project coordinator
University of Alberta at 780-248-2053

Appendix 4 - Screening Questionnaire used during recruitment

Health Canada Santé Canada

SCREENING QUESTIONNAIRE/ SCRIPT
Residential Indoor Air Quality Study in Edmonton, Alberta

ID: ________________ **Date:** ____________________

Name (LAST, First): __________________________ **Phone number:** ________________

Hello, this is (CALLER'S NAME) ____________________ calling from University of Alberta in Edmonton.

As part of a larger project sponsored by Health Canada, we are conducting a study of indoor air quality in homes in Edmonton Municipality this winter. The study involves nine visits to your home over a two week period. You will receive the results of the air quality tests and $25 to cover the cost of electricity for the sampling devices. ***Would you be interested in seeing if your home qualifies to be included in the study?***

Yes .... [GO TO QUESTION 1]
No................ [THANK AND TERMINATE]

1. Do you **own your home?**

Yes .... [GO TO QUESTION 2]
No................ [THANK AND TERMINATE]

2. **Which of the following best describes your home?** [READ CATEGORIES]

Single detached house
Duplex/triplex (semi-detached house);
Mini or Mobile home;
Row house
Other, please specify: ______________ .... [THANK AND TERMINATE]

3. **Are there any smokers (including yourself) living in your home?**

Yes .... [THANK AND TERMINATE]
No................ [GO TO QUESTION 4]

4. **Do you have a back yard?**

Yes .... [GO TO QUESTION 5]
No................ [THANK AND TERMINATE]

[NEXT PAGE]

5. **In what year was your home built? If you are unsure please give me your best guess** [DO NOT READ CATEGORIES; FILL IN DATE AND CHECK APPROPRIATE BOX]

   ______ Year

   1945 or before
   1946-1960
   1961-1980
   1981-2000
   2004-2009

6. **Which of the following type of stove do you generally use for cooking?** [READ CATEGORIES, DO NOT INCLUDE MICROWAVE OVENS]

   Electric stove
   Propane stove
   Natural gas stove
   Other, please specify: ________________________

7. **Would you be available to have sampling equipment placed in your home for a period of a week in January, 2010?**

   Yes ....
   No................ [GO TO QUESTION 8]

8. **When would be a convenient time to have the sampling equipment placed in your home?**

   February
   March
   April
   A specific time period, please specify: ________________________________

   Anytime ***except*** a specific time period, please specify: ____________________

   No [THANK AND TERMINATE]

*If you are selected to participate in the study, it would involve nine visits to your home over a two week period, an interview about your home, having monitoring devices installed for 7 consecutive days in the main living area of your house and also in your backyard, keeping a daily diary to record activities occurring during monitoring that may influence air quality, and a separate visit in which a dust sample will be collected. For that final visit, you will be asked **not** to vacuum your living room for one week prior to the dust sampling.*

Address:_________ Edmonton, Winter 2010

As I mentioned, each participant will receive a confidential report at the end of the study that describes the level of certain air pollutants in his or her home. The report will also include advice on reducing air pollutants in the home. An amount of $25 will be paid to cover the cost of electricity used by the monitoring devices. This study will also be repeated in the summer of 2010. If you choose, you will have the opportunity to take part in this second round of sampling.

There are no other requirements for participating in this study and participation is entirely voluntary. Would you like your home to be considered for inclusion in the study?

Yes ↓
No................ [THANK AND TERMINATE]

Thank you. We will be reviewing all of the responses to make sure that we can collect information on homes of different ages. If your home is chosen to be part of the study, you will be contacted next week to be enrolled in the study.

Is there any other phone number where you can easily be reached to make an appointment?

____

May I take down your name?

____

In the meantime, should you have any questions, please do not hesitate to call Fayanna Li at University of Alberta, at (780) 248-2053. Thank you, and have a good day.

Appendix 5 – Monthly scheduling template designed by Health Canada

MARCH 2010						
Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	2	3	4	5	6	7
Follow-up $_4$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_5$** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_6$** **Tasks:** - Team 3 goes to the NAPs Station	**Take down** **Tasks:** - Team 3 goes to the NAPs Station **Day off:** - Lab techs	**Day off:** - Project Coordinator - Field Techs - Lab techs	**Day off:** - Project Coordinator - Field Techs - Lab techs	**Day off:** - Project Coordinator - Field Techs
8	9	10	11	12	13	14
PERIOD 6: **Set-up day** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_1$** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_2$** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_3$** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_4$** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_5$** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_6$** **Tasks:** - Team 3 goes to the NAPs Station
15	16	17	18	19	20	21
Take down **Tasks:** - Team 3 goes to the NAPs Station **Day off:** - Lab techs	**Day off:** - Project Coordinator - Field Techs - Lab techs	**Day off:** - Project Coordinator - Field Techs	**PERIOD 7:** **Set-up day** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_1$** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_2$** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_3$** **Tasks:** - Team 3 goes to the NAPs Station
22	23	24	25	26	27	28
Follow-up $_4$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_5$** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up $_6$** **Tasks:** - Team 3 goes to the NAPs Station	**Take down** **Tasks:** - Team 3 goes to the NAPs Station **Day off:** - Lab techs	**Day off:** - Project Coordinator - Field Techs - Lab techs	**Day off:** - Project Coordinator - Field Techs - Lab techs	**Day off:** - Project Coordinator - Field Techs

JANUARY 2010

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
				1	2	3
4	5	6	7	8	9	10
11	12	13	14 **PERIOD 1:** **Set-up day**	15 **Follow-up** 1 **Tasks:** - Team 3 goes to the NAPs Station	16 **Follow-up** 2 **Tasks:** - Team 3 goes to the NAPs Station	17 **Follow-up** 3 **Tasks:** - Team 3 goes to the NAPs Station
18 **Follow-up** 4 **Tasks:** - Team 3 goes to the NAPs Station	19 **Follow-up** 5 **Tasks:** - Team 3 goes to the NAPs Station	20 **Follow-up** 6 **Tasks:** - Team 3 goes to the NAPs Station	21 **Take down** **Tasks:** - Team 3 goes to the NAPs Station **Day off:** - Lab techs	22 **Day off:** - Project Coordinator - Field Techs - Lab techs	23 **Day off:** - Project Coordinator - Field Techs - Lab techs	24 **Day off:** - Project Coordinator - Field Techs
25 **PERIOD 2:** **Set-up day** **Tasks:** - Team 3 goes to the NAPs Station	26 **Follow-up** 1 **Tasks:** - Team 3 goes to the NAPs Station	27 **Follow-up** 2 **Tasks:** - Team 3 goes to the NAPs Station	28 **Follow-up** 3 **Tasks:** - Team 3 goes to the NAPs Station	29 **Follow-up** 4 **Tasks:** - Team 3 goes to the NAPs Station	30 **Follow-up** 5 **Tasks:** - Team 3 goes to the NAPs Station	31 **Follow-up** 6 **Tasks:** - Team 3 goes to the NAPs Station

FEBRUARY 2010						
Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	2	3	4	5	6	7
Take down **Tasks:** - Team 3 goes to the NAPs Station **Day off:** - Lab techs	**Day off:** - Project Coordinator - Field Techs - Lab techs	**Day off:** - Project Coordinator - Field Techs	**PERIOD 3:** **Set-up day** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_1$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_2$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_3$ **Tasks:** - Team 3 goes to the NAPs Station
8	9	10	11	12	13	14
Follow-up $_4$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_5$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_6$ **Tasks:** - Team 3 goes to the NAPs Station	**Take down** **Tasks:** - Team 3 goes to the NAPs Station **Day off:** - Lab techs	**Day off:** - Project Coordinator - Field Techs - Lab techs	**Day off:** - Project Coordinator - Field Techs - Lab techs	**Day off:** - Project Coordinator - Field Techs
15	16	17	18	19	20	21
PERIOD 4: **Set-up day** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_1$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_2$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_3$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_4$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_5$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_6$ **Tasks:** - Team 3 goes to the NAPs Station
22	23	24	25	26	27	28
Take down **Tasks:** - Team 3 goes to the NAPs Station **Day off:** - Lab techs	**Day off:** - Project Coordinator - Field Techs - Lab techs	**Day off:** - Project Coordinator - Field Techs	**PERIOD 5:** **Set-up day** **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_1$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_2$ **Tasks:** - Team 3 goes to the NAPs Station	**Follow-up** $_3$ **Tasks:** - Team 3 goes to the NAPs Station

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
29 **PERIOD 8:** **Set-up day** **Tasks:** - Team 3 goes to the NAPs Station	30 **Follow-up $_1$** **Tasks:** - Team 3 goes to the NAPs Station	31 **Follow-up $_2$** **Tasks:** - Team 3 goes to the NAPs Station				

APRIL 2010						
Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
			1 **Follow-up $_3$** **Tasks:** - Team 3 goes to the NAPs Station	2 **Follow-up $_4$** **Tasks:** - Team 3 goes to the NAPs Station	3 **Follow-up $_5$** **Tasks:** - Team 3 goes to the NAPs Station	4 **Follow-up $_6$** **Tasks:** - Team 3 goes to the NAPs Station
5 **Take down** **Tasks:** - Team 3 goes to the NAPs Station **Day off:** - Lab techs	6 **Day off:** - Project Coordinator - Field Techs - Lab techs	7 **Day off:** - Project Coordinator - Field Techs	8 **PERIOD 9:** **Set-up day** **Tasks:** - Team 3 goes to the NAPs Station	9 **Follow-up $_1$** **Tasks:** - Team 3 goes to the NAPs Station	10 **Follow-up $_2$** **Tasks:** - Team 3 goes to the NAPs Station	11 **Follow-up $_3$** **Tasks:** - Team 3 goes to the NAPs Station
12 **Follow-up $_4$** **Tasks:** - Team 3 goes to the NAPs Station	13 **Follow-up $_5$** **Tasks:** - Team 3 goes to the NAPs Station	14 **Follow-up $_6$** **Tasks:** - Team 3 goes to the NAPs Station	15 **Take down** **Tasks:** - Team 3 goes to the NAPs Station **Day off:** - Lab techs	16 **Day off:** - Project Coordinator - Field Techs - Lab techs	17 **Day off:** - Project Coordinator - Field Techs - Lab techs	18

June 2010						
SUNDAY	**MONDAY**	**TUESDAY**	**WEDN.**	**THURS.**	**FRIDAY**	**SATURDAY**
		1	2	3 PERIOD 1: Set-up day **Task:** **-Team 3 goes to the NAPs Station**	4 Follow-up $_1$ **Task:** **-Team 3 goes to the NAPs Station**	5 Follow-up $_2$ **Task:** **-Team 3 goes to the NAPs Station**
6 Follow-up $_3$ **Task:** **-Team 3 goes to the NAPs Station**	7 Follow-up $_4$ **Task:** **-Team 3 goes to the NAPs Station**	8 Follow-up $_5$ **Task:** **-Team 3 goes to the NAPs Station**	9 Follow-up $_6$ **Task:** **-Team 3 goes to the NAPs Station**	10 Take down **Task:** **-Team 3 goes to the NAPs Station** Day off: - Lab techs	11 Day off: - Proj. Coord. - Field Techs - Lab techs	12 Day off: - Proj. Coord. - Field Techs - Lab techs
13 Day off: - Proj. Coord. - Field Techs	14 PERIOD 2: Set-up day **Task:** **-Team 3 goes to the NAPs Station**	15 Follow-up $_1$ **Task:** **-Team 3 goes to the NAPs Station**	16 Follow-up $_2$ **Task:** **-Team 3 goes to the NAPs Station**	17 Follow-up $_3$ **Task:** **-Team 3 goes to the NAPs Station**	18 Follow-up $_4$ **Task:** **-Team 3 goes to the NAPs Station**	19 Follow-up $_5$ **Task:** **-Team 3 goes to the NAPs Station**
20 Follow-up $_6$ **Task:** **-Team 3 goes to the NAPs Station**	21 Take down **Task:** **-Team 3 goes to the NAPs Station** Day off: - Lab techs	22 Day off: - Proj. Coord. - Field Techs - Lab techs	23 Day off: - Proj. Coord. - Field Techs	24 PERIOD 3: Set-up day **Task:** **-Team 3 goes to the NAPs Station**	25 Follow-up $_1$ **Task:** **-Team 3 goes to the NAPs Station**	26 Follow-up $_2$ **Task:** **-Team 3 goes to the NAPs Station**
27 Follow-up $_3$ **Task:** **-Team 3 goes to the NAPs Station**	28 Follow-up $_4$ **Task:** **-Team 3 goes to the NAPs Station**	29 Follow-up $_5$ **Task:** **-Team 3 goes to the NAPs Station**	30 Follow-up $_6$ **Task:** **-Team 3 goes to the NAPs Station**			

