Fort Saskatchewan and Area Community Exposure and Health Effects Assessment Program

FINAL REPORT

June 2003

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The Fort Saskatchewan and Area Community Exposure and Health Effects Assessment Program is the third in a series of reports published by the Health Surveillance Branch at Alberta Health and Wellness.

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The Grande Prairie and Area Community Exposure and Health Effects Assessment Program: Final Report, 2002
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The Alberta Oil Sands Community Exposure and Health Effects Assessment Program: Technical Report, 2000.
The Alberta Oil Sands Community Exposure and Health Effects Assessment Program: Methods Report, 2000.
The Alberta Oil Sands Community Exposure and Health Effects Assessment Program: Pilot Study Report, 1997.

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This report provides the results of a community exposure and health effects assessment conducted in Fort Saskatchewan and the surrounding area during the summer and fall of 2001. The assessment used a protocol developed in Alberta to assess personal exposure and the potential health impact of airborne contaminants.

This report would not have been possible without the valuable contributions made by:

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1.0 Executive Summary

1.1 Objectives

This report summarizes the results of a community exposure and health effects assessment undertaken in Fort Saskatchewan to assess the impact of airborne contaminants on the health of the population. The report describes the population and personal distribution of exposure to airborne chemicals and particulates in the city of Fort Saskatchewan and the surrounding region. Using a personal exposure model, the relative contribution of various exposure sources and pathways to airborne chemicals is estimated and associations between exposure to airborne chemicals and human health effects are described.

1.2 Methods and Analysis

The data used for the analysis was collected over a 21-week period (June 12 to November 8, 2001), using volunteers from the city of Fort Saskatchewan as well as surrounding areas such as Bruderheim and Redwater. Data was evaluated and, where applicable, additional comparisons were made to the scientific literature or to comparable data collected elsewhere in Alberta. The study collected a variety of measures for each participant, including personal, indoor, and outdoor levels of selected contaminants (sulfur dioxide, nitrogen dioxide, ozone, a group of volatile organic compounds, and particulate matter), measures of other sources of exposure, diet and health behaviours, and selected health outcomes.

1.3 Significant Findings

Despite ongoing recruitment activities, the field co-ordinator was unable to obtain the targeted number of volunteers. This suggests that exposure to contaminants from air-borne sources may not be an issue of primary concern to most residents of Fort Saskatchewan and the surrounding areas. It seems inconsistent with expectations in view of the notoriety given to concerns with air quality in the region.

The sample, although slightly smaller than anticipated, provided measures of exposure from all areas of the city of Fort Saskatchewan, as well as the surrounding region. The sample generally represented the rest of the population in gender and level of education, but had a larger proportion of high-income households. A significantly smaller proportion of study participants were smokers compared to an independent assessment of the area.

Analysis of the individual measures of exposure indicated that:

- Nitrogen dioxide levels were low compared to existing guidelines and were comparable to levels found in similar studies.
- Levels of sulfur dioxide measured in Fort Saskatchewan were very low compared to existing guidelines.
- Ozone indoor and personal levels were very low. Outdoor levels were an order of magnitude higher, which suggests that ambient measures are an inadequate measure of personal exposure.
- Indoor concentrations were the predominant factor affecting personal exposure to VOCs. Other factors were of only minor relative importance, which suggests that exposure to VOCs was predominantly from sources affecting indoor levels.

- $PM_{2.5}$ outdoor concentrations measured in Fort Saskatchewan were similar with that found in other communities in that they were well below guidelines. Variations in outdoor concentrations were not important as a predictor of variations in personal exposure within this community while variations in indoor levels, time activity, and smoking were found to be more important.
- Personal exposure to PAHs bound to $PM_{2.5}$ is completely driven by outdoor levels except where smoking occurs (refer to *Appendix A: Measuring Exposure to Polycyclic Aromatic Hydrocarbons in Fort Saskatchewan, Alberta*).
- An examination of PAH levels with wind speed and direction data determined that local emissions in the town, background levels, and regional sources from the south-southwest (Edmonton and industries) each had a similar impact on the average PAH concentration during the study. Emissions from regional sources to the north-northeast of the city have roughly half of the impact of the other sources due to the fact the wind seldom blows from that direction (refer to *Appendix A*).
- Ambient concentrations were not a good predictor of personal exposures.
- The most important exposure source of nitrogen dioxide (NO_2) was identified as local sources. Influences from background and regional sources were not detected. The presence of indoor sources could not be confirmed.
- The most important exposure source of sulfur dioxide (SO_2) identified was local sources (urban emissions such as vehicle exhaust) followed by regional sources from the south-southwest (City of Edmonton and industries). An influence from background sources and indoor sources was not detected.
- The most important exposure source for ozone (O_3) was background sources. Indoor, local, and regional influences that increase exposure were not detected.

An exposure model was developed to describe variation in personal exposure. Nine general factors were examined as potential causes of exposure variation: 1) gender; 2) urban-rural location; 3) housing characteristics; 4) ownership of a garage; 5) job status; 6) smoking characteristics; 7) time activity pattern; 8) outdoor concentration levels; and 9) indoor concentration levels.

The major findings were:

- Indoor variation accounted for nearly one-half of the variation in personal NO_2 exposure described by the model. Time activity was also an important driver of personal exposure while smoking and housing characteristics had minor effects. The most important factor within time activity appears to be the amount of time spent indoors at work; higher exposure is associated with more indoor work time.
- Overall, variations of time activity patterns accounted for roughly one-half of the variation in personal SO_2 exposure explained by the model. Indoor air was also an important factor affecting personal exposure. Outdoor levels of SO_2 were the driver for personal exposure.
- The variation in personal O_3 exposure described by the model was due to outdoor levels and time activity acting directly and indirectly through indoor levels. Indoor concentrations were also an important factor. Housing characteristics were found to be of relatively minor importance.
- Variation in indoor concentrations are the predominant factor affecting personal VOCs exposure (except benzene), while other factors were of minor relative importance. Outdoor concentrations did not have a significant direct effect on personal exposure but had a small indirect effect through indoor air.

- In contrast, benzene exposure was influenced by time activity patterns. Specifically, time spent outdoors at home and at work were important influences.
- Indoor concentration levels were predictive of particulate matter exposure. In a breakdown of indoor concentration level, the sole variable that emerged as driving the predictive nature was the number of cigarettes smoked.

In addition to measuring exposure, the study examined a variety of indicators of health status. These included lifestyle behaviours, previous diagnoses and contacts with the health care system, in addition to objective measures of neurocognitive functioning and biomarkers of exposure and effect.

The major findings were:

- Participants indicated that they consumed less than the recommended servings of grain products and that they consumed an average of 1-2 servings of sweets or other non-nutritious foods each day. The average body mass index (BMI) for the sample was 27.4, higher than the estimated Canadian average of 25.4, indicating a higher level of obesity. The sample also reported an average amount of physical activity that barely met minimum recommendations established by Health Canada.

- Biomarkers of exposure for benzene, toluene, and nicotine were measurable (i.e., above laboratory detection limits), but all levels were unassociated with measures of exposure.

- No statistically significant differences in neurocognitive functioning were found between the study sample and reference populations.

- The most common self-reported diagnosis of chronic diseases in the sample were back problems and allergies (both at 29%).

1.4 Recommendations

1. Establish ongoing monitoring of personal exposure levels to air contaminants.

This study did not find evidence of significantly elevated personal exposure to airborne contaminants. A long-term program is recommended that would monitor personal exposure to contaminants in order to detect any changes over time.

2. Participate in the implementation of an organized approach to community exposure and health effects assessment in the province in support of long-term comparisons with other areas across the province.

Strategic information gathering on community exposure and health across the province is key to evidence higher-based decision-making, managing health risks, and the development of health promotion, disease prevention, and exposure control strategies. Such information is also important to public concerns about air contaminants and health and for the development of health based air quality guidelines at a local, regional, and provincial level. Therefore, in collaboration with other agencies and organizations such as Alberta Health and Wellness, regional health authorities, the Clean Air Strategic Alliance, Health Canada, and Alberta Environment, a co-ordinated system should be developed for the ongoing collection, analysis, and interpretation of air quality and health information. Such a system should be sustainable, cost-efficient, and should build on already existing resources without adding significant new costs.

3. **Adopt and promote the use of innovative methods and technologies such as personal exposure monitoring to further our understanding of the relationship between air quality and human health.**

The results of this study indicate that the ambient concentration of contaminants measured at monitoring stations is not a good predictor of individual exposure (i.e., personal exposure). In the study of health and air quality and in the development of human health-based air quality guidelines, it is important to go beyond traditional emission inventories and ambient air quality monitoring. Personal exposure monitoring is a method that can complement existing methods.

2.0 Introduction

Human health concerns related to air quality have been raised by various stakeholder groups throughout Alberta including First Nations, environmental associations, governments, and the Clean Air Strategic Alliance (CASA). In response, a long-term, systematic approach to data gathering has been implemented in Alberta that will improve our knowledge about the link between the environment and human health. The approach combines two broad concepts in an integrated population-based environmental health framework: (1) the direct measurement of personal and population exposure to environmental factors, and (2) the epidemiologic surveillance of health outcomes in the population.

Most of the major industries operating in the Fort Saskatchewan region are members of the Northeast Capital Industrial Association (NCIA). NCIA is a not-for-profit cooperative that seeks to understand and reduce the environmental impacts of member industries through collaborative efforts with the community and all levels of government while supporting sustainable industrial growth.

NCIA membership includes 18 major chemical, petrochemical and petroleum industries operating in the region. The member companies consist of Agrium (operates fertilizer manufacturing plants in Redwater and Fort Saskatchewan), Air Liquide (supplier of oxygen, hydrogen, nitrogen and other gases to industries), Albchem Industries (sodium chlorate plant), BP Canada (natural gas liquids processing facility), Degussa Canada (hydrogen peroxide manufacturer), Dow Chemical (world scale manufacturing facilities producing products to make basic chemicals and plastics), EnerPro Midstream (natural gas liquids processing facility), Guardian Chemicals (manufacturers industrial specialty chemicals), Marsulex (produces sulfur chemicals for use in water and sewage treatment, and in industry), Nexen Chemicals (sodium chlorate plant), Oxy Vinyls (PVC resin manufacturer), Praxair (producer and supplier of specialty gases), Sherritt International (metals and nitrogen fertilizer manufacturing facility), Shell Chemicals (world scale petrochemical facilities producing styrene and glycol) , Shell Canada (refinery facility for production of petroleum products), Umicore Canada (specialty cobalt refining facility), Westaim (specialty manufacturing facility) and Williams Energy (oil and gas processing facility). In addition to the industries mentioned, there are a number of smaller industries in the surrounding area and the region continues to experience growth and development.

The Fort Saskatchewan and Area Community Exposure and Health Effects Assessment Program is part of an ongoing effort by public health officials in Alberta to collect information on airborne contaminants and health concerns across the province. The information gathered in the Fort Saskatchewan region will become part of the province wide database and will allow comparisons of human exposure and levels of airborne contaminants across various communities in Alberta. Previous studies have examined Fort McMurray, Lethbridge, and Grande Prairie.

There are significant gaps in information that limit our understanding of the relationship between air quality and human health outcomes. These include:

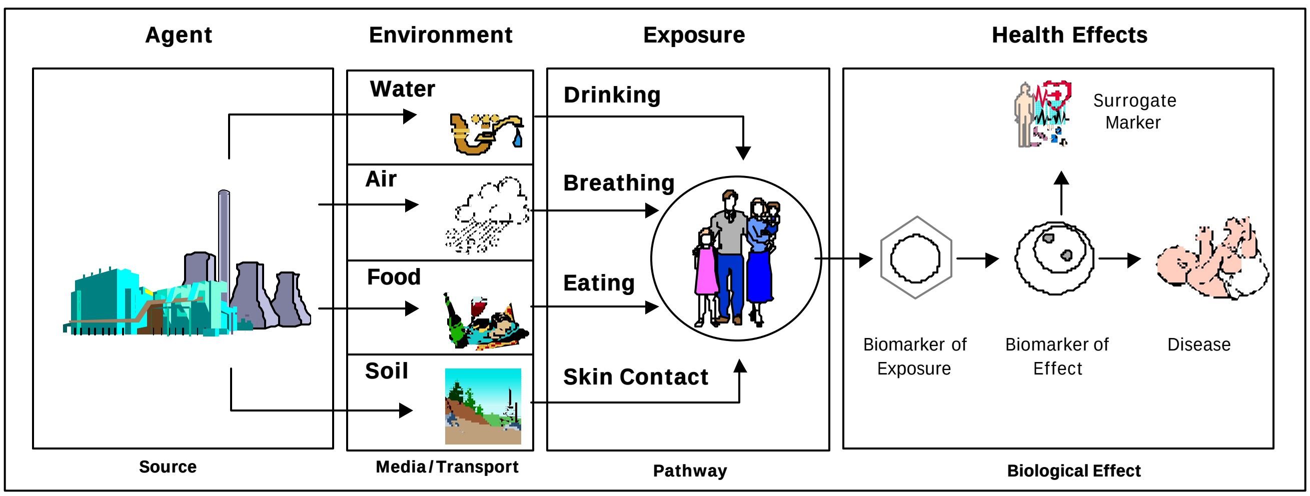
- An understanding of the population and personal distribution of exposure to airborne chemicals and particulates; and
- An understanding of the relative contribution of various exposure sources and pathways to airborne chemicals (i.e., the relative contribution of outdoor and indoor air to the total exposure).

The Fort Saskatchewan and Area Community Exposure and Health Effects Assessment Program was implemented using a scientific methodology and protocol that has evolved over many years and has been proven effective in previous assessment programs.[1]

3.0 Background and Rationale[1]

In general, exposure can be defined as any contact between a substance, biological agent, or radiation and an individual or community. We are all exposed to low levels of contamination in the air we breathe, the food we eat, the water we drink, and the consumer products we use. Contaminants can interfere with the normal biological functions, causing effects ranging from subtle biochemical changes to clinical disease and even death. Figure 1 displays this concept of a continuum from source of contamination to the final health effect, which is a basic feature of all contemporary risk models.

Figure 1: Continuum of Exposure



Determining the risk posed by environmental contaminants to populations requires knowledge about the following fundamental components:

- source(s) of contaminants;
- transport of agents in the environment;
- exposure of individuals and communities to chemicals;
- dose received by those exposed (biological markers of exposure);
- early biological effects resulting from the dose (biological markers of effect); and
- overt health effects (clinical disease, death).

[1] This section previously published in The Grande Prairie and Area Community Exposure and Health Effects Assessment Program: Final Report, 2002.

The output of each component in the chain of events serves as input to the next. The lack of information on any one component thus impairs our ability to make accurate assessments of the associated population health risks. Our knowledge about the source and transport of chemicals and other agents in the ambient environment is increasing as the result of environmental monitoring programs, however, there is a need to integrate these data with information on population exposure, biological markers, and health effects. This is very important in achieving new health-based protection levels.

In dealing with population health outcomes, which may be attributable to long-standing exposures to low-levels of contaminants, we are confronted with the difficult and complex problem of chronic health effects. A number of conditions, such as cancers, disorders of the cardiovascular system, neurological disease, chronic respiratory ailments, and many other diseases, have important environmental, behavioural, social, and genetic links. The causes of these conditions are multi-factorial in nature. Other characteristics, such as multistage development, long induction time, and the absence of information on individual and population exposure, make progress in chronic disease prevention slow and tenuous. In order to be able to address these issues, more than ever, there is a need to look beyond one-time epidemiologic studies.

Environmental health surveillance is a tool that can be used to gather data and information on the health of people for the purpose of tracking and detecting trends and associations among a broad range of environmental and health related variables. The process consists of an on-going, systematic collection, analysis, and interpretation of selected data on health outcomes, environmental quality parameters, and population exposure. In addition, data on behavioural, lifestyle, social, economic, and other confounding variables are also considered.

The Alberta Community Exposure and Health Effects Assessment Program protocol was developed to obtain measures of exposure across the continuum of exposure, including measures of contaminants in the environment, the quantity of contaminants to which an individual is exposed through these sources, and finally biological measures of exposure, effect and disease. Further details regarding the study protocol can be found in the Alberta Oil Sands Community Exposure and Health Effects Assessment Program: Methods Report.

4.0 Program Objectives

The Fort Saskatchewan and Area Community Exposure and Health Effects Assessment Program's primary objectives were to:

- Describe the population and personal distribution of exposure to airborne chemicals and particulates through:
  - estimation of the population distribution of selected airborne chemicals and particulates; and
  - characterization of the personal variation of exposure as a function of individual activity patterns.
- Quantify the relative contribution of indoor and outdoor air on personal exposure.
- Describe associations between exposure to airborne chemicals and human health effects by analyzing the occurrence of relationships between selected exposures, biomarkers and health outcomes.

5.0 Study Method and Protocol

5.1 Sample Selection and Recruitment

Data were collected during a period of approximately 21 weeks (June 12 to November 8, 2001) with an average rate of six individuals per week, for a total sample of approximately 138 individuals. Unpaid volunteers over the age of 18 years were recruited from the communities of Fort Saskatchewan, Redwater, Bruderheim, and surrounding rural areas.

Participation in the study places significant demands on the participants. As a result, the protocol recommends that recruitment of volunteers is preferable to a complex sampling design that would require participants to be solicited for participation. Considerations included the following:

- Participation rates would be expected to be so low as to defeat the purpose of a complex sampling design;
- Self-selection biases are not likely to affect exposure rates; and
- Cost would be substantially reduced.

Participants were recruited through advertising in various local media and through active recruitment at various industries, educational institutions, recreational facilities, and other public venues.

Children (<18 yr.) were excluded from the study sample for the following reasons:

- very young children cannot carry the personal exposure air monitors;
- children might not be able to provide reliable time-activity data;
- ingestion may be an important route of exposure to particulates for children that could not be evaluated within the parameters of the study;
- children are likely to have higher exposures to particles and chemical constituents than adults because of their activity patterns; and
- older children who could carry the monitor might be less likely than adults to wear it because it would interfere with normal activities.

5.2 Study Design

Several countries as well as the World Health Organization (WHO) are implementing exposure and health effects assessment approaches to address human health concerns related to environmental and other (e.g., occupational) factors. The Alberta Community Exposure and Health Effects Assessment Program is a complete study protocol that was designed to ensure that the results of exposure assessments conducted in Alberta are comparable. This approach provides information for comparison purposes and contributes toward a province-wide source of information on personal exposure measures. The protocol is modeled after an approach to exposure assessment developed by the US Environmental Protection Agency known as the TEAM approach.[2] The Program was designed to produce baseline population exposure and health outcome data through a population exposure assessment conducted in conjunction with a population health assessment. Previous studies have been completed to develop and test data collection methods for exposure assessment, develop and test data collection methods for the collection of additional data, and examine study logistics. The results of these studies are described in separate reports.[3-8] This report provides the results of the implementation of the Program protocol in the Fort Saskatchewan city and surrounding area.

Contaminants Measured

Data were gathered on the following contaminants:

- Nitrogen dioxide (NO_2) – a gas that results from combustion; sources include vehicular exhaust, gas stoves, tobacco smoke, kerosene heaters, wood-burning stoves and fireplaces, and gas pilot lights.
- Sulfur dioxide (SO_2) – a gas produced by several industrial processes; sources include vehicles, outdoor air, unvented kerosene heaters, and wood-burning heaters and stoves.
- Ozone (O_3) – a gas created through the interaction of hydrocarbons, nitrogen oxides, and sunlight; ozone is primarily found in outdoor air, although sources may also include residential electronic air cleaners, negative ion generators, photocopy machines, deodorizers, germicides, and some aerosol sprays.
- Volatile organic compounds (VOCs) – a number of compounds that are carbon-based vapours and gases, many of which are produced from chemical reactions; sources include air fresheners, moth balls, polyurethane floor finish, synthetic fabrics, furniture polish, latex paint, floor wax and wax strippers, shoe polish, solvents, particle board, floor and carpet adhesives, fluorescent lighting, and tobacco smoke.
- Inhalable particulates – microscopic particles that remain floating in the air and can enter the respiratory system; sources include tobacco smoke, kerosene heaters, home renovations, fabric lint, wood stoves or fireplaces, humidifier deposits, and dander.
- Polycyclic aromatic hydrocarbons (PAHs) – compounds that can be formed by incomplete combustion, some of which exhibit carcinogenic effects in humans; sources include gas flaring, teepee burners, automobile exhaust, and any type of natural (e.g., forest fires) or unnatural burning; indoor sources of may include fireplaces, tobacco smoke, and any other household smoke sources (e.g., burnt toast); refer to *Appendix A*.

Passive Air Sampling

All volunteers were required to wear passive sampling air monitors in their personal breathing zone continuously for a 7-day period.[2] The air-sampling monitors were analyzed for levels of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and a wide range of volatile organic compounds (VOCs) such as benzene and toluene. Similar air samplers were located inside and outside of participant's homes to provide measures of contaminants in and around their personal living space.

Polycyclic Aromatic Hydrocarbon (PAH) Air Sampling

Approximately 15% (1 in 7 volunteers) of the sample were requested to have polycyclic aromatic hydrocarbon (PAH) monitoring equipment located inside and outside of their homes continuously for a 7-day period to gather data on the levels of these contaminants in and around their personal living space. The monitoring of PAHs is at the pilot stage and is not part of the program. The results of the PAH monitoring is presented in *Appendix A*.

[2] In the original study protocol, four consecutive 24-hour samples were collected from each volunteer. This was modified in the Grande Prairie and Fort Saskatchewan studies to one continuous, 7-day sample to lower the method detection limit and to accommodate field logistics. A 7-day sample also provided a more representative exposure measure as it spanned both weekday and weekend activities for each volunteer.

Additional Data Sources

In addition to the exposure sampling listed above, all volunteers were requested to complete the following:

- review and sign a consent form outlining the participant's involvement in the study;
- a series of neurocognitive tests;
- two health and exposure related questionnaires, provided to the participants to complete at their convenience during the 7-day period of participation;
- one sample of blood and one 12-hour composite sample of urine; and
- a diary of personal activities throughout the 7-day period of participation.

Table 1 shows the various components and sources of data used for the study.

Table 1: Components of the Study

Component	Media or Source of Data	Purpose
Characteristics of the Sample	Vital Statistics Other Demographics	General information to characterize the samples and populations.
	Lifestyle behaviours	Sections of the questionnaire identified individual smoking habits, weight, height, nutritional intake, and physical activity levels.
	Time Activity Diary	The time activity diary identified potential routes of exposure in daily activities.
Exposure Measurement	Personal Exposure Monitors: Passive samplers Particulate/PAH samplers Ambient Station Data	Measures of the actual exposure levels of each participant during a regular week, using personal, indoor, and outdoor air monitors. Measures of exposure for particulate matter and polycyclic aromatic hydrocarbons (PAHs) were collected for a sub-sample. Ambient station monitors were also set-up for the duration of the study period.
	Other Sources of Exposure: Household sources Work sources Dietary sources	Sections of the questionnaire identify potential sources in the home and work environments, and identification of potential dietary sources of exposure.
Biomarkers of Exposure	Blood	Analysis included measures of cotinine (a metabolite of nicotine), pesticides, and phytoestrogens.
	Urine	Analysis included measures of metabolites of the BTEX compounds benzene, toluene, ethylbenzene, m-, p-, and o-xylene).

Table 1: Components of the Study (cont'd)

Biomarkers of Effect	Autoantibodies	Analysis included immunofluorescence microscopy to detect autoantibodies, which indicate elevated immune system reaction.
	Immunoglobulin gamma E (IgE)	High levels of IgE are associated with an increased incidence of diseases including bronchial asthma, allergic rhinitis, and eczema.
	Lung Function	Spirometry was used to measure the individual's lung capacity and volume during the exposure-monitoring period.
	Neurocognitive measurement	Neurocognitive tests to determine the potential impact of chronic exposure on neurocognitive functioning.
Measures of Health Outcome	Health Care System Records	Records of participant contacts with the health care system in the recent past identify health conditions not captured by the questionnaires. Diagnosis rates were compared to control communities.
	Questionnaires	Sections of the questionnaire identified general, occupational, emotional, and psychological health.
		Sections of the questionnaire identified previously diagnosed health problems.

5.3 Study Logistics

Science Team

A science team was established to lead the design and implementation of the program protocol. The science team was responsible for:

- the development of schedules for deployment and collection of samples;
- training field staff including the field co-ordinator and field monitoring teams;
- defining any alterations to the original protocol to address issues unique to the Fort Saskatchewan area; and
- statistical analysis of the data and preparation of the final report.

Field Staff

The field co-ordinator was responsible for selecting and screening participants, booking appointments for the field monitoring teams, maintaining the sampler inventory, and co-ordinating the flow of samplers to the laboratory for analysis. In addition, the field co-ordinator was responsible for co-ordinating the flow of sampling time information and respondent data, ensuring that all aspects of the study are administered to each of the participants, and entering all data electronically into various databases.

Field monitoring teams consisted of two trained personnel who were responsible for placing the samplers in an appropriate location in each participant's home, collecting spent samplers, and recording various sources of data. A multi-day training session was held for the field monitoring teams. Classroom training consisted of a review of the study and the requirements for successful completion. Each team member was required to practice and demonstrate the ability to correctly handle and locate samplers in a participant's home.

Field Operations

Each participant was requested to complete a standard protocol that included participation in all aspects of the program. The protocol requested each volunteer to visit the study office for initial testing. Each participant was required to sign a consent form and requested to provide their Personal Health Number (PHN) before beginning. Additional screening criteria included:

- availability for an interview at the study office to provide the required preliminary information and complete a set of neurocognitive tests; and
- availability that week to allow field monitoring teams to deploy and retrieve the air monitoring equipment at the beginning and end of the 7-day period.

The field co-ordinator explained the study in detail, stressing the requirements of complete participation. Samples of the monitoring equipment and typical placements were used as part of the explanation. After answering any questions about the study, the co-ordinator gave the participant time to read the consent form. If necessary, the co-ordinator read the consent form to the participant. At the completion of the data collection period, consent forms were separated from the other documents, sorted by identification number, and filed in secured storage. Since these forms contain names and linkages to other data, they were kept separate from other information to assure the confidentiality of respondent information.

After the initial screening was completed, the monitoring team appointment booked, and all forms signed, the participant was required to complete tests of visual acuity and colour-blindness, a respiratory health survey, and a variety of tests of neurocognitive functioning. Two questionnaires that request information about the individual's home, lifestyle, diet, and health were provided to each participant to complete during their participation in the study. The individual was also required to schedule an appointment at the Fort Saskatchewan Health Centre laboratory to provide a blood sample and a 12-hour urine sample.

The field monitoring teams deployed air-sampling devices at the participant's home that remained in place for the 7-day sampling period. The field monitoring teams retrieved the air monitoring equipment at the end of the sampling period.

Field monitoring teams operated in pairs to ensure safety and improve accuracy. Each team received a list of participants who had completed the initial testing phase described above and the appointment times. The teams were responsible for contacting the participant at the previously arranged appointment time to place the samplers in the home and on the individual. On arrival, the monitoring teams provided details about the equipment being placed in the home and explained what to do if there were problems with the equipment. The monitoring teams also provided additional details about the time activity diary that the participant was requested to complete: participants were asked to record their activities throughout the 7-day sampling period. At the conclusion of the 7-day period, the field monitoring teams reviewed and collected the time activity diaries, self-administered surveys, and answered any final questions.

Data Entry and Analysis

All information collected by the field staff was returned to the study office at the end of the day. The field co-ordinator reviewed it to verify completeness and, if necessary, follow-up with the participant to complete any missing information. Data was entered by the field co-ordinator. The field co-ordinator then sent the electronic and paper files to Alberta Health and Wellness where a database co-ordinator verified data entry and cleaned records. Once data entry was completely verified, the electronic files were compiled and merged as necessary into a database for analysis. All data components were made identifiable by the arbitrarily assigned participant identification number only; other identifiable information was stripped from the records to ensure confidentiality of the results. Data analysis was then conducted by the science team at Alberta Health and Wellness offices using SAS and SPSS statistical packages.

5.4 Exposure Monitoring Procedures

The field-monitoring protocol was designed to collect sufficient samples to characterize the exposure of a representative population to nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), volatile organic compounds (VOCs), and inhalable particulates (up to 2.5μm in aerodynamic diameter). Each compound of interest was monitored for a 7-day period in three locations: personal (in the participant's breathing zone), indoors (in an appropriate location inside the participant's home), and outdoors (in an appropriate location outside the participant's home). To enhance quality assurance and quality control procedures the field teams also deployed "blanks", or unexposed samplers. Blanks were handled and analyzed in an identical manner as the other air monitors, but, unlike the other monitors, they were not exposed to the environment.

Meteorological data was obtained from Alberta Environment's Ambient Station situated in the town site of Fort Saskatchewan. The measurements regularly taken included: wind speed, wind direction, temperature, and relative humidity.

Monitoring Equipment

Passive Air Monitors

Nitrogen Dioxide (NO_2): A passive air monitor was used for measuring nitrogen dioxide. The clip-on air monitor contains a chemical adsorbent that collects nitrogen dioxide indicators by passive diffusion.

Sulfur Dioxide (SO_2): A passive air monitor was used for measuring sulfur dioxide. The clip-on air monitor contains a chemical adsorbent that collects sulfur dioxide indicators by passive diffusion.

Ozone (O_3): A passive air monitor was used for measuring ozone. The clip-on air monitor contains a chemical adsorbent that collects ozone indicators by passive diffusion.

Volatile Organic Compounds (VOCs): A passive air monitor was used for measuring a variety of VOCs. The clip-on air monitor contains a chemical adsorbent that collects various VOCs by passive diffusion.

All four passive air monitors were designed to be worn in the participant's breathing zone to measure personal exposure. The participants were encouraged to continue normal activities while wearing the monitor. During activities such as sleeping or showering, however, the sampler was to be kept as near to the person as practical while protecting the sampler from damage and high humidity environments.

One of each type of sampler was deployed inside and outside the participant's home using a stationary stand constructed to house and shelter the monitors during the 7-day exposure period. The air monitors were attached to identically constructed indoor and outdoor stationary stands approximately one (1) metre above the floor or ground. The outdoor passive air monitoring stand has a rain shield approximately 30cm in diameter for shelter.

The method detection limits (MDL) of the passive samplers were based on field blanks and the limit of quantitation of the laboratory analysis. The detection limits for VOCs were based on the laboratory limit of quantitation (150 ng/sampler) when more than 90% of the field banks were less than the limit of quantitation and are indicated by an asterisk in the table. For the other compounds, the detection limit was based on three standard deviations of the field blank levels and may vary slightly between the batches of samplers through the study. The average detection limits over the study for the compounds investigated (assuming a 7-day sample) are listed in the third column of Table 2. Columns 4 to 6 in the table show the fraction of the measurements that were above the detection limit. Measurements below the detection limits remain useful in characterizing community exposures.

Table 2: Summary of Passive Sampler Detection Limits

Sampler Compound	Sample Rate (ml/min)	Detection Limit (µg/m^3)	Fraction of samples less than MDL		
			Personal	Indoor	Outdoor
NO_2	120	2.1	0%	0%	25%
SO_2	218	1.1	80%	90%	60%
O_3	24.5	0.82	10%	25%	0%
Hexane	32	2.2	25%	60%	100%
Methylhexane	28.9	0.51 *	10%	40%	90%
Benzene	35.5	0.42 *	5%	15%	35%
Heptane	28.9	0.51 *	5%	10%	85%
Toluene	31.4	2.6	5%	5%	40%
Octane	26.6	0.56 *	30%	50%	100%
Ethylbenzene	27.3	0.55 *	10%	25%	90%
m-, p-Xylene	27.3	1.0	0%	10%	50%
o-Xylene	27.3	0.55 *	10%	20%	75%
Nonane	24.6	0.60 *	25%	55%	95%
Decane	23.1	0.64 *	15%	30%	95%
Limonene	30	0.50 *	0%	0%	95%

*** Detection limit based on laboratory limit of quantitation (150 ng/sampler) assuming 7-day sample period.**

An estimate of the accuracy of the NO_2, SO_2, and O_3 samplers was obtained by comparing 7-day passive samples taken at Fort Saskatchewan ambient monitoring station with the results of the continuous monitoring equipment. Figures 2 to 4 show a comparison of the passive and ambient station data.

The data show the passive samplers were reasonably accurate with fairly good agreement between the passive samplers and the ambient station monitors.