July 2010						
SUNDAY	**MONDAY**	**TUESDAY**	**WEDN.**	**THURS.**	**FRIDAY**	**SATURDAY**
				1 **Take down** **Task:** **-Team 3 goes to the NAPs Station** **Day off:** - Lab techs	2 **Day off:** - Proj. Coord. - Field Techs - Lab techs	3 **Day off:** - Proj. Coord. - Field Techs - Lab techs
4 **Day off:** - Proj. Coord. - Field Techs	5 **PERIOD 4:** **Set-up day** **Task:** **-Team 3 goes to the NAPs Station**	6 **Follow-up $_1$** **Task:** **-Team 3 goes to the NAPs Station**	7 **Follow-up $_2$** **Task:** **-Team 3 goes to the NAPs Station**	8 **Follow-up $_3$** **Task:** **-Team 3 goes to the NAPs Station**	9 **Follow-up $_4$** **Task:** **-Team 3 goes to the NAPs Station**	10 **Follow-up $_5$** **Task:** **-Team 3 goes to the NAPs Station**
11 **Follow-up $_6$** **Task:** **-Team 3 goes to the NAPs Station**	12 **Take down** **Task:** **-Team 3 goes to the NAPs Station** **Day off:** - Lab techs	13 **Day off:** - Proj. Coord. - Field Techs - Lab techs	14 **Day off:** - Proj. Coord. - Field Techs	15 **PERIOD 5:** **Set-up day** **Task:** **-Team 3 goes to the NAPs Station**	16 **Follow-up $_1$** **Task:** **-Team 3 goes to the NAPs Station**	17 **Follow-up $_2$** **Task:** **-Team 3 goes to the NAPs Station**
18 **Follow-up $_3$** **Task:** **-Team 3 goes to the NAPs Station**	19 **Follow-up $_4$** **Task:** **-Team 3 goes to the NAPs Station**	20 **Follow-up $_5$** **Task:** **-Team 3 goes to the NAPs Station**	21 **Follow-up $_6$** **Task:** **-Team 3 goes to the NAPs Station**	22 **Take down** **Task:** **-Team 3 goes to the NAPs Station** **Day off:** - Lab techs	23 **Day off:** - Proj. Coord. - Field Techs - Lab techs	24 **Day off:** - Proj. Coord. - Field Techs - Lab techs
25 **Day off:** - Proj. Coord. - Field Techs	26 **PERIOD 6:** **Set-up day** **Task:** **-Team 3 goes to the NAPs Station**	27 **Follow-up $_1$** **Task:** **-Team 3 goes to the NAPs Station**	28 **Follow-up $_2$** **Task:** **-Team 3 goes to the NAPs Station**	29 **Follow-up $_3$** **Task:** **-Team 3 goes to the NAPs Station**	30 **Follow-up $_4$** **Task:** **-Team 3 goes to the NAPs Station**	31 **Follow-up $_5$** **Task:** **-Team 3 goes to the NAPs Station**

August 2010						
SUNDAY	**MONDAY**	**TUESDAY**	**WEDN.**	**THURS.**	**FRIDAY**	**SATURDAY**
1 **Follow-up$_{6}$** **Task:** **-Team 3 goes to the NAPs Station**	2 **Take down** **Task:** **-Team 3 goes to the NAPs Station** **Day off:** - Lab techs	3 **Day off:** - Proj. Coord. - Field Techs - Lab techs	4 **Day off:** - Proj. Coord. - Field Techs	5 **PERIOD 7: Set-up day** **Task:** **-Team 3 goes to the NAPs Station**	6 **Follow-up$_{1}$** **Task:** **-Team 3 goes to the NAPs Station**	7 **Follow-up$_{2}$** **Task:** **-Team 3 goes to the NAPs Station**
8 **Follow-up$_{3}$** **Task:** **-Team 3 goes to the NAPs Station**	9 **Follow-up$_{4}$** **Task:** **-Team 3 goes to the NAPs Station**	10 **Follow-up$_{5}$** **Task:** **-Team 3 goes to the NAPs Station**	11 **Follow-up$_{6}$** **Task:** **-Team 3 goes to the NAPs Station**	12 **Take down** **Task:** **-Team 3 goes to the NAPs Station** **Day off:** - Lab techs	13 **Day off:** - Proj. Coord. - Field Techs - Lab techs	14 **Day off:** - Proj. Coord. - Field Techs - Lab techs
15 **Day off:** - Proj. Coord. - Field Techs	16 **PERIOD 8: Set-up day** **Task:** **-Team 3 goes to the NAPs Station**	17 **Follow-up$_{1}$** **Task:** **-Team 3 goes to the NAPs Station**	18 **Follow-up$_{2}$** **Task:** **-Team 3 goes to the NAPs Station**	19 **Follow-up$_{3}$** **Task:** **-Team 3 goes to the NAPs Station**	20 **Follow-up$_{4}$** **Task:** **-Team 3 goes to the NAPs Station**	21 **Follow-up$_{5}$** **Task:** **-Team 3 goes to the NAPs Station**
22 **Follow-up$_{6}$** **Task:** **-Team 3 goes to the NAPs Station**	23 **Take down** **Task:** **-Team 3 goes to the NAPs Station** **Day off:** - Lab techs	24 **Day off:** - Proj. Coord. - Field Techs - Lab techs	25 **Day off:** - Proj. Coord. - Field Techs	26 **PERIOD 9: Set-up day** **Task:** **-Team 3 goes to the NAPs Station**	27 **Follow-up$_{1}$** **Task:** **-Team 3 goes to the NAPs Station**	28 **Follow-up$_{2}$** **Task:** **-Team 3 goes to the NAPs Station**
29 **Follow-up$_{3}$** **Task:** **-Team 3 goes to the NAPs Station**	30 **Follow-up$_{4}$** **Task:** **-Team 3 goes to the NAPs Station**	31 **Follow-up$_{5}$** **Task:** **-Team 3 goes to the NAPs Station**	**Sept. 1** **Follow-up$_{6}$** **Task:** **-Team 3 goes to the NAPs Station**	**Sept. 2** **Take down** **Task:** **-Team 3 goes to the NAPs Station** **Day off:** - Lab techs	**Sept. 3** **Day off:** - Proj. Coord. - Field Techs - Lab techs	**Sept. 4** **Day off:** - Proj. Coord. - Field Techs - Lab techs

Appendix 6 – Consent Form

Health Canada Santé Canada

Participant ID: ______

CONSENT FORM – WINTER 2010

Residential Indoor Air Quality Study in Edmonton, Alberta

Introduction:

When contacted regarding a study of indoor air quality in homes conducted jointly by Health Canada and University of Alberta in winter 2010, you expressed interest in participating in this study. After reviewing your responses to the screening interview, we determined that your dwelling meets the inclusion criteria. We are therefore inviting you to participate in the study and we thank you for your interest.

Purpose and Description of the Research:

To develop or update residential indoor air quality guidelines, Health Canada needs to know the concentrations of indoor air pollutants that are actually found in Canadian homes, and to determine why some homes have higher concentrations than others.

This study is on residential indoor air quality in 50 homes in Edmonton. Specifically, the study involves noting the characteristics of these houses by means of questionnaires and measuring concentrations of a number of pollutants inside and outside of houses during winter 2010.

In order to investigate seasonal differences of pollutant levels in Edmonton homes, this study will be repeated in summer 2010. If you agree, you will be contacted again to invite you to participate in the summer sampling phase.

Description of what is required for your participation:

In total, the study involves nine visits to your home (see attached calendar):

- pollutants will be measured continuously inside and outside your home each day across an eight-day sampling period (or 7 consecutive periods of 24-hours);
- house dust will be collected on a visit scheduled separately.

Each visit can only take place when an adult resident is present in your home.

The following measurements will be taken in your living room: temperature, relative humidity, carbon monoxide, carbon dioxide, nitrogen dioxide, sulphur dioxide, ozone, aldehydes, naphthalene, volatile organic compounds (VOCs), different fractions of particulate matter, and air exchange rate. Also, naphthalene will be measured in your garage and basement, if you have any. In addition, nitrogen dioxide, sulphur dioxide, ozone, VOCs, and different fractions of particulate matter will be measured outside of your home.

On the first visit, air pollution monitors will be installed inside your home (mainly in the living area) and in your backyard. This should take 2 hours.

During the sampling period, you will be asked on a daily basis to fill out a diary. It will record events that occurred during the measurement period and that could influence the results (e.g. use of an air conditioner, housework, or your absence). This should take 15 minutes per day.

In addition, on a separate visit, house dust will be collected and a baseline questionnaire will be administered. This questionnaire will collect personal household information as well as information on the characteristics of your house and on how your daily habits are likely to affect air quality. If you are not sure of the answer to some questions, the technician may offer to check it with you, but you will have no obligation to accept. To ensure the collection of enough dust, you will be asked not to vacuum or clean your living room for one week prior to the sampling. This separate visit should last 1 hour.

Technicians will ensure that air pollution monitors are located in a position that will not interfere with your usual activities and that they present no hazards to you or your family.

If changes are made to the study or new information becomes available, you will be informed.

Potential Harms, Injuries, Discomforts or Inconvenience:

This study will cause you no harm or discomfort.

The only inconvenience to you are the duration of the interview, the potential visual assessment of your house by the technician, the presence of monitoring equipment in your house and backyard for 7 days, and the time required by you to fill in the daily questionnaires.

The technique that will be used to measure the air change rate will release a very small amount of inert gases in your home. These gases are not harmful to health.

Some of the devices make a small amount of noise, similar to having a fan operating in the room. You will be asked not to touch them during the entire sampling period.

Benefits:

You will receive an individualized report on your home's indoor air quality, comparing concentration of pollutants with Health Canada's current guidelines as well as with other homes that were sampled as part of this study. The report will also include advice on how to reduce concentrations of pollutants in your home. This report should be available in March 2011.

Confidentiality:

Confidentiality will be respected and no information that discloses your identity will be released or published without your consent unless required by law. This legal obligation includes a number of circumstances, such as, but not limited to, suspected child abuse, infectious disease, and expression of suicidal ideas where research documents are ordered to be produced by a court of law or where researchers are obliged to report to the appropriate authorities. Also, if there is a hazard to your health such as an excessive concentration of an indoor air pollutant, the research team will take the necessary measures to advise the homeowner and anyone who might be present in the home as soon as possible. Moreover, the principal investigator at University of Alberta will be required to notify the Alberta Health Services Medical Officer of Health for Capital Region who will take corrective action.

The data will be anonymously provided to Health Canada by University of Alberta with a unique code that can be linked back to the participants by the research team at University of Alberta.

University of Alberta will prepare individualized reports identified by this code, and provide these to the participants.

Access to Research Information:

The information that includes your identification (name and address) will be kept at the Department of Public Health Sciences of University of Alberta for a period of 2 years, after which it will be shredded.

Questionnaires and laboratory results sent to Health Canada will be identified only by a coded number. Your name and address will not be communicated to Health Canada, except your home's latitude and longitude information. The latter is needed only to know in what part of the City you live, and to study the influence of outdoor air pollution on indoor air quality.

Your contact information will be kept by University of Alberta until the summer of 2012, and then destroyed. After the summer of 2012, Health Canada and University of Alberta will keep a database with study results, but no information enabling the identification of participants (name and address) will be kept.

Sponsorship and Compensation:

This study is funded by Health Canada. Upon completion of the study, you will receive $25.00 for each season in which you participate to cover the power supply used by the monitoring devices.

Participation:

Your participation in this research project is voluntary. If you choose to participate in this study you can withdraw from the study at any time.

If you decide not to complete one of the study questionnaires, this will be considered as an indication of your withdrawal from the study. Samples collected from your home will therefore not be analyzed, as Health Canada and University of Alberta can test only a limited number of homes. Another home will be recruited to replace yours in the study. As such, any results from your home cannot be reported to you, and you will not be entitled to the compensation.

If you withdraw from this study prior to the second set of visits in the summer of 2010, you will still be compensated for the power supply used by the monitoring devices in the winter season.

You will be given a copy of the consent form to keep once it is signed.

Contact:

The research team members:

Warren Kindzierski, Ph.D.
University of Alberta, Department of Public Health Sciences
warren.kindzierski@ualberta.ca
780-492-0382

Marie-Ève Héroux
Health Canada, Air Quality Programs Division
marie-eve_heroux@hc-sc.gc.ca
613 957-3490

Amanda Wheeler
Health Canada, Exposure Assessment Section
amanda_wheeler@hc-sc.gc.ca
613-948-3686

If you have any questions about this study, please contact:

Fay Li, the project coordinator
University of Alberta
780-248-2053

This study will be done in accordance to ethical guidelines outlined by the Canadian Tri-Council Guidelines for Involvement of Human Subjects in Research published by the National Sciences and Engineering Research Council (NSERC), the Social Sciences and Humanities Research Council (SSHRC) and the Canadian Institutes for Health Research (CIHR).