Figure 2: Passive Sampler Data Compared to Ambient Station Data for NO_2

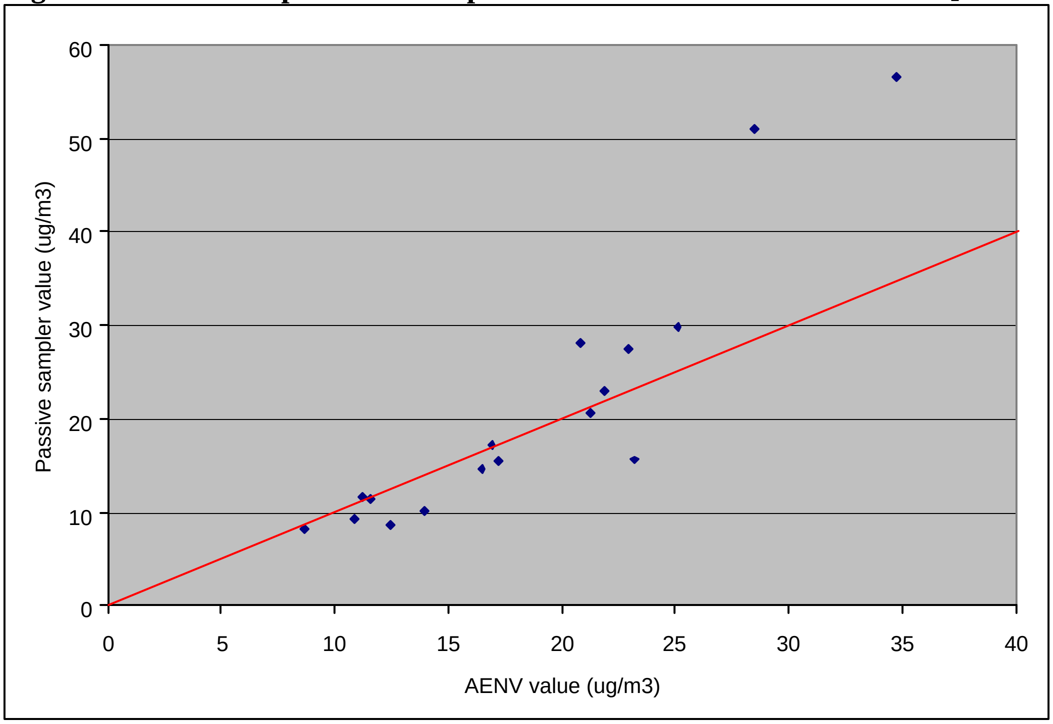


Figure 3: Passive Sampler Data Compared to Ambient Station Data for SO_2

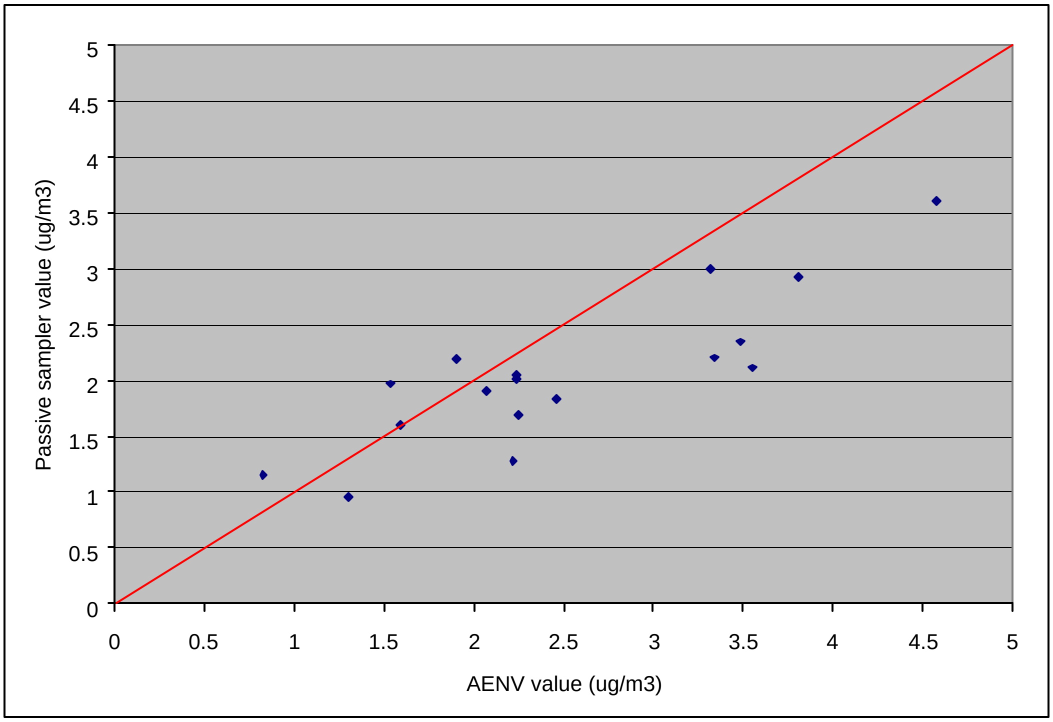
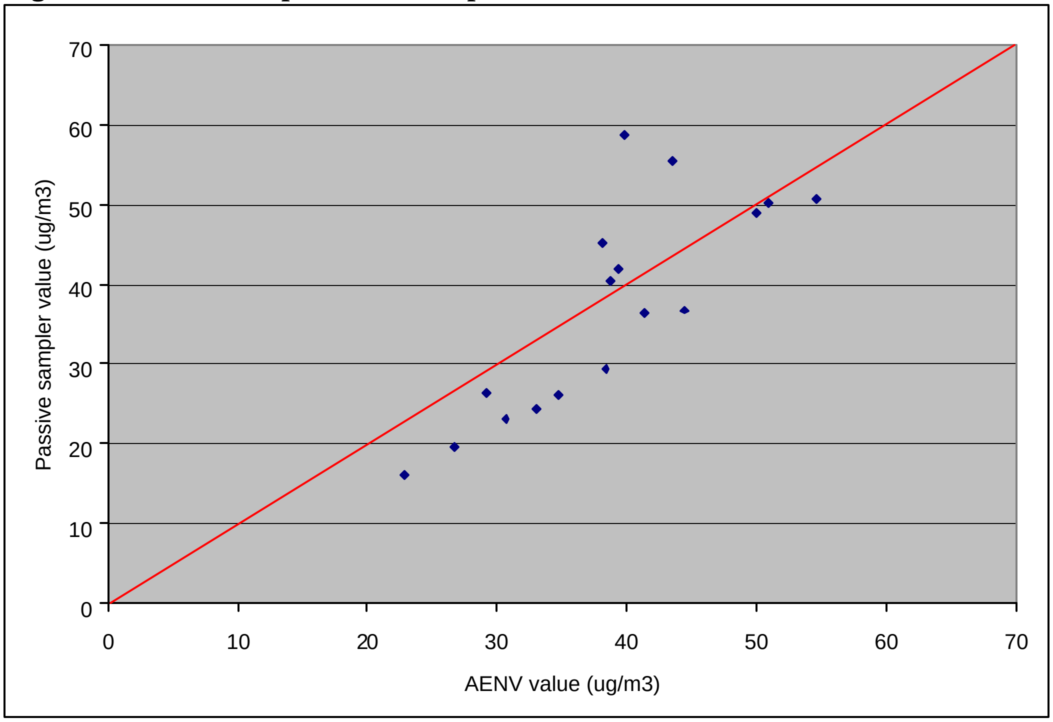


Figure 4: Passive Sampler Data Compared to Ambient Station Data for O_3



Active Air Monitors

Particulates/PAHs: For measurement of respirable particulates from indoor and outdoor environments at the participant's home, the stationary indoor and outdoor air particulate pumps were used to house particulate sampling heads and filters. The particulate sampling heads were oriented in a position that avoided particle deposition due to gravity and were attached to the particulate pumps approximately one (1) metre above the floor or ground. Before and after exposure monitoring, the particulate filters were weighed, and the information was recorded along with the filter identification numbers for analysis purposes after the 7-day exposure period.

Sampler Placement Strategy

All sampler locations were determined during the initial visit to each home. Locations were selected after carefully determining the layout of the home, based on the daily habits of the participant, the type of dwelling (home, apartment, etc.), and the outside layout of the yard or grounds. Samplers were placed in the main living area of the participant (the room in which the participant spends the most time while awake), ensuring that the samplers were at least two metres away from exterior doors, windows, and ventilation registers.

The protocol specifies that the participant's backyard is the preferred location for outdoor sampling and that the monitors should not be located within one metre of trees and bushes or within five metres of any type of air vent. For second floor apartments, a "yardarm" was deployed from a window or balcony to support the sampling devices. If a yardarm was not possible, the protocol considers collection of samples at ground level acceptable for second floor apartments. Non-ideal situations required some reasonable compromises, but were identified by the field teams for consideration during data analysis.

5.5 Neurocognitive Functioning

Participants were requested to complete a series of computerized neurobehavioral tests using the Neurobehavioral Evaluation System (NES2)[9] software installed on an IBM compatible computer. Participants were informed that they could stop and ask questions or, if absolutely necessary, leave the premises at any time, and they should not feel pressured to continue to respond. Prior to completing the series of neurobehavioral tests, subjects were given a brief explanation of how they were expected to respond (e.g., what keys to use) and were introduced to the joystick (required for some of the tests). Subjects were also given visual tests to ensure normal visual acuity and colour vision (required for the colour-word test). A pre-test questionnaire was completed to identify the subject's general well-being and current health status.

The NES2 tests administered included: finger tapping test; hand-eye co-ordination task; simple reaction time test; continuous performance test; pattern comparison test; symbol-digit substitution test; pattern memory test; serial digit learning test; associate learning test; associate learning delayed recognition test; vocabulary test; switching attention test; colour-word test; and mood test. The auditory digit span from the Wechsler Memory Scale (WMS-R) and the Neuropsychological Impairment Scale were added to provide a non-automated and non-visual activity. These activities were administered by a trained interviewer.

5.6 Questionnaires

Two questionnaires were given to each participant following the completion of the neurocognitive functioning tests for completion at their convenience during the 7-day testing period. The first questionnaire, the Demographic and Exposure Questionnaire, was designed to collect information about participant demographics, occupational health, and their work and home environments, including potential sources of contaminants. This questionnaire also includes all of the questions included on the Basic Standard Environmental Inventory Questionnaire, designed to help classify relative concentration estimates.[10]

The second questionnaire, the Health and Nutrition Questionnaire, was designed to collect a variety of health indicators, including mental and physical health, physical activity levels, and nutritional intake. The questions on nutrition attempt to characterize actual nutrition levels using the amounts dictated by the Canadian Food Guidelines. Two standardized scales of general health were included in The Health and Nutrition Survey: the General Health Questionnaire (GHQ) and the Short-Form-60 Health Survey (SF-60). Both questionnaires are well validated and documented tools for assessing health. The GHQ assesses psychological well-being, and the SF-60 assesses physical functioning, role limitations, bodily pain, social functioning, general mental health, vitality, and general perceptions. Additional measures from the National Population Health Survey, conducted by Statistics Canada, were also included to provide information about physical activity level.

5.7 Biological Tests

A laboratory technologist from the Fort Saskatchewan Health Centre laboratory extracted a sample of each participant's blood for testing by the laboratory to identify biomarkers of exposure. The participant was also requested to submit a 12-hour urine sample. Biological samples were generally obtained during the final day of the sampling period.

5.8 Health Records Analysis

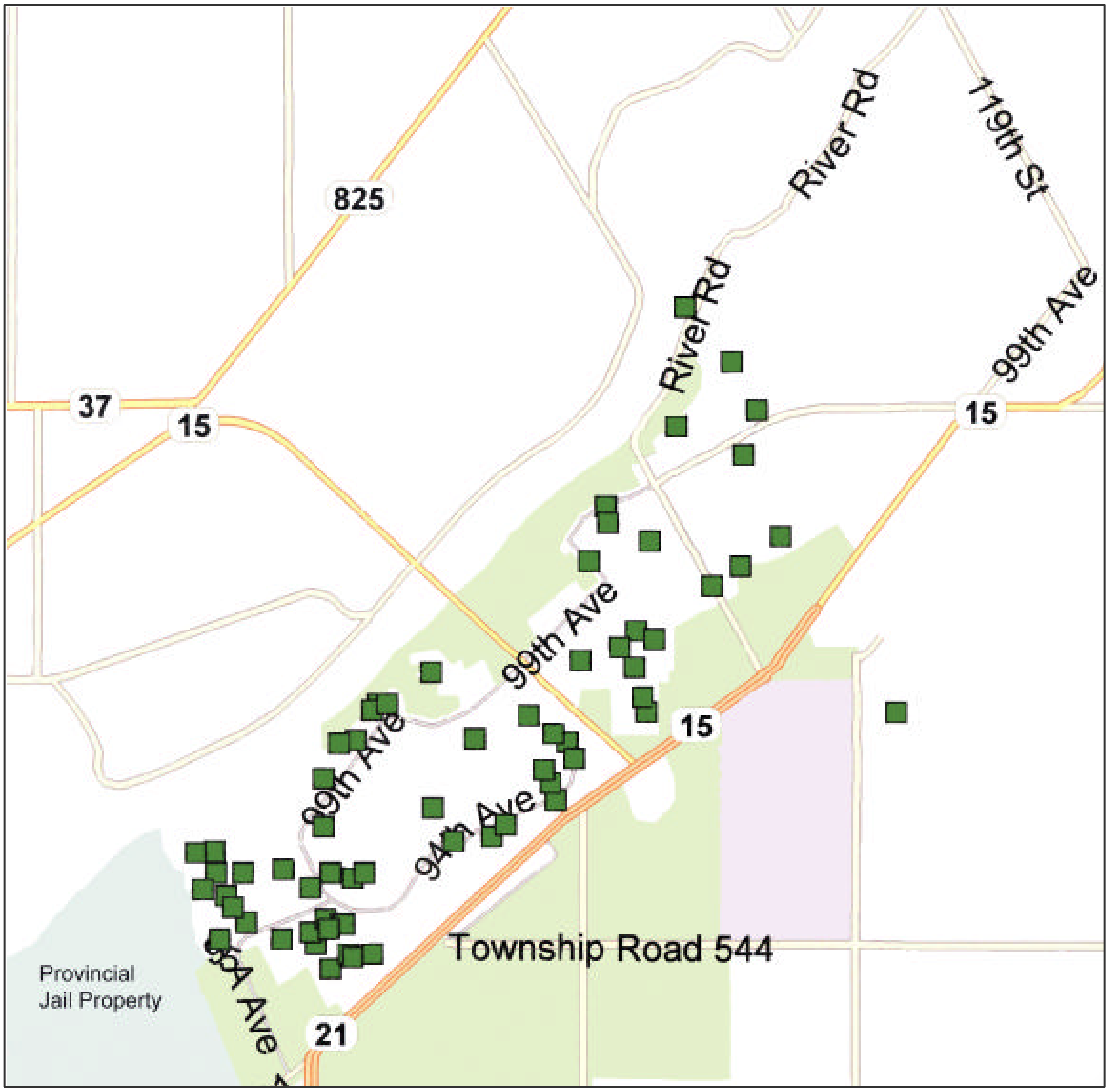
All participants were requested to provide a Personal Health Number, and give written consent for its use in retrieving administrative information for use in the evaluation. The primary data sources used for analysis were hospital discharge summaries, physician billing claims, and the Alberta Vital Statistics Death Registry. These data were used to identify health status of and mortality rates of the study participants and of the Fort Saskatchewan population.

The age-specific proportion of visits to a physician and the average number of visits in a year for specific illnesses by study participants were calculated and compared to that of the total population of the community. Age-adjusted morbidity and mortality measures were computed for Fort Saskatchewan and surrounding area and the control community. Graphs of adjusted odds ratio for selected respiratory disorders and of age-adjusted mortality rate and its 95% confidence interval were used to represent disease trends over time and across geographic areas.

6.0 Characteristics of the Sample

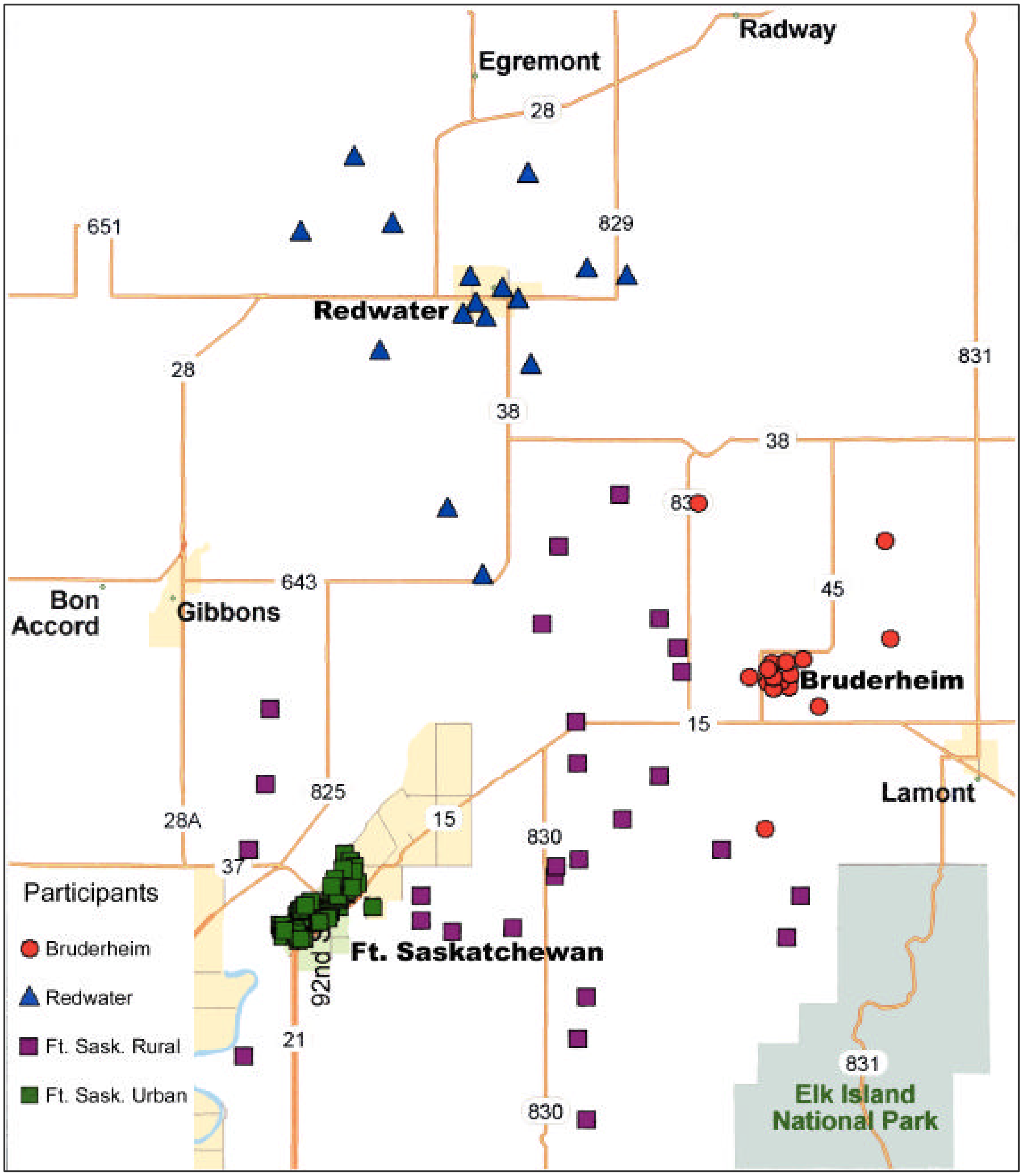
The Fort Saskatchewan and Area Community Exposure and Health Effects Assessment Program included 138 residents of Fort Saskatchewan and the surrounding area. All participants were at least 18 years of age. Figure 5 shows the distribution of the participants in the city of Fort Saskatchewan, and Figure 6 shows the distribution of the participants living outside the city limits of Fort Saskatchewan as well as in surrounding areas of Bruderheim and Redwater. Samples of exposure were obtained from all areas of the city.

Figure 5: Distribution of Urban Participants



Note: Locations of residences have been slightly randomized to protect confidentiality of participants.

Figure 6: Distribution of Rural Participants



6.1 Sample Size

The protocol recommended a minimum sample size of 150 participants. Obtaining volunteers was difficult and the optimum sample size was not obtained, despite an aggressive recruitment campaign. A total of 138 people volunteered to participate in the assessment, but only 126 participants provided enough of the required information to be included in all analyses. Table 3 shows the number of participants who completed various components of the study.

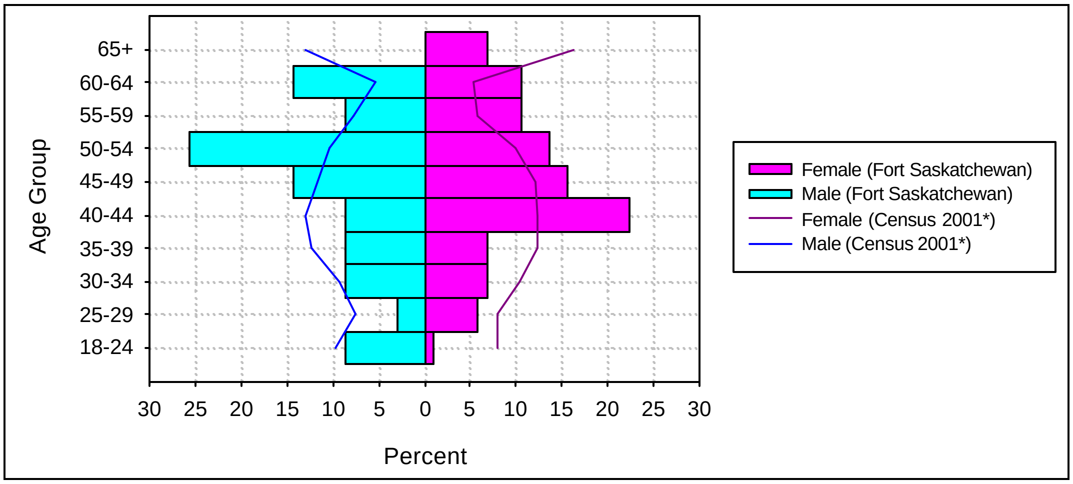
Table 3: Number of Participants Completing Each Study Component

Study Component	Number of Participants
Total number in study	138
Passive exposure assessment	138
Particulate exposure assessment	66
Completed demographic questionnaire	126
Completed health questionnaire	126
Completed neurocognitive assessment	138
Completed respiratory health survey	134
Completed spirometry tests	136
Completed time-activity diary	135
Total with Complete Data	**126**

6.2 Age and Gender

The average age of the sample was 47.38 years (N = 138; SD = 11.46). More than half of the sample was female (74.64%) and the average age of the women (48 years) was older than the average age of the men (46 years) included in the sample. Figure 7 shows the age and gender distribution of the sample compared to the age and gender distribution of the Fort Saskatchewan and area population in the 2001 Census.

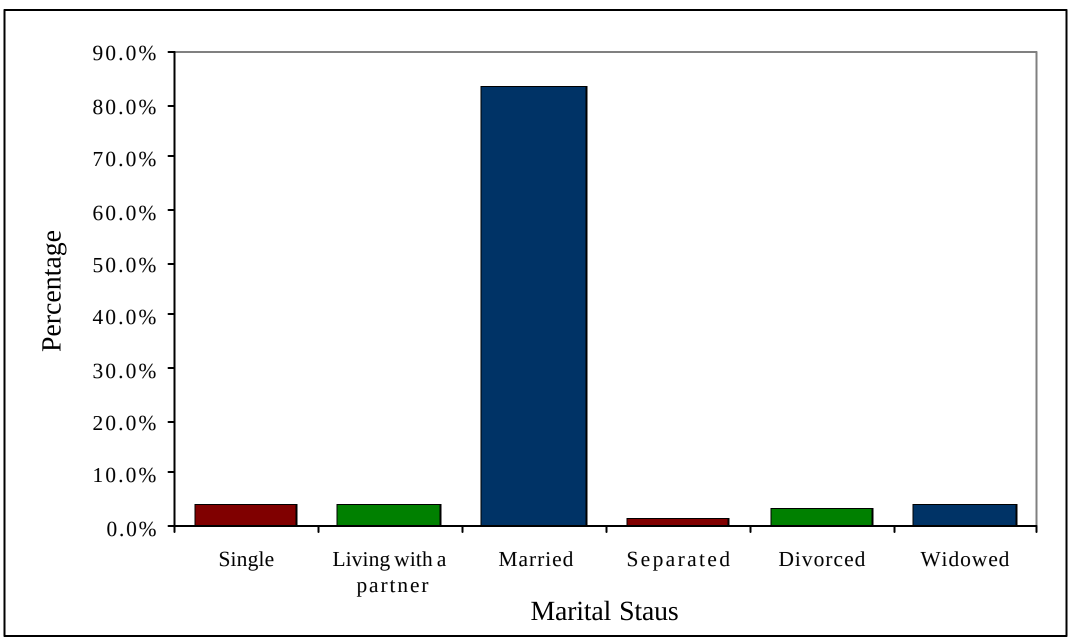
Figure 7: Age and Gender Distribution



6.3 Marital Status

Participants in the study were asked about their marital status. As shown by Figure 8, the majority of participants were either currently married (83.3%) or living with a partner (4.0%). Only 3.2% of the sample were divorced, 4.0% were single, 1.6% were separated, and 4.0% were widowed.

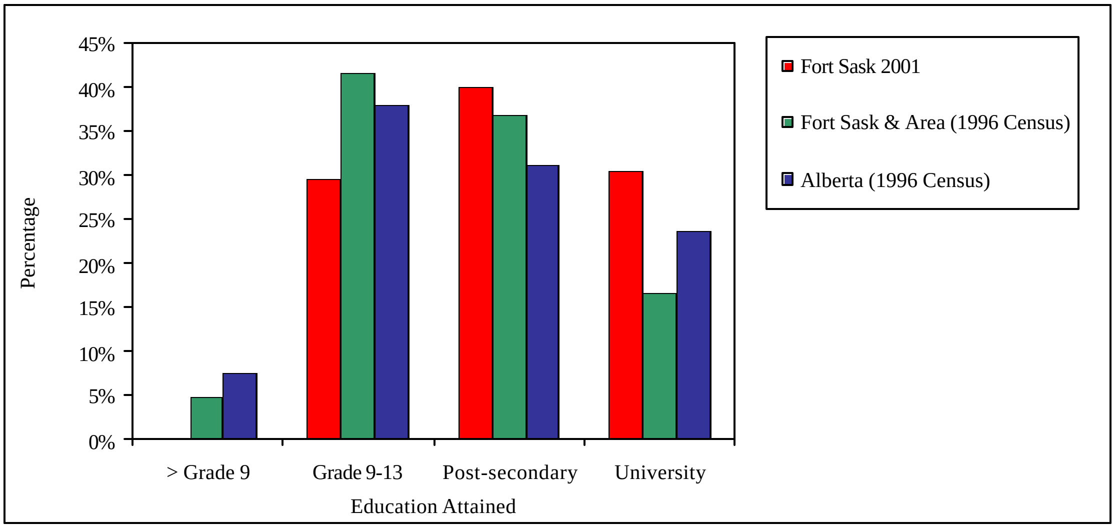
Figure 8: Marital Status



6.4 Education

Figure 9 compares the levels of education for the Fort Saskatchewan sample population with the population living in the Fort Saskatchewan area in 1996 and with the province of Alberta in 1996. The average number of years of education reported by the Fort Saskatchewan sample was 13.9 years (N = 138; SD = 2.21). Over half of the Fort Saskatchewan sample had completed at least one year of post secondary education. The Fort Saskatchewan sample population had a higher level of education compared to the population living in the Fort Saskatchewan area in the 1996 census and compared to the overall Alberta population in 1996 estimated level of education.

Figure 9: Education Level



6.5 Language

English was indicated as the native language of 90.6% of the Fort Saskatchewan sample. In the 2001 census, 90.4% of the inhabitants from Fort Saskatchewan and area specified English as their mother tongue, which is equivalent to our Fort Saskatchewan sample.

6.6 Occupation

A majority of the participants indicated that they were currently employed by a health organization (11.9%). The next greatest number was employed by an educational organization (6.4%). Table 4 shows the participants' primary employment status and whether this employment was full- or part-time.

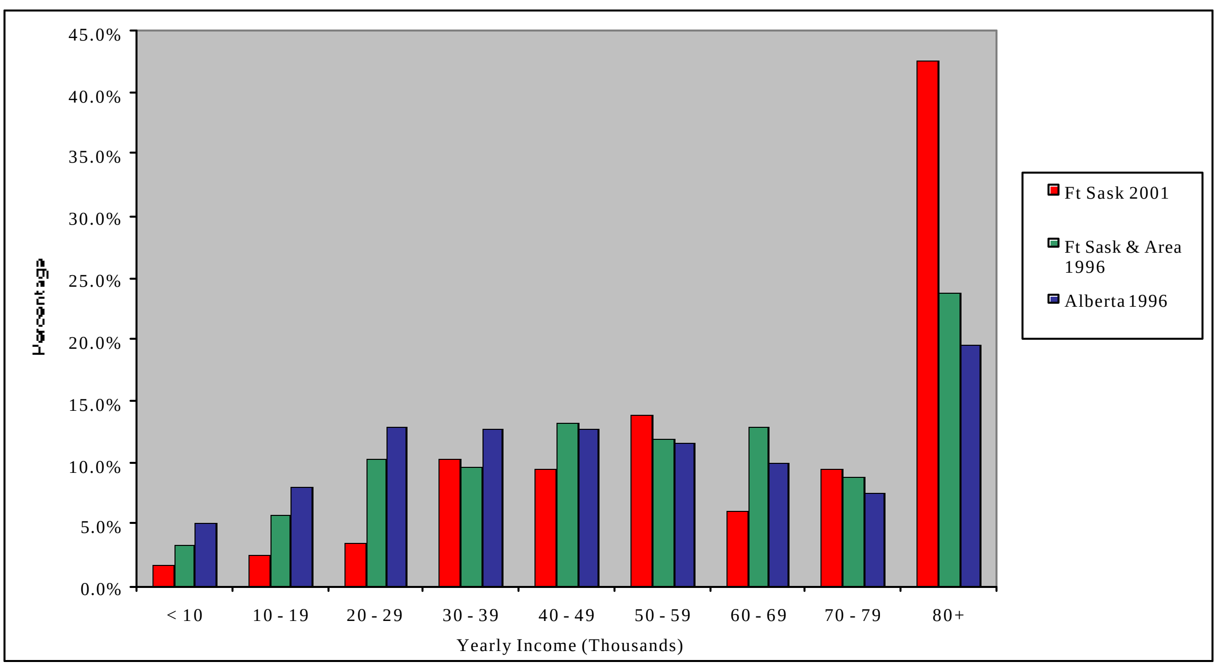
Table 4: Primary Work or Employment Status

	Percentage of Sample (N = 120)	
Have a paid job outside of home	57.1%	66.7% full time
		30.6% part time
Self-employed in home	7.9%	20.0% full time
		50.0% part time
Student	0.8%	100% full time
		0.0% part time
Full-time homemaker	10.3%	
Currently unemployed	1.6%	
Retired or disabled	19.8%	
Other	2.4%	

6.7 Income

Over half (57.4%) of the participants indicated their annual household income to be less than $80,000. Figure 10 displays the distribution of household income for the Fort Saskatchewan sample population as well as for the Fort Saskatchewan and area based on 1996 census data and for the province of Alberta. As is confirmed by the Fort Saskatchewan sample population data, the percentage of households making at least $80,000 annual income is about twice that of both the Fort Saskatchewan and area census data and Alberta as a whole. The Fort Saskatchewan and area census average is similar to the provincial average.

Figure 10: Distribution of Household Income



6.8 Smoking

Of the Fort Saskatchewan respondents, 46.8% indicated they had smoked as much as one cigarette a day for as long as one year. Whether the participants currently smoked or not, when they did smoke they smoked between one (1) and thirty (30) cigarettes per day. At the time of the study, only 9.5% of the respondents indicated that they currently smoke.

Another report has shown that smoking rates in the Lakeland Regional Health Authority were approximately 29%.[11] Smokers were less likely to volunteer for the study as evidenced by the low smoking rate in the study sample (9.5%), compared to the rate found in this independent survey of the region.

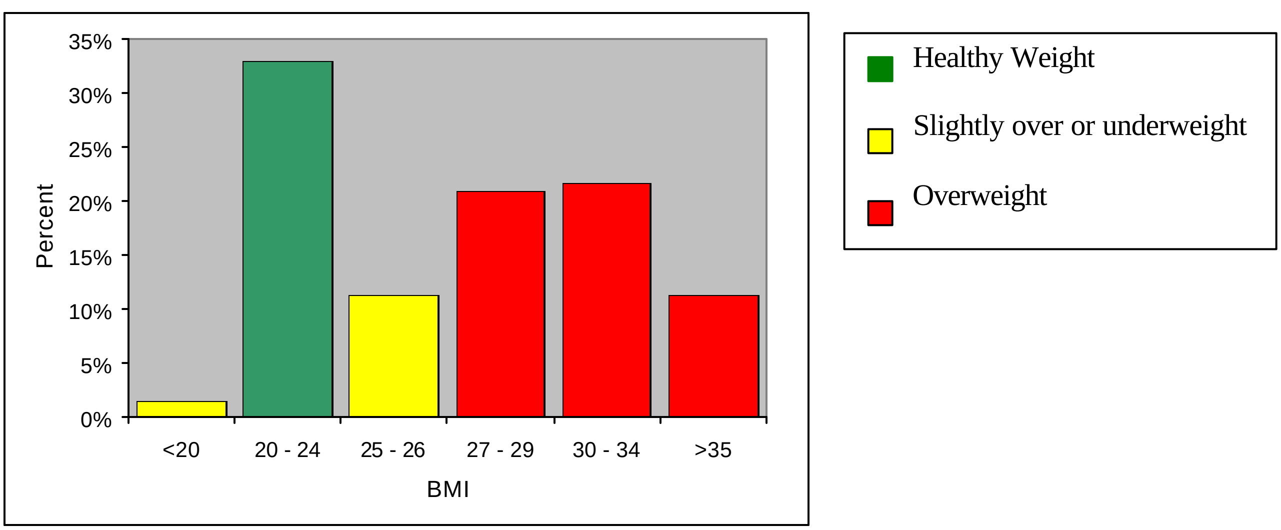
The majority of Fort Saskatchewan (73.4%) respondents indicated that they worked in a non-smoking environment; however, the average daily exposure to cigarette smoke (second-hand smoke) varied greatly across participants, from no exposure to as much as 960 minutes (or 16 hours) per day.

6.9 Body Mass Index

A body mass index (BMI) was calculated from reported height and weight for each participant. The BMI is considered a valid measure of obesity because it correlates well with skinfold and body density measures, and has been adopted in the *Canadian Guidelines for Health Weights*.[12] A BMI of less than 20 indicates that the individual is underweight for their height, and there may be some associated health problems. A BMI between 20 and 24 is considered a healthy range. A BMI of between 25 and 27 indicates that the individual is slightly overweight, which may lead to health problems for some people, while a BMI over 27 indicates an increased risk of health problems associated with weight.

Figure 11 shows the distribution of BMI for the sample population. The average BMI for the Fort Saskatchewan participants was 27.4. Just under twelve percent (11.3%) of the Fort Saskatchewan participants were slightly overweight (BMI of 25 to 26); 54.0% had a BMI greater than 27. The estimated average BMI for the Canadian population is 25.4, lower than the study population.[13] Fewer study participants had a BMI in the lower or healthy range compared to the Canadian estimates. A larger percentage of study participants (33.1%) had a BMI greater than 30 compared to the Canadian estimates (14.0%).

Figure 11: Distribution of Body Mass Index



6.10 Nutritional Intake

Participants were asked about their usual dietary habits. The participants indicated that they ate less than the recommended 5 to 12 servings of grain products each day, and that they ate approximately seven servings of fruits and vegetables each day, which is the average (5-10) recommended number of servings. The average number of servings of milk products corresponded to the recommended number (2 to 3), and the number of servings of meat and alternatives also corresponded to the minimum number of servings recommended by the Canada Food Guide (2 to 3). Respondents indicated that they consumed an average of 1 to 2 servings of sweets or other non-nutritious foods each day. Participants drank an average of two cups of coffee per day, and less than one drink per day of cola or alcohol. Participants also estimated that they consume an average of 8.5 cups of liquids (2.12 L) per day.

6.11 Local Wild Food Sources

The frequency of consumption of local wild food sources was recorded because this can indicate whether there are other sources of contaminants or pathways of exposure that are unique to the local population. Ninety-seven percent (96.8%) of the Fort Saskatchewan participants indicated that they eat locally grown fruits and vegetables when available. Eighty-one percent (80.8%) of the participants indicated that they ate local wild berries. Consumption of local wild game was not as common as consumption of wild fruits, although 26.4% of the sample population stated that they ate local deer, and 16.8% stated they ate local moose. A relatively large portion of the Fort Saskatchewan sample consumed goose (5.6%) and grouse (4.8%). A number of participants (34.4%) indicated that they ate locally caught fish. Perch was the most frequently mentioned fish in Fort Saskatchewan (27.2%), followed by pike (20.0%) and walleye (18.4%).

6.12 Sources of Drinking Water

Data was collected on characteristics of household drinking water and personal drinking water habits. Most Fort Saskatchewan respondents indicated their source of tap water was the city water treatment facility (81.0%). Other sources of drinking water accounted for 19.1%. Tap water was used for drinking and drink mixes by 84.1% of participants. When drinking water from the tap, only 47.2% indicated that they run the water for a period of time before filling their glass and 32.1% indicated that they sometimes do. About one-third (34.1%) of respondents indicated that they have a filter of some type that purifies the water, most of which were the activated carbon type (e.g., Brita, Amway). Bottled water was used by 25.4% of respondents, and another 31.7% indicated that they sometimes used bottled water. Of those that used bottled water, 40.3% indicated they use it for all drinking, while others limited their use of bottled water to travelling (55.6%), at work or school (29.2%), cooking (8.3%), or other uses (2.8%).

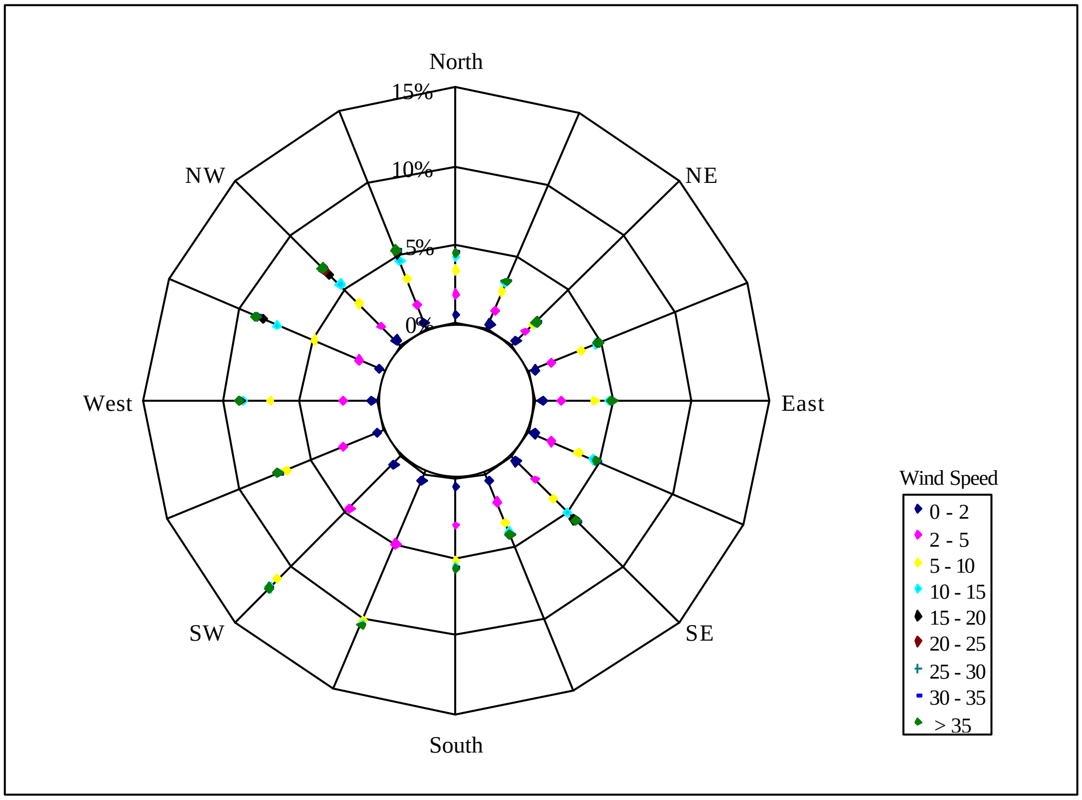
6.13 Physical Activity Level

The physical activity section of the Health Habits and Diet Survey assessed participants' involvement in a variety of physical activities. Health Canada recommends at least 20-30 minutes of vigorous activity, or 60 minutes of light effort, every day, to maintain good health.[14] The mean time spent in physical activity in the Fort Saskatchewan sample was 5.5 hours/week (47 minutes/day), indicating that many participants barely meet Health Canada's minimum requirements for physical activity. This also corresponds with the large proportion of participants with a BMI greater than the healthy range.

6.14 Meteorological Data

The wind diagram in Figure 12 describes the percent of time the wind blows from various directions and speeds. As the wind diagram shows, the predominant wind direction is from the southwest and the west.

Figure 12: Wind Rose Diagram Showing Wind Characteristics During the Study



6.15 Time Activity Diaries

Participants were asked to record the time spent in activities at various general locations for the duration of their participation. Figure 13 shows the average levels for the participant group as a whole.

There were trade-off relationships among the relative mixes of general activities across different individuals. The primary trade-off involved time spent indoor at home versus time spent in other indoor or outdoor activities; and independently time spent indoors at home versus time spent indoors at work.

Table 5 shows that gender and job status are also a major determinant of the relative activity mix between home and work.

Figure 13: Average Proportion of Time in a Day

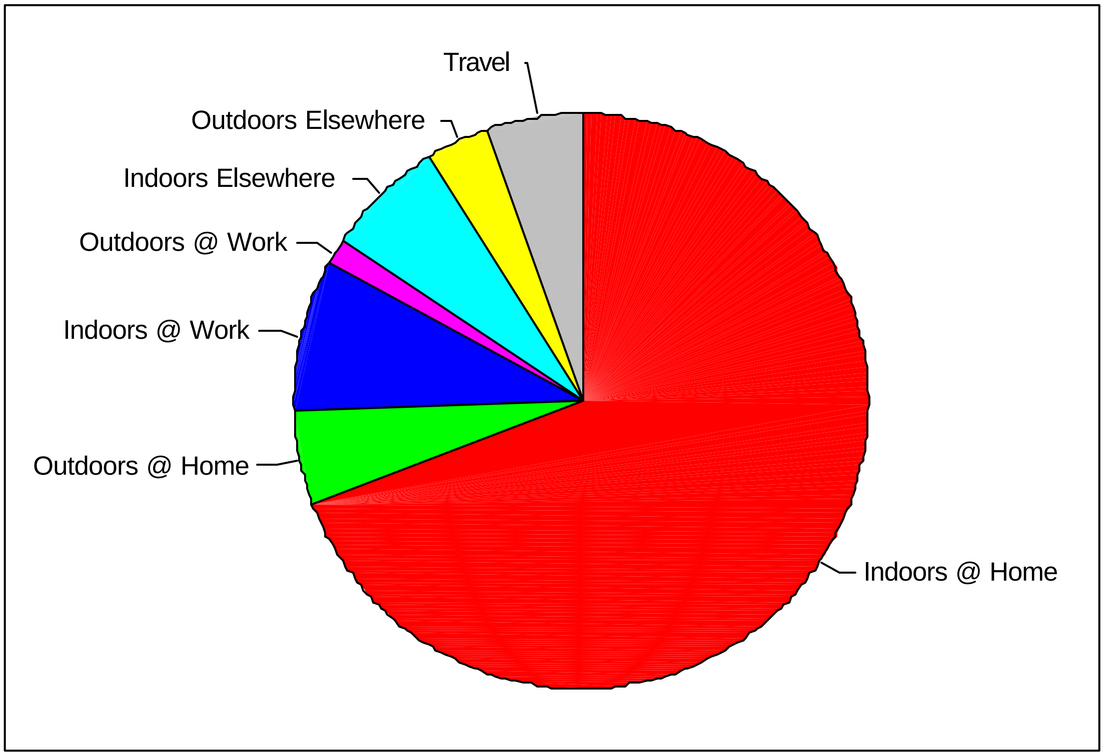


Table 5: Activity Mix by Gender and Job Status

	Indoors at Home (proportion)	Indoors at Work (proportion)
Female		
Not employed	.77	.00
Part time Job	.71	.09
Full time Job	.68	.15
Male		
Not employed	.72	.00
Part time Job	-	-
Full time Job	.58	.18

7.0 Air-Borne Contaminants

7.1 Passive Samplers

Passive air quality measurements were taken with four separate samplers, each deployed for a one-week period. Each participant carried samplers around their neck hanging in their breathing zone (Personal sample), had a sampler deployed inside their home (Indoor sample), and had a sampler deployed in the environment immediately outside their home (Outdoor sample). Table 6 shows the sampler types and the chemicals monitored by each sampler.

Table 6: Samplers and Chemical Concentrations Measured

Sampler	**Chemical Concentrations Measured**
NO_2	Nitrogen Dioxide
SO_2	Sulfur Dioxide
O_3	Ozone
Volatile Organic Compounds	Hexane
	3-methylhexane
	Benzene
	Heptane
	Toluene
	Octane
	Ethylbenzene
	m-, p-xylene
	o-xylene
	Nonane
	Decane
	Limonene

The Field Teams successfully deployed 2,556 personal exposure monitors (PEMs) throughout the course of the study. Of these, only nine PEMs had missing data due to lost or missing monitors. Table 7 shows how the remaining 2,547 PEMs were distributed.

Table 7: Distribution of Personal Exposure Monitors (PEMs)

Number by Location	Number by Type
552 Personal	138 NO_2
	138 SO_2
	138 O_3
	138 VOCs
688 Indoor	172 NO_2
	172 SO_2
	172 O_3
	172 VOCs
688 Outdoor	173 NO_2
	171 SO_2
	172 O_3
	172 VOCs
551 Blank	137 NO_2
	139 SO_2
	138 O_3
	137 VOCs
68 Ambient	17 NO_2
	17 SO_2
	17 O_3
	17 VOCs
Total	**2,547**

Calculation of the concentrations of each chemical from the amount of material detected on each sampler filter involved formulae relating sampling rates to concentration levels. In addition, a time correction was applied to correct for the precise amount of time (in minutes) that the samplers were exposed to air. A correction for blank levels (levels measured on unexposed sampler filters) was also applied. This correction itself involved an examination of the variability of the blank values over the course of the study, and for some chemicals resulted in a complex time dependent correction.

In the sections that follow, three graphs are presented to describe the study results for each chemical.

The first graph shows the distribution of all measures taken through the study from the Fort Saskatchewan and area location for each of the sample types: personal, indoor, and outdoor. The graph plots the calculated average concentration in the air to which the sampler was exposed plotted against the percentile of this exposure level in the particular sample type across all samples collected. The median exposure level is located at the point where a vertical line drawn from the 50th percentile mark on the horizontal axis intersects with the curve. The concentration level at that point is read from the vertical axis by drawing a horizontal line from that point on the curve to the vertical axis. The vertical axis is presented as a logarithmic scale that reflects the general finding of positive skew in distributions of chemicals in air. If the line deviates from a straight line and especially if the curvature is marked at either end (usually the end indicating higher exposure levels), this indicates a skewed distribution of exposure to that chemical more marked than the log normal distribution. The degree of slope in the linear section of the curve is related to the overall variability of the sample such that steeper slopes indicate more variable distributions. Curves that do not appear to start at percentile 0 indicate that a proportion of cases fell below the blank level for the sampler for that chemical. The proportion of samples for which this is true is determined by noting the percentile level at which the curve begins.

The second graph represents a line of best fit derived by locally weighted regression methods to show the temporal trend in the sampled concentrations for each sample type. The lines appear smooth, but they typically represent a very weak relationship between season and concentration. To illustrate that this relationship is weak, the individual concentrations are plotted on this graph as points. As well, the duration of the sampling (approximately 5 months) restricts the ability to fully determine the shape of any yearly cycle that might be present in the data.

The third graph was designed to give an indication of the degree of relationship between levels of personal exposure and levels of indoor and outdoor concentrations respectively. It is created as follows: first, personal exposure values are ranked from highest to lowest; second, a graph is created which orders the data from highest to lowest (where the concentration is given on the vertical axis, and the order values for each participant are presented along the horizontal axis); third, the values for outdoor and indoor concentrations are plotted at the horizontal point in the graph at which the point indicating the personal concentration for that participant had previously been plotted; fourth, a locally weighted regression line is produced to help visualize the association between personal exposure and indoor exposure and between personal exposure and outdoor exposure. For strong relationships, the interpolated lines for the associated sampler sites will mimic the general downward trend of the line for personal exposure (and at the same time the points will cluster closely around this line). The stronger the relationship, the closer the curves will be to being parallel to each other. Weak or non-existent relationships will be characterized by interpolated lines that are parallel or close to parallel to the horizontal axis. In general, even strong apparent relationships had only moderate correlations (0.4-0.5) between personal exposure and either indoor or outdoor exposure.

Nitrogen Dioxide (NO_2)

Figure 14 shows the cumulative distribution of NO_2 concentrations for the three types of samplers (personal, indoor, and outdoor). Concentrations measured on the personal samplers were generally greater than the other sampler locations, but the differences were not large.

The indoor and personal samples were above the method detection limit (MDL) of 1.8 $\mu g/m^3$ while 20% of the outdoor samples were below the detection limit. While the imprecision associated with individual outdoor samples increases dramatically when measures fall below the detection limit, the data provides a prediction of overall community exposure.

The median and 95th percentile NO_2 levels ($\mu g/m^3$) for the different locations are summarized and compared to guidelines and levels in other communities in Table 8. In addition, the relative levels of NO_2 at the locations are compared by the ratios of personal to indoor (P/I), personal to outdoor (P/O), and indoor to outdoor (I/O). The indoor and outdoor levels of NO_2 were an order of magnitude below guideline levels and were similar to levels found in other relevant studies.

Figure 14: Distribution of Nitrogen Dioxide

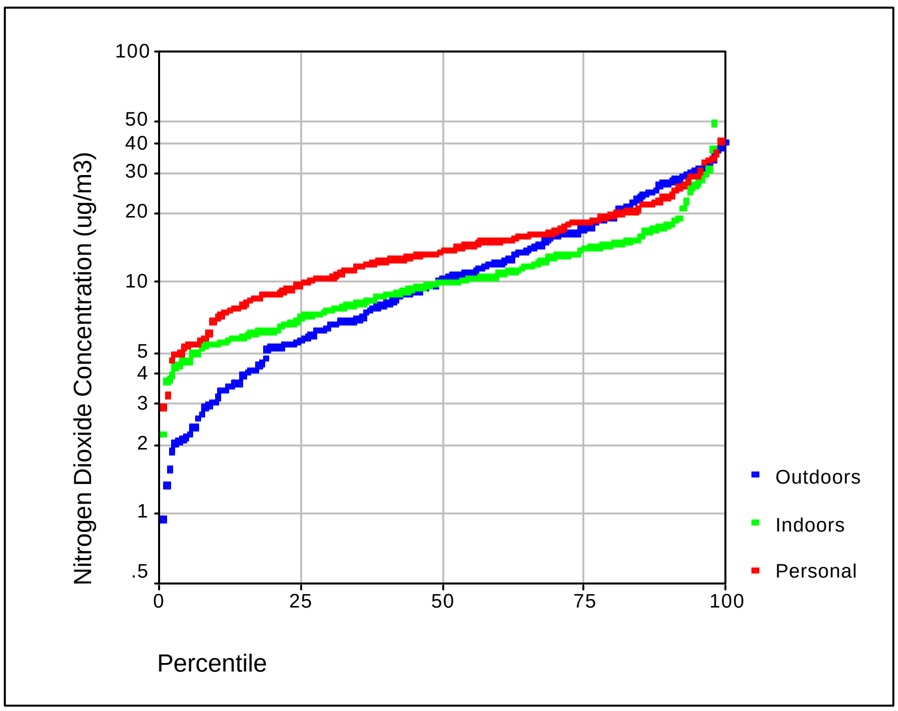


Table 8: Comparison of NO_2 Levels in μg/m^3 with Guidelines and Other Studies[15, 16, 17]

Parameter	Personal	Indoor	Outdoor	Ambient Station	P/I ratio	P/O ratio	I/O ratio
Fort Saskatchewan Median	13.7	10.0	10.4	N/A	1.4	1.6	1.2
Fort Saskatchewan 95th	30.6	27.2	30.9	N/A	1.1	1.0	0.9
Grande Prairie Median	11.6	9.1	4.7	N/A	1.3	2.5	2.0
Grande Prairie 95th	30.2	25.8	16.5	N/A	1.2	1.8	1.5
Fort McMurray Median	15.9	8.6	9.5	10.8	1.9	1.7	0.90
Fort McMurray 95th	53.2	30.0	38.5	36	1.8	1.4	0.78
Lethbridge Median	17.7	9.8	13.8	N/A	1.8	1.3	0.71
Lethbridge 95th	41.6	30.3	42.8	N/A	1.4	1.0	0.71
Relevant Studies	N/A	6*	12*	N/A	N/A	0.65*	
Guideline/Reference Level	N/A	100 (long term) 480 (hour)***	200 (day) AENV	400 (hour) AENV	N/A	N/A	

* Hagenbjork-Gustafsson et al., 1996.
** Spengler et al., 1983.
*** Health Canada, 1989.

Figure 15 shows smoothed curves (produced by locally weighted regression) to represent the temporal trend in NO_2 concentrations. Outdoor concentrations appear to increase in the fall months.

Figure 15: Temporal trend in Nitrogen Dioxide Concentration

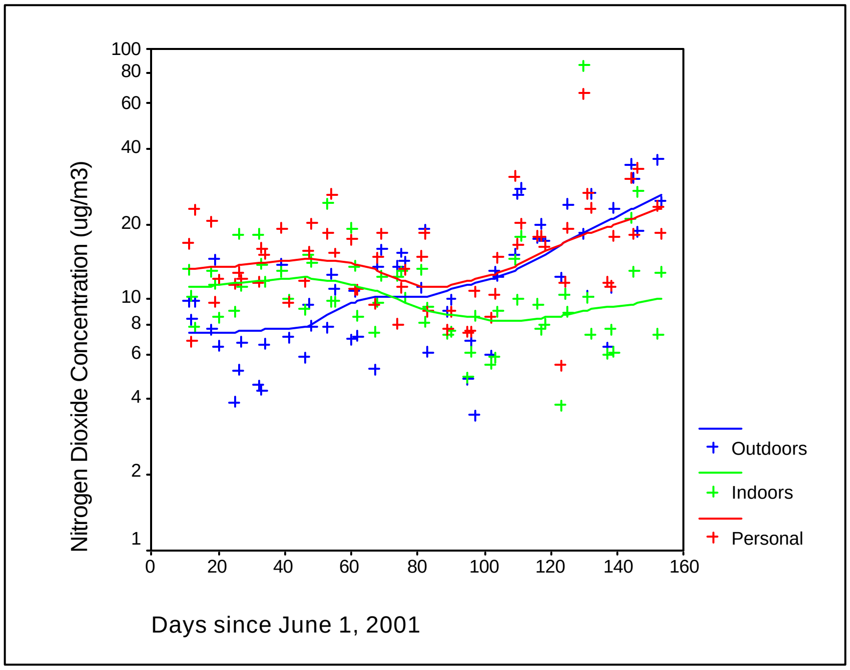
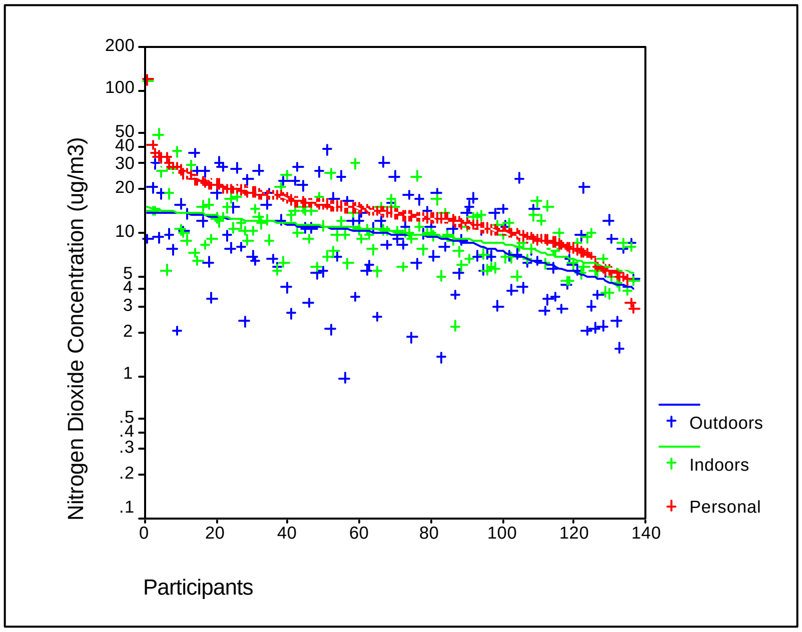


Figure 16 shows the relationship between the NO_2 concentrations monitored personally, indoors and outdoors. The graph shows the ordered personal exposure levels for each subject in the study, and their corresponding levels of indoor and outdoor concentration levels. A locally weighted regression curve has been added for indoor and outdoor concentration levels to give an indication of the strength of the association between personal levels and indoor and outdoor levels respectively. A horizontal line would show no relationship, while positive associations would be shown by sloped lines (and particularly by the relative degree of scatter of the individual points around those lines). This graph shows high relationships between measures of indoor and outdoor compared to personal concentrations.

Figure 16: Relationship between Exposures to Nitrogen Dioxide by Sampler Site



Sulfur Dioxide (SO_2)

Figure 17 shows the cumulative distribution of SO_2 concentrations for the three types of samplers (personal, indoor, and outdoor). The median outdoor concentrations were approximately double the personal concentrations.

Levels of SO_2 were highest in outdoor air and lowest in home indoor environments. Overall, levels were low with 25% of indoor samples collected falling below the MDL of 0.28µg/m^3.

The median and 95th percentile SO_2 levels (µg/m^3) for the different locations are summarized in Table 9 and compared to guidelines and levels in other communities. The levels of SO_2 measured in Fort Saskatchewan were much lower than guidelines. There is good agreement between the passive samples and the ambient station.

Figure 17: Distribution of Sulfur Dioxide

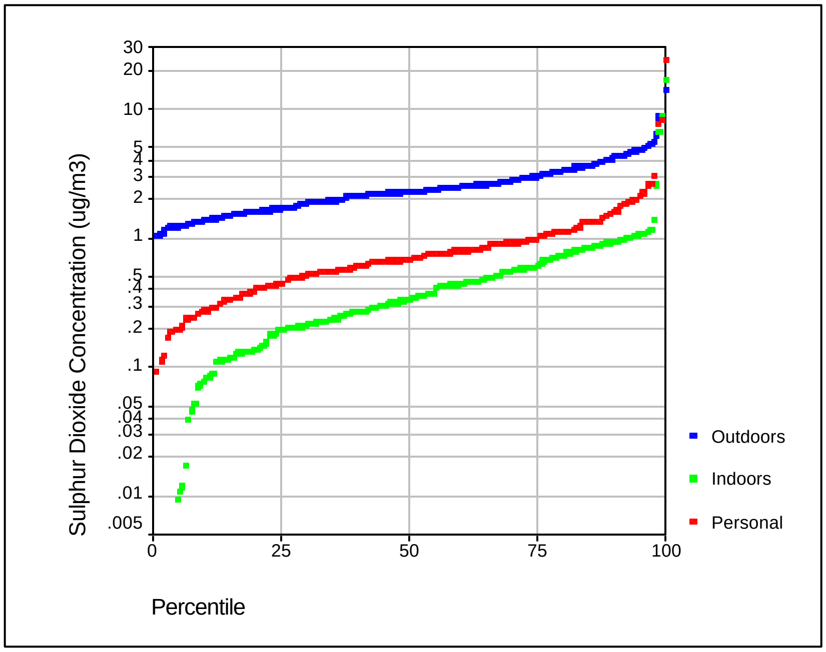


Table 9: Comparison of SO_2 Levels in mg/m^3 with Guidelines and Other Studies[18]

Parameter	Personal	Indoor	Outdoor	Ambient Station	P/I ratio	P/O ratio	I/O ratio
Fort Saskatchewan Median	0.70	0.34	2.30	N/A	2.19	0.30	0.14
Fort Saskatchewan 95th	2.27	1.08	4.94	N/A	1.89	0.42	0.22
Grande Prairie Median	0.37	.017	0.86	N/A	2.14	0.42	0.20
Grande Prairie 95th	1.83	1.18	2.23	N/A	1.54	0.82	0.53
Fort McMurray Median	0.87	0.41	1.6	2.0	2.1	0.53	0.25
Fort McMurray 95th	5.6	4.1	8.0	6.5	1.4	0.70	0.52
Lethbridge Median	0.21	0.16	1.1	N/A	1.3	0.19	0.15
Lethbridge 95th	3.1	2.9	5.2	N/A	1.1	0.59	0.56
Relevant Studies	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Guideline/Reference Level	N/A	50 (long term) 1000 (5 minutes)*	150 (day) AENV	450 (hour), 150 (day), 30 (year) AENV 39-60 (year) EC 340 (hour) WHO	N/A	N/A	N/A

* Health Canada, 1989.

Figure 18 shows smoothed curves (produced by locally weighted regression) to represent the temporal trend in SO_2 concentrations.

Figure 18: Temporal Trend in Sulfur Dioxide Concentration

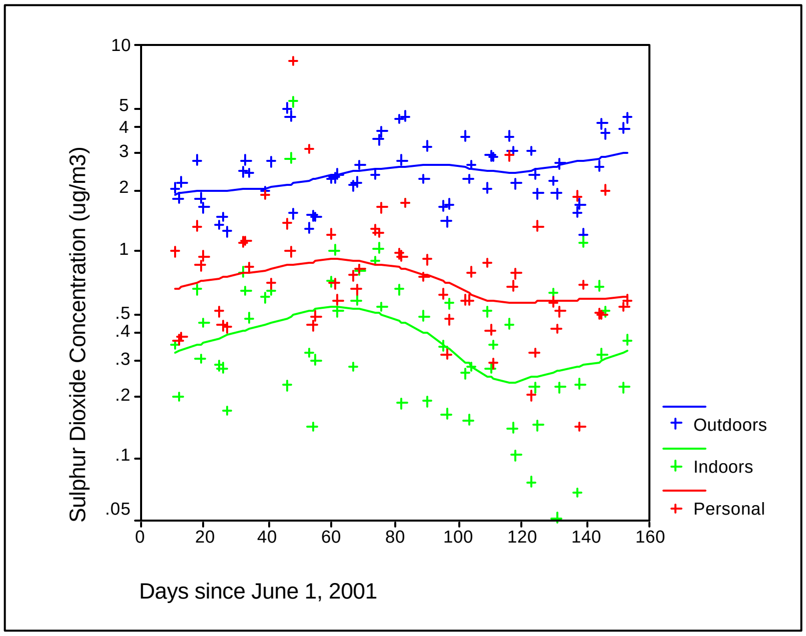
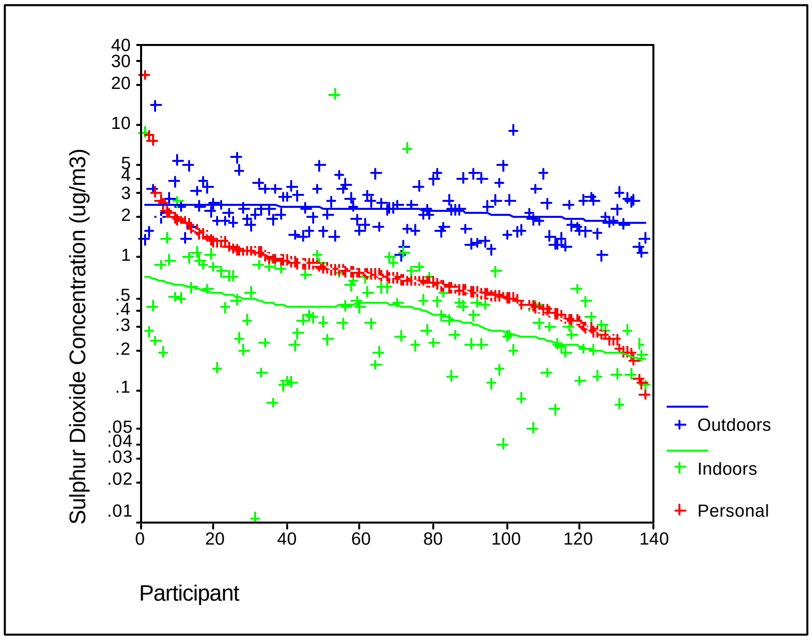


Figure 19 shows the relationship between the concentrations monitored personally, indoors and outdoors. This graph shows a relationship between personal and indoor concentrations and a weaker relationship between personal and outdoor concentrations.

Figure 19: Relationship between Exposures to Sulfur Dioxide by Sampler Site



Ozone

Figure 20 shows the cumulative distribution of ozone concentrations for the three types of samplers (personal, indoor, and outdoor). The median outdoor concentrations were approximately one order of magnitude higher than the personal and indoor concentrations. Other researchers[19] have also reported that ambient and outdoor concentrations are considerably above personal exposure levels in other locales, though less dramatically than was seen here. This finding speaks to the inherent inaccuracy of using ambient concentration levels as a proxy for personal exposure. While all distributions are positively skewed, none of the concentrations for personal exposures exceeded 50 µg/m^3 while over half of the concentration measures for the outdoor sample exceeded that level.

As the figure demonstrates, median indoor and personal levels of O_3 were less than 10% of outdoor levels. All the outdoor samples were above the MDL of 1.3 µg/m^3 while 25% of the indoor and 10% of the personal samples were below the MDL. The MDL achieved in this study was low compared to other studies using passive samplers.[20, 21]

The median and 95th percentile O_3 levels (µg/m^3) for the different locations are summarized in Table 10 and compared to guidelines and levels in other communities. Levels of O_3 measured in this study were comparable to Lethbridge and Fort McMurray values. The indoor and personal levels in Fort Saskatchewan were lower than other studies and much lower than the guideline.

Figure 20: Distribution of Ozone

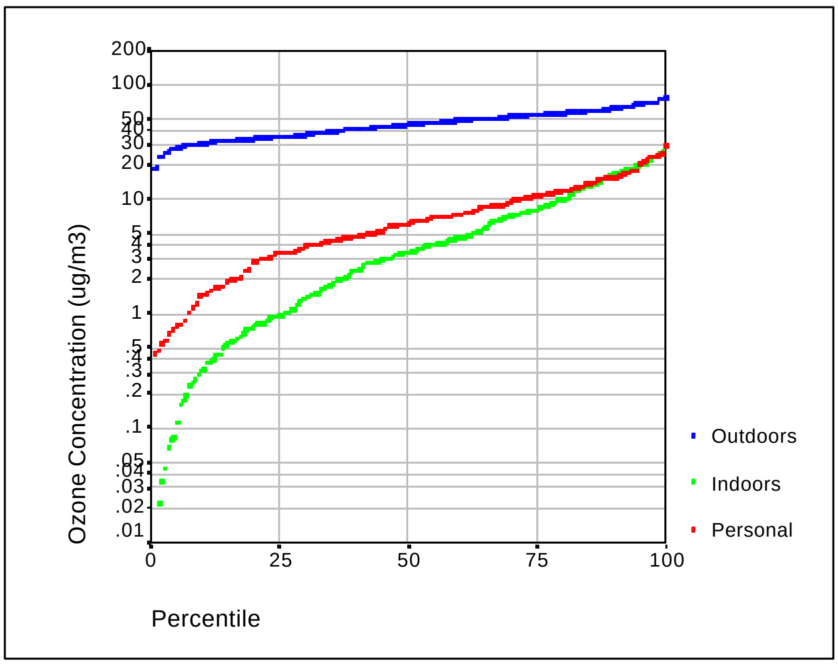


Table 10: Comparison of O_3 Levels in mg/m^3 with Guidelines and Other Studies[22,23, 24]

Parameter	Personal	Indoor	Outdoor	Ambient Station	P/I ratio	P/O ratio	I/O ratio
Fort Saskatchewan Median	6.1	4.0	47.4	N/A	1.5	0.1	0.1
Fort Saskatchewan 95th	21.0	19.8	69.7	N/A	1.1	0.3	0.3
Grande Prairie Median	4.7	2.2	51.2	N/A	2.15	0.09	0.04
Grande Prairie 95th	16.5	13.6	94.3	N/A	1.21	0.17	0.14
Fort McMurray Median	3.3	2.4	39	50	1.3	0.08	0.06
Fort McMurray 95th	18	15	91	100	1.2	0.20	0.16
Lethbridge Median	4.9	2.4	57	N/A	2.0	0.09	0.04
Lethbridge 95th	20	11	140	N/A	1.8	0.15	0.08
Relevant Studies	16 (summer)* 2.6 (winter)*	14 (summer)* 3.1 (winter)*	37 (summer)* 30 (winter)*	N/A	1.2 (summer)* 0.81 (winter)*	0.43 (summer)* 0.08 (winter)*	0.41**; 0.37 (summer)* 0.10 (winter)*
Guideline/Reference Level	N/A	240 (hour)***	160 (hour) AENV 125 (8 hour)****	160 (hour) AENV	N/A	N/A	N/A

* Lui, et al., 1995.
** Bernard et al., 1999.
*** Health Canada, 1989.
****Canada-wide standard, 2010

Figure 21 shows smoothed curves (produced by locally weighted regression) to represent the temporal trend in ozone exposures. Outdoor concentration levels peak in the spring at levels approximately double the summer and fall lows. Indoor levels appear to peak in the summer.

Figure 21: Temporal Trend in Ozone Concentration

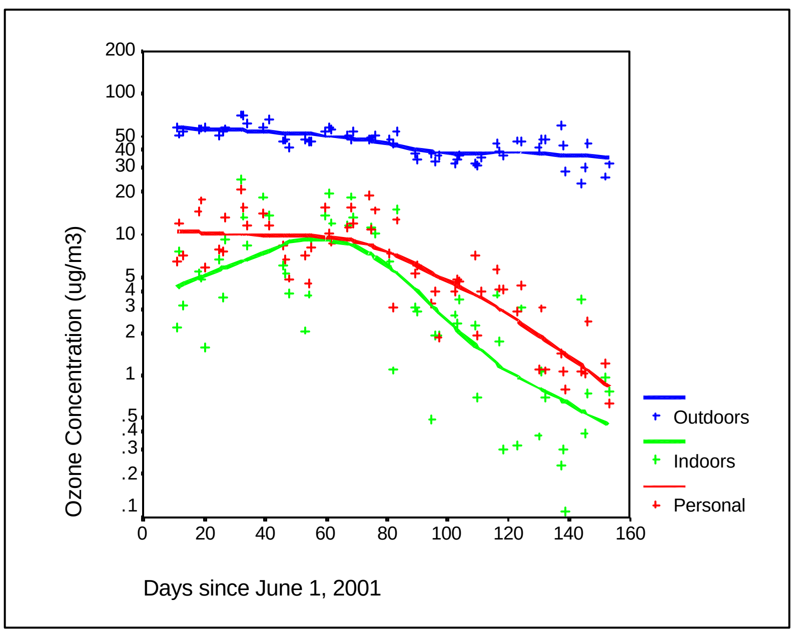
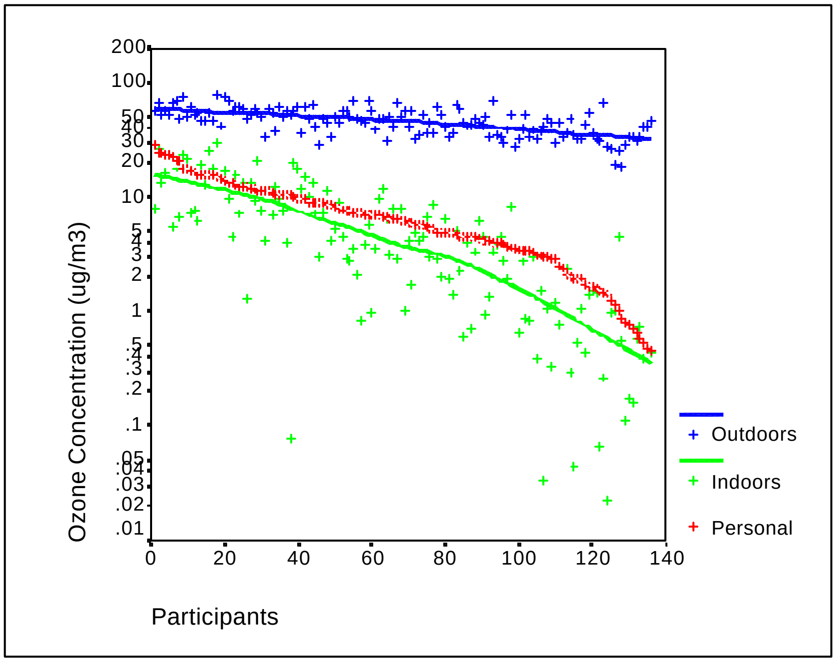


Figure 22 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows the ordered personal exposure levels for each subject in the study, and his or her corresponding levels of indoor and outdoor concentration levels. The current figure shows a strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. The relationship between outdoor exposures and personal exposures is considerably weaker, but positive nonetheless. The relative levels of the three exposures is strongly suggestive of a model of ozone diffusion which moves from outdoors to indoors and then to the person, who also moves outdoors often enough to raise personal exposure levels above the indoor concentration levels. A more detailed analysis is presented in a later section.