If you have questions about your rights as a research participant, you may contact:

Research Ethics Board Secretariat
Health Canada
Holland Cross, Tower B
Postal Locator 3104[a]
Ottawa, Ontario
K1A 0K9
Telephone: (613) 941-5199 (Collect calls will be accepted)
Fax: (613) 948-6781
Email: reb-cer@hc-sc.gc.ca

Health Research Ethics Board Administration Office
University of Alberta
308 Campus Tower
8625-112 Street
Edmonton, AB T6G 1K8
Website: www.hreb.ualberta.ca/
Phone: (780) 492-0302
Fax: (780) 492-9429

Participant ID: ______ Edmonton, Winter 2010

CONSENT:

By signing this form, I agree that:

• The study has been explained to me.	Yes	No
• All my questions were answered.	Yes	No
• The possible harms and discomforts and the possible benefits (if any) of this study have been explained to me.	Yes	No
• I understand that I have the right not to participate and the right to stop at any time.	Yes	No
• I understand that I may refuse to participate without any consequences to me.	Yes	No
• I have a choice of not answering any specific questions.	Yes	No
• I am free now, and in the future, to ask any questions about the study.	Yes	No
• I have been told that my personal information will be kept confidential.	Yes	No
• I understand that no information that would identify me will be released or printed without asking me first, except if a health hazard is identified, in which case the principal investigator at University of Alberta will be required to notify Alberta Health Services Medical Officer of Health for Capital Region, who will take corrective action.	Yes	No
• I was informed that I am not liable for any damage to or loss of air pollution monitoring equipment that has been installed in my residence and on my property.	Yes	No
• I understand that I will receive a signed copy of this consent form.	Yes	No

AUTHORIZATION FOR FUTURE CONTACT:

I agree to be contacted again to participate in the second phase of this study that will be carried out in summer 2010.	Yes	No

PARTICIPANT:

I, (First and Last Name) __________________________, hereby consent to participate,

______________________________ ___________________

Signature Date

Date of birth (dd/mm/yyyy): _________________ Telephone at home: ______________

TECHNICIAN:

Name of technician who obtained consent: ____________________________________

______________________________ ___________________

Signature Date

5

Appendix 7 – Baseline Questionnaire

Health Canada Santé Canada

Participant ID: ______

Technician name: ______________________________ Date: ____________________

BASELINE QUESTIONNAIRE –WINTER 2010
Residential Indoor Air Quality Study in Edmonton, Alberta

The purpose of this questionnaire is to obtain information about your residence. We are asking the same questions of each participant in the study. All the information will be kept confidential.

HOUSEHOLD PERSONAL INFORMATION

1. For the primary homeowner(s), please complete the following table.

Occupation	Ethnic/Racial group	Highest grade or level of education completed
1. __________	White Aboriginal / Native Indian Black Asian / Oriental Other: ______________	No schooling Elementary High School Community or Technical College CEGEP University or Teacher's College Other : ____________________
2. __________	White Aboriginal / Native Indian Black Asian / Oriental Other: ______________	No schooling Elementary High School Community or Technical College CEGEP University or Teacher's College Other : ____________________

2. In which of the following ranges did your TOTAL HOUSEHOLD INCOME fall for the last year? Include all income, before taxes and deductions.
   - Less than $35,000
   - $35,000 to $80,000
   - More than $80,000
   - I prefer not to say
   - Don't know

HOUSEHOLD INFORMATION

3. What type of dwelling is your home?
   - Detached house
   - Duplex/triplex
   - Row house
   - Other, please specify: ____________________

4. How many above grade stories do you have in your home? (For example, a Bungalow has 1 storey) ________________

5. In what year was your home built? ________

6. How many people live inside your home?

1	2
3	4
5	6 or more

7. How long have you lived in this house?

Less than one year	3 to 4 years
1 to 2 years	More than 4 years

8. How many bedroom(s) do you have in your current home?

1	4
2	5
3	6 or more

9. How many rooms in total do you have in your home, including the kitchen but not the bathroom(s)/hallways?

1 to 2	7 to 8
3 to 4	9 to 10
5 to 6	11 or more

10. What is your primary water source in your home?

Well	City

Other: ________________________________

11. Is your home located within approx. 90 meters or 1 block of a new construction site, or any other sources of dust (e.g. construction, commercial garage, etc.)?
No
Yes. Please specify: ____
____

12. Is your home located within approx. 90 meters or 1 block of a volatile organic compounds source such as a chemical manufacturer, a gas station, a laundromat, dry cleaners, a landfill or an auto mechanic garage?
No
Yes. Please specify: ____
____

13. Do you have a garage?
    No
    Yes, specify type: Detached or separate carport
    Attached, with no connecting door
    Attached, door connecting it to the home

    Please identify from this list of items those which you store in your garage (Check all that apply):
    Parking one car | Tar
    Parking two or more cars | Paint
    Gasoline | Lawn mower or other gas operated tools
    Other, please specify: ______________________________

14. Check off any of the following equipment you are using in your home this winter (check all that apply):
    Room humidifier | Humidifier on furnace
    Stand-alone dehumidifier | Open sump
    Wood stove | Gas fireplace
    Washing machine | Storm windows
    Vented clothes dryer | Unvented clothes dryer
    Other: ______________

15. What is the main heating system fuel used in your home?
    Wood | Natural Gas
    Electricity (including heat pumps) | Oil
    Mixed/other, please specify:______________________________

16. What is the main heating distribution system used in your home?
    Radiators (steam or hot water) | Forced air furnace (vents)
    Baseboard heater | Radiant Floor or Ceiling panels
    Other, please specify: ______________

17. Do you use supplemental heating used in your home? (Check all that apply)
    No other heating sources | Electric space heater
    Pellet stove | Kerosene space heater
    Wood burning stove | Gas space heater
    Wood fireplace | Gas fireplace
    Other, please specify: ______________________________

18. If you have a woodstove, how often (on average) do you use it during winter?
    5 to 7 days weekly | 3 to 5 days weekly
    Once or twice weekly | Less often than once or twice weekly
    Never | Don't have a wood stove

19. Is there any interior wood storage in your home?
    No
    Yes, specify where and the quantity:
        Living space _________ ft^3
        Kitchen _________ ft^3
        Basement _________ ft^3
        Other, please specify: ______________ _________ft^3

20. What is the energy source that heats water in your residence?
    Gas/Propane　　Oil
    Electricity　　Wood
    Other: ________________________

21. What type of cooking device do you have in your home?
    Electric cooking stove　　Natural gas stove
    Propane stove　　Other, specify: _____________________

22. What type of **home** ventilation systems do you use and how is it controlled?
    None

	Temperature[1]	*Humidity*[2]	*Continuous*	*Timer*
Central Exhaust				
Heat recovery ventilator				
Air exchanger				
Other: _____________				

[1]*Temperature control;* [2]*Humidity control*

23. What type of **cooking** ventilation systems do you use and how is it controlled?
    None

	Continuous	*Timer*
Kitchen fan with exhaust to outdoors*		
Kitchen fan without exhaust to outdoors*		
Other: _____________		

24. What type of **bathroom** ventilation systems do you use and how is it controlled?
    None

	Humidity Control	*Continuous*	*Timer*
Bathroom fan with exhaust to outdoors*			
Other: _____________			

* *Fan with exhaust to the outdoors: extracts air or excess moisture from the interior of a home to the outside.*

25. If you have a washing machine and dryer, are they located in a separate room (e.g. a laundry room)?
    Yes
    No, please specify location: _________________________
    Don't have washing machine

26. Do you have a clothes dryer?
    No
    Yes, specify how it is powered:
        Gas
        Electric
        Other, specify; ________________________________

    Is it vented to the outside?
        Yes
        No

27. Is there a pilot light* (e.g. operated using natural gas) on your oven or clothes dryer?
    No
    Don't know
    Yes, specify appliance(s): ________________________________

    Does this pilot light burn continuously?
        Yes
        No

* *A pilot light is a small light that ignites a larger gas burner when needed to provide hot water or heat.*

28. Are you using any air cleaning devices on the furnace?
    No
    Yes

    A. What types? (mark all that apply)

Premium Filter (1'')	Electrostatic Precipitator
Charcoal Filter	Other: ________________

    B. How often do you change/clean your furnace filter:

Every month	3-6 months
1-3 months	More than 6 months

29. How often do you use any type of stand-alone air cleaning device (for example, filter, ion or ozone generator or electrostatic air cleaner) in your home?
    Never
    Rarely
    Sometimes
    Often
    Always

    Please, specify brand name: ________________________________

30. Do you have carpets (wall-to-wall or of a significant size) in your home?
    No
    Yes, where and when were they installed?
    Bedroom — Date (dd/mm/yyyy) _________
    Bathroom — Date (dd/mm/yyyy) _________
    Kitchen — Date (dd/mm/yyyy) _________
    Living room — Date (dd/mm/yyyy) _________
    Other, specify: ___________ — Date (dd/mm/yyyy) _________

31. Have you done any painting, finishing, or varnishing (floor or furniture) within the last year?
    No
    Yes, please specify (location within the home, type of work and product used):

Room	**Monitored room**	**Floor**	**Type of work**	**Product used**	**Work completed (dd/mm/yyyy)**
1. _________	Yes No	Basement 1st floor 2nd floor Other : _______	Painting Finishing Varnishing Other : _________	Latex paint Alkyd paint Varnish Other : _______	
2. _________	Yes No	Basement 1st floor 2nd floor Other: _______	Painting Finishing Varnishing Other: _________	Latex paint Alkyd paint Varnish Other: _______	
3. _________	Yes No	Basement 1st floor 2nd floor Other: _______	Painting Finishing Varnishing Other: _________	Latex paint Alkyd paint Varnish Other: _______	
4. _________	Yes No	Basement 1st floor 2nd floor Other: _______	Painting Finishing Varnishing Other: _________	Latex paint Alkyd paint Varnish Other: _______	
5. _________	Yes No	Basement 1st floor 2nd floor Other: _______	Painting Finishing Varnishing Other: _________	Latex paint Alkyd paint Varnish Other: _______	
6. _________	Yes No	Basement 1st floor 2nd floor Other: _______	Painting Finishing Varnishing Other: _________	Latex paint Alkyd paint Varnish Other: _______	

32. Have you done any renovations/updates to your home since it was built that would affect the air exchange/infiltration?
    No
    Upgrade wall insulation
    Upgrade ceiling/attic insulation
    Upgrade windows
    Housewrap

33. Have you done any **other** major renovations (including installing new floors, replacing windows, replacing insulation, etc.) within the last year?
    No
    Yes, specify renovations: ______________________________

    If yes, were these renovations done in the last:
    6-12 months
    1-3 months
    3-6 months
    Less than 1 month

34. Have you had any new construction to your home during the last 6 months that involved plywood or particle board, including cabinets, or any other pressed wood products?
    No
    Yes

35. Have you bought any new furniture or rugs within the last year?
    No
    Yes, please specify (type of furniture, material and location within the home):

Type of furniture	Material	Room	Monitored room	Floor	Date installed (dd/mm/yyyy)
1. ________	Leather, Fabric, Melamine, Particleboard, Wood, Plywood, MDF*, Other : ________	________	Yes, No	Basement, 1^{st} floor, 2^{nd} floor, Other : ______	
2. ________	Leather, Fabric, Melamine, Particleboard, Wood, Plywood, MDF*, Other : ________	________	Yes, No	Basement, 1^{st} floor, 2^{nd} floor, Other: ______	
3. ________	Leather, Fabric, Melamine, Particleboard, Wood, Plywood, MDF*, Other : ________	________	Yes, No	Basement, 1^{st} floor, 2^{nd} floor, Other: ______	
4. ________	Leather, Fabric, Melamine, Particleboard, Wood, Plywood, MDF*, Other : ________	________	Yes, No	Basement, 1^{st} floor, 2^{nd} floor, Other: ______	

**MDF: Medium-density fibreboard*

36. Do you keep any paints or solvents at home?
    No
    Yes, please specify where:
        In home
        In garage
        Outside (e.g. structures not attached to house)
        Other, please specify: ____________________

37. In the past 12 months, have you been troubled by any of the following pests within your home? Mark all that apply.

Rats	Ants
Cockroaches	Termites
Spiders	Don't know
Mice	No problems with pests
Other: ________________	

38. In the past 12 months, have you or anyone else used any pesticides (for example, bug sprays or rodent poison) inside your home? Include anyone who might have used pesticides, including a professional exterminator.
    No Yes Don't know

39. We need some information about how often and when you last did certain cleaning operations so we can evaluate the results of our inspection.