Figure 22: Relationship between Exposures to Ozone by Sampler Site



Volatile Organic Compounds

The analyses of the volatile organic compounds (VOCs) detailed in the following pages share several general features: 1) there were generally many measurements that were below detection limits; 2) personal exposure levels were generally higher than indoor and outdoor levels; and 3) the strongest relationships occurred between personal and indoor levels of concentration, suggesting indoor sources of exposure for most of these chemicals.

Hexane

Figure 23 shows the cumulative distribution of hexane concentrations for the three types of samplers (personal, indoor, and outdoor). At the 50th percentile, personal and indoor concentrations were much higher than outdoor concentrations.

Figure 23: Distribution of Hexane

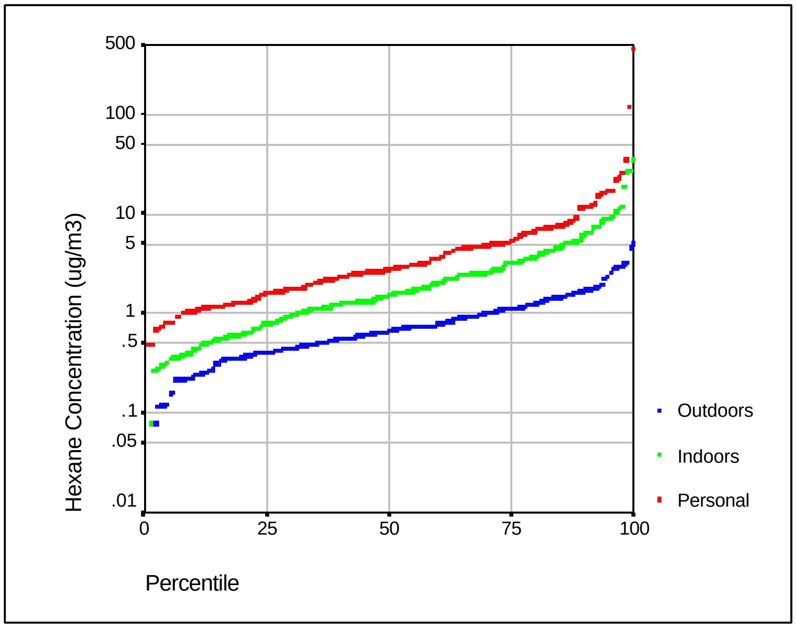


Figure 24 shows the temporal trend in hexane concentrations. There is little evidence to support a seasonal cycle.

Figure 24: Temporal Trend in Hexane Concentration

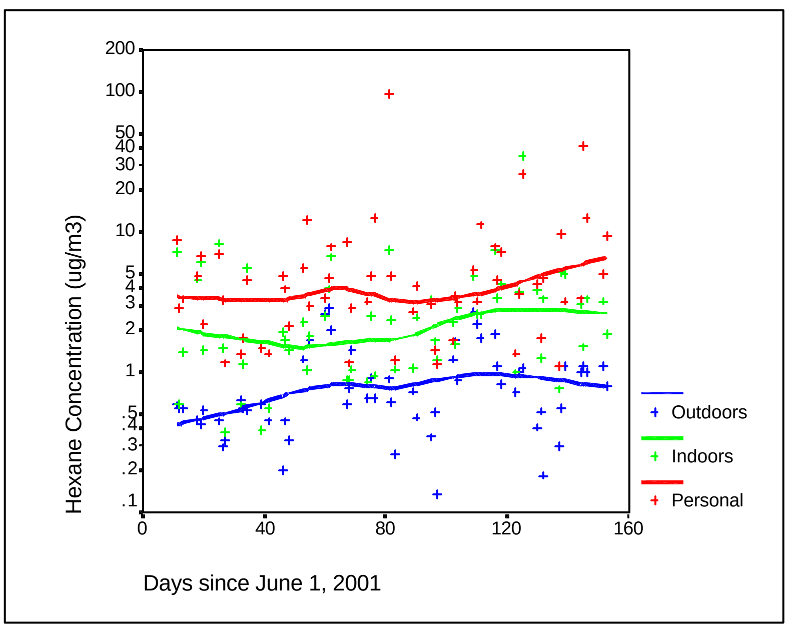
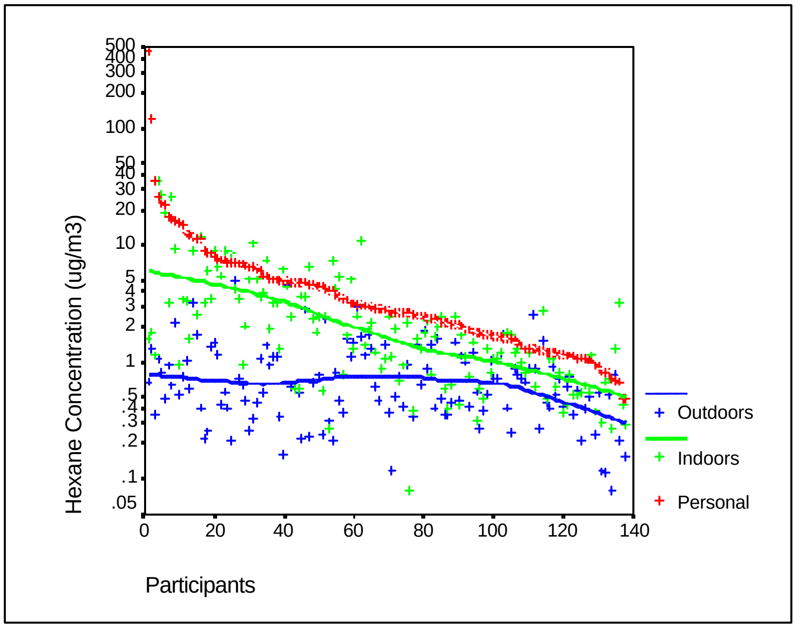


Figure 25 shows the relationship between the concentration obtained from the personal, indoor and outdoor samplers. There is a moderate relationship between measures of indoor and personal concentration.

Figure 25: Relationship between Exposures to Hexane by Sampler Site



3-Methylhexane

Figure 26 shows the cumulative distribution of 3-methylhexane concentrations for the three types of samplers (personal, indoor, and outdoor). About 30% of the indoor samplers and more than 75% of the outdoor samplers had concentrations of 3-methylhexane below detectable limits. Personal and indoor concentrations were much higher than outdoor concentrations.

Figure 26: Distribution of 3-methylhexane

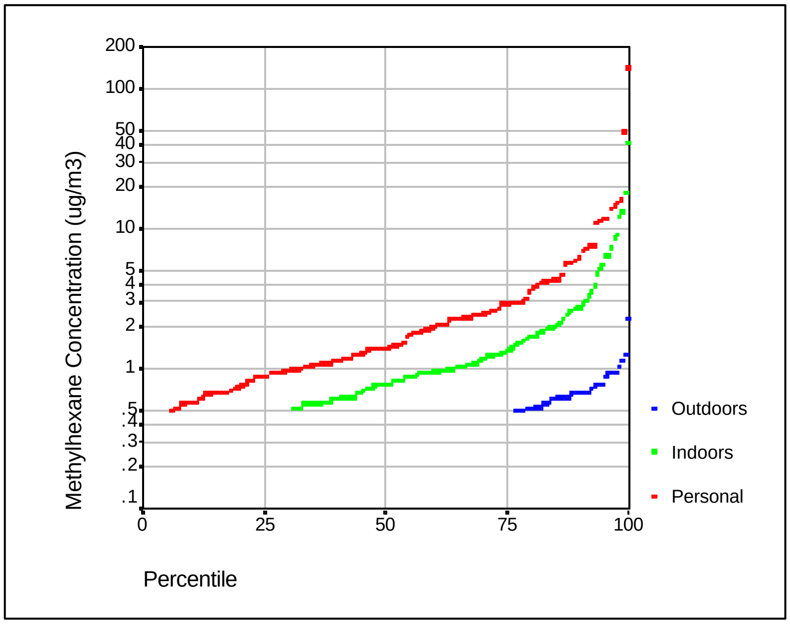


Figure 27 shows the temporal trend in 3-methylhexane concentrations.

Figure 27: Temporal Trend in 3-methylhexane Concentration

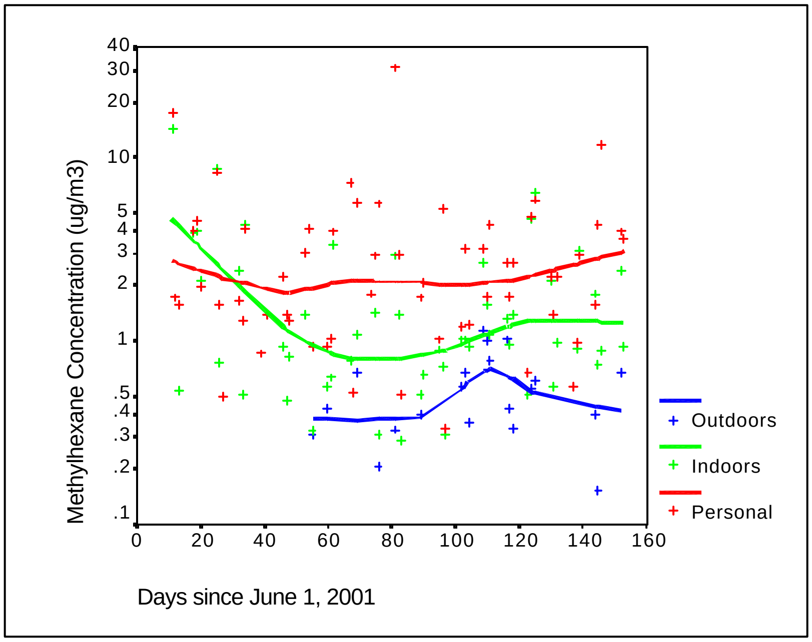
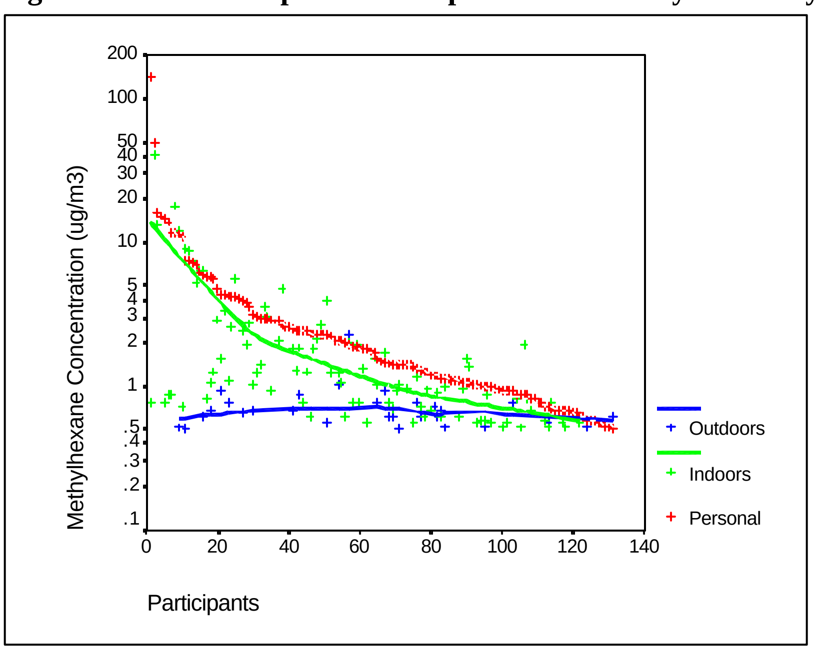


Figure 28 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There is no relationship between outdoor exposures and personal exposures.

Figure 28: Relationship between Exposures to 3-methylhexane by Sampler Site



Benzene

Figure 29 shows the cumulative distribution of benzene concentrations for the three types of samplers (personal, indoor, and outdoor).

Table 11 contains a summary of the benzene measures taken during the study showing the median and 95th percentile levels (µg/m^3) compared to guidelines and levels at other relevant communities. With fewer samples taken in Lethbridge during the study, estimates of median indoor and outdoor levels were not reliable and are not included. The outdoor benzene levels were low and comparable to levels reported for rural areas in Canada. The median personal levels were roughly 2.5 times the outdoor levels and roughly 10% of the levels reported in the TEAM study. The TEAM study also found that the highest levels of benzene were from the personal samplers, followed by the indoor sampler levels, while the outdoor samplers contained the lowest levels of benzene.[25]

Figure 29: Distribution of Benzene

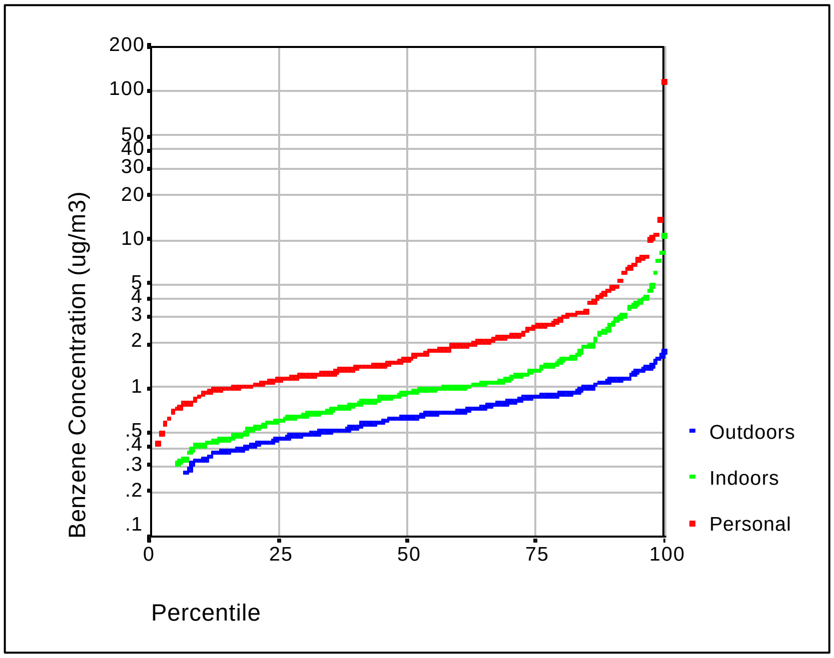


Table 11: Comparison of Benzene Levels in mg/m^3 with Guidelines and Other Studies[26, 27]

Parameter	Personal	Indoor	Outdoor	Ambient Station	P/I ratio	P/O ratio	I/O ratio
Fort Saskatchewan Median	1.55	0.29	0.61		1.72	2.54	1.48
Fort Saskatchewan 95th	7.10	4.36	1.36		1.63	5.22	3.21
Grande Prairie Median	1.45	0.89	0.52		1.63	2.79	1.71
Grande Prairie 95th	7.53	4.89	1.61		1.54	4.67	3.03
Fort McMurray Median	2.8	1.7	1.3	1.2	1.7	2.05	1.23
Fort McMurray 95th	10.0	6.6	5.5	3.1	1.5	.82	1.20
Lethbridge Median	2.1	*	*	N/A	N/A	N/A	N/A
Lethbridge 95th	6.7	4.8	3.6	N/A	1.4	1.90	1.34
Relevant Studies	15 (TEAM)**	10 (TEAM)**	2.6***	4.4 (urban) 0.6 to 1.2 (rural)**	1.5**	2.5**	1.7**
Guideline/Reference Level	N/A	N/A	30 (hour) AENV	16 UK current 3.2 UK future	N/A	N/A	N/A

* Estimate not available due to small number of Lethbridge samples.
** Wallace, 1996.
*** Median value from monitoring across Canada (Dann et al., 1995).

Figure 30 shows little temporal trend in benzene concentrations.

Figure 30: Temporal Trend in Benzene Concentration

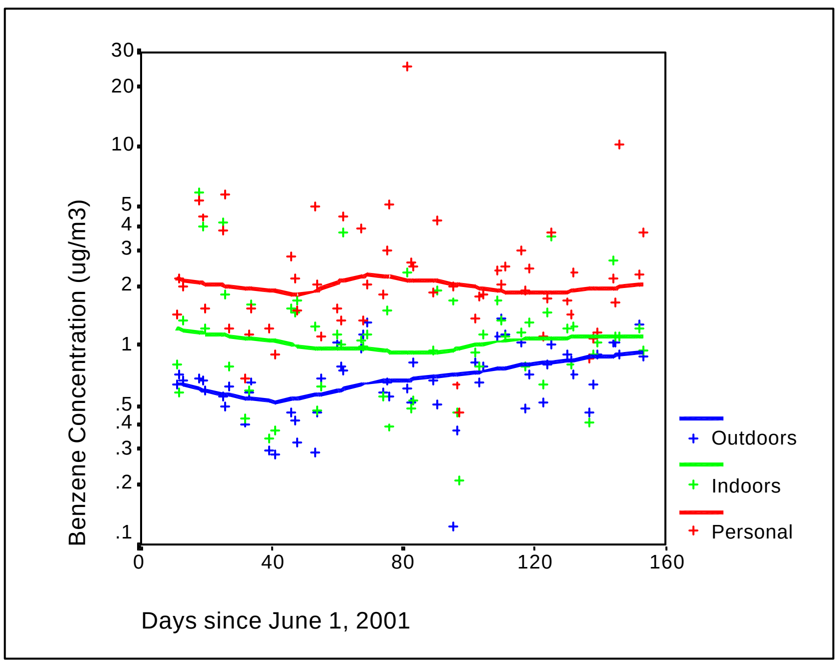
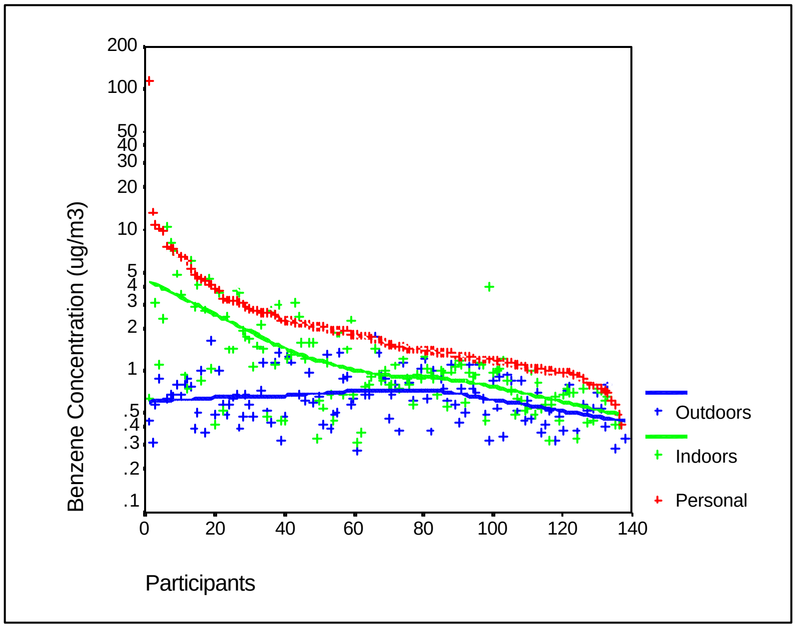


Figure 31 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a moderate relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There appears to be no relationship between personal exposure and outdoor.

Figure 31: Relationship between Exposures to Benzene by Sampler Site



Heptane

Figure 32 shows the cumulative distribution of heptane concentrations for the three types of samplers (personal, indoor, and outdoor). Just below 75% of the outdoor samplers had concentrations of heptane below detectable limits. Personal and indoor concentrations were much higher than outdoor concentrations.

Figure 32: Distribution of Heptane

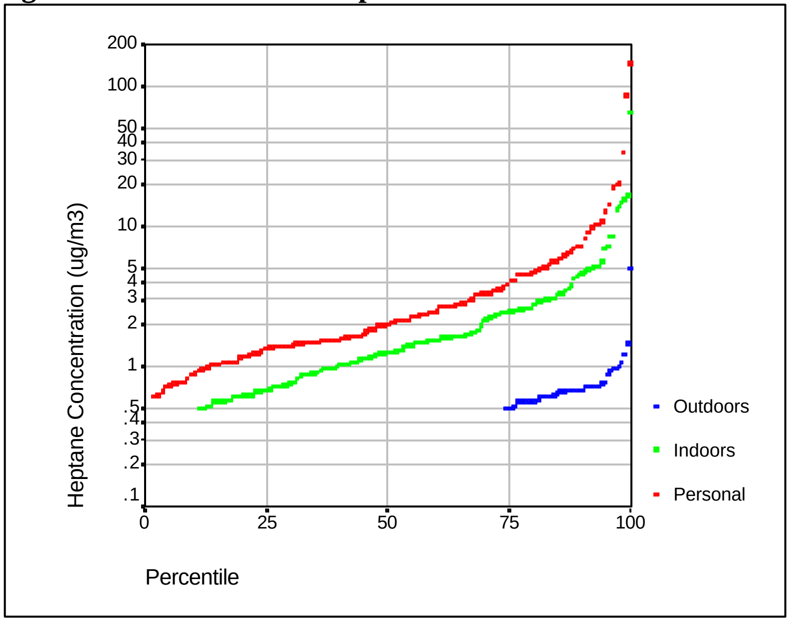


Figure 33 shows the temporal trend in heptane concentrations. There is insufficient evidence to conclude that heptane concentrations differ across the seasons.

Figure 33: Temporal Trend in Heptane Concentration

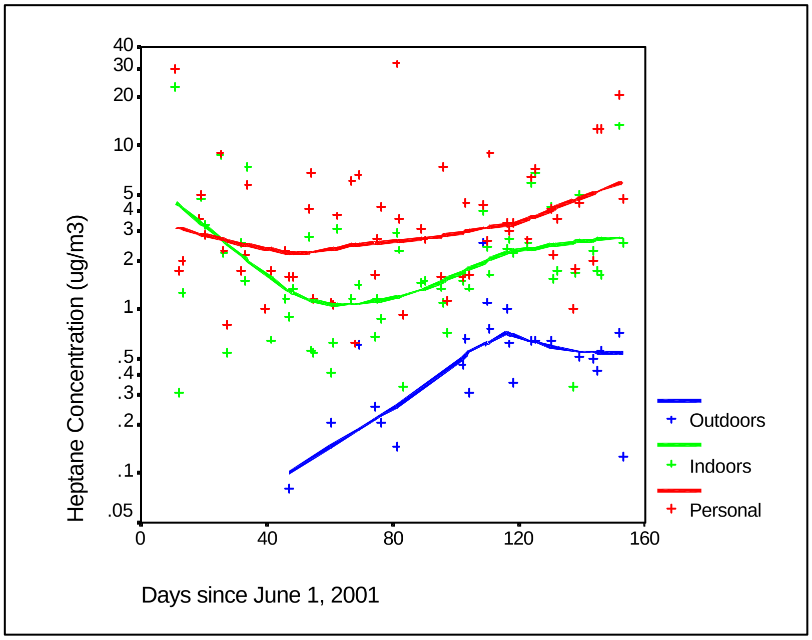
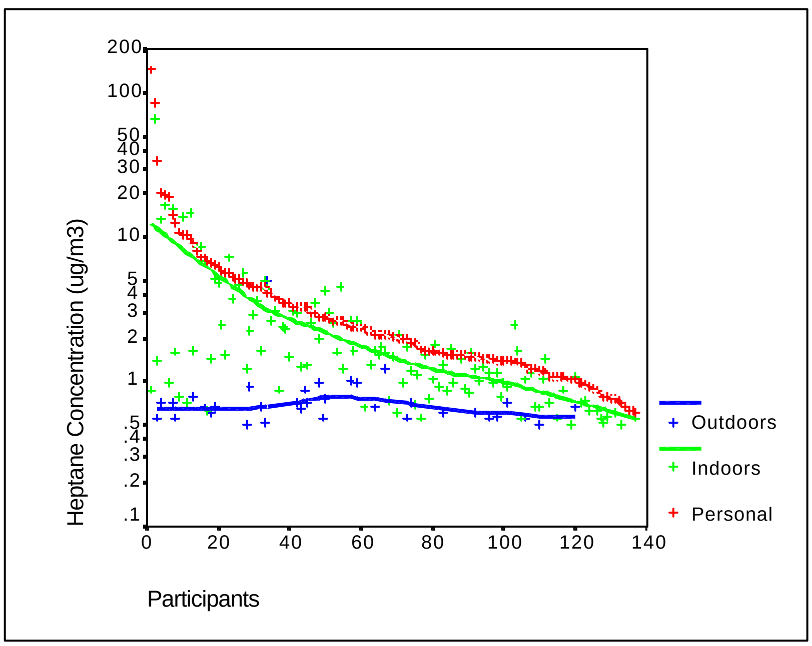


Figure 34 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a relatively strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There is no apparent relationship between outdoor exposures and personal exposures.

Figure 34: Relationship between Exposures to Heptane by Sampler Site



Toluene

Figure 35 shows the cumulative distribution of toluene concentrations for the three types of samplers (personal, indoor, and outdoor). At the 50th percentile, personal and indoor concentrations were almost an order of magnitude higher than outdoor concentrations.

Figure 35: Distribution of Toluene

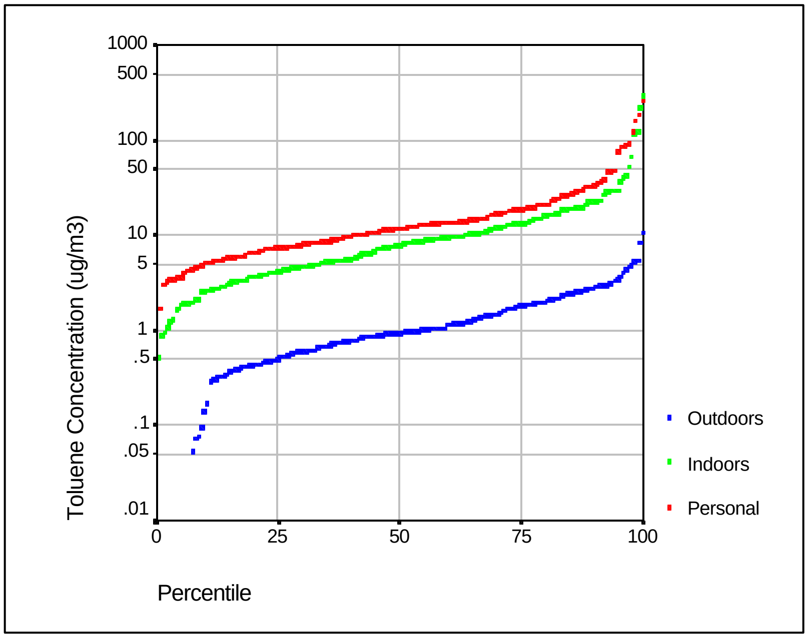


Figure 36 shows the temporal trend in toluene concentrations. There is insufficient evidence to conclude that concentrations differ across the seasons.

Figure 36: Temporal Trend in Toluene Concentration

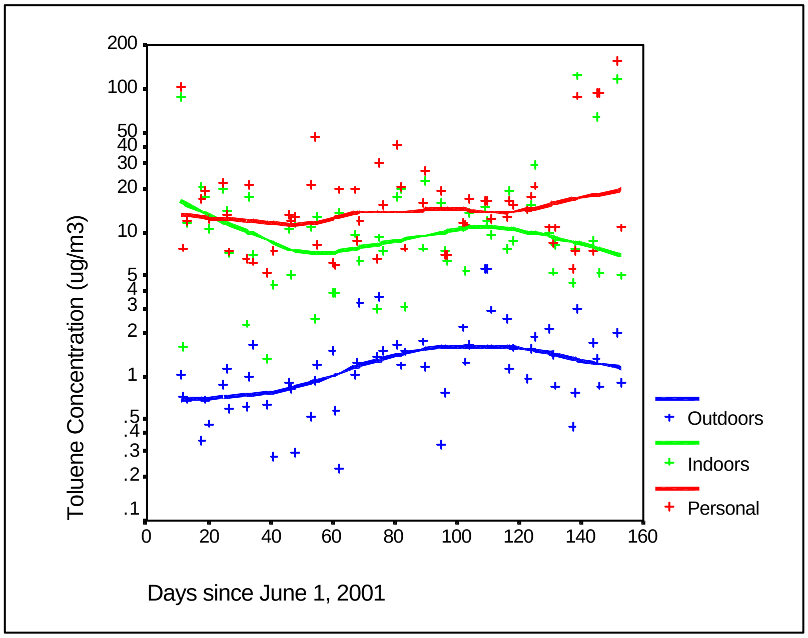
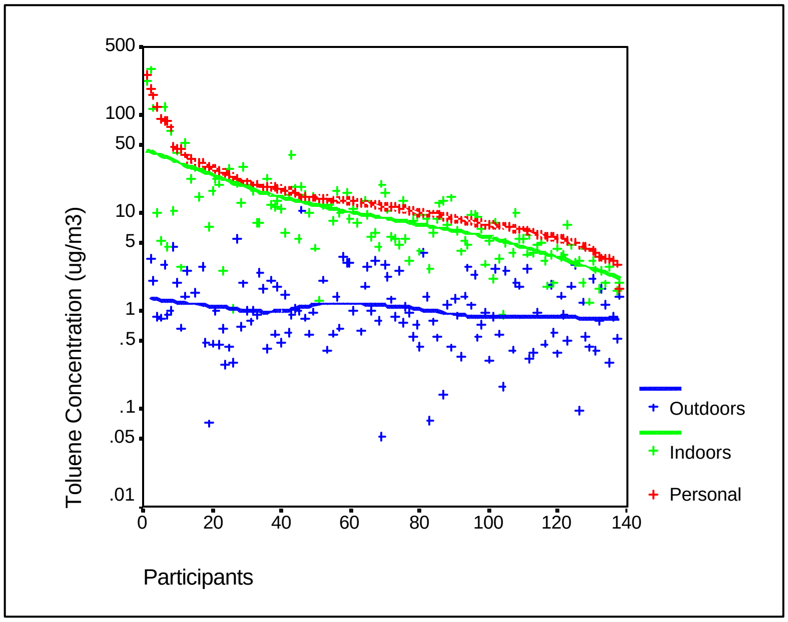


Figure 37 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal exposure concentrations and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There appears to be no relationship between personal and outdoor exposures.

Figure 37: Relationship between Exposures to Toluene by Sampler Site



Octane

Figure 38 shows the cumulative distribution of octane concentrations for the three types of samplers (personal, indoor, and outdoor). Very few outdoor samplers had detectable concentrations of octane. Personal levels are higher than indoor levels.

Figure 38: Distribution of Octane

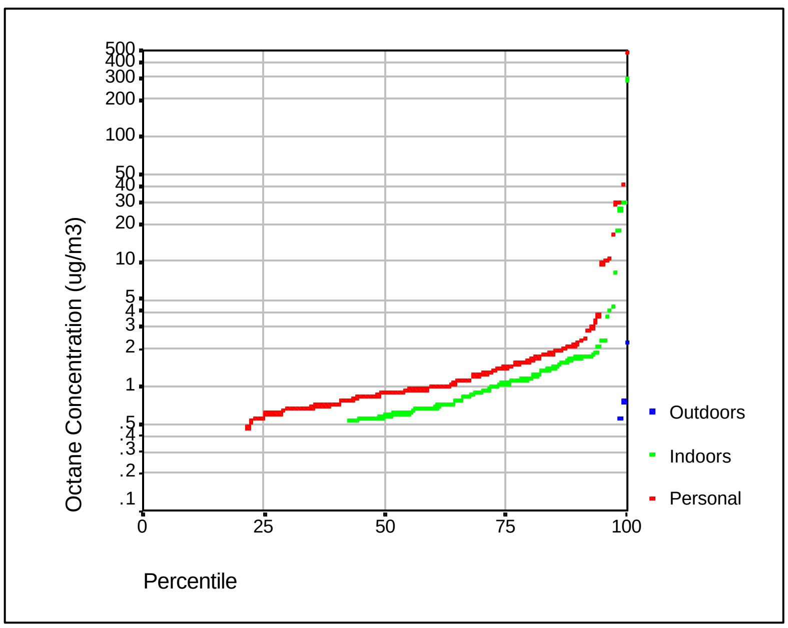


Figure 39 shows the temporal trend in octane concentrations. There is insufficient evidence to conclude that concentrations differ across the seasons.

Figure 39: Temporal Trend in Octane Concentration

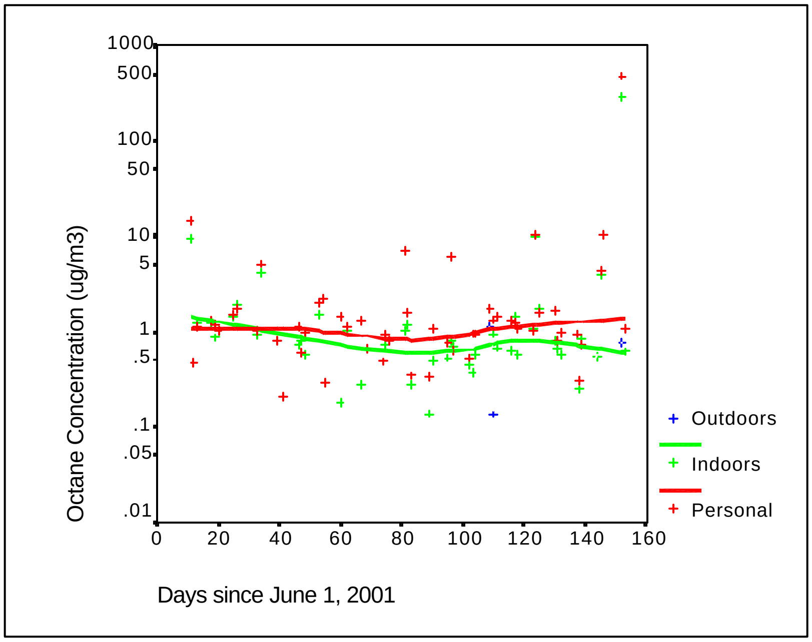
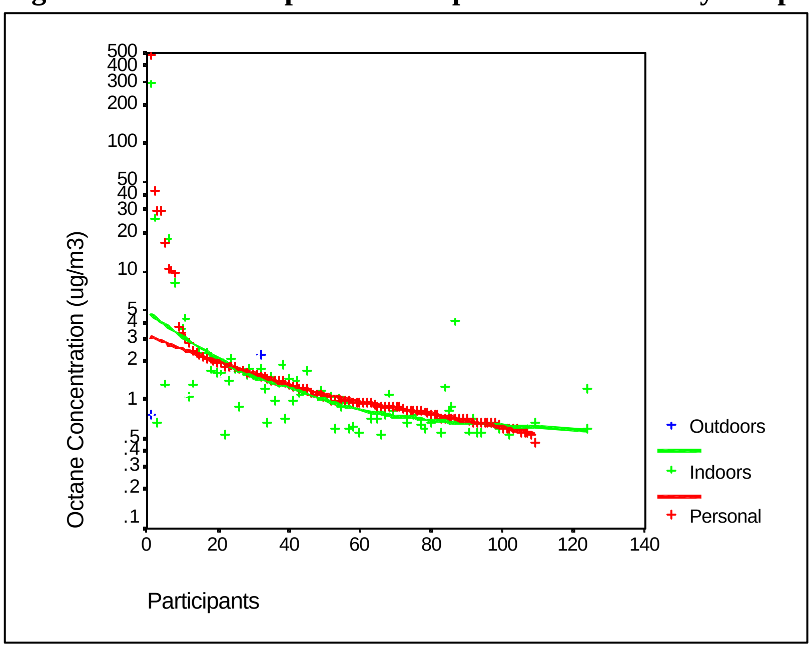


Figure 40 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations, but no relationship with outdoor concentrations.

Figure 40: Relationship between Exposures to Octane by Sampler Site



Ethylbenzene

Figure 41 shows the cumulative distribution of ethylbenzene concentrations for the three types of samplers (personal, indoor, and outdoor). More than 60% of the outdoor samplers had concentrations of ethylbenzene below detectable limits. Once again, personal concentrations were greater than indoor concentrations.

Figure 41: Distribution of Ethylbenzene

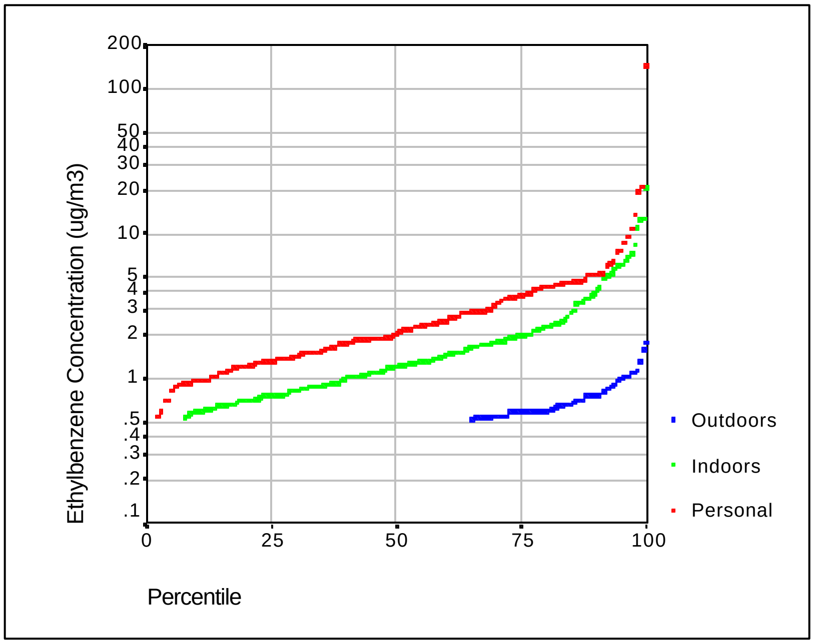


Figure 42 shows the temporal trend in ethylbenzene concentrations. There is insufficient evidence to conclude that concentrations differ across the seasons.

Figure 42: Temporal Trend in Ethylbenzene Concentration

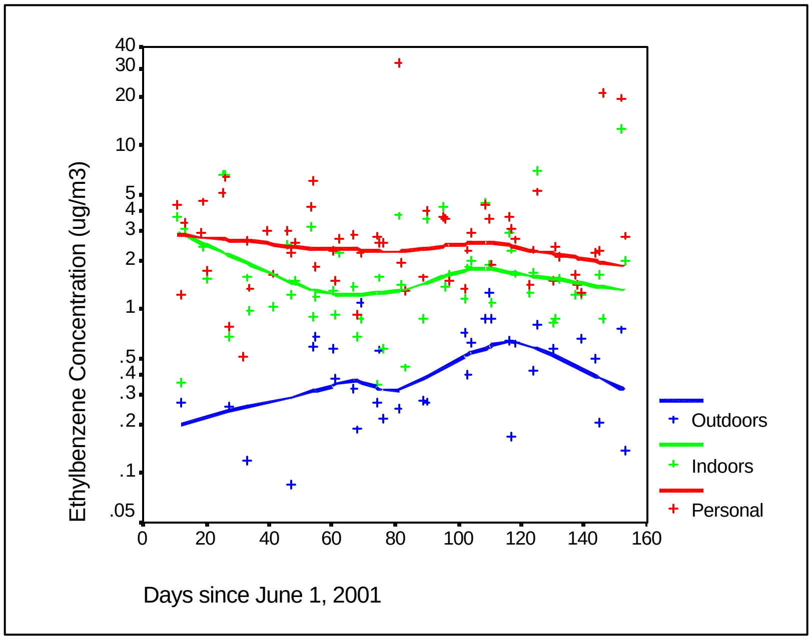
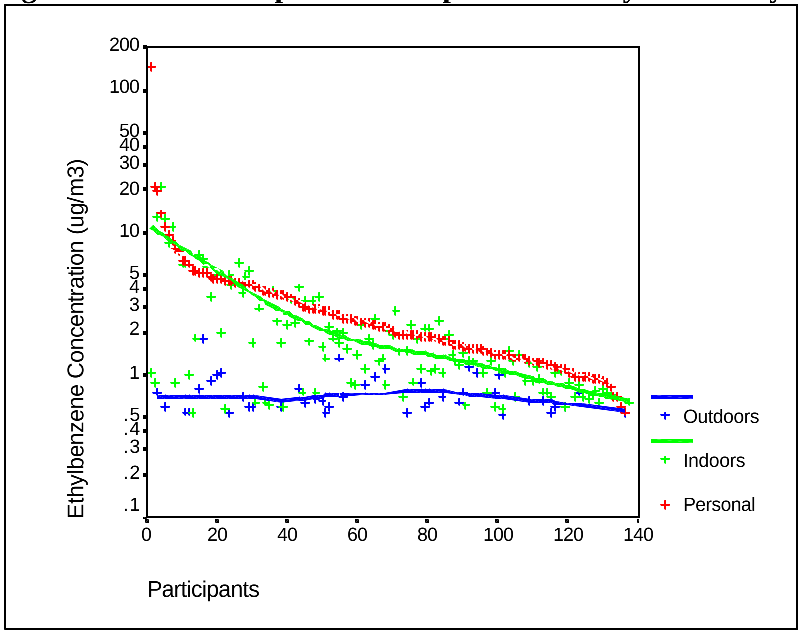


Figure 43 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations but no relationship between personal and outdoor exposures concentrations.

Figure 43: Relationship between Exposures to Ethylbenzene by Sampler Site



M-, P-xylene

Figure 44 shows the cumulative distribution of m-, p-xylene concentrations for the three types of samplers (personal, indoor, and outdoor). At the 50th percentile, personal and indoor concentrations were more than triple outdoor concentrations.

Figure 44: Distribution of m-, p-xylene

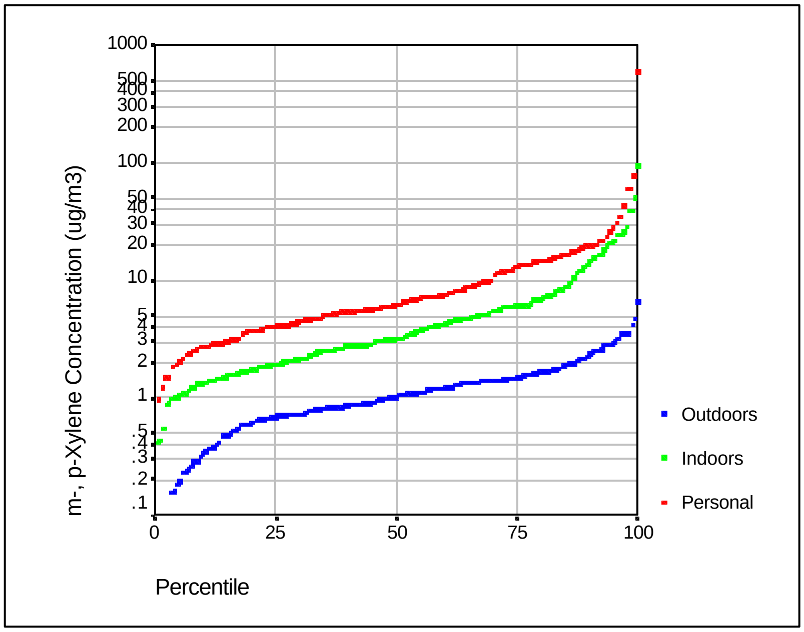


Figure 45 shows the temporal trend in m-, p-xylene concentrations. There is insufficient evidence to conclude that concentrations differ across the seasons.

Figure 45: Temporal Trend in m-, p-xylene Concentration

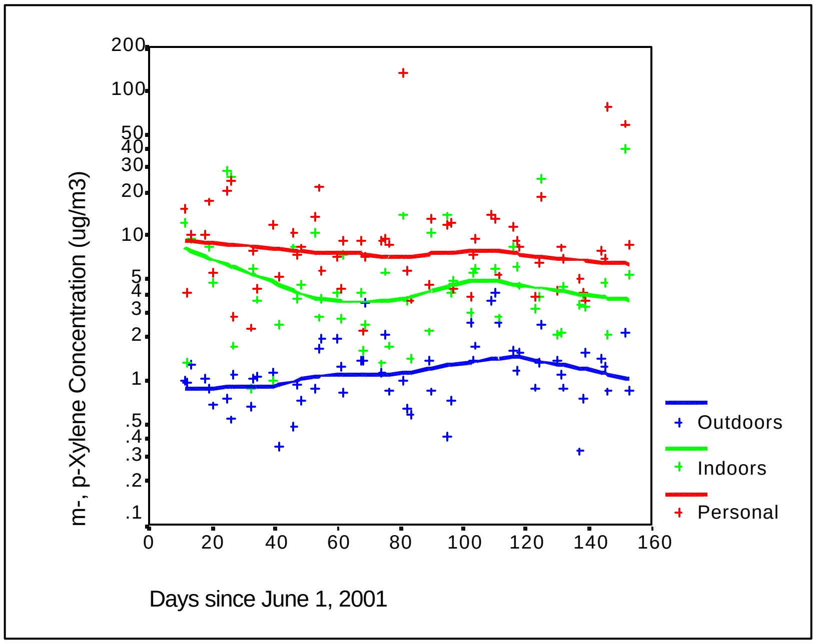
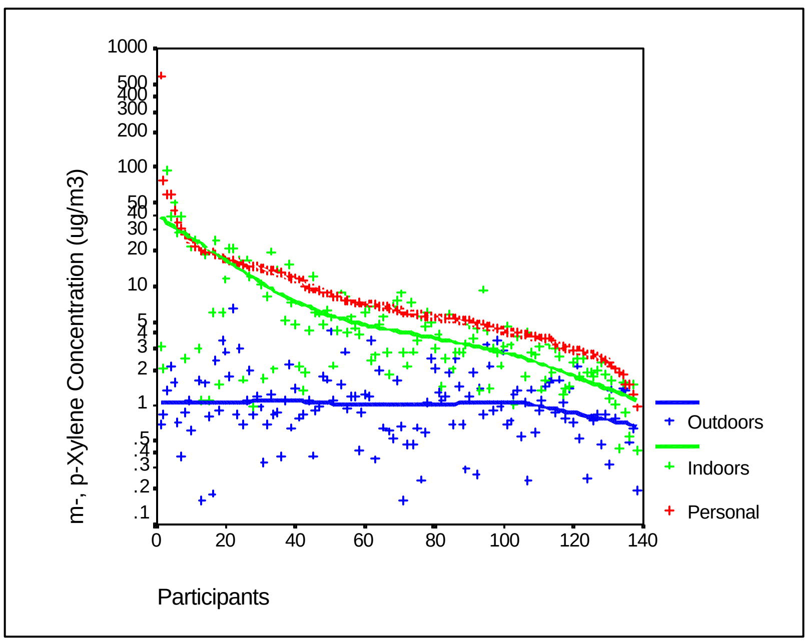


Figure 46 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations and no relationship with outdoor exposure concentrations.

Figure 46: Relationship between Exposures to m-, p-xylene by Sampler Site



O-Xylene

Figure 47 shows the cumulative distribution of o-xylene concentrations for the three types of samplers (personal, indoor, and outdoor). About 50% of the outdoor samplers had concentrations of o-xylene below detectable limits. Personal concentrations were about double indoor concentrations.

Figure 47: Distribution of O-Xylene

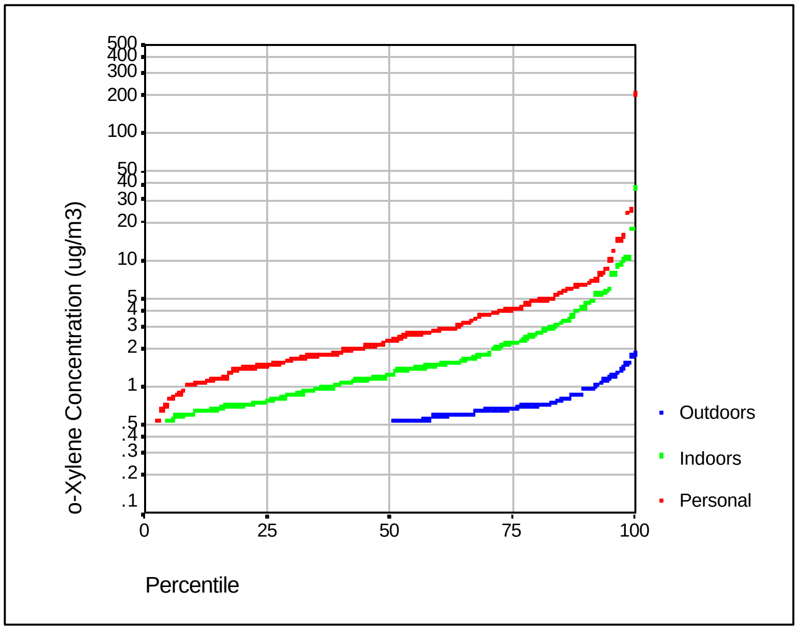


Figure 48 shows the temporal trend in o-xylene concentrations. There is insufficient evidence to conclude that concentrations differ across the seasons.

Figure 48: Temporal Trend in o-xylene Concentration

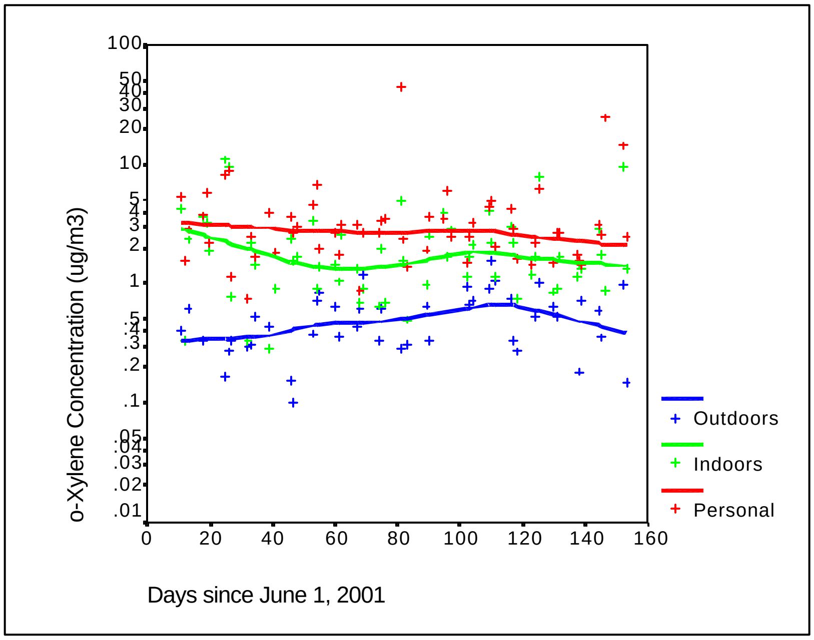
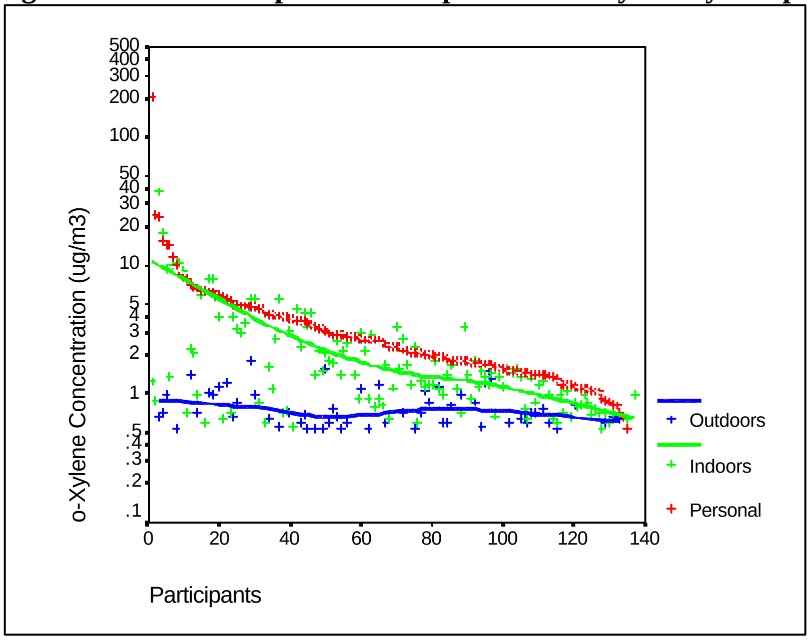


Figure 49 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations but no relationship between personal exposures and outdoor exposures.

Figure 49: Relationship between Exposures to o-xylene by Sampler Site



Nonane

Figure 50 shows the cumulative distribution of nonane concentrations for the three types of samplers (personal, indoor, and outdoor). Very few outdoor samplers recorded detectable nonane. Personal concentrations were higher than indoor concentrations.

Figure 50: Distribution of Nonane

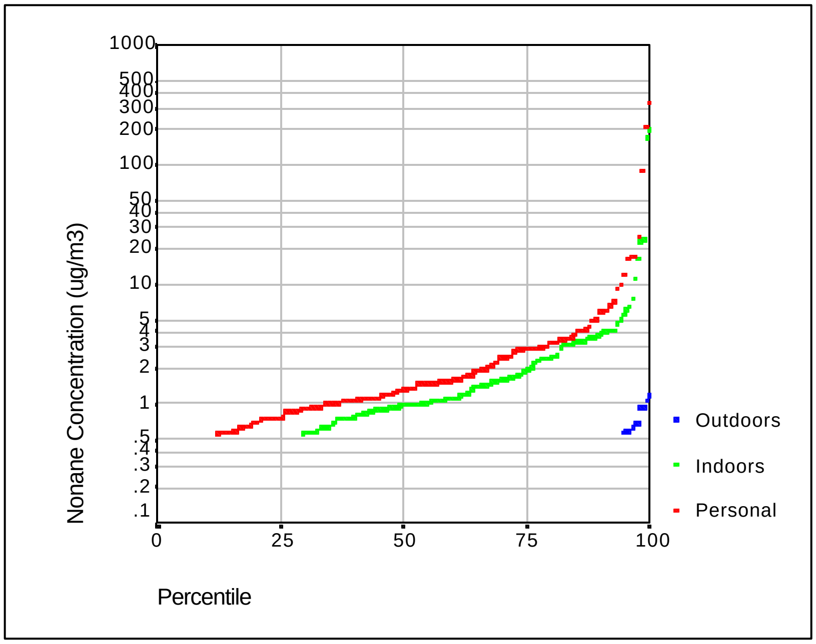


Figure 51 shows the temporal trend in nonane concentrations. There is insufficient evidence to conclude that concentrations differ across the seasons, though nonane levels may decrease in the summer.

Figure 51: Temporal Trend in Nonane Concentration

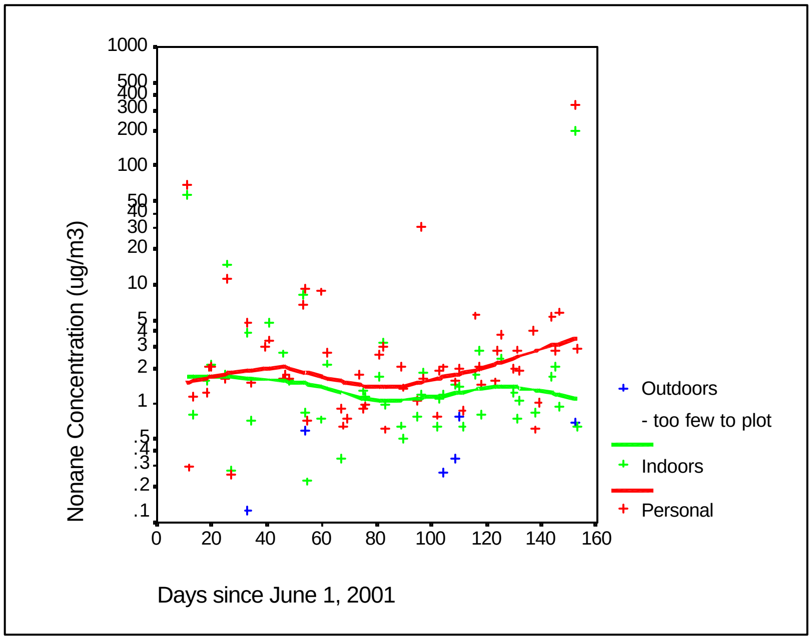
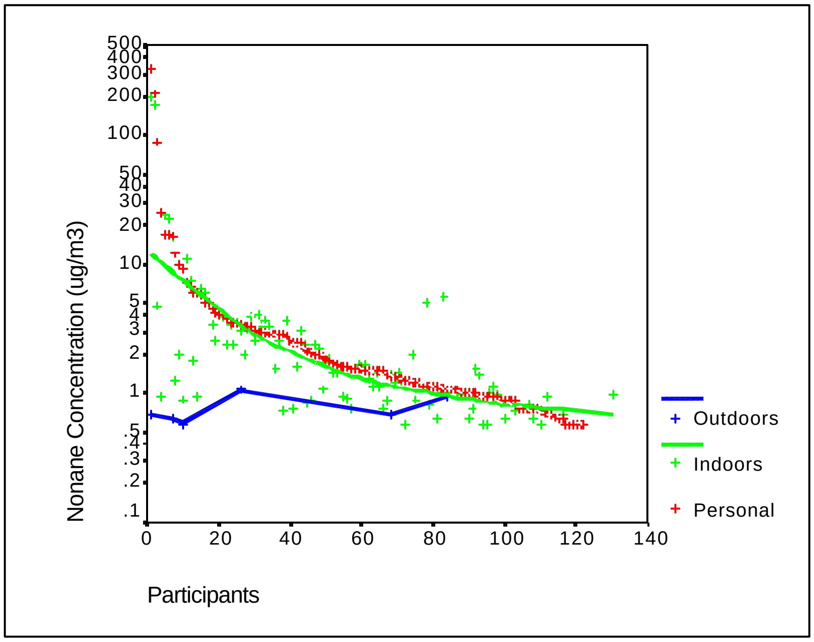


Figure 52 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations, but no relationship between personal exposures and outdoor exposures.

Figure 52: Relationship between Exposures to Nonane by Sampler Site



Decane

Figure 53 shows the cumulative distribution of decane concentrations for the three types of samplers (personal, indoor, and outdoor). About 80% of the outdoor samplers had concentrations of decane below detectable limits. Personal concentrations were higher than indoor concentrations.

Figure 53: Distribution of Decane

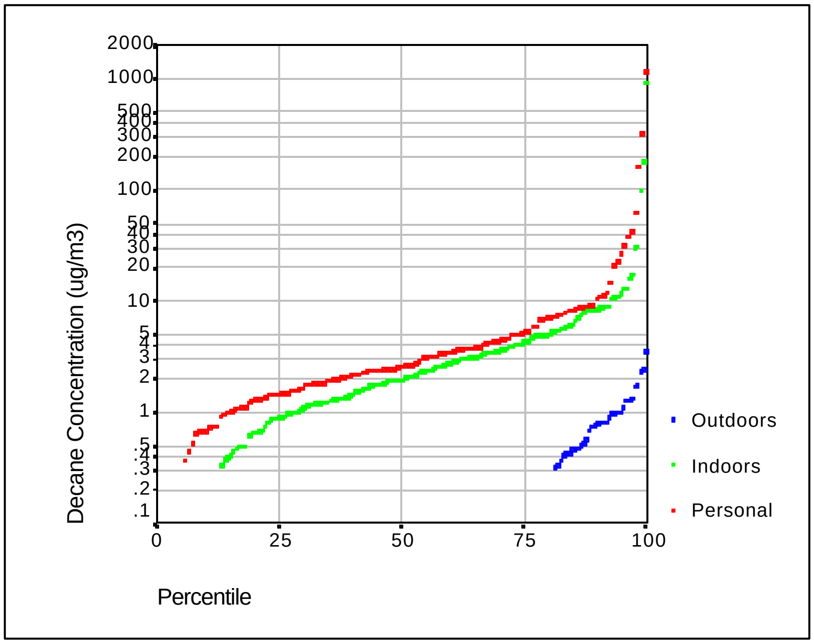


Figure 54 shows the temporal trend in decane concentrations. There is insufficient evidence to conclude that concentrations differ across the seasons.

Figure 54: Temporal Trend in Decane Concentration

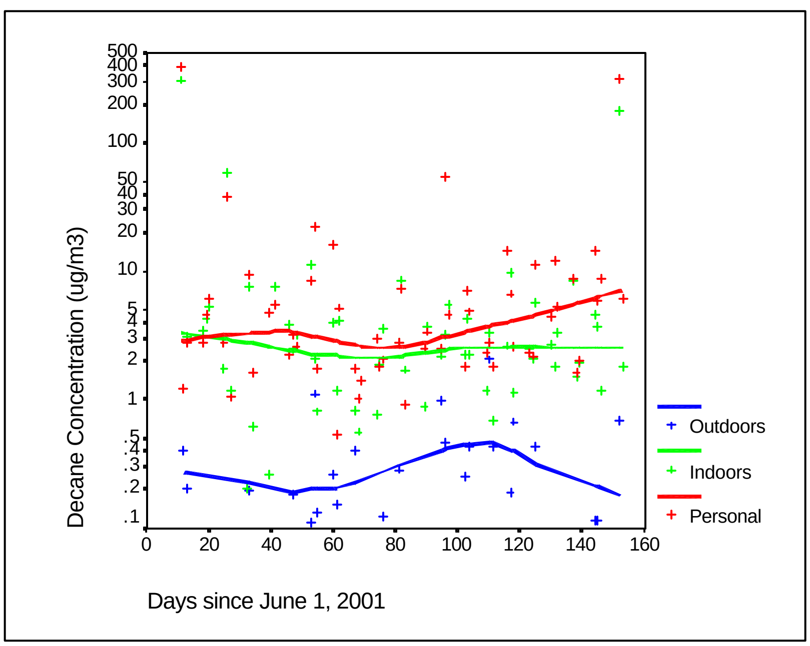
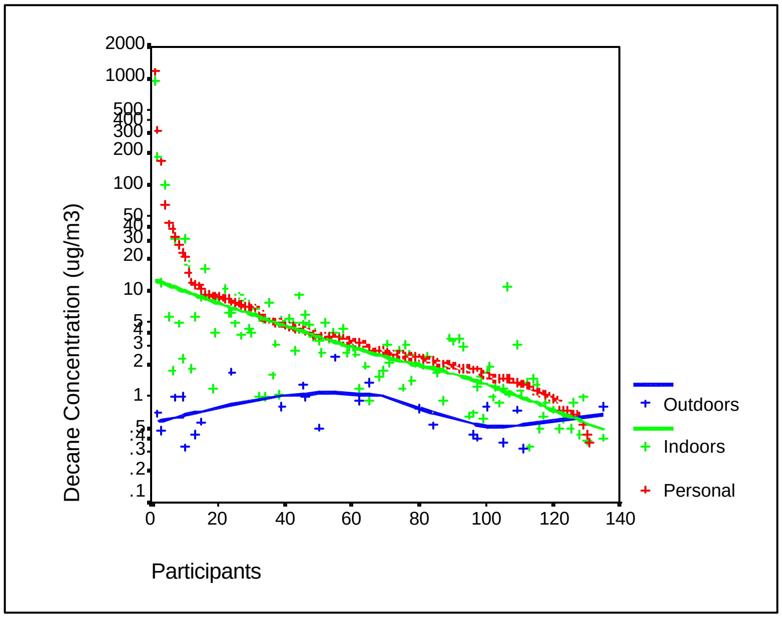


Figure 55 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There is no relationship between outdoor exposures and personal exposures.

Figure 55: Relationship between Exposures to Decane by Sampler Site



Limonene

Figure 56 shows the cumulative distribution of limonene concentrations for the three types of samplers (personal, indoor, and outdoor). Almost all of the personal and indoor samplers had measurable concentrations of limonene, while very few of the outdoor samplers had measurable concentrations of this contaminant. Personal exposure is slightly higher than indoor exposure.

Figure 56: Distribution of Limonene

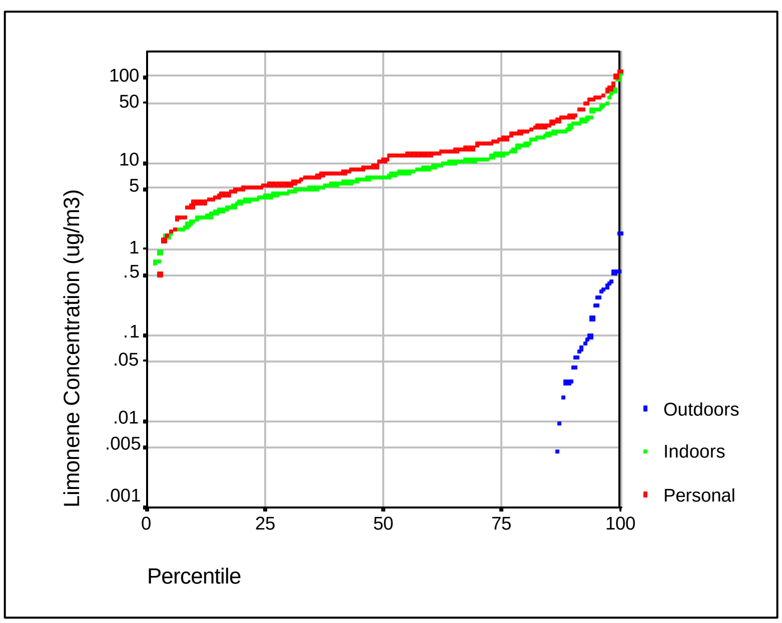


Figure 57 shows the temporal trend in limonene concentrations. There is insufficient evidence to conclude that concentrations differ across the seasons.

Figure 57: Temporal Trend in Limonene Concentration

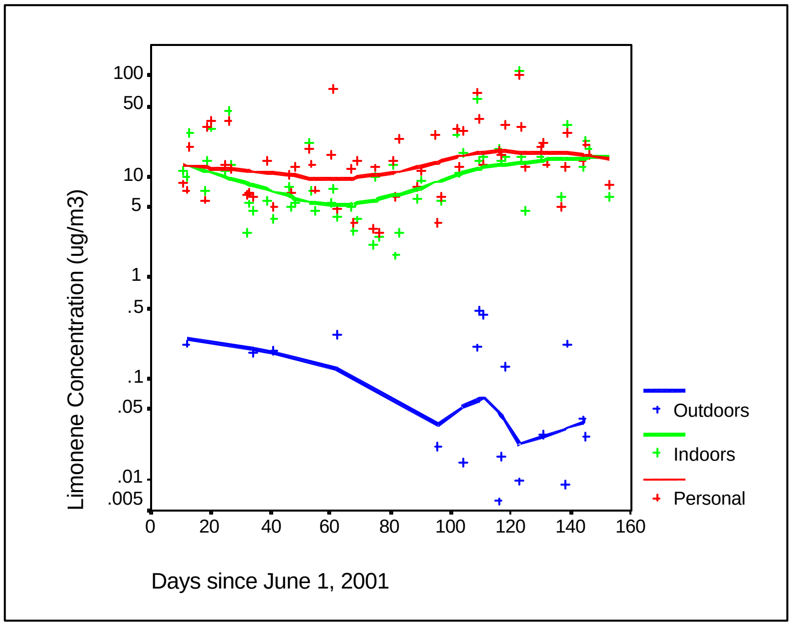
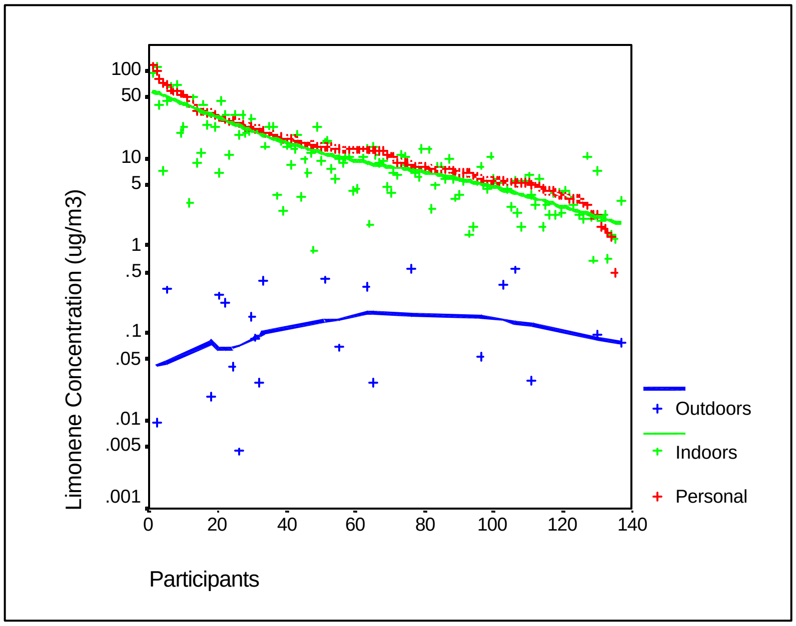


Figure 58 shows the relationships between concentrations monitored personally, indoors, and outdoors. The graph shows a very strong relationship between personal and indoor exposure concentrations such that high levels of personal exposure are consistently associated with higher levels of indoor exposure concentrations. There is no relationship between outdoor exposures and personal exposures.

Figure 58: Relationship between Exposures to Limonene by Sampler Site



7.2 Particulate Samplers

Particulate matter (PM) samples were also collected from selected participants in the Fort Saskatchewan region. As with the PEMs, the particulate filters were deployed inside and outside the households, and attached in the area of the individual's breathing zone, and blanks were also completed for quality assurance and control purposes. Particulate matter samples were all of the $PM_{2.5}$ range (smaller air-borne particles less than 2.5 µm in size). As with the PEMs, all samples were deployed for a consecutive 7-day period.

From each sample it was possible to determine the concentration of particles in the air. Each sample was also analyzed for the quantity of each of a large number of metals. Table 12 shows the metals that were analyzed.