Home Location	Cleaning operations	Normal Frequency	Approx. Last Done (dd/mm/yyyy)
Main bedroom(s)	Vacuumed, dust, swept floor or carpet	___ times/month	
	Shampooed carpet	___ times/year	
	Changed bedding	___ times/month	
Living Room	Vacuumed dust, swept floor or carpet	___ times/month	
	Shampooed carpet	___ times/month	

40. How often have you cleaned your oven within the last year? __________ times

41. Do you have your heating ducts cleaned?
    No
    Yes; please specify how often: ____

42. What type of vacuum cleaner do you use:

HEPA* filter	Central Vacuum
Normal	Don't know

* *HEPA: High Efficiency Particulate Air filter.*

HOUSE INSPECTION

43. Please specify frame type of predominant windows:
    Wood
    Vinyl
    Metal (e.g. aluminum or steel):
        With thermal break*
        Without thermal break*
    Other: ______________________________

* *Thermal break: wide strip of low conductivity material used as heat and sound insulation.*

44. Please specify roof type:

	Vented Attic*	Cathedral ceiling**
Flat		
Pitched		

Other: ______________________________

* *Vented attic: An attic with openings to provide ventilation to the outside which removes humid air from the attic so that moisture and heat do not accumulate.*

** *Cathedral ceiling: A high open ceiling that provides a large vaulted space by eliminating the attic.*

BELOW GRADE SPACE

(Any part of the house that is underground or beneath ground level)

45. What is your below grade space?
 None/Slab on grade* (skip to question 51)
 Above grade crawl space**
 Below grade crawl space**
 Basement
 Combination specify; ____________________

Please, specify the % of below grade space finished as living space ________ %

* *Slab on grade: type of foundation where the concrete slab is formed from a mould set into the ground, leaving no space between the ground and the structure, and therefore leaving no space for a basement. This type of construction is more often seen in warmer climates.*

** *Crawl space: type of basement in which one cannot stand up, with the surface often being dirt. Often used as storage.*

46. Below grade wall construction:

A. Foundation Construction
 Rubble Masonry/Rock
 Poured concrete Wall
 Concrete Block Wall
 Insulated Concrete Formed (ICF)
 Preserved Wood Foundation (PWF)
 No below grade wall
 Other: ______________________

B. Insulation of below grade walls
 No Insulation
 Exterior Insulation
 Interior Insulation
 No below grade wall

47. Below Grade Floor Construction:

A. Foundation Floor
 Soil
 Concrete
 Soil covered by plastic
 Other, specify: ____________________

Is your foundation floor insulated?
Yes
No

B. Finishing on foundation floor
None/Paint
Tile on Concrete
Carpet on Concrete
Laminate
Wood covering, specify covering: ________________________________

C. Do you have any visible Mould Growth on your below grade level? (Mark all that apply)
Windows
Walls
Floors
Ceilings
Bathroom
Other: ____________________________

48. Detailed Inspection of the Kitchen and Bathroom(s):

Inspection	Kitchen	Main Bathroom	2nd Bathroom
Predominant Window Covering	Usually not covered Usually covered by curtains or blinds including shears Sealed with plastic or interior storms Not covered during day, covered at night	Usually not covered Usually covered by curtains or blinds including shears Sealed with plastic or interior storms Not covered during day, covered at night	Usually not covered Usually covered by curtains or blinds including shears Sealed with plastic or interior storms Not covered during day, covered at night
Floors	Hard surface 30% to 70 % carpet >70% carpet	Hard surface 30% to 70 % carpet >70% carpet	Hard surface 30% to 70 % carpet >70% carpet
Visible Mould Growth			
Windows	Yes No	Yes No	Yes No
Walls	Yes No	Yes No	Yes No
Floors	Yes No	Yes No	Yes No
Ceilings	Yes No	Yes No	Yes No
Fridge Pan	Yes No		
Bath enclosure		Yes No	Yes No
Other: ________	Yes No	Yes No	Yes No

49. Detailed Inspection of the Living Spaces:

Inspection	Main Bedroom	2nd Bedroom	Living Space
Predominant Window Covering	Usually not covered Usually covered by curtains or blinds including shears Sealed with plastic or interior storms Not covered during day, covered at night	Usually not covered Usually covered by curtains or blinds including shears Sealed with plastic or interior storms Not covered during day, covered at night	Usually not covered Usually covered by curtains or blinds including shears Sealed with plastic or interior storms Not covered during day, covered at night
Floors	Room area: ______ ft^2 Carpet area: ______ ft^2	Room area: ______ ft^2 Carpet area: ______ ft^2	Room area: ______ ft^2 Carpet area: ______ ft^2
Appliances in room	Humidifier Dehumidifier Room Air Conditioner	Humidifier Dehumidifier Room Air Conditioner	Humidifier Dehumidifier Room Air Conditioner
Other Moisture sources	Yes No	Yes No	Yes No
Visible Mould Growth			
Windows	Yes No	Yes No	Yes No
Walls	Yes No	Yes No	Yes No
Floors	Yes No	Yes No	Yes No
Ceilings	Yes No	Yes No	Yes No
Other: ________	Yes No	Yes No	Yes No

MOULD INSPECTION

50. For any area in the home where mold is currently present, please complete the following table using the legend below.

Event	Mould Growth Site	Probable Source of Moisture	Affected Area (cm^2)	Severity (%)
	Insert number below: 1. Main bedroom 2. Second bedroom 3. Living area 4. Balance of living floors 5. Basement Others (specify)	*Insert number below:* i. Precipitation entering through leaks, walls, windows and roofs ii. Condensation on envelope elements iii. Condensation on pipes or cold systems iv. Wicking of moisture from ground v. Improperly drained surface water vi. Plumbing vii. Other (specify)		*Insert number below:* I. Less than 10% II. Between 10 to 60% III. More than 60%
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				

49. Detailed Inspection of the Living Spaces:

Inspection	Main Bedroom	2nd Bedroom	Living Space
Predominant Window Covering	Usually not covered Usually covered by curtains or blinds including shears Sealed with plastic or interior storms Not covered during day, covered at night	Usually not covered Usually covered by curtains or blinds including shears Sealed with plastic or interior storms Not covered during day, covered at night	Usually not covered Usually covered by curtains or blinds including shears Sealed with plastic or interior storms Not covered during day, covered at night
Floors	Room area: ______ ft^2 Carpet area: ______ ft^2	Room area: ______ ft^2 Carpet area: ______ ft^2	Room area: ______ ft^2 Carpet area: ______ ft^2
Appliances in room	Humidifier Dehumidifier Room Air Conditioner	Humidifier Dehumidifier Room Air Conditioner	Humidifier Dehumidifier Room Air Conditioner
Other Moisture sources	Yes No	Yes No	Yes No
Visible Mould Growth			
Windows	Yes No	Yes No	Yes No
Walls	Yes No	Yes No	Yes No
Floors	Yes No	Yes No	Yes No
Ceilings	Yes No	Yes No	Yes No
Other: ________	Yes No	Yes No	Yes No

MOULD INSPECTION

50. For any area in the home where mold is currently present, please complete the following table using the legend below.

Event	**Mould Growth Site**	**Probable Source of Moisture**	**Affected Area** (cm^2)	**Severity (%)**
	Insert number below: 1. Main bedroom 2. Second bedroom 3. Living area 4. Balance of living floors 5. Basement Others (specify)	*Insert number below:* i. Precipitation entering through leaks, walls, windows and roofs ii. Condensation on envelope elements iii. Condensation on pipes or cold systems iv. Wicking of moisture from ground v. Improperly drained surface water vi. Plumbing vii. Other (specify)		*Insert number below:* I. Less than 10% II. Between 10 to 60% III. More than 60%
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				

HISTORICAL DETAILS ON WATER DAMAGE

51. Summarize water damage to the building or its contents (e.g. from broken pipes, leaks or flood) or wet or damp spots on any surfaces (e.g. on walls, wallpaper, ceilings or carpets, basement floors) that you have experienced in your home:

Event No.	Specific Site Location	Identified by	Occurred in last 12 month	Currently wet or damp
1		Occupant Technician	No Yes Don't know	No Yes Don't know
2		Occupant Technician	No Yes Don't know	No Yes Don't know
3		Occupant Technician	No Yes Don't know	No Yes Don't know
4		Occupant Technician	No Yes Don't know	No Yes Don't know
5		Occupant Technician	No Yes Don't know	No Yes Don't know

Note for Technician: look for signs of stains on ceiling or floor near windows, doors or walls

52. For each event that has occurred, complete a separate **Water Damage Report** (copies are at the end of the baseline questionnaire). If no water damage, skip to the next question.

53. Has there ever been mould or mildew on any surfaces inside this home?
    Don't know
    No
    Yes, please specify:

Site No.	Specific Site Location	Identified by	Occurred in last 12 month	Currently wet or damp
1		Occupant Technician	No Yes Don't know	No Yes Don't know
2		Occupant Technician	No Yes Don't know	No Yes Don't know
3		Occupant Technician	No Yes Don't know	No Yes Don't know
4		Occupant Technician	No Yes Don't know	No Yes Don't know
5		Occupant Technician	No Yes Don't know	No Yes Don't know

54. Have you ever experienced musty odours in any area of your home?
Don't know
No
Yes, please specify:

A. Where did this occur?

Main bedroom	Bathroom(s)
Second bedroom	Kitchen
Other bedroom	Basement
Attic	Crawl space
Living/dining/family rooms	
Other room: ____________________	

B. Did this occur within the past 12 months?
Don't know
No
Yes

C. Does this occur seasonally? If yes, what season(s)? (Check all that apply)

Winter	Summer
Spring	Fall

WATER DAMAGE REPORT

Wetting Event No.2
Date: ________________

1. Location Area:
   Main bedroom
   Second bedroom
   Other bedroom
   Living/dining/family rooms
   Crawl space
   Bathroom(s)
   Kitchen
   Basement
   Attic
   Other rooms: _____________________

2. Where was it wet? (Exact location and area affected)
   ____

3. Amount of water:
   Damp
   Dripping / puddles
   Standing water

4. What is the probable source of moisture (where did water come from), as observed by: Occupant Technician

   Precipitation entering through leaks in wall or roof
   Condensation on envelope elements
   Condensation on pipes or cold systems
   Wicking of moisture from ground
   Improperly drained surface water
   Plumbing malfunction
   Other ____________________________________

5. Frequency of Wetting:
   Almost all the time
   Frequently (for example on most rainy days)
   Occasionally (for example only heavy rains)
   Rarely or not at all
   Don't know

6. For how many days was it wet/damp in the past 12 months?
   0-2 days
   3-7 days
   8-30 days
   More than 30 days
   Don't know

7. If currently wet, for how many days has moisture been present?
   Not currently wet
   0-2 days
   3-7 days
   8-30 days
   More than 30 days
   Don't know

WATER DAMAGE REPORT

Wetting Event No.3
Date: _______________

1. Location Area:
   Main bedroom | Bathroom(s)
   Second bedroom | Kitchen
   Other bedroom | Basement
   Living/dining/family rooms | Attic
   Crawl space | Other rooms: ____________________

2. Where was it wet? (Exact location and area affected)
   ____

3. Amount of water:
   Damp
   Dripping / puddles
   Standing water

4. What is the probable source of moisture (where did water come from), as observed by: Occupant Technician

   Precipitation entering through leaks in wall or roof
   Condensation on envelope elements
   Condensation on pipes or cold systems
   Wicking of moisture from ground
   Improperly drained surface water
   Plumbing malfunction
   Other ___________________________________

5. Frequency of Wetting:
   Almost all the time
   Frequently (for example on most rainy days)
   Occasionally (for example only heavy rains)
   Rarely or not at all
   Don't know

6. For how many days was it wet/damp in the past 12 months?
   0-2 days | More than 30 days
   3-7 days | Don't know
   8-30 days

7. If currently wet, for how many days has moisture been present?
   Not currently wet | 8-30 days
   0-2 days | More than 30 days
   3-7 days | Don't know

WATER DAMAGE REPORT

Wetting Event No.4
Date: ________________

1. Location Area:
   Main bedroom | Bathroom(s)
   Second bedroom | Kitchen
   Other bedroom | Basement
   Living/dining/family rooms | Attic
   Crawl space | Other rooms: _____________________

2. Where was it wet? (Exact location and area affected)
   ____

3. Amount of water:
   Damp
   Dripping / puddles
   Standing water

4. What is the probable source of moisture (where did water come from), as observed by: Occupant Technician

   Precipitation entering through leaks in wall or roof
   Condensation on envelope elements
   Condensation on pipes or cold systems
   Wicking of moisture from ground
   Improperly drained surface water
   Plumbing malfunction
   Other ____________________________________

5. Frequency of Wetting:
   Almost all the time
   Frequently (for example on most rainy days)
   Occasionally (for example only heavy rains)
   Rarely or not at all
   Don't know

6. For how many days was it wet/damp in the past 12 months?
   0-2 days | More than 30 days
   3-7 days | Don't know
   8-30 days

7. If currently wet, for how many days has moisture been present?
   Not currently wet | 8-30 days
   0-2 days | More than 30 days
   3-7 days | Don't know

WATER DAMAGE REPORT

Wetting Event No.5
Date: ________________

1. Location Area:
   Main bedroom
   Second bedroom
   Other bedroom
   Living/dining/family rooms
   Crawl space
   Bathroom(s)
   Kitchen
   Basement
   Attic
   Other rooms: ______________________

2. Where was it wet? (Exact location and area affected)
   ____

3. Amount of water:
   Damp
   Dripping / puddles
   Standing water

4. What is the probable source of moisture (where did water come from), as observed by: Occupant Technician

   Precipitation entering through leaks in wall or roof
   Condensation on envelope elements
   Condensation on pipes or cold systems
   Wicking of moisture from ground
   Improperly drained surface water
   Plumbing malfunction
   Other ______________________________________

5. Frequency of Wetting:
   Almost all the time
   Frequently (for example on most rainy days)
   Occasionally (for example only heavy rains)
   Rarely or not at all
   Don't know

6. For how many days was it wet/damp in the past 12 months?
   0-2 days
   3-7 days
   8-30 days
   More than 30 days
   Don't know

7. If currently wet, for how many days has moisture been present?
   Not currently wet
   0-2 days
   3-7 days
   8-30 days
   More than 30 days
   Don't know

Appendix 8 – Winter Indoor Logsheet

Edmonton Indoor Air Quality Study -Winter
Log Sheet: INDOOR

Start Date (dd/mm/yyyy): ___________ Stop Date (dd/mm/yyyy): ___________

Operator Initials Setup: ____ Takedown: ____ PARTICIPANT ID: ___________

Cascade Impactor (PM) (24 hour sample, 5.0 to 5.1 Lpm)

Pump ID	Flow Meter ID	Start Time (hh:mm)	Pump Display Time (min)	Stop Time (hh:min)	Pump Display Time (min)
Label ID:			**Start Flow (lpm)**	**End Flow (lpm)**	**Flow Meter ID**
$PM_{1.0}$ (EW10PM)					
$PM_{2.5-1.0}$ (EW10PF)					
Coarse PM (EW10PF)					
Comments:					

Chemcomb (EC/OC) (24 hour sample on days 1, 3, 5, 7. 10.0 to 10.2 Lpm)

Pump ID	Flow Meter ID	Start Time (hh:mm)	Pump Display Time (min)	Stop Time (hh:min)	Pump Display Time (min)
Label ID:			**Start Flow (lpm)**	**End Flow (lpm)**	**Flow Meter ID**
Comments:					

Blanks (as applicable)

Cascade Impactor			ChemComb
$PM_{1.0}$ (EW10PM)	$PM_{2.5-1.0}$ (EW10PF)	Coarse PM (EW10PF)	

Edmonton Indoor Air Quality Study -Winter

Log Sheet: INDOOR

Formaldehyde Passive Sample (24 hour sample)

Label ID	Start Time (hh:mm)	Stop Time (hh:mm)	Comments:

Ogawa Passive Samples (24 hour samples)

Pollutant	Label ID	Start Time (hh:mm)	Stop Time (hh:mm)	Comments:
NO_2/SO_2				

VOC Canisters (24 hour sample)

Sample ID (i.e. canister)	Gauge ID	Start Pressure: (mmHg)	Start Time (hh:mm)	Stop Pressure: (mmHg)	Stop Time (hh:mm)
Comments:					

Blanks (as applicable)

NO_2/SO_2	Formaldehyde

Appendix 9 – Winter Outdoor Logsheet

Edmonton Indoor Air Quality Study -Winter
Log Sheet: OUTDOOR

Start Date (dd/mm/yyyy): ___________ Stop Date (dd/mm/yyyy): ___________

Operator Initials Setup: ____ Takedown: ____ PARTICIPANT ID: ___________

Cascade Impactor (PM) (24 hour sample, 5.0 to 5.1 Lpm)

Pump ID	Flow Meter ID	Start Time (hh:mm)	Pump Display Time (min)	Stop Time (hh:min)	Pump Display Time (min)
Label ID:			**Start Flow (lpm)**	**End Flow (lpm)**	**Flow Meter ID**
$PM_{1.0}$ (EW10PM)					
$PM_{2.5-1.0}$ (EW10PF)					
Coarse PM (EW10PF)					
Comments:					

Chemcomb (EC/OC) (24 hour sample on days 1, 3, 5, 7. 10.0 to 10.2 Lpm)

Pump ID	Flow Meter ID	Start Time (hh:mm)	Pump Display Time (min)	Stop Time (hh:min)	Pump Display Time (min)
Label ID:			**Start Flow (lpm)**	**End Flow (lpm)**	**Flow Meter ID**
Comments:					

Ogawa Passive Samples (24 hour samples)

Pollutant	Label ID	Start Time (hh:mm)	Stop Time (hh:mm)	Comments:
NO_2/SO_2				

VOC Canisters (24 hour sample)

Sample ID (i.e. canister)	Gauge ID	Start Pressure: (mmHg)	Start Time (hh:mm)	Stop Pressure: (mmHg)	Stop Time (hh:mm)
Comments:					

Blanks (as applicable)

Cascade Impactor			Chemcomb	NO_2/SO_2
$PM_{1.0}$ (EW10PM)	$PM_{2.5-1.0}$ (EW10PF)	Coarse PM (EW10PF)		

Appendix 10 – Chain of Custody Tracking Sheet.

Week:		Participant:		Napthalene:		O3:	
Pollutant	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
PM 1							
PUF 2.5							
PUF 10							
EC/OC							
NO2 Ogawa							
NO2 AMEC							
CATS							
FORMALDEHYDE							

Appendix 11 – Winter Daily Diary Questionnaire

Health Canada Santé Canada

Participant ID: ______

Technician name: ______________________ Visit: ______

This questionnaire covers the period from (date and time) __________________________ to (date and time) _______________________

DAILY DIARY QUESTIONNAIRE – WINTER 2010

Residential Indoor Air Quality Study in Edmonton, Alberta

The purpose of this questionnaire is to obtain information about you and your residence since the last technician visit. We are asking the same questions of each participant in the study. All the information will be kept confidential.

THE PARTICIPANTS

1. How many people spent at least four hours in your home since the last visit? _____

2. Did [1] **anyone** use personal care products since the last visit?
   No
   Yes, specify:

What type(s)	*What times*	*How many times*
Perfume, cologne or aftershave	___________	___________
Roll-on deodorant	___________	___________
Spray deodorant	___________	___________
Hair spray	___________	___________
Nail polish or nail polish remover	___________	___________
Mouthwash	___________	___________
Other, specify: ___________	___________	___________

3. Did **anyone** pick up any dry-cleaned clothes since the last visit?
   No
   Yes

4. Did **anyone** wear any clothes since the last visit that have been dry-cleaned within the last week?
   No
   Yes

5. Did **anyone**, including visitors, smoke cigarettes inside your home since the last visit?
   No
   Yes, specify approximately how many cigarettes were smoked: ____________
   At what time(s) were cigarettes smoked? ______________________

[1] By anyone, we mean anyone in your household including yourself.

6. Did **anyone**, including visitors, smoke cigarettes outside your home before entering?
   No
   Yes, specify approximately how many cigarettes were smoked: ____________

7. Were any showers taken in your home since the last visit?
   No
   Yes, specify how many ________________ and at what times ________________

8. Did **anyone** use the bathroom fan while taking a shower since the last visit?
   No
   Yes, specify when _________________________ and how long _(min.)
   specify when _________________________ and how long _______(min.)
   specify when _________________________ and how long _______(min.)

9. Did **anyone** use any of the following since the last visit?
   No

	When	*How long (min.)*
Hair dryer	________________	___________
Vacuum cleaner	________________	___________
Power tools	________________	___________
Kitchen appliances with electric motors (blenders, coffee grinders,..)	________________	___________

COOKING

10. *Complete the table.* Since the last visit, did **anyone use for cooking the**:

Question		**Use for**	**Number of times**	**When**	**How long (min.)**
Stove	No Yes	Frying	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Grilling	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Sautéing	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Boiling/ Steaming	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
Oven	No Yes	Broiling	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Grilling	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Baking	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
Toaster oven	No Yes	Toasting	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Broiling	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Grilling	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Baking	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
Toaster	No Yes		______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
Exhaust fan	No Yes		______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
Burn any food	No Yes		______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____

CLEANING and CHEMICALS

11. *Complete the table*. Since the last visit, did **anyone**:

Question	Answer	What type	When	How long (min.)
Clean your home?	No Yes Don't know	Vacuuming Dusting Sweeping	______ ______ ______	______ ______ ______
Use cleaning products in your home? (eg. pinesol)	No Yes Don't know	Cleaners Brand : 1. ______ 2. ______ 3. ______	______ ______ ______	______ ______ ______
Use mothballs or moth crystals in your home?	No Yes Don't know			
Use any other chemicals (e.g. paint, insect repellents, glue, welding fumes, toilet bowl cleaners, deodorant block for toilets, diaper pails etc.)?	No Yes	Name Brand*: 1. ______ 2. ______ 3. ______ 4. ______ 5. ______	______ ______ ______ ______ ______	______ ______ ______ ______ ______

* Example: Off! Skintastic Insect Repellent, Citrus Scented or Grand & Toy glue stick

THE HOME

12. *Complete the following table.* Since the last visit, were any:

Question	Answer	Brand	Name	When	How long (min.)
Scented candles used	No Yes	______	______	______	______
Candles used	No Yes	______	______	______	______
Incense used	No Yes	______	______	______	______
Scented oil used	No Yes	______	______	______	______

13. Were any air fresheners used in your home since the last visit?
No
Yes, specify:

What type (Example: Glade Aerosol Spray, Melon Burst)	Brand	How many times	When	Sampled room
☐ Plug-in				No Yes
☐ Stick-on				No Yes
☐ Spray				No Yes
☐ Spray continuously*				No Yes
☐ Other: ______				No Yes

* Air fresheners that spray at regular intervals.

14. At what temperature was your thermostat set since the last visit?
Daytime: ____________ °C or °F (circle unit)
Night-time: ____________ °C or °F (circle unit)

15. At what setting was your furnace set since the last visit?
AUTO (When the furnace operates) On a switch
ON (Continuously) Other, specify; _______________

16. Were any ultrasonic or "cool mist" humidifiers used in your home since the last visit?
No
Yes, specify when ______________ and for how long _______________ (hrs).

What type of water was used?
Tap water
Bottled, distilled or deionized
Other, specify type: ____

In which room of your home was the humidifier used?
Main bedroom
Other bedroom (e.g. second room)
Living room
Kitchen
Other, specify type: ____

17. Was an air cleaner used in your home since the last visit?
No
Yes, specify when ______________ and for how long _______________ (hrs)
Brand name: ____

18. Have you used a computer laser printer in your home since the last visit?
No
Yes

19. Was the dishwasher used since the last visit?
No
Yes, specify how many loads ___________ and at what time(s) ______________
Brand name of detergent used _____________________________________

20. Were any loads of laundry washed and dried in your home since the last visit?
No
Yes, specify how many loads were:

Washed ___________ and at what time(s) ____________________
Brand name of detergent used ______________________________

Dried _____________ and at what time(s) ____________________
Specify: Drying machine Drying rack

21. Were any windows open since the last visit?
    No
    Yes, specify how many were open _______ and *Complete the table.*

#	What room	When	How long (hrs)	Open more than 6 inches	Same floor as the monitors
1.				No Yes	No Yes
2.				No Yes	No Yes
3.				No Yes	No Yes
4.				No Yes	No Yes
5.				No Yes	No Yes
6.				No Yes	No Yes
7.				No Yes	No Yes
8.				No Yes	No Yes
9.				No Yes	No Yes
10.				No Yes	No Yes

22. Did you use supplemental heating in your home since the last visit? (Check all that apply)
    No
    Yes, please specify and *Complete the following table.*

Type of heating system	When	How long (min.)
Open stove		
Electric space heater		
Kerosene space heater		
Decorative fireplace		
Wood fireplace		
Gas fireplace		
Gas space heater		
Wood burning stove		
Pellet stove		
Other, please specify:		

23. Were there any pets inside your home since the last visit?
    No
    Yes, specify how many: __________ and what kind __________________________

    Were these pets inside the house all day?
    □ No, specify time inside __________ and how long inside ______________ (hrs)
    specify time inside __________ and how long inside ______________ (hrs)
    specify time inside __________ and how long inside ______________ (hrs)
    specify time inside __________ and how long inside ______________ (hrs)
    Yes

24. If you use a garage (attached or detached from your home) to store your car(s), did you move your car(s) into or out of your garage since the last visit?
    No
    Yes, specify how many times:___________

* *Driving your car out of your garage and then back into your garage equals 2 times.*

25. Did you leave your car(s) idling in the garage since the last visit?
    No
    Yes, for how long:
        Less than 30 seconds 1 – 2 minutes
        30 seconds – 1 minute More than 2 minutes

26. If you use a garage (attached or detached from your home) to store motorized equipment such as a snow blower, did you leave it idling in the garage since the last visit?
    No
    Yes, for how long:
        Less than 30 seconds 1 – 2 minutes
        30 seconds – 1 minute More than 2 minutes

Appendix 12 – Summer Daily Diary Questionnaire

Health Canada Santé Canada

Participant ID:_________

Technician name:______________________ Visit:______

This questionnaire covers the period from (date and time) _________________________

to (date and time) ______________________

DAILY DIARY QUESTIONNAIRE - SUMMER 2010

Residential Indoor Air Quality Study in Edmonton, Alberta

The purpose of this questionnaire is to obtain information about you and your residence since the last technician visit. We are asking the same questions of each participant in the study. All the information will be kept confidential.