Table 12: Metals Analyzed from Particulate Samples

Standard Chemical Abbreviation	Chemical Name	Standard Chemical Abbreviation	Chemical Name
AG	Silver	MN	Manganese
AL	Aluminum	MO	Molybdenum
AS	Arsenic	NA	Sodium
B	Boron	NI	Nickel
BA	Barium	P	Phosphorus
BE	Beryllium	PB	Lead
BI	Bismuth	S	Sulfur
CA	Calcium	SB	Antimony
CD	Cadmium	SE	Selenium
CL	Chlorine	SI	Silicon
CO	Cobalt	SN	Tin
CR	Chromium	SR	Strontium
CU	Copper	TH	Thorium
FE	Iron	TI	Titanium
HG	Mercury	TL	Thallium
K	Potassium	U	Uranium
LI	Lithium	V	Vanadium
MG	Magnesium	ZN	Zinc

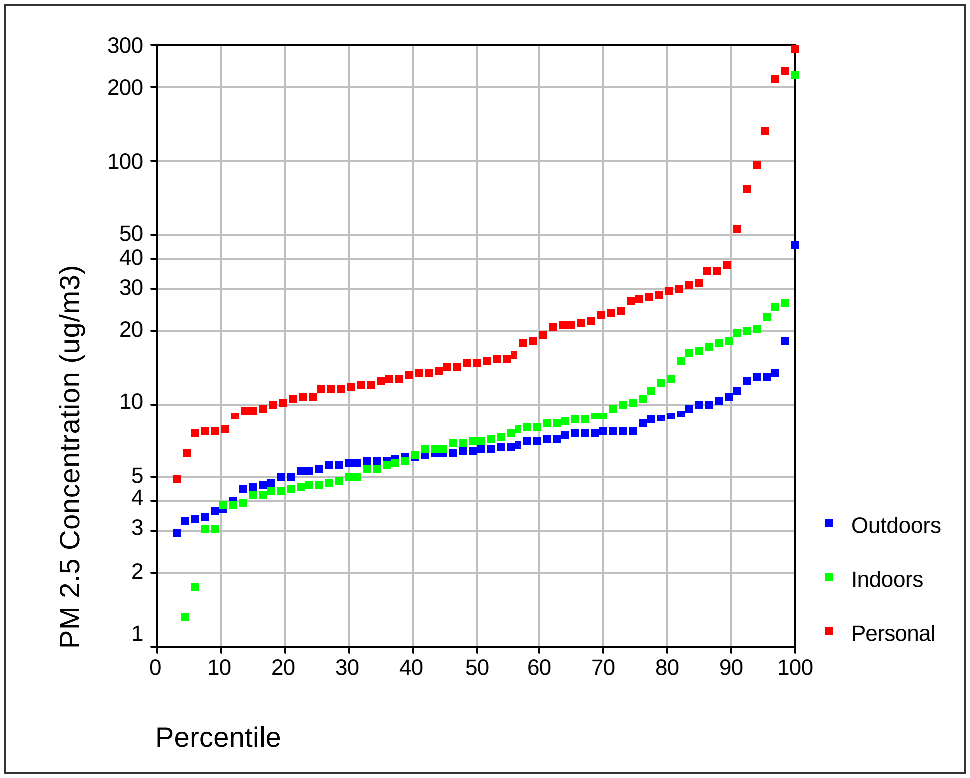
A total of 66 Fort Saskatchewan participants wore the particulate samplers. Table 13 shows the distribution of the 240 particulate matter filters that were used during the study.

Table 13: Distribution of Particulate Matter ($PM_{2.5}$) Filters

Location	Totals
Personal	66
Indoor	67
Outdoor	81
Blank	26
Total	240

Figure 59 shows the cumulative distribution of $PM_{2.5}$ concentrations for the three types of samplers. The median and 95th percentile $PM_{2.5}$ levels for the different locations are summarized in Table 14 and compared to guidelines and levels in other communities. The $PM_{2.5}$ guideline is currently under review and will be replaced by a Canadian wide standard of 30µg/m^3 over a 24-hour period by 2010. The levels of outdoor $PM_{2.5}$ levels measured in Fort Saskatchewan and surrounding area were similar to other communities in that they were well below guidelines. Median levels of indoor and personal $PM_{2.5}$ also appear low, however, it is difficult to draw firm conclusions from the completed analysis because of the limited sample size.

Figure 59: Distribution of $PM_{2.5}$



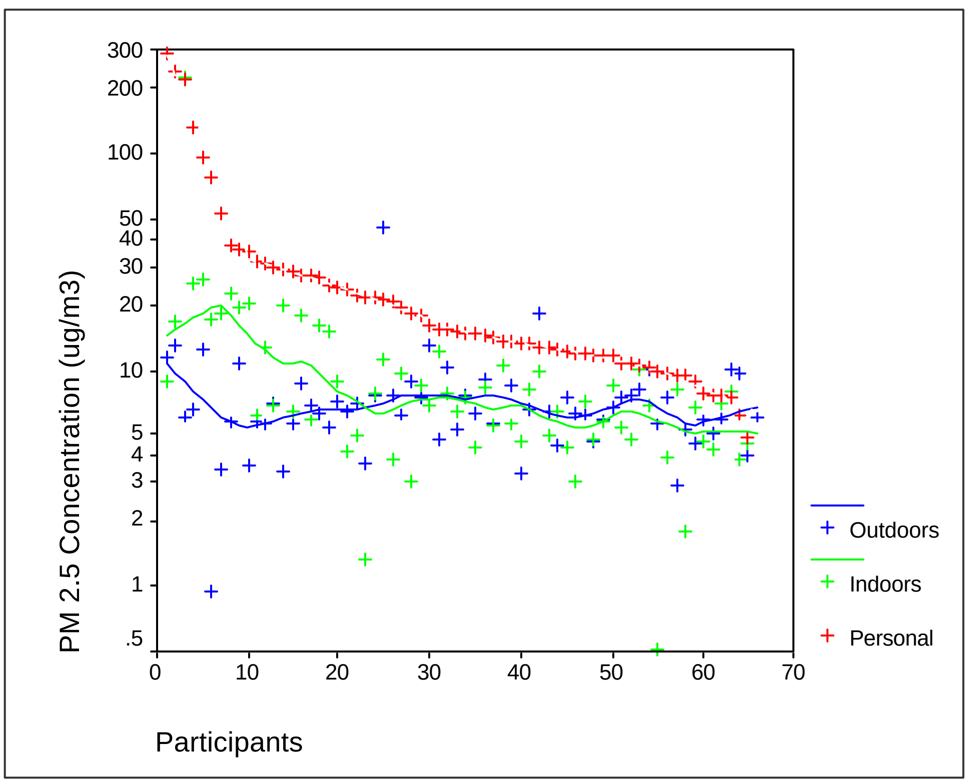
There were too few measurements to determine temporal trends. Figure 60 shows the personal exposure concentrations compared to average indoor and outdoor concentrations. There is a moderate correlation between personal and indoor concentrations, and no relationship to outdoor concentrations.

Table 14: Comparison of $PM_{2.5}$ Levels (mg/m^3) with Guidelines and Other Studies[28, 29, 30]

Parameter	Personal	Indoor	Outdoor	Ambient Station	P/I ratio	P/O ratio	I/O ratio
Fort Saskatchewan Median	15.1	6.98	6.56	N/A	2.2	2.3	1.06
Fort Saskatchewan 95th	187.9	24.3	13.18	N/A	7.7	14.2	1.8
Grande Prairie Median	19.9	8.7	4.4	N/A	2.3	4.6	2.0
Grande Prairie 95th	116.3	52.9	9.5	N/A	2.2	12.3	5.6
Fort McMurray Median	25	8.6	8.4	6.2	2.7	3.20	1.17
Fort McMurray 95th	88	3.5	23.2	13.3	2.6	4.88	1.88
Lethbridge Median	22.3	6.7	6.3	N/A	3.3	3.55	1.06
Lethbridge 95th	27.4	12.3	16.8	N/A	2.2	1.64	0.73
Relevant Studies	18.7*	15.4*	13.2*	9**	1.21*	1.42*	1.17*
Guideline/Reference Level	N/A	40 long term*** 100 (hour)***	N/A	15 (year) 65 (day) USEPA 30 (24-hour)****	N/A	N/A	N/A

* Pellizzari et al., 1999.
** Cheng et al., 1998.
*** Health Canada, 1989.
**** Proposed Canadian wide standard

Figure 60: Relationship between Exposures to $PM_{2.5}$ by Sampler Site



Further analysis involved the relative amounts of the analyzed metals found in the samples. The following figures (Figures 61 to 62) show the relative amounts of the various metals in the particulate samples. Figure 61 shows the average amounts of metal (in ng/m^3) across all sampler types. Figure 62 shows personal, indoor, and outdoor relative concentrations of metals in $PM_{2.5}$ in the same order as shown in the previous graph.

Figure 61: Overall Concentration of Metals in Particulate

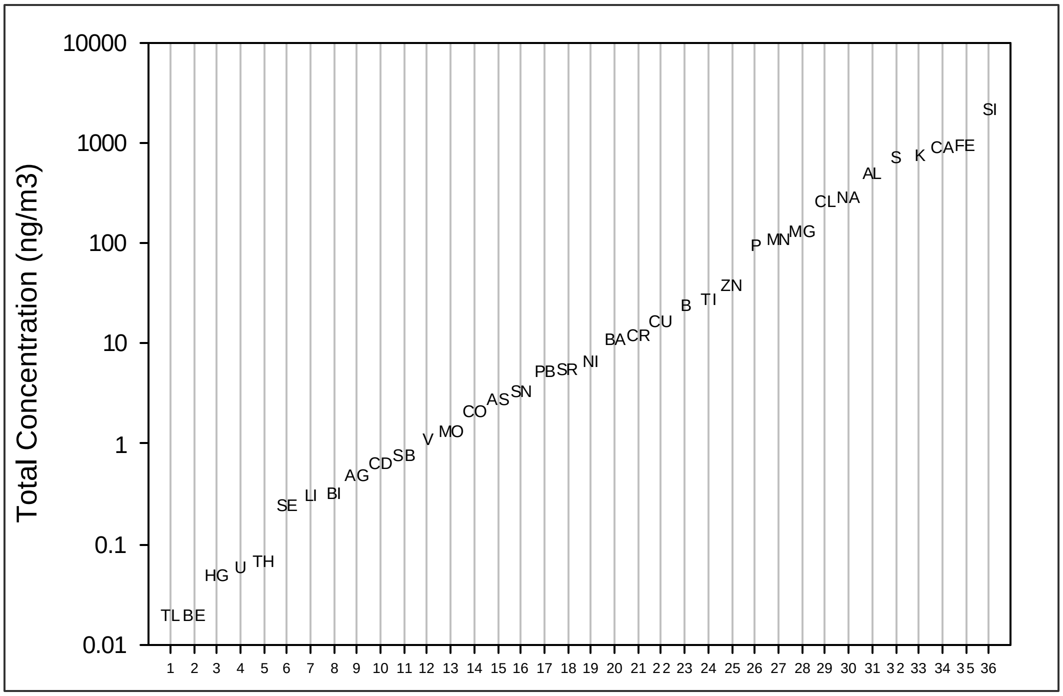
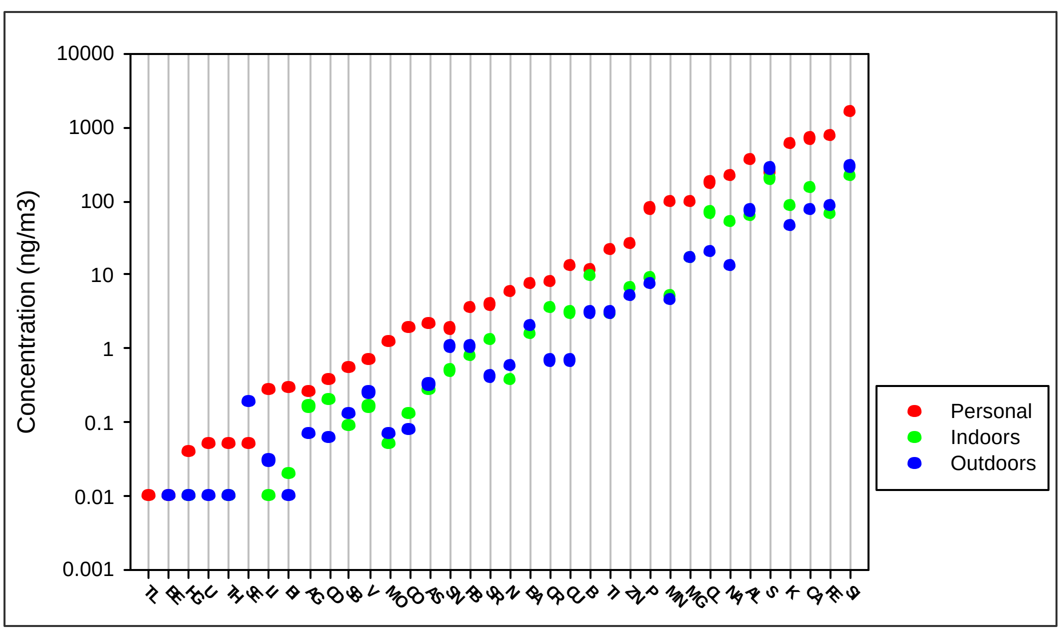


Figure 62: Concentration of Metals in $PM_{2.5}$



8.0 Exposure Relationships

8.1 A General Model of Potential Relationships[3]

The factors that determine the level of chemicals to which an individual is exposed are numerous, and often specific to the individual. The current study measured personal exposure levels integrated over one-week periods, and did not measure moment-to-moment concentration levels of the chemicals being monitored. This restricts the ability to provide definitive evidence of the exact causes of fluctuations in personal exposure levels. Nevertheless, a number of potential contributors to personal exposure levels were monitored and could be examined in the context of a general model of the potential causes of fluctuations in personal exposure levels. The statements below summarize some of the general expectations about relationships between exposure levels and other factors. The "→" symbol is used to postulate a causal relationship.

Concentration Interrelations:

Indoor concentration levels → Personal concentration levels
Outdoor concentration levels → Indoor concentration levels
Outdoor concentration levels→ Personal concentration levels

Activity Variations:

Fluctuations in Weekly Activity Pattern → Fluctuations in Personal concentration levels
Smoking Activity → Personal, Indoor concentration levels

Residence Characteristics:

Characteristics of the principal residence → Indoor, Personal concentration levels

For each of these potential relationships, variables were available. They are briefly described below, and a label is provided for use in interpreting the tables of results that follow. (Variables in brackets are reference categories against which other category members are compared).

Exposure:

pcon - Personal concentration levels
icon3 - Indoor concentration levels
ocon3 - Outdoor levels

Time-Activity:

ih Proportion of time inside at home
oh Proportion of time outside at home
iw Proportion of time inside at work
ow Proportion of time outside at work
ia Proportion of time other indoor activities
oa Proportion of time other outdoor activities
t Proportion of time in travel

[3] This section previously published in The Grande Prairie and Area Community Exposure and Health Effects Assessment Program: Final Report, 2002.

Smoking:

smkhome	Indicates if smoking occurs in the home
smkcar	Indicates if smoking occurs in the vehicle
smkamt	Number of cigarettes smoked per day (divided by 10)
smkexp2	Hours per day exposed to cigarette smoke

Job Status:

jobft	Has a full time job
jobpt	Has a part time job

Garage

attg	Attached Garage
detg	Detached garage
(no garage)	No garage

Housing Characteristics:

new	Built after 1985
med	Built between 1975 and 1985
trailor	Mobile home
mult2	Multiple housing (apartment or townhouse)
(single)	Single family detached dwelling
unpaved	Unpaved driveway
nfcdair	Indicates heating other than forced air
caret	Indicates presence of a cold air return

Urban-Rural

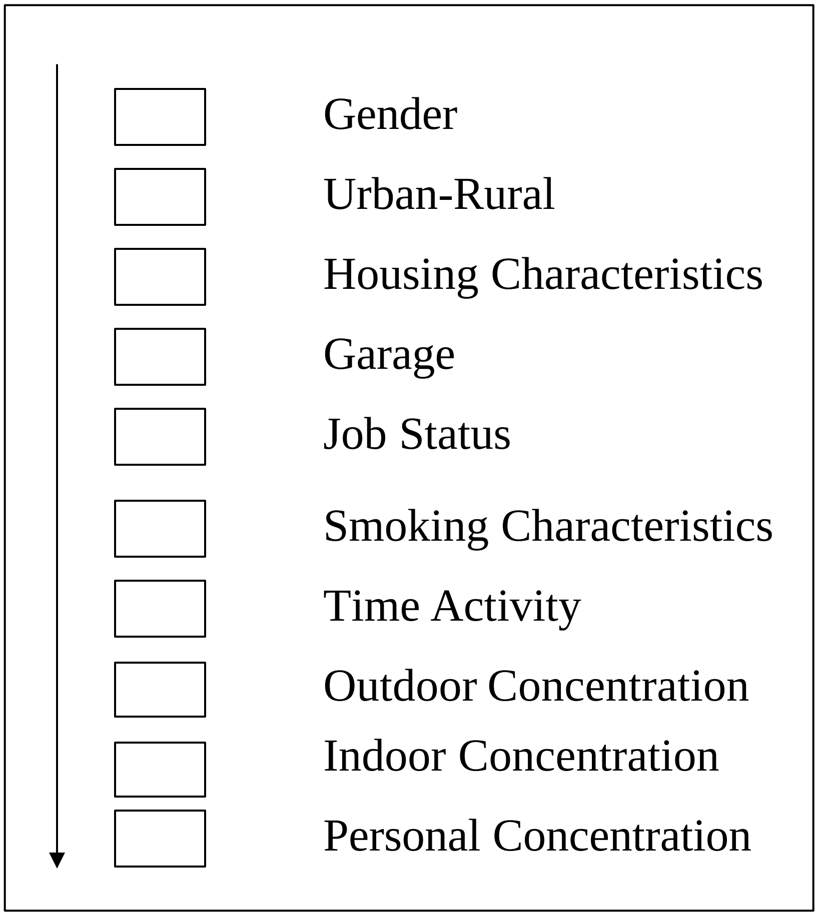
(urban)	located in Fort Saskatchewan town site
Ft Sask rural	located in Fort Saskatchewan rural area
Bruderheim	located in Bruderheim area
Redwater	located in Redwater area

Gender

gender	Female or Male

Further consideration of these variables and the hypothesized relationships led to the postulation of the following general recursive model to guide analysis and interpretation.

Figure 63: A General Ordering of Factors Influencing Exposure



A recursive ordering, such as this, is intended to capture a causal ordering among sets of variables. Specifically, as a hypothesis, it suggests that variables earlier (or higher) in the chain can have a causal effect on variables later (or lower) in the chain, but not vice versa. In addition, no reciprocal causal relations are postulated. Finally, for variables within a set, no causal ordering or priority is postulated.

There are various intuitive relationships that are captured by this ordering such as the notion that gender will influence job status, that job status will influence time and activity patterns, and that indoor concentrations will influence personal concentrations. There are a number of relationships that might be taken to be implied by the model which are not specifically intended, and which in a more detailed model could be explicitly left out (i.e. placing housing characteristics ahead of smoking characteristics in the model). There are also some relationships that may be excluded by this ordering which might nevertheless appear to obtain under some circumstances. For example, it may be postulated that indoor concentrations might have an effect on outdoor concentrations rather than the reverse. In the current model, outdoor concentrations were placed ahead of indoor concentrations because the major source of concern for exposure is the possibility that an external source leads to high indoor concentrations.

This recursive ordering was used as a heuristic device to structure the specific analyses of the concentrations of the individual chemicals. The data are blind to this ordering, and alternate hypotheses could be examined either by independent analysts or as a later follow-up to the current analyses. What the heuristic model does allow is a hypothetical partitioning of causal influence between total and direct effects within the model. Direct effects refer to the strength of relationships directly between an independent variable or variable set and a dependent variable, while total effects include relationships between the independent variables or variable sets and the dependent variables that include other independent variables as mediators of the influence. For example, 'having a full time job' might have a total effect on 'personal exposure to octane', even though the causal force might be carried by a relationship between 'having a full time job' and 'amount of time travelling in a car' and by a relationship 'amount of time travelling in a car' and 'personal exposure to octane'. It should be noted that in the model presented in Figure 63, there are a large number of ways in which a variable group or factor may have an indirect effect on personal exposure levels.

8.2 Methods of Analysis

The analysis of each contaminant used regression analyses to quantify the amount of the variability in personal exposure that could be attributed to variability in each factor. The traditional measure used for this purpose is a proportion of variance, R^2, derived from the correlation, r, or multiple correlation, R, of the variable(s) to personal levels when the effects of including other variables in the model are taken into account. The measure R^2 will vary from 0.0 when there is no effect to 1.0 when personal levels can be perfectly predicted by variation in some other factor or factors. In the simplest case, where only two variables are being considered, a scatterplot of these two variables can be presented which shows the degree of relationship between them. It is usually accompanied by a correlation coefficient that quantifies the strength of that relationship and, which when squared represents the proportion of variance measure (R^2). Unfortunately, simple scatterplots are not available as a tool when many variables are being simultaneously considered.

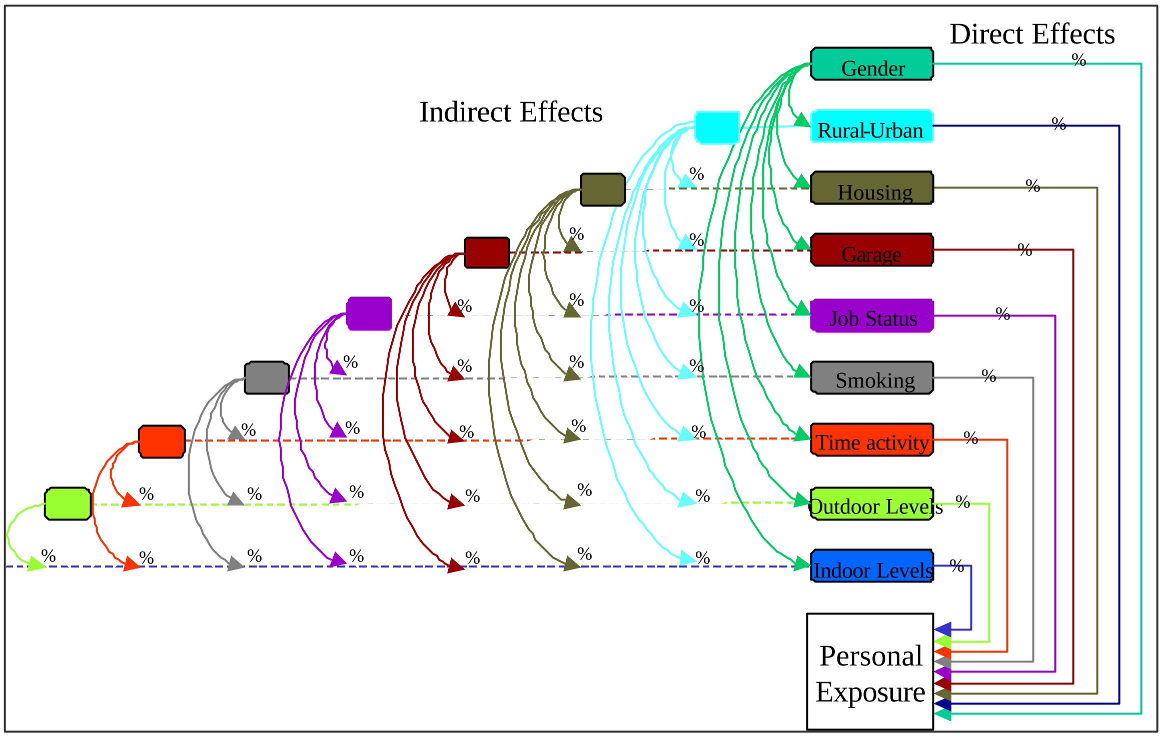
In general, the analysis of each contaminant proceeded as follows: a hierarchical set regression analysis[31] was performed in which variables were entered into the regression equation by set in the order specified by the recursive ordering and intermediate results were generated to give information about the relationships between variable sets. This form of analysis closely follows the logic of the recursive model in Figure 63. It can identify variables which have an indirect effect upon personal exposure levels by effecting changes in other variable sets intermediate between them and personal exposure in the recursive ordering. Such a multi-step procedure is necessary since a single analysis of all variables will obscure the intermediate relationships. In addition, since the concentration of exposures was typically positively skewed, in all cases, a generalized linear model was used in which the concentrations were assumed to follow a log normal distribution.

All analyses of passive samplers were conducted on 126 Fort Saskatchewan and area residents for whom complete data were available.

8.3 Presentation of Results

Comparing the effect of many factors simultaneously on personal exposure can become very complex, not only because of the increased number of factors but also because of the numerous potential pathways between the factors. Communicating the results can also be difficult if the goal is to describe effects due to each factor (direct effects) as well as the numerous interrelationships between the factors (indirect effects) that may be noteworthy. In an effort to communicate these results clearly, a pictorial description of the general model used in this analysis was developed and is presented in Figure 64. The figure, which is an extension of the recursive model presented in Figure 63, shows the factor groups in coloured boxes interconnected with black arrows to the box representing personal exposure. A coloured arrow connecting the factor and personal exposure on the right side of the figure represents the potential direct effect of each factor group on personal exposure. The potential indirect effects of each factor on personal exposure acting through the subsequent factors are shown by the cascading coloured arrows on the left of the figure. The arrows are colour coded to represent the factor groups. In subsequent sections of this report when this model is displayed for a contaminant only the largest effects and factor groups are displayed. The magnitude of the effect is written beside the arrow as a percentage and is reflected in the size of the arrow. The summations of the percentages on the figures will roughly total the variation in personal exposure described by the model and that is also noted on the figure.

Figure 64: General Model of Personal Exposure Used to Investigate Direct and Indirect Effects



In addition to figures such as Figure 64 that are presented for a selection of the contaminant models, two tables present the results of the hierarchical set regression conducted on each contaminant and provide the information required to construct the summary figure.

The first table presents comparative multiple correlation coefficients (Rs) derived from the hierarchical set analysis. The second column shows the total effect of the variable set in a regression analysis of personal exposure on this set of variables alone. The third column shows the total effect of the variable set with all variable sets higher in the causal ordering already entered into the regression. A decrease in the values from the second to the third column indicates that the variable sets higher in the recursive ordering had an effect on the variable set under consideration. Conversely, small differences suggest that a variable set is independent of those higher in the recursive ordering. The fourth column indicates the effect of a variable set (called the semi-partial R) with all other variable sets already in the regression. It indicates the direct effects of the variable set. If there is a decrease in the fourth column from the third column, this indicates that a variable set influences a variable set lower in the recursive ordering (and hence has an indirect effect). Small values in all columns indicate small effects. Though a detailed examination of confidence intervals was not performed, in general, multiple correlation coefficients in excess of 0.20 are likely to differ significantly from 0.0 and indicate a real effect. Clearly, the validity of this table depends upon the validity of the chosen recursive ordering, and alternative orderings would change the values in the second column (and likely the ordering of the table which follows the recursive ordering) as well.

The square of the fourth column of this table (multiplied by 100) represents the percentage of the variation in personal exposure accounted for directly by a particular factor as presented on the right side of the summary figure. The total indirect effects (from which the figures on the left of the summary figure are derived) are obtained by subtracting this figure from the square of the value in the second column.

The second table reports the β weights and multiple correlation coefficients for each variable from each variable set for each stage in the recursive ordering analysis. The β weights give a method of comparing relative size of effects of different variables, though the range of variation within the sample of individuals studied, especially if small, may need to be considered in interpreting these weights. The main value of the table is that it provides insight into the relative importance of individual variables within each of the variable sets, and can also suggest direct and indirect effects for individual variables.

This table is used to partition the indirect effects of a factor between alternate pathways presented in a summary diagram. The change in the sum of the squared coefficients for the variables in a single group from column to column indicate the relative proportion of variance due to a particular set of indirect pathways (specifically that indirect pathway that is present in only one of the columns under consideration).

8.4 Nitrogen Dioxide (NO_2)

Results of the analysis of relationships between personal exposures and the factors that may affect exposure to NO_2 are found in Table 15. The second column of the table shows individual factors' relationships to personal exposure if considered alone. These are the R^2 values that resulted from simple bivariate scatterplots of the factor and personal exposure. The third column shows the amount of variation in personal exposure described by each factor in the context of the model. The fourth column shows the direct effects. Overall, the model accounted for about 67% (57% adjusted) of the variability in personal exposure levels. Table 16 shows the results of the regressions done for the modeling.

Table 15: Comparative Multiple Regression Coefficients for Variable Sets

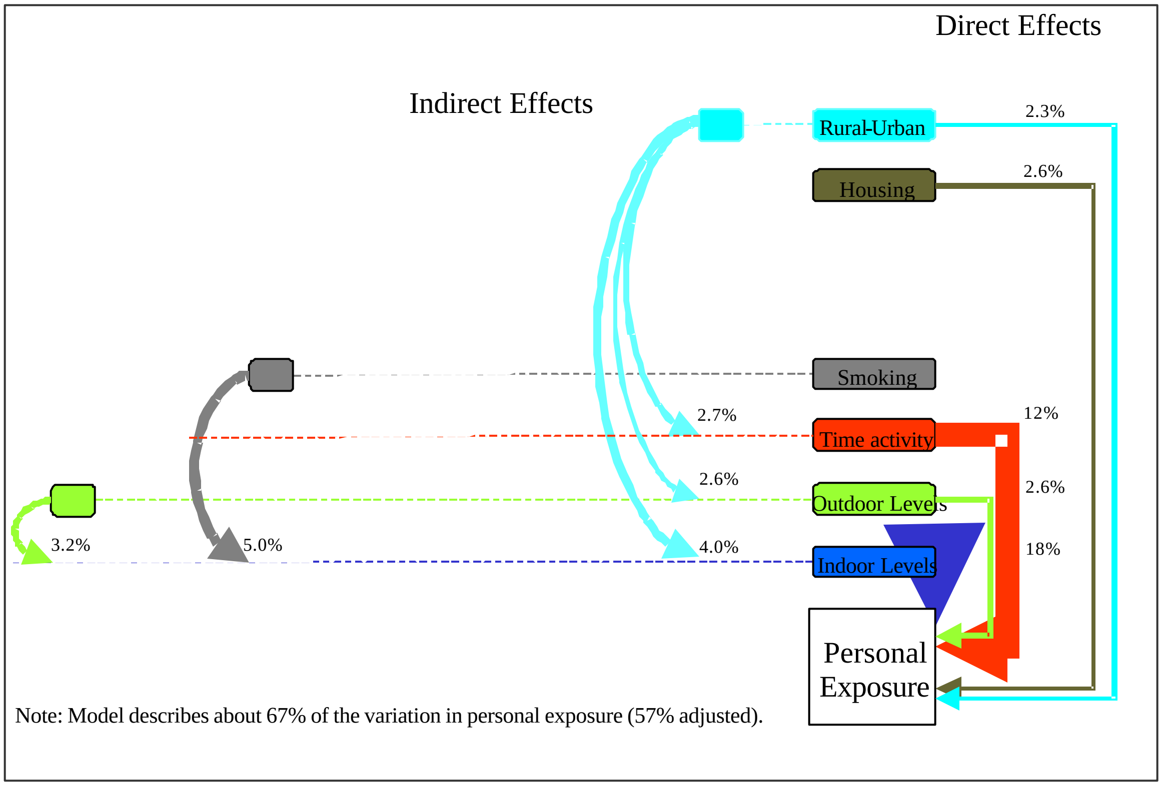
Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.10	0.10	0.04
Rural-Urban	0.37	0.36	0.15
Housing Characteristics	0.19	0.22	0.16
Garage	0.25	0.17	0.11
Job Status	0.21	0.18	0.07
Smoking Characteristics	0.23	0.25	0.11
Time Activity	0.49	0.34	0.34
Outdoor Concentration	0.37	0.24	0.16
Indoor Concentration	0.57	0.42	0.42

Table 16: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.05	-.03	.05	.06	.09	.09	.08	.06	.10
FT SASK RURAL	.13	.09	-.01	.06	.04	.03	-.04	-.09	
BRUDERHEIM	-.07	-.15	-.17	-.20	-.21	-.21	-.25	-.25	
REDWATER	-.07	-.18	-.27	-.35	-.33	-.36	-.36	-.31	
TRAILOR	.06	-.04	-.05	.05	.03	.04	.07		
MULT2	-.07	-.08	-.07	-.05	-.04	-.07	-.03		
NEW	-.08	-.07	-.15	-.16	-.20	-.15	-.18		
MED	-.15	-.23	-.26	-.26	-.24	-.20	-.19		
NFCDAIR	-.01	.00	-.01	-.04	-.06	-.07	-.08		
CARET	.11	.11	.16	.15	.10	.11	.13		
ATTG	-.13	-.22	-.21	-.29	-.28	-.31			
DETG	-.20	-.22	-.20	-.26	-.28	-.28			
UNPAVED	-.06	-.08	-.08	-.16	-.11	-.11			
JOBFT	-.04	-.05	-.07	.18	.20				
JOBPT	.06	.02	.01	.15	.17				
SMKHOME	.12	.26	.23	.22					
SMKCAR	-.05	-.21	-.20	-.13					
SMKAMT	.04	.05	.07	.04					
SMKEXP2	.05	.12	.11	.14					
IH	-.16	-.27	-.31						
OH	-.25	-.16	-.25						
IW	.18	.13	.10						
OW	.07	.01	-.07						
IA	.07	.08	.06						
OA	-.11	-.14	-.19						
T	-.06	-.11	-.18						
OCON3	.21	.32							
ICON3	.52								
R	.81	.70	.66	.56	.50	.47	.44	.37	.10

The modeling results in Tables 15 and 16 were combined and have been represented pictorially in Figure 65. Only direct effects with R^2 values greater than 0.02 (i.e., 2%) are displayed while indirect effects of R^2 greater than 2.5% are displayed.

Figure 65: Results of Model of Personal Exposure to Nitrogen Dioxide



The major effects on personal exposure levels identified in this diagram were:

- ***Indoor levels,*** directly (18.0%)
- ***Time activity,*** directly (12.0%)
- ***Smoking,*** operating indirectly through effects on indoor levels (5.0%)
- ***Rural-urban,*** operating indirectly through effects on indoor levels (4.0%)
- ***Outdoor levels,*** operating indirectly through indoor levels (3.2%)
- ***Rural-urban,*** operating indirectly through effects on time activity (2.7%)
- ***Housing,*** directly (2.6%)
- ***Outdoor levels,*** directly (2.6%)
- ***Rural-urban,*** directly (2.3%)

Overall, indoor variation accounted for roughly one-half of the variation in personal exposure described by the model. Time activity was also an important driver of personal exposure while smoking and housing had more minor effects.

The most important factor within time activity appears to be the amount of time spent indoors at work; higher exposure is associated with more indoor work time.

8.5 Sulfur Dioxide (SO_2)

Results of the analysis of relationships between personal exposures and the factors that may affect exposure to SO_2 are found in Table 17. The second column of the table shows the relationship between individual factors and personal exposure if considered alone. These are the R^2 values that resulted from simple bivariate scatterplots of the factor and personal exposure. The third column shows the amount of variation in personal exposure described by each factor in the context of the model. The fourth column shows just the direct effects. The model accounted for about 59% (46% adjusted) of the variation in personal exposure.