THE PARTICIPANTS

1. How many people spent at least four hours in your home since the last visit?_____

2. Did [1] **anyone** use personal care products since the last visit?
   No
   Yes, specify:

What type(s)	*What times*	*How many times*
Perfume, cologne or aftershave	____________	____________
Roll-on deodorant	____________	____________
Spray deodorant	____________	____________
Hair spray	____________	____________
Nail polish or nail polish remover	____________	____________
Mouthwash	____________	____________
Other, specify: ____________	____________	____________

3. Did **anyone** pick up any dry-cleaned clothes since the last visit?
   No
   Yes

4. Did **anyone** wear any clothes since the last visit that have been dry-cleaned within the last week?
   No
   Yes

5. Did **anyone**, including visitors, smoke cigarettes inside your home since the last visit?
   No
   Yes, specify approximately how many cigarettes were smoked: ______________
   At what time(s) were cigarettes smoked? 1. ______ 2. ______ 3. ______

[1] By anyone, we mean anyone in your household including yourself.

Participant ID:_________

4. ______ 5. ______ 6. ______ 7. ______ 8. ______ 9. ______ 10. ______

6. Did **anyone**, including visitors, smoke cigarettes outside your home before entering since the last visit?
   No
   Yes, specify approximately how many cigarettes were smoked: ______
   At what time(s) were cigarettes smoked?
   1. ________ 2. ________ 3. ________ 4. ________ 5. ________ .

7. Were any showers taken in your home since the last visit?
   No
   Yes, specify how many ________________ and at what times ________________

8. Did **anyone** use the bathroom fan while taking a shower since the last visit?
   No
   Yes, specify when __________________________ and how long _(min.)
   specify when __________________________ and how long _______(min.)
   specify when __________________________ and how long _______(min.)

9. Did **anyone** use any of the following inside your home since the last visit?
   No

	When	*How long (min.)*
Hair dryer	________________	___________
Vacuum cleaner	________________	___________
Power tools	________________	___________
Kitchen appliances with electric motors (blenders, coffee grinders,..)	________________	___________

COOKING

10. *Complete the table.* Since the last visit, did **anyone use for cooking the**:

Question		**Use for**	**Number of times**	**When**	**How long (min.)**
Stove	No Yes	Frying	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Grilling	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Sautéing	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Boiling/ Steaming	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
Oven	No Yes	Broiling	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Grilling	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Baking	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
Toaster oven	No Yes	Toasting	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Broiling	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Grilling	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
		Baking	______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
Toaster	No Yes		______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
Exhaust fan	No Yes		______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
Burn any food	No Yes		______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____
BBQ on your property	No Yes		______	1.________ 3. ________ 2.________	1._____ 3. _____ 2._____

CLEANING and CHEMICALS

11. *Complete the table.* Since the last visit, did **anyone**:

Question	**Answer**	**What type**	**When**	**How long** (min.)
Clean your home?	No Yes Don't know	Vacuuming Dusting Sweeping	______ ______ ______	______ ______ ______
Use cleaning products in your home? (eg. pinesol)	No Yes Don't know	Cleaners Brand : 1. ______ 2. ______ 3. ______	______ ______ ______	______ ______ ______
Use mothballs or moth crystals in your home?	No Yes Don't know			
Use any other chemicals (e.g. paint, insect repellents, glue, welding fumes, toilet bowl cleaners, deodorant block for toilets, diaper pails etc.)?	No Yes	Name Brand*: 1. ______ 2. ______ 3. ______ 4. ______ 5. ______	______ ______ ______ ______ ______	______ ______ ______ ______ ______

* Example: Off! Skintastic Insect Repellent, Citrus Scented or Grand & Toy glue stick

THE HOME

12. *Complete the following table.* Since the last visit, were any:

Question	**Answer**	**Brand**	**Name**	**When**	**How long (min.)**
Scented candles used	No Yes	______	______	______	______
Candles used	No Yes	______	______	______	______
Incense used	No Yes	______	______	______	______
Scented oil used	No Yes	______	______	______	______

13. Were any air fresheners used in your home since the last visit?
No
Yes, specify:

What type (Example: Glade Aerosol Spray, Melon Burst)	**Brand**	**How many times**	**When**	**Sampled room**
□ Plug-in				No Yes
□ Stick-on				No Yes
□ Spray				No Yes
□ Spray continuously*				No Yes
□ Other:				No Yes

* Air fresheners that spray at regular intervals.

14. Was a room air conditioners used in your home since the last visit?
    No
    Yes, specify:
    1. Room ________ what times __________ & for how long (hrs) ______
    2. Room ________ what times __________ & for how long (hrs) ______
    3. Room ________ what times __________ & for how long (hrs) ______
    4. Room ________ what times __________ & for how long (hrs) ______
    5. Room ________ what times __________ & for how long (hrs) ______
    6. Room ________ what times __________ & for how long (hrs) ______
    7. Room ________ what times __________ & for how long (hrs) ______

15. Did you use a central air conditioner in your home since the last visit?
    No
    Yes

    At what temperature was your thermostat set since the last visit?
    Daytime: ____________ °C or °F or relative humidity % (circle unit)
    Night-time: ____________ °C or °F or relative humidity % (circle unit)

    At what setting was your air conditioner set since the last visit?
    AUTO (When the furnace operates)
    ON (Continuously)
    On a switch
    Other, specify; ________________

16. Were any ultrasonic or "cool mist" humidifiers used in your home since the last visit?
    No
    Yes, specify when ______________ and for how long _______________ (hrs).

    What type of water was used?
    Tap water
    Bottled, distilled or deionized
    Other, specify type: ____

    In which room of your home was the humidifier used?
    Main bedroom
    Other bedroom (e.g. second room)
    Living room
    Kitchen
    Other, specify type: ____

17. Was a portable air cleaner used in your home since the last visit?
    No
    Yes, specify when ______________ and for how long _______________ (hrs)
    Brand name: ____

18. Have you used a computer laser printer in your home since the last visit?
    No
    Yes

19. Was the dishwasher used since the last visit?
    No
    Yes, specify how many loads ___________ and at what time(s) ______________
    Brand name of detergent used: ____________________________________

20. Were any loads of laundry washed and dried in your home since the last visit?
    No
    Yes, how many loads were Washed ______ and at what time(s) ______________
    Specify the Brand name of detergent used: __________________________

    How many loads were Dried________and at what time(s) ______________
    Specify: Drying machine Drying rack

21. Were any windows open since the last visit?
    No
    Yes, specify how many were open _______ and *Complete the table.*

#	What room	When	How long (hrs)	Open more than 6 inches	Same floor as the monitors
1.				No Yes	No Yes
2.				No Yes	No Yes
3.				No Yes	No Yes
4.				No Yes	No Yes
5.				No Yes	No Yes
6.				No Yes	No Yes
7.				No Yes	No Yes
8.				No Yes	No Yes
9.				No Yes	No Yes
10.				No Yes	No Yes

22. Did you use supplemental heating in your home since the last visit? (Check all that apply)
    No
    Yes, please specify and *Complete the following table.*

Type of heating system	When	How long (min.)
Open stove		
Electric space heater		
Kerosene space heater		
Decorative fireplace		
Wood fireplace		
Gas fireplace		
Gas space heater		
Wood burning stove		
Pellet stove		
Other, please specify:		

23. Were there any pets inside your home since the last visit?
No
Yes, specify how many __________ and what kind ______________________

Were these pets inside the house all day?
☐ No, specify time inside _________ and how long inside _____________ (hrs)
specify time inside _________ and how long inside _____________ (hrs)
specify time inside _________ and how long inside _____________ (hrs)
specify time inside _________ and how long inside _____________ (hrs)
Yes

24. If you use a garage (attached or detached from your home) to store your car(s), did you move your car(s) into or out of your garage since the last visit?
No
Yes, specify how many times: __________

* *Driving your car out of your garage and then back into your garage equals 2 times.*

25. Did you leave your car(s) idling in the garage since the last visit?
No
Yes, for how long:
Less than 30 seconds ☐ 1 – 2 minutes
30 seconds – 1 minute ☐ More than 2 minutes

26. If you use a garage (attached or detached from your home) to store motorized equipment such as a lawn mower, did you leave it idling in the garage since the last visit?
No
Yes, for how long:
Less than 30 seconds ☐ 1 – 2 minutes
30 seconds – 1 minute ☐ More than 2 minutes

27. Did **anyone** do any yard maintenance (i.e. lawn mowing, hedge trimming, etc.) since the last visit?
No

Yes, specify:
- Gasoline-powered tool
- Electric-powered tool
- Battery-powered tool
- Hand-powered tool

Appendix 13 – Returning Baseline Questionnaire

Health Canada   Santé Canada

Participant ID: ______

Technician name:______________________________   Date:___________________

BASELINE QUESTIONNAIRE – RETURNING PARTICIPANT – SUMMER 2010

Residential Indoor Air Quality Study in Edmonton, Alberta

The purpose of this questionnaire is to obtain information about your residence. We are asking the same questions of each participant in the study. All the information will be kept confidential.

HOUSEHOLD INFORMATION

1. How many people live inside your home?

1	2
3	4
5	6 or more

2. Is your home located within approx. 90 meters or 1 block of a new construction site, or any other sources of dust (e.g. construction, commercial garage, etc.)?
   No
   Yes. Please specify: ____
   ____

3. Is your home located within approx. 90 meters or 1 block of a volatile organic compounds source such as a chemical manufacturer, a gas station, a Laundromat, a dry cleaner, a landfill or an auto mechanic garage?
   No
   Yes. Please specify: ____
   ____

4. Check off any of the following equipment you are using in your home this summer (check all that apply):

Room humidifier	Humidifier on furnace
Stand-alone dehumidifier	Open sump
Wood stove	Gas fireplace
Washing machine	Storm windows
Vented clothes dryer	Unvented clothes dryer
Room unit Air conditioning	Central unit Air conditioning
Wood fire	Other: __________________

5. How often do you use any type of stand-alone air cleaning device (for example, filter, ion or ozone generator or electrostatic air cleaner) in your home?
   Never
   Rarely
   Sometimes
   Often
   Always

   Please, specify brand name: ________________________________

6. Have you done any painting, finishing, or varnishing (floor or furniture) within the last year?
   No
   Yes, please specify (location within the home, type of work and product used):

Room	Monitored room	Floor	Type of work	Product used	Work completed (dd/mm/yyyy)
1. _________	Yes No	Basement 1st floor 2nd floor Other : ______	Painting Finishing Varnishing Other : ________	Latex paint Alkyd paint Varnish Other : ______	
2. _________	Yes No	Basement 1st floor 2nd floor Other: ______	Painting Finishing Varnishing Other: ________	Latex paint Alkyd paint Varnish Other: ______	
3. _________	Yes No	Basement 1st floor 2nd floor Other: ______	Painting Finishing Varnishing Other: ________	Latex paint Alkyd paint Varnish Other: ______	
4. _________	Yes No	Basement 1st floor 2nd floor Other: ______	Painting Finishing Varnishing Other: ________	Latex paint Alkyd paint Varnish Other: ______	
5. _________	Yes No	Basement 1st floor 2nd floor Other: ______	Painting Finishing Varnishing Other: ________	Latex paint Alkyd paint Varnish Other: ______	
6. _________	Yes No	Basement 1st floor 2nd floor Other: ______	Painting Finishing Varnishing Other: ________	Latex paint Alkyd paint Varnish Other: ______	

7. Have you done any renovations/updates to your home since it was built that would have affect the air exchange/infiltration?
   No
   Upgrade wall insulation
   Upgrade ceiling/attic insulation
   Upgrade windows
   Housewrap

8. Have you done any **other** major renovations (including installing new floors, replacing windows, replacing insulation, etc.) within the last year?
   No
   Yes, specify renovations: ____
   ____
   ____

   If yes, were these renovations done in the last:
   6-12 months   1-3 months
   3-6 months   Less than 1 month

9. Have you had any new construction to your home during the last 6 months that involved plywood or particle board, including cabinets, or any other pressed wood products?
   No
   Yes

10. Have you bought any new furniture or rugs within the last year?
   No
   Yes, please specify (type of furniture, material and location within the home):

Type of furniture	Material		Room	Monitored room	Floor	Date installed (dd/mm/yyyy)
1. __________	Leather Melamine Wood MDF*	Fabric Particleboard Plywood Other : _______	__________	Yes No	Basement 1st floor 2nd floor Other : ______	
2. __________	Leather Melamine Wood MDF*	Fabric Particleboard Plywood Other : _______	__________	Yes No	Basement 1st floor 2nd floor Other: ______	
3. __________	Leather Melamine Wood MDF*	Fabric Particleboard Plywood Other : _______	__________	Yes No	Basement 1st floor 2nd floor Other: ______	
4. __________	Leather Melamine Wood MDF*	Fabric Particleboard Plywood Other : _______	__________	Yes No	Basement 1st floor 2nd floor Other: ______	

**MDF: Medium-density fibreboard*

11. Do you keep any paints or solvents at home?
   No
   Yes, please specify where:
      In home
      In garage
      Outside (e.g. structures not attached to house)
      Other, please specify: ______________________

12. Since we last monitored your home, have you been troubled by any of the following pests within your home? Mark all that apply.

Rats
Ants
Cockroaches
Termites
Spiders
Don't know
Mice
No problems with pests
Other: ________________

13. Since we last monitored your home, have you or anyone else used any pesticides (for example, bug sprays or rodent poison) inside your home? Include anyone who might have used pesticides, including a professional exterminator.

No
Yes
Don't know

14. We need some information about how often and when you last did certain cleaning operations so we can evaluate the results of our inspection.

Home Location	**Cleaning operations**	**Normal Frequency**	**Approx. Last Done (dd/mm/yyyy)**
Main bedroom(s)	Vacuumed dust, swept floor or carpet	___ times/month	
	Shampooed carpet	___ times/year	
	Changed bedding	___ times/month	
Living room	Vacuumed dust, swept floor or carpet	___ times/month	
	Shampooed carpet	___ times/month	

Appendix 14 – Data of all participants in winter and summer seasons

Legend for the Table:

W: Winter

S: Summer

3-Day Mean of Benzene: mean of VOC samples measured on Tuesday, Wednesday and Thursday.

7-Day Mean of Benzene: mean of VOC samples measured for at least five 24-hour periods.

*: Benzene samples from Tuesday, Wednesday and Thursday

[1]: Data point not available because 2 or more of the seven-day sampling periods were unavailable.

[2]: Data point not available because 1 or more of the three-day sampling periods were unavailable.

[3]: Refer to Table 6 for details on garage type.

[4]: Refer to Table 4 for details on house age stratification.

Neighborhood	Traffic Volume (VPD)	Proximity to Downtown Core (m)	Proximity to Downtown Core Group	Year of House Construction	Age Stratum[5]	House Value ($)	Garage Type[4]	Number of Residents	Air Exchange Rate		3-day Mean of Benzene* ($\mu g/m^3$)		5-day Mean of Benzene ($\mu g/m^3$)			
									Winter Indoor	Summer Indoor	Winter Outdoor	Summer Outdoor	Winter Outdoor	Winter Outdoor	Summer Indoor	Summer Outdoor
GB	100	5,889	4000	1966	2	415,000	7	4	0.27340		1.64		1.69	1.59		
GB	400	5,877	4000	2010	2	416,500	7	2	0.36846		1.70		1.54	1.56		
TT	17,800	11,862	8000	2005	5	622,500	8	5	0.17213		N/A[2]		3.42	N/A[1]		
FH	7,500	10,383	8000	1999	4	545,500	4	5	0.15244	0.23466	0.67	0.28	1.99	1.23	0.76	0.38
GB	400	5,725	4000	1957	2	372,000	7	2	0.13928	0.15461	1.73	0.35	1.83	1.56	0.57	0.49
GB	100	6,104	4000	1958	2	340,500	7	2	0.17439	0.27100	2.14	0.74	1.90	1.82	0.54	0.54
TT	5,300	11,566	8000	2004	5	419,000	1	4	0.34060	0.96506	1.44	0.22	1.31	1.09	0.21	0.21
FH	17,900	10,188	8000	1990	4	567,000	4	6	0.26436		1.42		1.41	1.05		
TT	5,300	11,313	8000	2004	5	506,500	4	4	0.27399		1.35		2.05	1.05		
RF	20,800	12,711	8000	2004	5	761,000	4	5	0.19624	0.18992	N/A[2]	0.24	2.29	0.97	4.44	0.30
FH	7,500	10,249	8000	1991	4	473,500	4	3	0.16261	0.16996	1.35	0.29	1.73	1.05	0.80	0.30
RF	20,800	12,688	8000	2004	5	539,500	4	4	0.21078		1.50		6.21	1.08		
DT	28,900	4,809	4000	1971	3	459,500	7	4	0.04729		1.99		1.18	1.27		
PD	18,500	3,619	0	1912	1	165,000	5	4	0.73779		0.73		4.13	1.57		
DT	11,740	4,731	4000	1968	3	394,500	7	4	0.20269	0.32336	2.17	0.52	1.32	1.35	0.58	0.48

Neighborhood	Traffic Volume (VPD)	Proximity to Downtown Core (m)	Proximity to Downtown Core Group	Year of House Construction	Age Stratum[5]	House Value ($)	Garage Type[4]	Number of Residents	Air Exchange Rate		3-day Mean of Benzene* (µg/m³)		5-day Mean of Benzene (µg/m³)			
									Winter Indoor	Summer Indoor	Winter Outdoor	Summer Outdoor	Winter Outdoor	Winter Outdoor	Summer Indoor	Summer Outdoor
B	400	5,761	4000	1957	2	338,500	1	4	0.25300		1.70		1.26	1.16		
T	11,740	4,795	4000	1962	3	354,500	7	2	0.15235		2.00		1.26	1.26		
T	3,700	4,142	4000	1963	3	382,500	7	4	0.19335	0.94057	2.10	1.75	1.55	1.31	1.58	1.40
V M	36,400	2,632	0	1932	1	339,500	6	2	0.87674	0.36005	0.75	0.26	0.98	0.92	0.44	0.34
X	2,500	9,275	8000	1990	4	450,000	4	2	0.16142	0.56709	0.72	0.49	2.78	1.10	0.96	0.36
C	36,200	9,050	8000	1973	3	366,500	7	2	0.21434	0.46400	0.99	0.31	1.63	1.23	0.50	0.32
X	24,300	9,417	8000	1988	3	418,500	4	4	0.25621		0.69		1.63	1.11		
V M	45,750	3,117	0	1929	1	409,000	7	2	0.35218	0.52258	0.78	0.73	1.03	0.78	0.62	0.75
V M	14,050	2,936	0	1930	1	323,000	7	2	0.51635		0.88		1.19	1.18		
S	700	12,533	8000	2007	5	498,000	4	4	0.23120	0.40177	1.06	0.20	1.69	0.77	3.57	0.18
X	2,500	9,183	8000	1990	4	469,500	4	3	0.19292		1.58		2.97	1.21		
C	63,200	8,287	8000	1972	3	341,500	7	2	0.18664	0.68364	1.41	0.47	1.50	1.01	0.59	0.41
A	39,900	2,419	0	1941	1	222,500	6	3	0.18709	N/A[3]	2.04	0.69	3.14	1.33	N/A[1]	0.54
A	66,600	2,329	0	1941	1	210,500	5	3	0.65562		1.91		1.90	1.27		
V M	37,000	2,966	0	1941	1	396,000	6	2	0.29679	2.15714	0.80	0.50	0.80	0.76	0.48	0.50

Neighborhood	Traffic Volume (VPD)	Proximity to Downtown Core (m)	Proximity to Downtown Core Group	Year of House Construction	Age Stratum[5]	House Value ($)	Garage Type[4]	Number of Residents	Air Exchange Rate		3-day Mean of Benzene* (μg/m³)		5-day Mean of Benzene (μg/m³)			
									Winter Indoor	Summer Indoor	Winter Outdoor	Summer Outdoor	Winter Outdoor	Winter Outdoor	Summer Indoor	Summer Outdoor
TC	52,000	8,660	8000	1973	3	351,000	7	6	0.11825	0.69125	0.69	0.31	0.89	0.68	0.39	0.32
ST	3,400	2,306	0	1946	2	350,000	7	4	0.23539		0.85		0.99	0.79		
TS	700	12,971	8000	2006	5	331,500	4	2	0.16454	0.21301	0.54	0.22	2.96	0.60	0.61	0.25
TC	51,600	9,014	8000	1973	3	343,000	7	3	0.20419	0.14336	0.88	0.25	1.58	0.85	1.03	0.34
ST	30,800	2,764	0	1953	2	345,500	1	4	0.26525		0.78		1.14	0.79		
ST	25,000	2,502	0	1953	2	395,500	6	2	0.37638	0.23284	0.53	0.54	0.85	0.62	0.77	0.58
PD	18,500	3,467	0	1923	1	197,000	6	2	0.30081	N/A[3]	0.49	0.66	0.75	0.62	N/A[1]	N/A[1]
ST	23,600	2,541	0	1953	2	379,500	7	2	0.24846		0.46		0.71	0.59		
TS	700	12,945	8000	2006	5	334,000	4	4	0.23632		0.44		2.29	0.42		
W M	45,800	2,962	0	1921	1	342,000	7	1	0.48730	0.68104	0.58	0.57	0.66	0.58	0.58	0.47
DT	3,700	4,257	4000	1964	3	328,500	7	1	0.12586		0.64		0.67	0.56		
DX	2,500	9,323	8000	1994	4	394,500	4	3	0.19292	0.20484	0.62	1.98	0.96	0.60	2.60	1.53
TC	94,300	8,526	8000	1971	3	348,000	7	2	0.21651	0.65194	0.57	0.30	0.75	0.63	0.37	0.33
TT	9,600	11,544	8000	2004	5	576,000	4	4	0.12780		0.42		2.91	0.43		
FH	7,500	10,381	8000	1999	4	538,500	4	4	0.14289		0.44		1.68	0.41		

Neighborhood	Traffic Volume (VPD)	Proximity to Downtown Core (m)	Proximity to Downtown Core Group	Year of House Construction	Age Stratum[5]	House Value ($)	Garage Type[4]	Number of Residents	Air Exchange Rate		3-day Mean of Benzene* (µg/m^3)		5-day Mean of Benzene (µg/m^3)			
									Winter Indoor	Summer Indoor	Winter Outdoor	Summer Outdoor	Winter Outdoor	Winter Outdoor	Summer Indoor	Summer Outdoor
FH	25,400	9,907	8000	1999	4	402,000	4	2	0.10840		0.49		0.72	0.43		
SA	54,500	2,220	0	1931	1	183,000	5	2	0.65550		0.71		0.80	0.64		
ST	23,600	2,629	0	1953	2	365,000	7	2	0.22501		0.57		0.53	0.47		
TT	28,900	11,114	8000	2005	5	439,500	7	4	0.23037	0.30903	0.38	0.21	0.63	0.37	0.34	0.25
OX	52,000	8,996	8000	1996	4	418,000	3	2	0.56177	0.82268	0.55	0.54	1.41	0.47	0.75	0.60
ST	23,600	2,506	0	1949	2	307,500	7	2		0.14581		0.27			0.69	0.47
SA	39,900	2,712	0	1943	1	254,500	7	5		0.72405		0.40			0.51	0.38
W M	22,200	2,992	0	1943	1	530,500	2	3		0.51641		0.30			0.56	0.54
TT	9,600	11,500	8000	2004	5	645,500	4	4		0.11572		0.18			0.34	0.21
TT	11,543	12,158	8000	2004	5	375,000	7	4		0.10627		0.21			0.43	0.27
FH	7,500	10,505	8000	1998	4	446,500	4	3		0.34172		0.17			2.77	0.21
ST	3,700	2,108	0	1957	2	434,000	7	5		0.08056		0.32			0.43	0.54
FH	1,600	10,192	8000	1990	4	612,500	4	4		0.52389		0.30			0.44	0.25
ST	14,000	2,854	0	2004	2	406,000	7	2		0.12016		0.56			N/A[1]	N/A[1]
TT	9,600	11,353	8000	1931	5	636,000	4	1		0.27168		0.28			2.76	0.50