Table 17: Comparative Multiple Regression Coefficients for Variable Sets

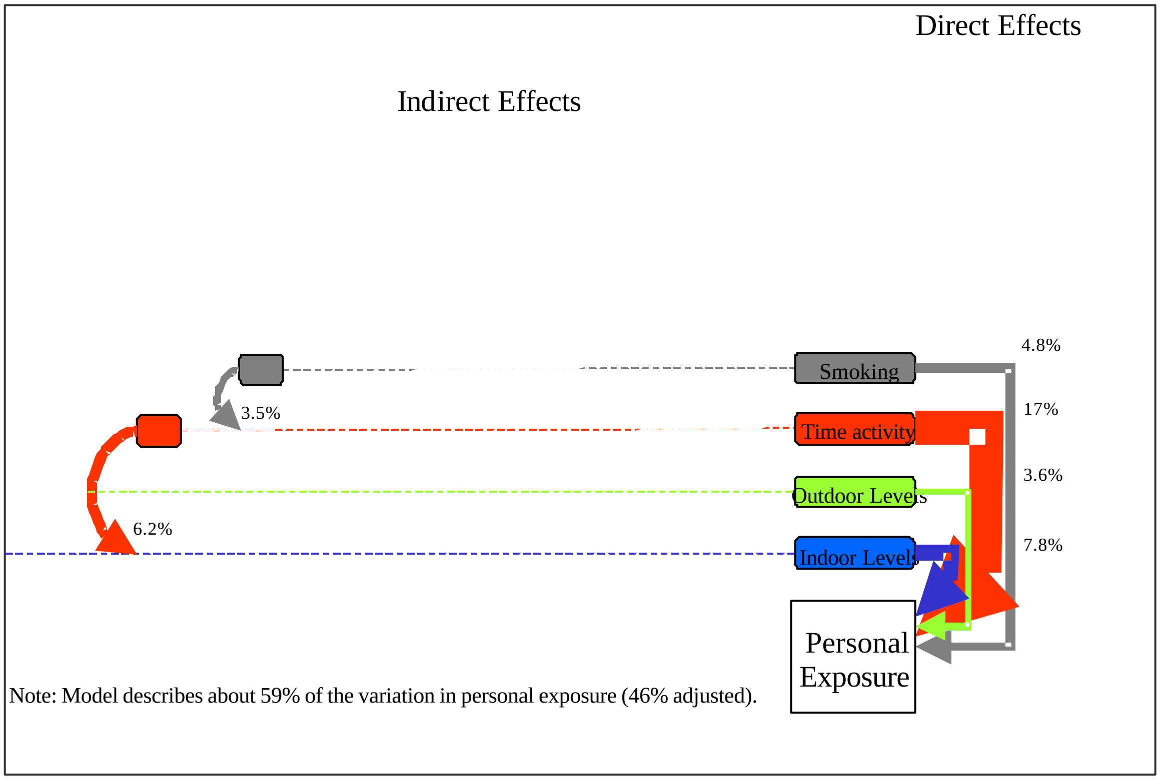
Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.14	0.14	0.02
Rural-Urban	0.24	0.25	0.12
Housing Characteristics	0.25	0.24	0.09
Garage	0.17	0.07	0.09
Job Status	0.04	0.02	0.13
Smoking Characteristics	0.35	0.32	0.22
Time Activity	0.53	0.48	0.41
Outdoor Concentration	0.23	0.18	0.19
Indoor Concentration	0.46	0.28	0.28

Table 18: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.03	.00	.02	.14	.19	.18	.18	.16	.14
FT SASK RURAL	.11	.08	.11	.19	.15	.16	.15	.15	
BRUDERHEIM	.13	.20	.25	.22	.22	.23	.22	.22	
REDWATER	-.01	.04	.10	.12	.15	.15	.16	.13	
TRAILOR	-.03	-.06	-.10	-.08	-.09	-.09	-.08		
MULT2	-.01	.03	.05	.02	.06	.06	.07		
NEW	.11	.13	.06	.05	.07	.07	.10		
MED	.01	-.06	-.09	-.17	-.15	-.14	-.13		
NFCDAIR	-.01	-.03	-.04	-.02	.04	.04	.04		
CARET	.02	.04	.07	-.01	-.02	-.02	.00		
ATTG	-.07	-.09	-.05	-.05	-.03	-.04			
DETG	-.15	-.20	-.21	-.16	-.09	-.10			
UNPAVED	-.03	-.07	-.06	-.06	-.01	-.02			
JOBFT	-.17	-.13	-.15	.01	.00				
JOBPT	.00	-.01	-.02	.04	.03				
SMKHOME	-.05	-.06	-.05	-.10					
SMKCAR	.21	.20	.18	.21					
SMKAMT	.06	.11	.12	.17					
SMKEXP2	.04	.10	.09	.11					
IH	-.61	-.71	-.69						
OH	-.14	-.15	-.15						
IW	-.33	-.43	-.40						
OW	.22	.24	.24						
IA	-.22	-.27	-.22						
OA	-.18	-.18	-.17						
T	-.19	-.26	-.29						
OCON3	.22	.21							
ICON3	.34								
R	.76	.71	.69	.49	.38	.38	.37	.29	.14

The modeling results in Tables 17 and 18 were combined and have been represented pictorially in Figure 66. Only direct effects with R^2 values greater than 0.02 (i.e., 2%) are displayed while indirect effects of R^2 greater than 2.5% are displayed.

Figure 66: Results of Model of Personal Exposure to Sulfur Dioxide



A qualitative estimate of the pathways of the indirect effects has been made. The major effects identified in the analysis were as follows:

- ***Time activity,*** directly (17.0%)
- ***Indoor levels,*** directly (7.8%)
- ***Time activity,*** operating indirectly apparently through effects on indoor levels (6.2%)
- ***Smoking,*** directly (4.8%)
- ***Outdoor levels,*** directly (3.6%)
- ***Smoking,*** operating indirectly through time activity (3.5%)

Overall, variations in activity patterns accounted for almost half the variation in personal exposure. Time spent indoors at home resulted in reduced SO_2 exposure while time spent outside at work increased exposure. Indoor variation had important effects on personal exposure. Smoking in the car was an important variable affecting SO_2 exposure.

8.6 Ozone (O_3)

The results of the analysis comparing effects of factors on personal O_3 exposure is shown in Tables 19 and 20 and pictorially in Figure 67.

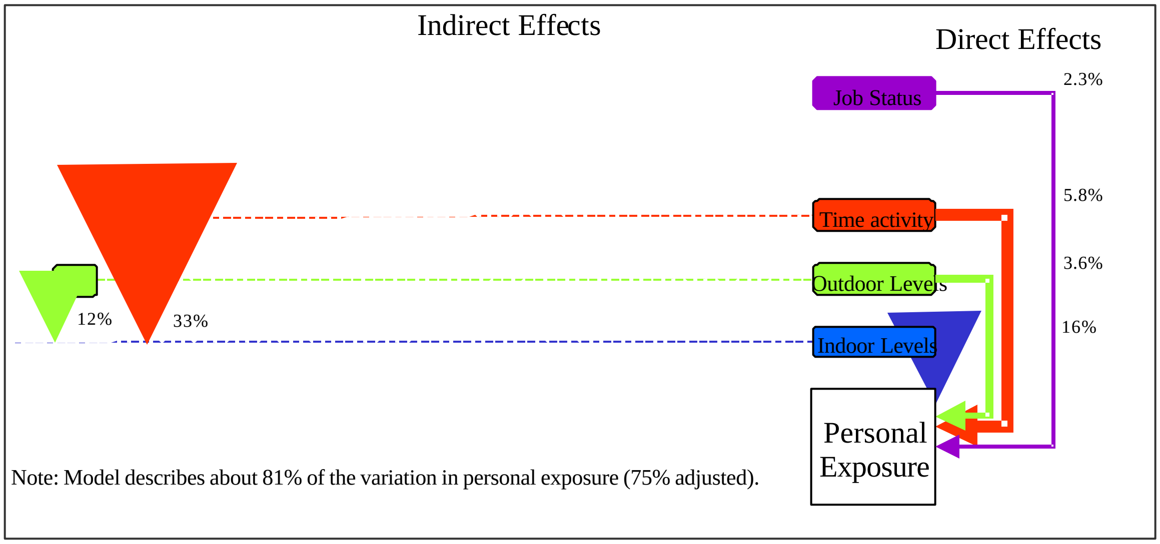
Table 19: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.01	0.01	0.01
Rural-Urban	0.06	0.06	0.07
Housing Characteristics	0.15	0.15	0.08
Garage	0.17	0.18	0.14
Job Status	0.23	0.22	0.15
Smoking Characteristics	0.09	0.09	0.08
Time Activity	0.58	0.62	0.23
Outdoor Concentration	0.65	0.39	0.19
Indoor Concentration	0.79	0.40	0.40

Table 20: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	-.02	-.14	-.29	-.08	-.06	-.05	-.03	-.02	-.01
FT SASK RURAL	.07	-.04	.02	.10	.09	.10	.03	.05	
BRUDERHEIM	-.04	-.09	-.06	.00	.00	-.01	-.03	-.03	
REDWATER	.00	.08	.03	.08	.07	.10	.02	.00	
TRAILOR	.06	.00	-.02	-.06	-.06	-.07	-.11		
MULT2	.00	.05	.07	-.01	-.01	.03	.01		
NEW	.02	.04	.14	.08	.08	.03	.08		
MED	.05	.05	.09	.02	.02	-.02	-.02		
NFCDAIR	.02	-.04	-.07	-.06	-.05	-.03	-.03		
CARET	.02	-.01	-.01	-.08	-.08	-.10	-.08		
ATTG	.15	.26	.16	.24	.24	.28			
DETG	.15	.27	.20	.20	.21	.22			
UNPAVED	-.17	-.17	-.23	-.13	-.12	-.12			
JOBFT	-.23	-.20	-.23	-.21	-.21				
JOBPT	-.06	-.14	-.24	-.22	-.23				
SMKHOME	-.04	-.16	-.01	-.03					
SMKCAR	.08	.17	.14	.09					
SMKAMT	-.04	-.09	-.12	-.02					
SMKEXP2	.05	.07	.05	.05					
IH	.28	.24	-.09						
OH	.37	.53	.56						
IW	.36	.30	.06						
OW	.24	.28	.30						
IA	.07	.12	-.06						
OA	.16	.15	.18						
T	.17	.19	.23						
OCON3	.27	.50							
ICON3	.56								
R	.90	.81	.70	.34	.32	.24	.16	.06	.01

Figure 67: Results of Model of Personal Exposure to Ozone



The model predicted about 81% of the variation in personal O_3 exposure across individuals and days. Important factors influencing variations in O_3 exposures were as follows:

- ***Time activity,*** operating indirectly through effects on indoor air (33.0%)
- ***Indoor levels,*** directly (16.0%)
- ***Outdoor levels,*** operating indirectly through indoor air (12.0%)
- ***Time activity,*** directly (5.8%)
- ***Outdoor levels,*** directly (3.6%)
- ***Job status,*** directly (2.3%)

The variation in personal exposure described by the model was mostly due to time activity acting directly and indirectly through indoor levels related to time spent indoors at home. Variations in indoor concentrations were also an important factor as well as outdoor levels acting directly and indirectly through indoor air.

8.7 Volatile Organic Compounds

The results of the investigation into the VOCs will be presented as a group. A more focused discussion is presented for benzene due to the unique exposure pattern and the health concerns associated with this compound.

Tables 21 to 44 show the modeled results for all the VOCs investigated. Figures 68 to 79 show pictorial representations of the exposure model results for these compounds.

All the VOC compounds investigated in this study except benzene demonstrate a pattern of exposure that showed the variation in indoor air levels dominated personal exposure and account for at least half of the variation explained by the model in most cases. Benzene exposure showed the factor of time activity patterns to be slightly more important than indoor air levels with each factor accounting for most of the variation in personal exposure explained by the model. Among the time activity factors, time spent outdoor at work and indoors elsewhere were the important influences.

Toluene, nonane, m- and p-xylene, o-xylene, and ethylbenzene showed exposure influenced by factors acting through indoor air. Housing was an important direct effect for most compounds. Rural-urban was important for heptane and hexane. Interestingly, gender showed an effect operating indirectly through indoor air. It should be emphasized that all of these factors are minor in comparison to indoor concentration levels.

Benzene

Figure 68: Results of Model of Personal Exposure to Benzene

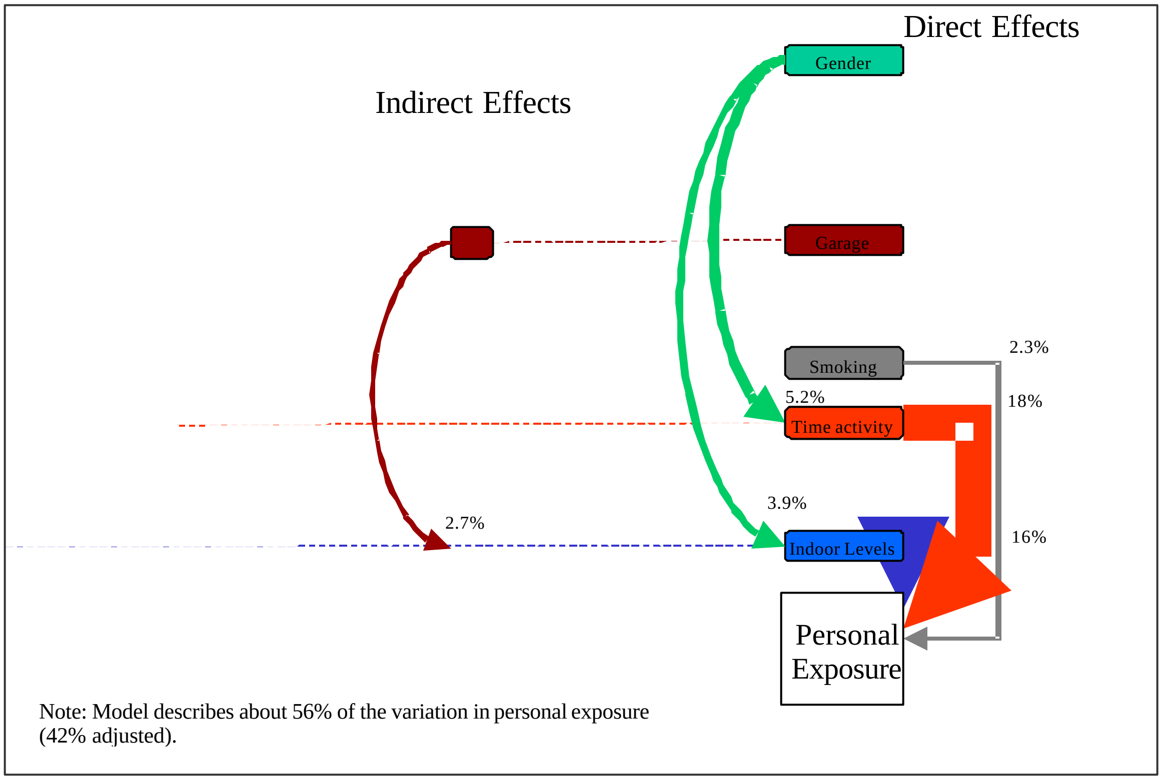


Table 21: Comparative Multiple Regression Coefficients for Variable Sets

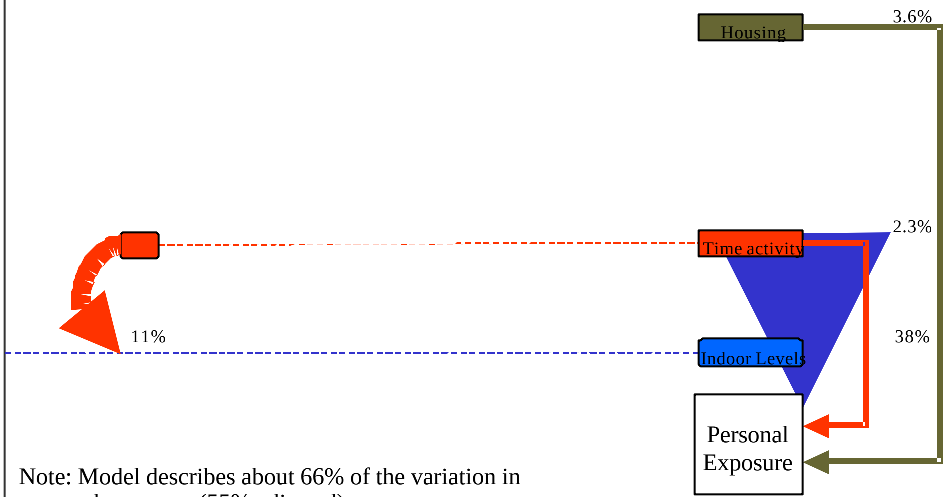
Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.38	0.38	0.13
Rural-Urban	0.04	0.04	0.09
Housing Characteristics	0.13	0.13	0.10
Garage	0.22	0.19	0.07
Job Status	0.14	0.06	0.08
Smoking Characteristics	0.17	0.12	0.15
Time Activity	0.46	0.41	0.42
Outdoor Concentration	0.12	0.14	0.04
Indoor Concentration	0.48	0.40	0.40

Table 22: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.17	.22	.25	.37	.39	.38	.39	.38	.38
FT SASK RURAL	-.02	-.09	-.13	-.03	-.04	-.04	.00	-.03	
BRUDERHEIM	.05	-.06	-.11	.01	.01	.01	.03	.03	
REDWATER	.10	.08	.07	.05	.03	.03	.04	.02	
TRAILOR	-.09	-.13	-.13	-.05	-.04	-.05	-.07		
MULT2	-.01	-.03	-.04	-.01	-.01	.00	-.03		
NEW	-.03	.00	-.05	-.13	-.11	-.13	-.01		
MED	-.01	.01	-.03	-.03	-.04	-.05	-.04		
NFCDAIR	-.04	.04	.03	.02	.04	.05	.07		
CARET	.04	.04	.05	.08	.09	.09	.11		
ATTG	.02	.29	.31	.29	.29	.29			
DETG	-.03	.04	.09	.06	.09	.08			
UNPAVED	.09	.13	.10	.04	.04	.03			
JOBFT	-.08	-.07	-.09	-.06	-.08				
JOBPT	-.11	-.08	-.08	-.03	-.04				
SMKHOME	-.08	-.09	-.12	-.15					
SMKCAR	.11	.08	.10	.10					
SMKAMT	.04	.02	.01	.01					
SMKEXP2	-.16	-.09	-.09	.03					
IH	.11	.33	.27						
OH	.11	.20	.17						
IW	.11	.30	.28						
OW	.29	.30	.26						
IA	.34	.45	.45						
OA	.05	.05	.02						
T	.24	.29	.25						
OCON3	.05	.19							
ICON3	.51								
R	.75	.63	.62	.46	.45	.44	.40	.38	.38

Toluene

Figure 69: Results of Model of Personal Exposure to Toluene



Note: Model describes about 66% of the variation in personal exposure (55% adjusted).

Table 23: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.14	0.14	0.05
Rural-Urban	0.19	0.18	0.10
Housing Characteristics	0.26	0.24	0.19
Garage	0.16	0.14	0.11
Job Status	0.08	0.06	0.02
Smoking Characteristics	0.10	0.07	0.08
Time Activity	0.36	0.36	0.15
Outdoor Concentration	0.10	0.04	0.04
Indoor Concentration	0.75	0.62	0.62

Table 24: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.07	.24	.26	.22	.21	.19	.17	.13	.14
FT SASK RURAL	.06	-.10	-.11	-.10	-.08	-.08	-.06	-.15	
BRUDERHEIM	.10	-.07	-.08	-.01	-.01	.00	.00	-.07	
REDWATER	.12	-.18	-.17	-.14	-.13	-.13	-.09	-.14	
TRAILOR	-.12	-.07	-.07	-.05	-.05	-.06	-.03		
MULT2	.10	.00	.00	.07	.07	.06	.09		
NEW	.06	.13	.11	.11	.11	.12	.05		
MED	-.05	-.02	-.03	.01	.02	.02	.02		
NFCDAIR	-.10	-.06	-.06	-.03	-.04	-.05	-.05		
CARET	-.02	.15	.16	.22	.23	.23	.21		
ATTG	-.22	-.18	-.17	-.21	-.21	-.23			
DETG	-.18	-.14	-.13	-.11	-.11	-.13			
UNPAVED	-.05	.12	.11	.07	.06	.05			
JOBFT	.03	.05	.04	.00	.00				
JOBPT	.00	.04	.05	.06	.07				
SMKHOME	-.09	.02	.01	.02					
SMKCAR	-.02	-.05	-.05	-.05					
SMKAMT	.02	.07	.06	.02					
SMKEXP2	.01	-.12	-.12	-.06					
IH	.18	.63	.61						
OH	.12	.13	.10						
IW	.11	.33	.31						
OW	.11	.21	.19						
IA	.19	.38	.37						
OA	-.01	-.11	-.12						
T	.11	.10	.08						
OCON3	-.05	.06							
ICON3	.80								
R	.81	.52	.52	.37	.36	.36	.33	.23	.14

Ethylbenzene

Figure 70: Results of Model of Personal Exposure to Ethylbenzene

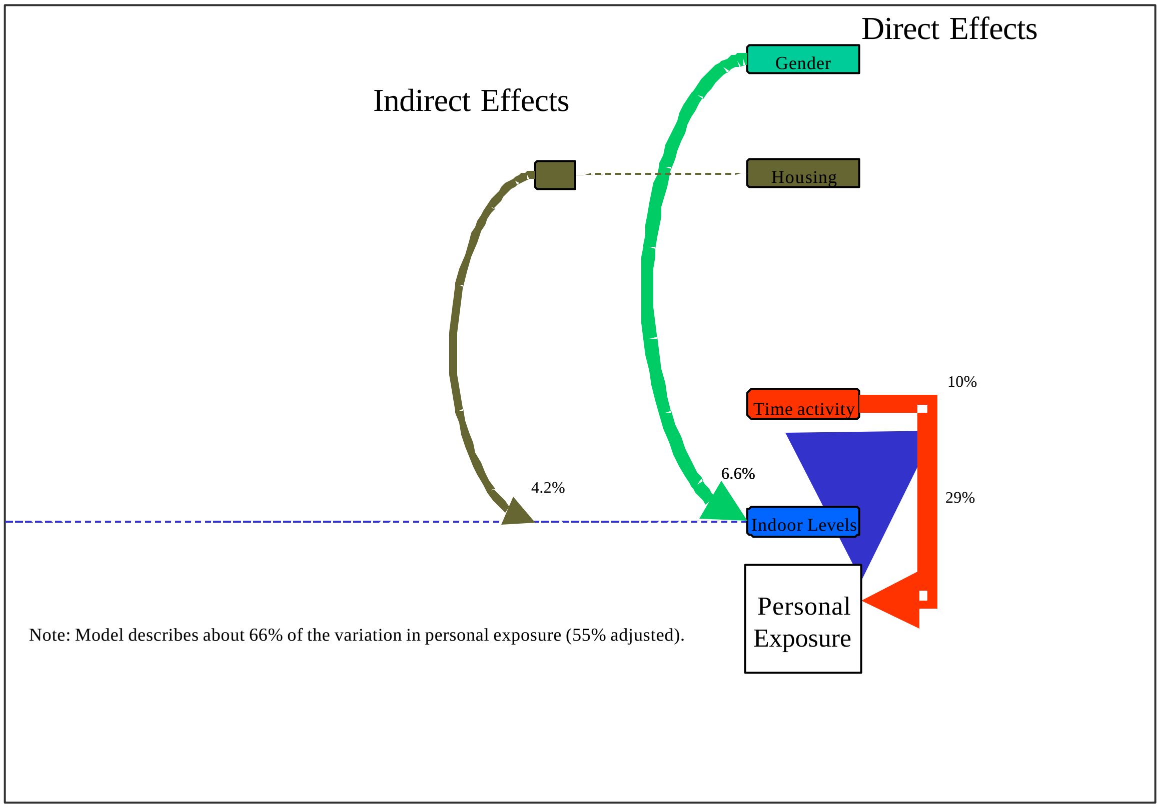


Table 25: Comparative Multiple Regression Coefficients for Variable Sets

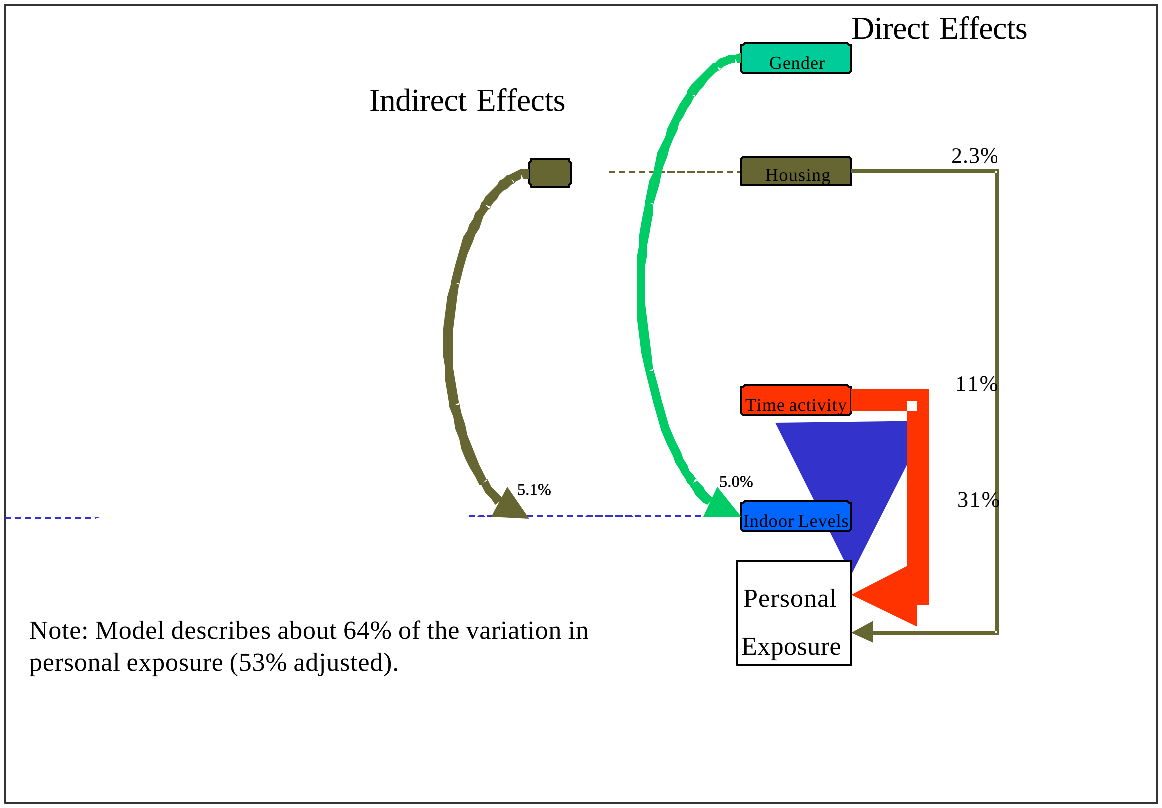
Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.35	0.35	0.11
Rural-Urban	0.10	0.08	0.14
Housing Characteristics	0.26	0.26	0.14
Garage	0.18	0.13	0.14
Job Status	0.11	0.03	0.08
Smoking Characteristics	0.11	0.12	0.09
Time Activity	0.34	0.33	0.31
Outdoor Concentration	0.13	0.15	0.08
Indoor Concentration	0.65	0.54	0.54

Table 26: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.14	.30	.34	.39	.36	.36	.36	.34	.35
FT SASK RURAL	.11	-.02	-.06	.00	.02	.02	-.02	-.05	
BRUDERHEIM	.17	.02	-.02	.06	.06	.06	.04	.03	
REDWATER	.13	.00	-.01	-.03	-.03	-.02	-.02	-.05	
TRAILOR	-.11	-.15	-.16	-.08	-.08	-.08	-.07		
MULT2	-.07	-.19	-.19	-.15	-.15	-.15	-.12		
NEW	.00	.05	.02	-.02	-.01	-.01	.03		
MED	-.07	-.07	-.07	-.05	-.05	-.05	-.04		
NFCDAIR	.02	.13	.13	.12	.12	.12	.13		
CARET	.04	.10	.11	.15	.17	.17	.19		
ATTG	-.20	-.11	-.08	-.11	-.12	-.12			
DETG	-.23	-.26	-.20	-.22	-.22	-.22			
UNPAVED	-.13	.04	.04	-.03	-.06	-.07			
JOBFT	-.05	-.04	-.06	-.03	-.03				
JOBPT	-.11	-.08	-.07	-.02	-.02				
SMKHOME	-.03	-.02	-.02	-.04					
SMKCAR	.03	-.04	-.04	-.04					
SMKAMT	.02	.05	.06	.04					
SMKEXP2	-.10	-.17	-.19	-.09					
IH	.06	.25	.23						
OH	.12	.07	.02						
IW	.13	.22	.22						
OW	.17	.16	.13						
IA	.26	.38	.35						
OA	.06	-.03	-.05						
T	.18	.19	.17						
OCON3	.09	.18							
ICON3	.66								
R	.81	.60	.58	.47	.46	.46	.44	.35	.35

O-Xylene

Figure 71: Results of Model of Personal Exposure to O-Xylene



Note: Model describes about 64% of the variation in personal exposure (53% adjusted).

Table 27: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.29	0.29	0.09
Rural-Urban	0.12	0.11	0.12
Housing Characteristics	0.29	0.29	0.15
Garage	0.16	0.09	0.12
Job Status	0.09	0.05	0.08
Smoking Characteristics	0.15	0.10	0.12
Time Activity	0.34	0.34	0.33
Outdoor Concentration	0.11	0.11	0.03
Indoor Concentration	0.65	0.56	0.56

Table 28: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.11	.25	.28	.32	.31	.30	.30	.29	.29
FT SASK RURAL	.06	-.05	-.09	-.03	-.02	-.01	-.05	-.09	
BRUDERHEIM	.14	.00	-.03	.06	.06	.06	.03	.02	
REDWATER	.11	-.01	-.02	-.02	-.04	-.03	-.03	-.07	
TRAILOR	-.11	-.14	-.15	-.09	-.08	-.09	-.07		
MULT2	-.09	-.20	-.20	-.16	-.17	-.16	-.14		
NEW	.06	.12	.09	.05	.07	.06	.06		
MED	-.04	-.03	-.03	-.01	-.02	-.03	-.02		
NFCDAIR	-.01	.13	.13	.13	.14	.14	.14		
CARET	.05	.14	.15	.17	.19	.19	.20		
ATTG	-.24	-.13	-.11	-.14	-.15	-.14			
DETG	-.18	-.20	-.16	-.17	-.16	-.17			
UNPAVED	-.07	.07	.04	-.03	-.05	-.06			
JOBFT	-.03	-.04	-.04	-.05	-.06				
JOBPT	-.11	-.07	-.06	-.04	-.04				
SMKHOME	-.11	-.04	-.04	-.09					
SMKCAR	.08	.00	.01	.01					
SMKAMT	.02	.00	.01	.00					
SMKEXP2	-.09	-.15	-.16	-.06					
IH	.08	.14	.12						
OH	.07	-.02	-.06						
IW	.07	.05	.06						
OW	.20	.18	.15						
IA	.27	.30	.29						
OA	.06	-.05	-.07						
T	.19	.16	.14						
OCON3	.04	.15							
ICON3	.68								
R	.80	.57	.56	.45	.43	.43	.42	.31	.29

M-, P-Xylene

Figure 72: Results of Model of Personal Exposure to M-, P-Xylene

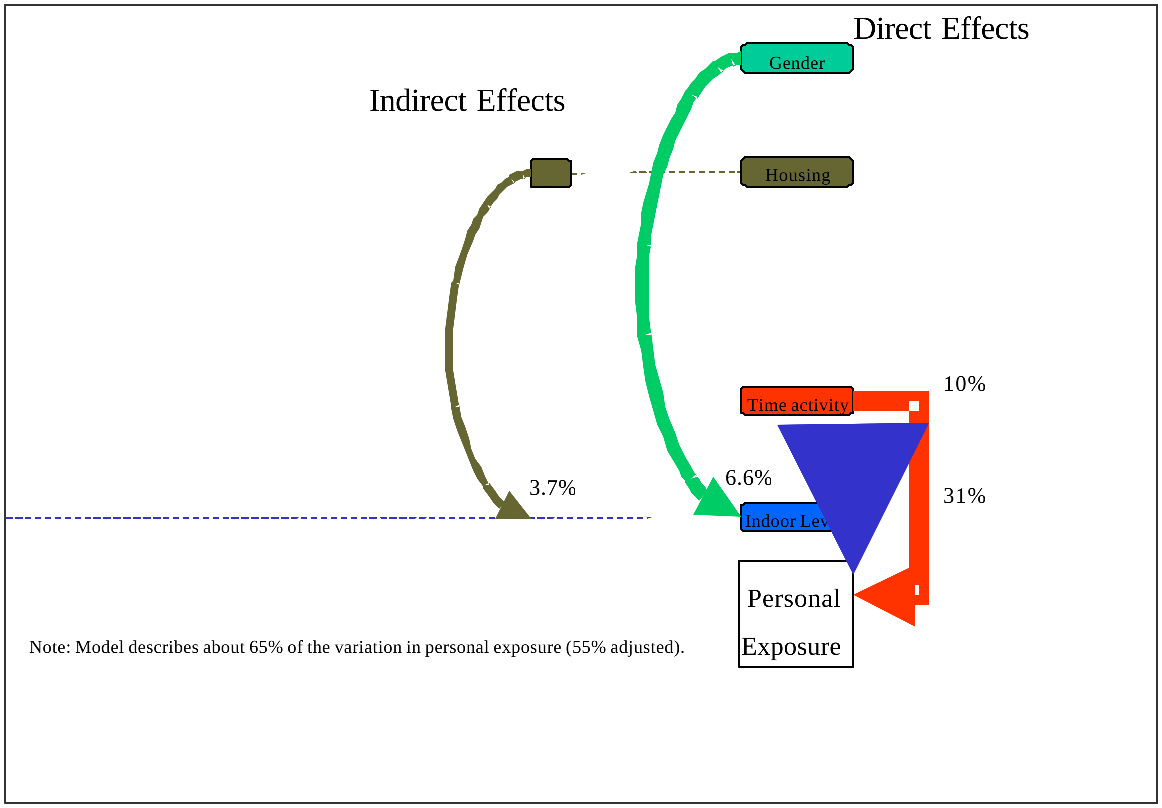


Table 29: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.34	0.34	0.07
Rural-Urban	0.12	0.09	0.11
Housing Characteristics	0.27	0.26	0.14
Garage	0.17	0.09	0.10
Job Status	0.13	0.01	0.09
Smoking Characteristics	0.12	0.10	0.09
Time Activity	0.33	0.33	0.32
Outdoor Concentration	0.14	0.14	0.08
Indoor Concentration	0.67	0.56	0.56

Table 30: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.09	.27	.31	.37	.35	.35	.35	.33	.34
FT SASK RURAL	.10	-.04	-.09	-.02	-.01	-.01	-.02	-.05	
BRUDERHEIM	.14	-.01	-.06	.02	.02	.02	.01	.00	
REDWATER	.10	-.02	-.05	-.06	-.06	-.06	-.04	-.08	
TRAILOR	-.10	-.16	-.16	-.09	-.09	-.08	-.07		
MULT2	-.07	-.16	-.16	-.12	-.13	-.13	-.11		
NEW	.03	.10	.05	.00	.02	.02	.05		
MED	-.07	-.05	-.06	-.04	-.04	-.04	-.03		
NFCDAIR	.01	.14	.13	.13	.13	.13	.14		
CARET	.04	.12	.12	.16	.18	.17	.19		
ATTG	-.18	-.08	-.04	-.07	-.08	-.08			
DETG	-.16	-.19	-.14	-.16	-.15	-.15			
UNPAVED	-.06	.11	.07	.01	-.02	-.02			
JOBFT	-.02	-.02	-.03	.00	-.01				
JOBPT	-.11	-.06	-.06	-.01	-.01				
SMKHOME	-.05	-.01	-.03	-.06					
SMKCAR	.04	-.02	-.02	-.01					
SMKAMT	.02	.02	.03	.02					
SMKEXP2	-.10	-.18	-.18	-.08					
IH	.20	.17	.26						
OH	.18	.04	.05						
IW	.22	.15	.22						
OW	.27	.18	.17						
IA	.30	.32	.35						
OA	.09	-.06	-.06						
T	.23	.18	.17						
OCON3	.11	.20							
ICON3	.69								
R	.81	.58	.56	.46	.45	.45	.44	.35	.34