Traffic Volume (VPD)	Proximity to Downtown Core (m)	Proximity to Downtown Core Group	Year of House Construction	Age Stratum[5]	House Value ($)	Garage Type[4]	Number of Residents	Air Exchange Rate		3-day Mean of Benzene* (µg/m³)		5-day Mean of Benzene (µg/m³)			
								Winter Indoor	Summer Indoor	Winter Outdoor	Summer Outdoor	Winter Outdoor	Winter Outdoor	Summer Indoor	Summer Outdoor
66,600	2,278	0	1988	1	316,500	9	5		1.29184		0.54			0.86	0.52
2,500	9,408	8000	1958	4	411,500	4	3		0.47833		0.45			0.61	0.42
250	5,591	4000	1960	2	327,000	7	2		0.08500		0.72			0.73	0.82
3,700	4,145	4000	2007	3	384,000	7	2		0.54246		0.90			1.04	0.83
700	12,704	8000	1963	5	342,500	7	3		1.68870		0.68			0.42	0.52
34,300	5,197	4000	1994	3	390,500	7	2		0.19166		0.61			0.75	0.61
24,300	9,272	8000	2007	4	466,000	4	4		0.36032		1.59			2.97	1.42
700	12,591	8000	1963	5	321,000	7	4		0.34267		0.93			1.63	1.03
13,300	4,353	4000	1958	3	381,000	7	4		0.24271		1.49			1.61	1.29
100	5,795	4000	1953	2	330,000	7	1		0.17456		2.44			1.49	1.48
20,200	2,661	0	1930	2	367,500	7	3		0.24083		N/A[2]			0.66	N/A[1]
39,900	2,488	0	1997	1	278,500	4	2		0.18954		0.44			0.59	0.54
25,400	10,158	8000	1957	4	460,500	4	2		0.53681		0.34			2.75	0.34
250	5,609	4000	1949	2	312,500	7	1		0.30903		0.64			0.54	0.61

Appendix 15 – Indoor vs. Outdoor Environments – Statistical Analysis

t-tests: independent two-sample
Hypothesized mean difference of zero
α=0.05

Comparison of Benzene Levels in the Winter Season:

Statistical Measure	Indoor	Outdoor
Mean ($\mu g/m^3$)	1.66	0.94
Standard Deviation	0.7866	
Number of Observations	49	49
T Critical two-tail	4.60	
p-value	<0.0001	

Comparison of Benzene Levels in the Summer Season:

Statistical Measure	Indoor	Outdoor
Mean ($\mu g/m^3$)	1.06	0.55
Standard Deviation	0.7203	
Number of Observations	47	48
T Critical two-tail	3.40	
p-value	0.0012	

t-tests: paired two-sample
Hypothesized mean difference of zero
α=0.05

Comparison of Benzene Levels in the Winter Season:

Statistical Measure	Indoor	Outdoor
Mean ($\mu g/m^3$)	1.50	0.93
Standard Deviation	0.5795	
Number of Observations	26	26
T Critical two-tail	4.47	
p-value	0.0002	

Comparison of Benzene Levels in the Summer Season:

Statistical Measure	Indoor	Outdoor
Mean ($\mu g/m^3$)	1.00	0.48
Standard Deviation	1.041	
Number of Observations	24	24
T Critical two-tail	2.44	
p-value	0.0226	

*statistical measures reflect values from paired groupings (i.e., if one participant is missing from one comparison group, it will also be removed from the other).

Appendix 16 – Winter vs. Summer – Statistical Analysis

t-tests: independent two-sample
Hypothesized mean difference of zero
α=0.05

Comparison of Benzene Levels in the Outdoor Environment:

Statistical Measure	**Winter**	**Summer**
Mean ($\mu g/m^3$)	0.94	0.55
Standard Deviation under Ho	0.3557	
Number of Observations	49	48
t value	-5.57	
p-value	<0.0001	

Rank Sums: independent two-sample
Hypothesized mean difference of zero
α=0.05

Comparison of Benzene Levels in the Indoor Environment:

Statistical Measure	**Winter**	**Summer**
Mean ($\mu g/m^3$)	1.66	1.06
Standard Deviation under Ho	145.0575	
Number of Observations	50	50
p-value	5.063E-7	

t-tests: paired two-sample
Hypothesized mean difference of zero
α=0.05

Comparison of Benzene Levels in the Outdoor Environment:

Statistical Measure	**Winter**	**Summer**
Mean (µg/m^3)	0.95	0.49
Standard Deviation	0.4724	
Number of Observations	25	25
t value	4.87	
p-value	<0.0001	

Rank Sums: paired two-sample
Hypothesized mean difference of zero
α=0.05

Comparison of Benzene Levels in the Indoor Environment:

Statistical Measure	**Winter**	**Summer**
Mean (µg/m^3)	1.46	1.00
Standard Deviation	1.0677	
Number of Observations	24	24
s value	84	
p-value	0.0129	

*statistical measures reflect values from paired groupings (i.e., if one participant is missing from one comparison group, it will also be removed from the other).

Appendix 17 – Traffic Volume – Statistical Analysis

t-tests: independent two-sample
Hypothesized mean difference of zero
α=0.05

Comparison of Benzene Levels in the Winter Season:

Statistical Measure	Quartile 1	Quartiles 3+4
Mean (μg/m^3)	1.23	1.01
Standard Deviation	0.5436	
Number of Observations	12	12
t value	0.98	
p-value	0.3381	

Comparison of Benzene Levels in the Summer Season:

Statistical Measure	Quartile 1	Quartiles 3+4
Mean (μg/m^3)	0.78	0.44
Standard Deviation	0.4923	
Number of Observations	13	13
t value	1.74	
p-value	0.1043	

Appendix 18 - Proximity to Downtown Core – Statistical Analysis

Statistical test: independent two-sample
Hypothesized mean difference of zero
α=0.05

Comparison of Benzene Levels in the Winter Season:

Statistical Measure	**0 vs. 8000**		**0 vs. 4000**		**4000 vs. 8000**	
Statistical test used	t-test		Rank Sums		Rank Sums	
Mean ($\mu g/m^3$)	0.86	0.83	0.86	1.34	1.34	0.83
Standard Deviation	0.3126		18.0278		26.4575	
Number of Observations	15	24	15	10	10	24
t value	0.34		/		/	
p-value	0.7365		0.0080		4.702E-5	

Comparison of Benzene Levels in the Summer Season:

Statistical Measure	**0 vs. 8000**		**0 vs. 4000**		**4000 vs. 8000**	
Statistical test used	t-test (log distribution)		t-test (log distribution)		Rank Sums	
Mean ($\mu g/m^3$)	0.51	0.45	0.51	0.85	0.85	0.45
Standard Deviation	/		/		/	
Number of Observations	12	25	12	10	10	25
t value	2.37		-2.93		/	
p-value	0.0236		0.0124		3.875E-4	

Appendix 19 – SES- Statistical Analysis

t-tests: independent two-sample
Hypothesized mean difference of zero
α=0.05

Comparison of Benzene Levels in the Winter Season:

Statistical Measure	Quartile 1	Quartiles 3+4
Mean ($\mu g/m^3$)	1.81	2.49
Standard Deviation	1.1916	
Number of Observations	13	13
t value	-1.46	
p-value	0.1579	

Comparison of Benzene Levels in the Summer Season:

Statistical Measure	Quartile 1	Quartiles 3+4
Mean ($\mu g/m^3$)	0.76	1.81
Standard Deviation	1.0475	
Number of Observations	13	13
t value	-2.53	
p-value	0.0243	

Appendix 20 – Garage Type – Statistical Analysis

t-tests: independent two-sample
Hypothesized mean difference of zero
$\alpha=0.05$

Comparison of Benzene Levels in the Winter Season (regardless of car ownership or usage):

Statistical Measure	**No Garages vs. Attached**		**No Garages vs. Detached**		**Attached vs. Detached**	
Mean ($\mu g/m^3$)	1.24	2.28	1.24	1.32	2.28	1.32
Standard Deviation	1.1616		0.7497		0.9714	
Number of Observations	3	18	3	29	18	29
t value	-3.57		-0.57		2.97	
p-value	0.0022		0.5742		0.0063	

Comparison of Benzene Levels in the Summer Season (regardless of car ownership or usage):

Statistical Measure	**Attached vs. Detached**	
Mean ($\mu g/m^3$)	1.62	0.73
Standard Deviation	0.8666	
Number of Observations	18	28
t value	2.83	
p-value	0.0106	

Group 4 = homes with attached garages, connecting doors, and had used their cars during sampling days.

Group 7 = homes with detached garages and had used their cars during sampling days.

Comparison of Benzene Levels between Group 4 and Group 7 in the Winter Season:

Statistical Measure	Group 4 vs. Group 7	
Mean ($\mu g/m^3$)	2.27	1.19
Standard Deviation	0.8838	
Number of Observations	16	21
t value	3.29	
p-value	0.0041	

Comparison of Benzene Levels between Group 4 and Group 7 in the Summer Season:

Statistical Measure	Group 4 vs. Group 7	
Mean ($\mu g/m^3$)	1.80	0.74
Standard Deviation	0.876	
Number of Observations	15	25
t value	2.92	
p-value	0.0102	

Appendix 21 – Occupancy – Statistical Analysis

t-tests (log distribution): independent two-sample
Hypothesized mean difference of zero
α=0.05

Comparison of Benzene Levels in the Winter Season:

Statistical Measure	2 Occupants or Less	4 Occupants or More
Mean (μg/m^3)	1.24	1.99
Number of Observations	22	22
t value	-2.95	
p-value	0.0052	

Comparison of Benzene Levels in the Summer Season:

Statistical Measure	2 Occupants or Less	4 Occupants or More
Mean (μg/m^3)	1.55	1.24
Number of Observations	22	17
t value	-0.40	
p-value	0.6955	

Appendix 22 – Pearson correlation: benzene concentrations, house age and AER

Pearson Correlation Test: independent two-sample for mean
Hypothesized correlation (rho) equals to zero
α=0.05

Pearson Correlations in winter (n = 50):

	Benzene Level	Year of Construction	AER
Benzene Level	1.00	0.30 0.04	-0.06 0.68
Year of Construction	0.30 0.04	1.00	-0.52 0.00
AER	-0.06 0.68	-0.52 0.00	1.00

Pearson Correlations in summer (n = 47):

	Benzene Level	Year of Construction	AER
Benzene Level	1.00	0.40 0.01	-0.24 0.10
Year of Construction	0.40 0.01	1.00	-0.17 0.26
AER	-0.24 0.10	-0.17 0.26	1.00

Appendix 23 - House age – Statistical AnalysisMu

t-test (log distribution): independent two-sample
Hypothesized mean difference of zero
α=0.05

Old: Strata 1 to 3
New: Strata 4 & 5

Comparison of Benzene Levels in the Winter Season:

Statistical Measure	**Old**	**New**
Mean ($\mu g/m^3$)	1.34	2.15
Number of Observations	30	20
t value	-3.17	
p value	0.0027	

Comparison of Benzene Levels in the Summer Season:

Statistical Measure	**Old**	**New**
Mean ($\mu g/m^3$)	0.71	1.51
Number of Observations	30	20
t value	-1.95	
p value	0.0636	

Appendix 24 – Multivariate Analysis – Step-wise Selection Regression

Automatic step-wise selection
α=0.25

The REG Procedure
Model: MODEL1
Dependent Variable: i_daily_mean_from_week

Number of Observations Read	100
Number of Observations Used	99
Number of Observations with Missing Values	1

Stepwise Selection: Step 1

Variable GT1 Entered: R-Square = 0.1894 and C(p) = 10.1743

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	19.90823	19.90823	22.66	<.0001
Error	97	85.21110	0.87846		
Corrected Total	98	105.11933			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	1.95258	0.15621	137.25273	156.24	<.0001
GT1	-0.93221	0.19582	19.90823	22.66	<.0001

Stepwise Selection: Step 2

Variable season_type Entered: R-Square = 0.2808 and C(p) = 0.3151

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	29.51637	14.75819	18.74	<.0001
Error	96	75.60295	0.78753		
Corrected Total	98	105.11933			

The REG Procedure
Model: MODEL1
Dependent Variable: i_daily_mean_from_week

Stepwise Selection: Step 2

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	1.64103	0.17272	71.09120	90.27	<.0001
season_type	0.62311	0.17839	9.60815	12.20	0.0007
GT1	-0.93715	0.18541	20.11884	25.55	<.0001

All variables left in the model are significant at the 0.0500 level.

No other variable met the 0.0500 significance level for entry into the model.

Summary of Stepwise Selection

Step	Variable Entered	Variable Removed	Label	Number Vars In	Partial R-Square	Model R-Square
1	GT1			1	0.1894	0.1894
2	season_type			2	0.0914	0.2808

Summary of Stepwise Selection

Step	C(p)	F Value	Pr > F
1	10.1743	22.66	<.0001
2	0.3151	12.20	0.0007