Limonene

Figure 73: Results of Model of Personal Exposure to Limonene

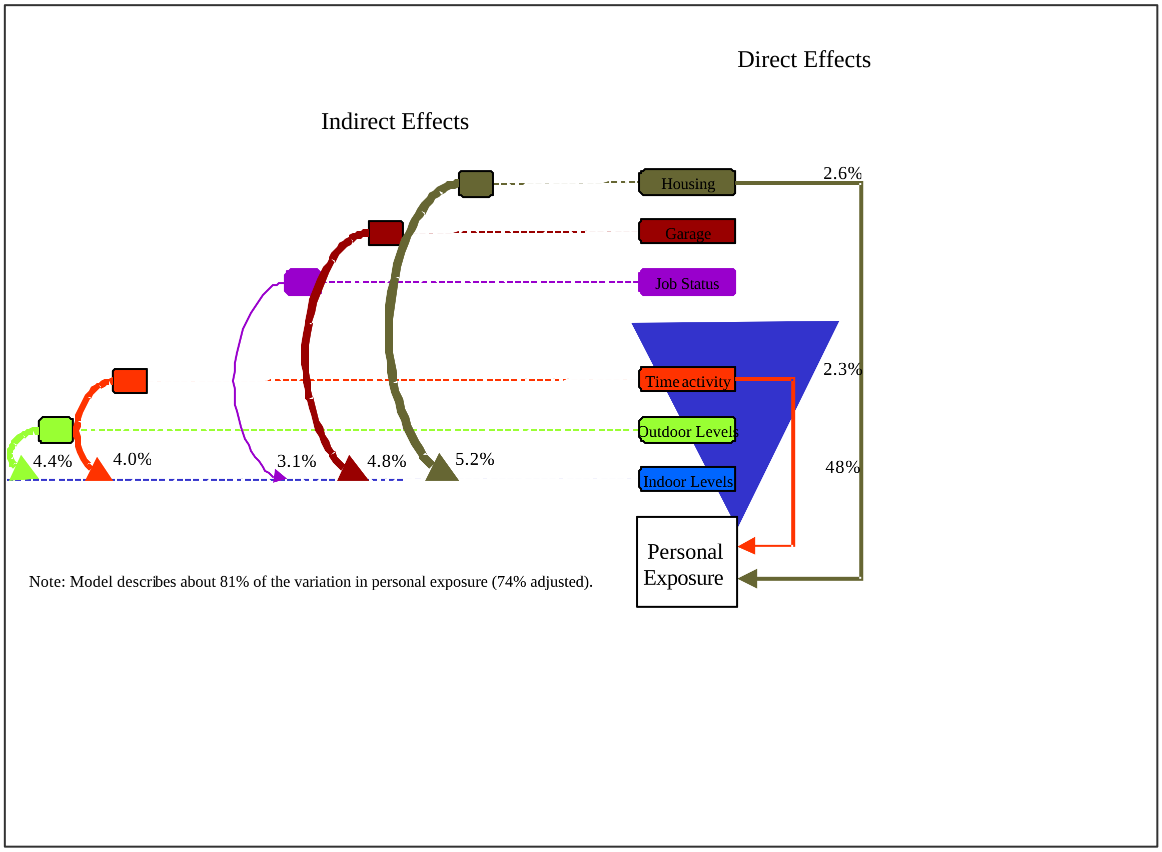


Table 31: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.08	0.08	0.06
Rural-Urban	0.07	0.08	0.07
Housing Characteristics	0.29	0.29	0.16
Garage	0.21	0.24	0.07
Job Status	0.22	0.25	0.12
Smoking Characteristics	0.17	0.10	0.14
Time Activity	0.25	0.25	0.15
Outdoor Concentration	0.13	0.21	0.00
Indoor Concentration	0.84	0.69	0.69

Table 32: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	-.07	.01	.01	-.02	-.04	-.10	-.08	-.09	-.08
FT SASK RURAL	-.04	-.03	-.02	-.08	-.06	-.06	-.04	-.01	
BRUDERHEIM	-.07	-.15	-.14	-.14	-.14	-.10	-.08	-.07	
REDWATER	.04	.05	.03	.05	.07	.05	.00	-.05	
TRAILOR	.07	.06	.05	.00	-.01	-.02	-.07		
MULT2	.00	.01	.01	.02	.03	-.01	-.05		
NEW	.15	.13	.11	.12	.14	.18	.14		
MED	.00	-.05	-.04	.00	.02	.06	.03		
NFCDAIR	.02	.34	.31	.29	.29	.26	.24		
CARET	-.14	.10	.07	.07	.09	.09	.06		
ATTG	.13	.39	.42	.39	.39	.32			
DETG	.14	.52	.52	.47	.49	.44			
UNPAVED	-.01	.03	.03	.05	.03	.02			
JOBFT	.13	-.01	.04	.11	.11				
JOBPT	.17	.28	.28	.30	.30				
SMKHOME	-.08	-.01	.02	-.02					
SMKCAR	.15	-.03	-.03	-.01					
SMKAMT	.05	.14	.12	.09					
SMKEXP2	-.02	-.03	-.04	-.09					
IH	.20	.90	.81						
OH	.09	.32	.25						
IW	.10	.78	.68						
OW	.15	.28	.24						
IA	.01	.19	.16						
OA	.15	.28	.26						
T	.11	.26	.25						
OCON3	-.01	.22							
ICON3	.85								
R	.90	.57	.53	.47	.46	.39	.31	.11	.08

Hexane

Figure 74: Results of Model of Personal Exposure to Hexane

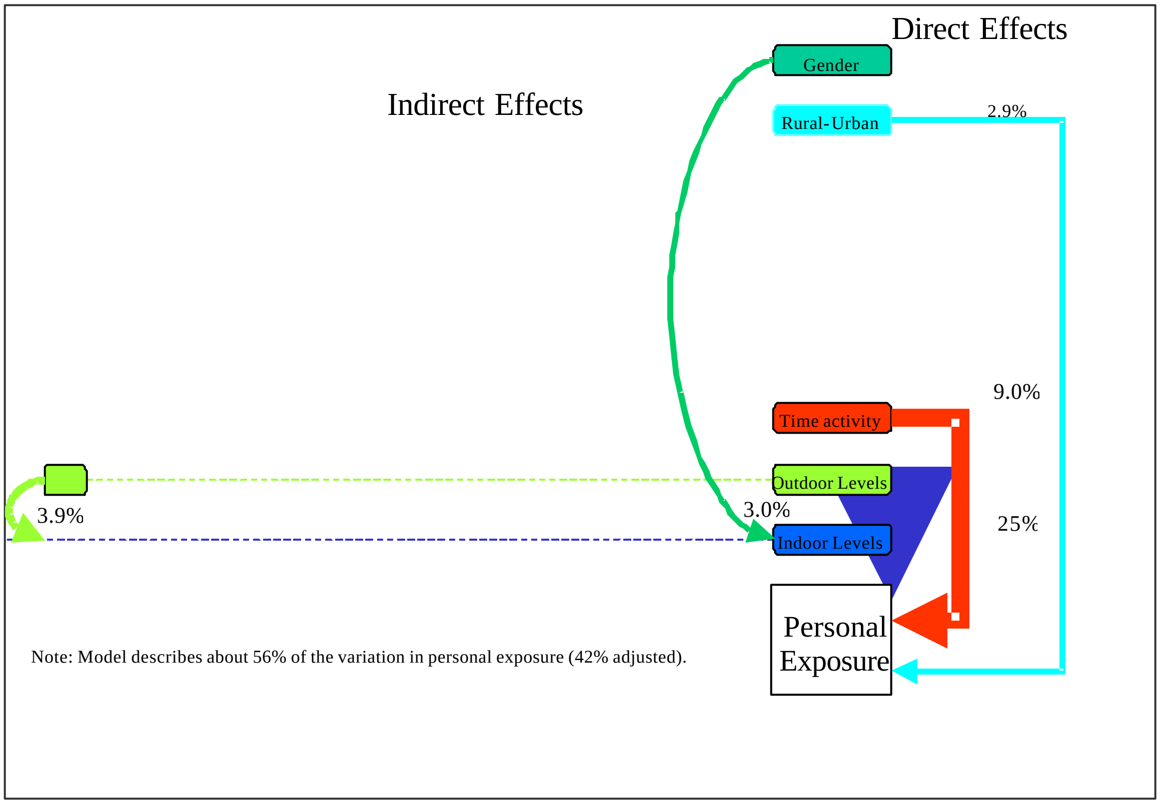


Table 33: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.27	0.27	0.10
Rural-Urban	0.17	0.17	0.17
Housing Characteristics	0.16	0.15	0.10
Garage	0.15	0.19	0.10
Job Status	0.03	0.09	0.04
Smoking Characteristics	0.18	0.13	0.08
Time Activity	0.34	0.30	0.30
Outdoor Concentration	0.19	0.20	0.03
Indoor Concentration	0.57	0.50	0.50

Table 34: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.13	.21	.26	.30	.31	.28	.28	.27	.27
FT SASK RURAL	.15	.13	.12	.14	.12	.13	.06	.02	
BRUDERHEIM	.20	.14	.16	.19	.19	.21	.17	.15	
REDWATER	.04	.07	.02	.00	-.04	-.04	-.04	-.06	
TRAILOR	-.03	-.17	-.15	-.09	-.07	-.09	-.07		
MULT2	-.03	-.13	-.14	-.10	-.11	-.10	-.07		
NEW	.01	.06	.00	-.04	-.02	-.03	.03		
MED	-.01	-.02	-.06	-.06	-.08	-.08	-.05		
NFCDAIR	-.10	-.06	-.07	-.06	-.05	-.05	-.04		
CARET	-.04	.03	.02	.02	.04	.03	.08		
ATTG	-.17	-.10	-.09	-.11	-.12	-.14			
DETG	-.14	-.28	-.28	-.28	-.27	-.30			
UNPAVED	-.09	.02	-.02	-.10	-.10	-.11			
JOBFT	-.06	-.09	-.09	-.06	-.08				
JOBPT	-.04	.00	.02	.05	.04				
SMKHOME	-.10	-.09	-.10	-.14					
SMKCAR	.05	.07	.06	.08					
SMKAMT	-.02	-.07	-.05	-.06					
SMKEXP2	.03	.01	-.01	.06					
IH	.23	.29	.30						
OH	.11	.00	-.04						
IW	.21	.26	.24						
OW	.23	.25	.22						
IA	.32	.37	.34						
OA	.16	.11	.07						
T	.19	.08	.04						
OCON3	.03	.23							
ICON3	.64								
R	.75	.56	.53	.43	.41	.40	.36	.32	.27

3-Methylhexane

Figure 75: Results of Model of Personal Exposure to Methylhexane

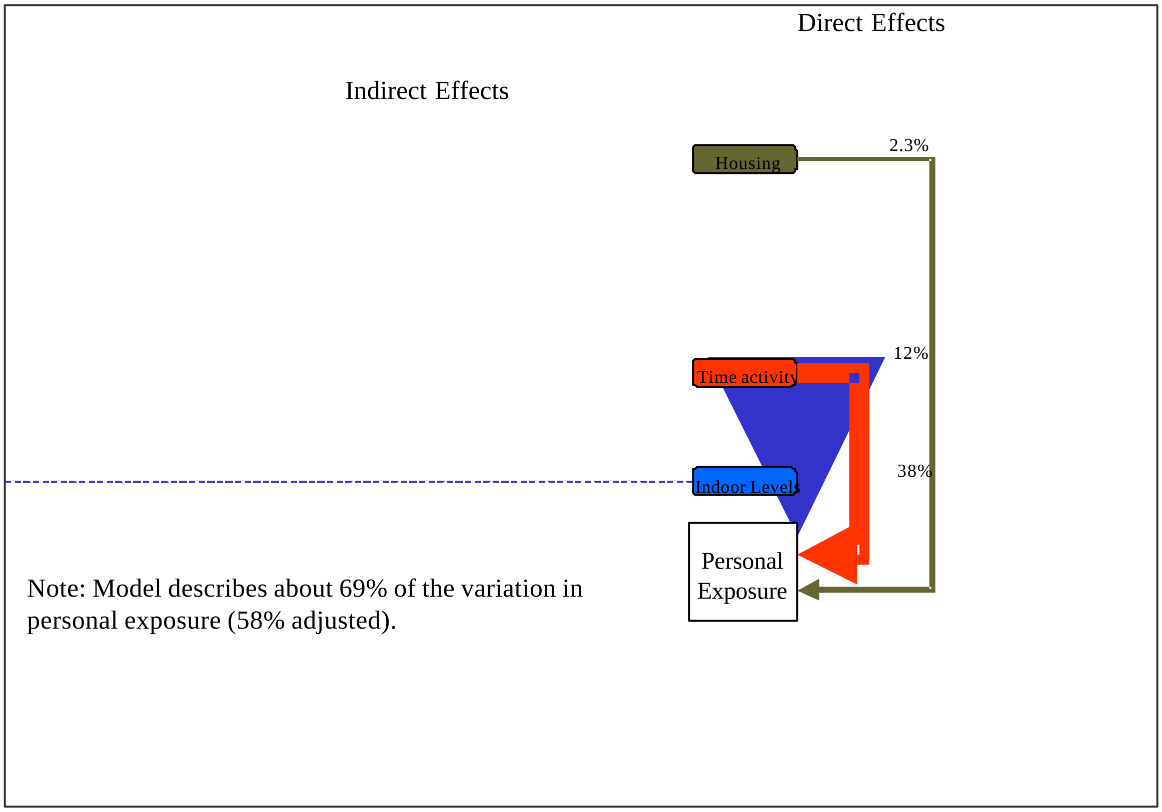


Table 35: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.18	0.18	0.02
Rural-Urban	0.11	0.11	0.13
Housing Characteristics	0.22	0.25	0.15
Garage	0.11	0.12	0.10
Job Status	0.04	0.07	0.06
Smoking Characteristics	0.25	0.20	0.11
Time Activity	0.40	0.36	0.34
Outdoor Concentration	0.04	0.03	0.03
Indoor Concentration	0.63	0.62	0.62

Table 36: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.03	.15	.15	.21	.22	.20	.19	.18	.18
FT SASK RURAL	.02	-.14	-.15	-.09	-.10	-.09	-.04	-.04	
BRUDERHEIM	.16	-.02	-.02	.05	.05	.06	.08	.08	
REDWATER	.05	-.10	-.10	-.11	-.17	-.17	-.10	-.04	
TRAILOR	.12	.12	.12	.20	.23	.22	.24		
MULT2	-.03	-.06	-.06	-.02	-.04	-.03	-.02		
NEW	-.03	.06	.05	.01	.03	.03	.07		
MED	-.05	-.04	-.05	-.05	-.07	-.07	-.06		
NFCDAIR	-.09	-.07	-.07	-.06	-.04	-.04	-.03		
CARET	-.08	-.09	-.08	-.05	-.03	-.03	-.02		
ATTG	-.19	-.03	-.02	-.05	-.07	-.09			
DETG	-.20	-.19	-.18	-.18	-.16	-.18			
UNPAVED	-.01	.19	.19	.11	.10	.09			
JOBFT	-.05	-.02	-.03	-.01	-.04				
JOBPT	-.08	.01	.02	.07	.05				
SMKHOME	-.13	-.20	-.20	-.23					
SMKCAR	.03	.10	.10	.11					
SMKAMT	-.03	-.06	-.06	-.08					
SMKEXP2	-.02	-.07	-.08	.03					
IH	.03	.26	.26						
OH	.05	.01	.00						
IW	.08	.20	.19						
OW	.20	.23	.23						
IA	.26	.40	.39						
OA	.03	-.05	-.05						
T	.18	.09	.08						
OCON3	-.04	.04							
ICON3	.73								
R	.82	.54	.54	.40	.35	.34	.32	.21	.18

Heptane

Figure 76: Results of Model of Personal Exposure to Heptane

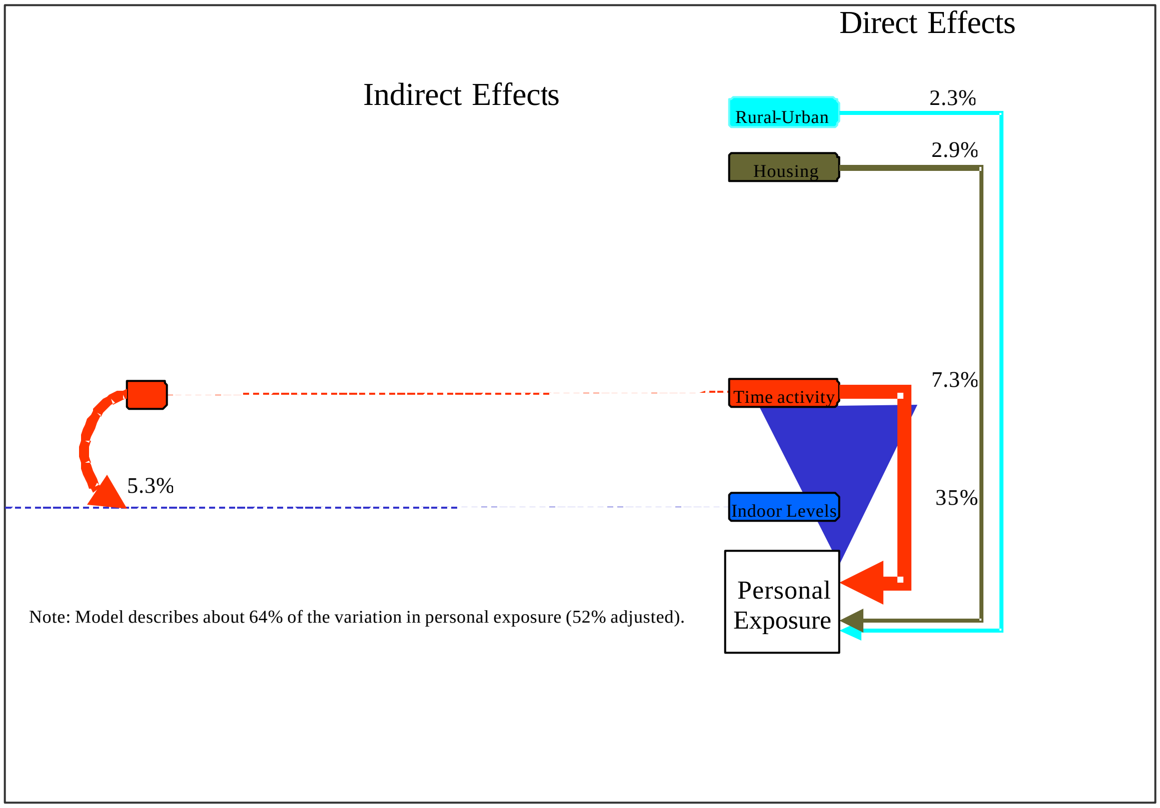


Table 37: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.15	0.15	0.03
Rural-Urban	0.15	0.15	0.15
Housing Characteristics	0.22	0.24	0.17
Garage	0.11	0.13	0.07
Job Status	0.03	0.08	0.03
Smoking Characteristics	0.18	0.13	0.11
Time Activity	0.40	0.36	0.27
Outdoor Concentration	0.16	0.11	0.04
Indoor Concentration	0.65	0.59	0.59

Table 38: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.04	.14	.17	.20	.20	.17	.16	.15	.15
FT SASK RURAL	.06	-.09	-.09	-.06	-.06	-.05	-.04	-.05	
BRUDERHEIM	.18	.06	.06	.12	.12	.13	.13	.13	
REDWATER	.08	-.06	-.07	-.11	-.14	-.14	-.09	-.04	
TRAILOR	.15	.12	.11	.21	.23	.21	.24		
MULT2	-.02	-.10	-.10	-.05	-.06	-.06	-.03		
NEW	.05	.12	.08	.04	.06	.05	.06		
MED	-.01	.00	-.02	-.02	-.03	-.04	-.03		
NFCDAIR	-.11	-.06	-.04	-.03	-.02	-.03	-.02		
CARET	-.05	-.08	-.06	-.02	.00	-.01	.00		
ATTG	-.12	-.15	-.14	-.16	-.17	-.19			
DETG	-.13	-.22	-.21	-.21	-.20	-.23			
UNPAVED	.00	.17	.16	.06	.04	.03			
JOBFT	.00	-.03	-.04	-.05	-.07				
JOBPT	-.03	.00	.02	.05	.04				
SMKHOME	-.13	-.13	-.13	-.14					
SMKCAR	.02	.06	.05	.07					
SMKAMT	.01	-.03	-.03	-.05					
SMKEXP2	-.04	-.10	-.10	.00					
IH	-.07	.25	.26						
OH	-.03	-.05	-.07						
IW	-.03	.17	.18						
OW	.07	.14	.13						
IA	.22	.41	.42						
OA	.02	.01	.01						
T	.09	.05	.04						
OCON3	.05	.13							
ICON3	.68								
R	.80	.53	.52	.38	.35	.34	.32	.21	.15

Octane

Figure 77: Results of Model of Personal Exposure to Octane

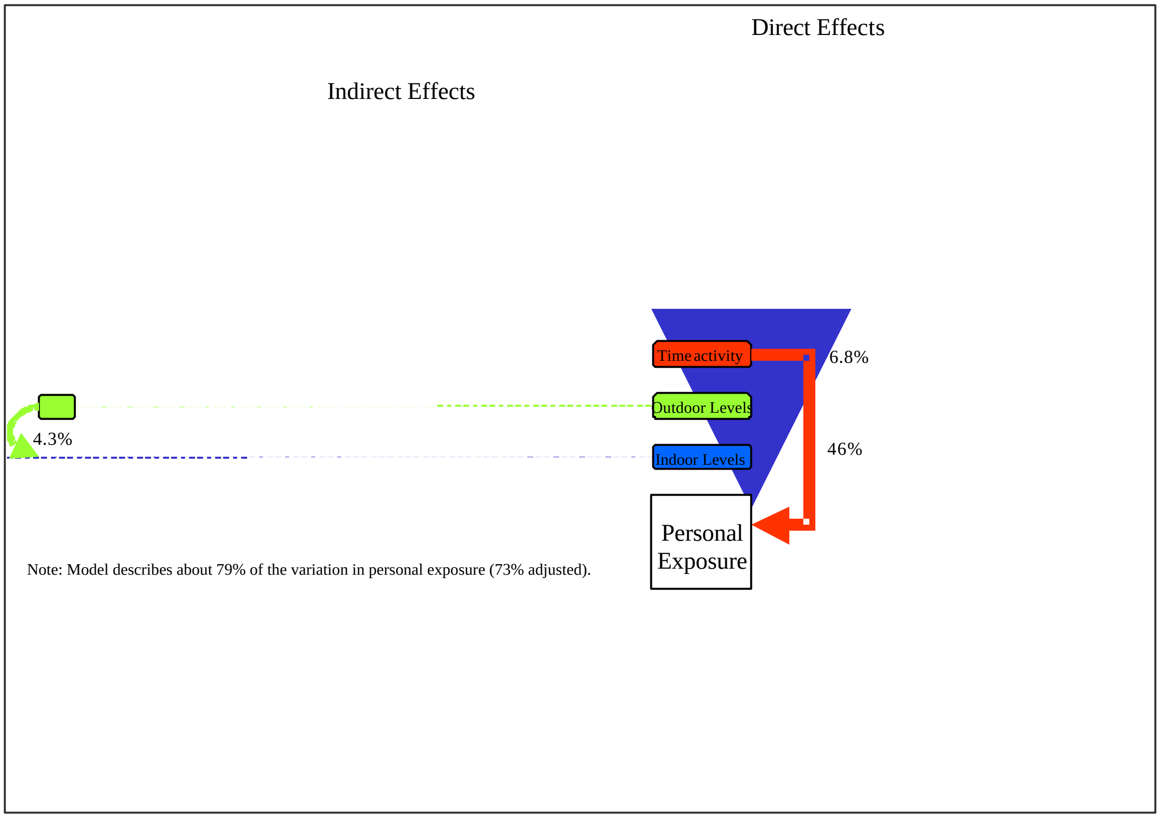


Table 39: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.20	0.20	0.05
Rural-Urban	0.11	0.10	0.05
Housing Characteristics	0.18	0.18	0.10
Garage	0.10	0.19	0.13
Job Status	0.13	0.07	0.06
Smoking Characteristics	0.08	0.07	0.07
Time Activity	0.38	0.40	0.26
Outdoor Concentration	0.29	0.21	0.04
Indoor Concentration	0.82	0.68	0.68

Table 40: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	-.06	.12	.19	.22	.21	.23	.21	.19	.20
FT SASK RURAL	.06	-.03	-.04	.00	.01	.01	.02	.02	
BRUDERHEIM	.06	.00	-.02	.06	.06	.05	.05	.06	
REDWATER	.04	-.06	-.07	-.11	-.11	-.11	-.07	-.07	
TRAILOR	-.10	-.11	-.11	.00	.00	.00	.04		
MULT2	.00	-.12	-.13	-.07	-.08	-.07	-.04		
NEW	.04	.17	.12	.06	.06	.05	-.04		
MED	-.02	.02	-.01	-.01	-.02	-.02	-.03		
NFCDAIR	.01	.15	.14	.16	.15	.16	.15		
CARET	.01	.06	.08	.16	.15	.15	.13		
ATTG	-.24	-.37	-.34	-.34	-.35	-.32			
DETG	-.15	-.20	-.20	-.18	-.19	-.18			
UNPAVED	.05	.12	.14	.04	.04	.04			
JOBFT	-.01	.10	.10	.00	.01				
JOBPT	-.07	-.09	-.08	-.07	-.07				
SMKHOME	-.09	.01	.01	.05					
SMKCAR	.04	.01	.01	.00					
SMKAMT	.00	-.05	-.04	-.06					
SMKEXP2	-.01	-.13	-.16	-.04					
IH	.40	.39	.32						
OH	.27	.11	.04						
IW	.35	.24	.14						
OW	.27	.11	.07						
IA	.39	.54	.53						
OA	.16	-.02	-.05						
T	.18	.04	.01						
OCON3	.05	.23							
ICON3	.84								
R	.89	.58	.54	.36	.35	.34	.29	.22	.20

Nonane

Figure 78: Results of Model of Personal Exposure to Nonane

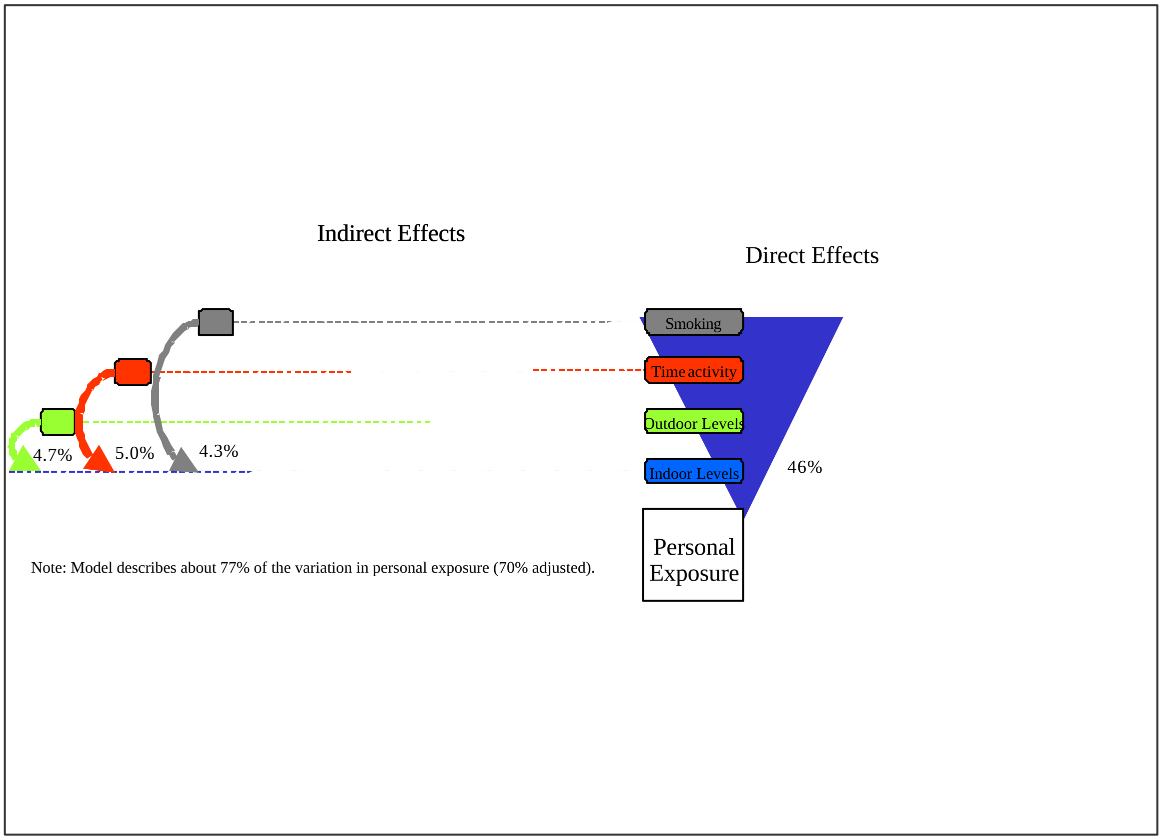


Table 41: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.15	0.15	0.02
Rural-Urban	0.19	0.18	0.04
Housing Characteristics	0.15	0.12	0.05
Garage	0.11	0.19	0.09
Job Status	0.14	0.11	0.03
Smoking Characteristics	0.18	0.24	0.10
Time Activity	0.25	0.27	0.11
Outdoor Concentration	0.30	0.23	0.08
Indoor Concentration	0.85	0.68	0.68

Table 42: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	-.03	.13	.17	.16	.11	.16	.13	.13	.15
FT SASK RURAL	.04	-.06	-.10	-.04	.01	.00	-.01	.00	
BRUDERHEIM	.04	.06	.03	.06	.06	.04	.03	.03	
REDWATER	-.01	-.20	-.24	-.26	-.21	-.21	-.17	-.17	
TRAILOR	-.03	-.08	-.09	-.02	-.04	-.03	.01		
MULT2	-.03	-.12	-.12	-.09	-.09	-.09	-.04		
NEW	-.01	.12	.08	.07	.05	.05	-.01		
MED	-.03	.02	.02	.03	.03	.03	.03		
NFCDAIR	.02	.14	.14	.13	.09	.10	.10		
CARET	.01	.03	.05	.09	.07	.08	.07		
ATTG	-.16	-.34	-.36	-.40	-.40	-.37			
DETG	-.12	-.25	-.26	-.27	-.32	-.28			
UNPAVED	-.09	.05	.08	.03	.00	.01			
JOBFT	-.01	-.09	-.07	.01	.04				
JOBPT	-.04	-.20	-.19	-.12	-.11				
SMKHOME	.02	.19	.20	.24					
SMKCAR	.07	-.13	-.14	-.12					
SMKAMT	-.01	-.01	-.01	-.05					
SMKEXP2	-.11	-.23	-.24	-.19					
IH	.07	-.01	-.02						
OH	.08	-.05	-.08						
IW	.10	.09	.07						
OW	.04	-.02	-.05						
IA	.11	.17	.17						
OA	-.04	-.19	-.20						
T	.07	-.02	-.04						
OCON3	.09	.24							
ICON3	.81								
R	.88	.55	.50	.42	.35	.33	.26	.23	.15

Decane

Figure 79: Results of Model of Personal Exposure to Decane

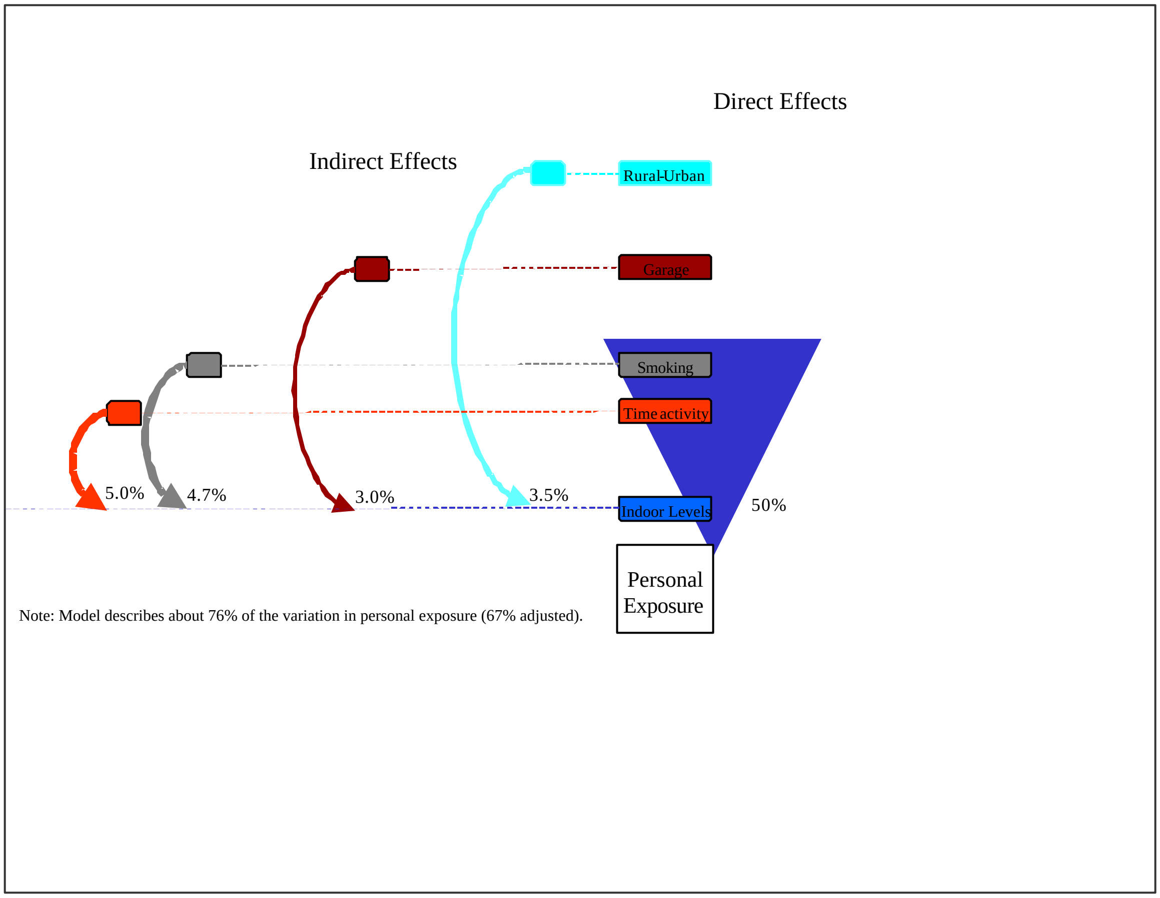


Table 43: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.09	0.09	0.02
Rural-Urban	0.21	0.21	0.08
Housing Characteristics	0.17	0.15	0.06
Garage	0.12	0.21	0.08
Job Status	0.08	0.05	0.04
Smoking Characteristics	0.19	0.25	0.11
Time Activity	0.23	0.24	0.09
Outdoor Concentration	0.14	0.07	0.02
Indoor Concentration	0.84	0.71	0.71

Table 44: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	.03	.13	.14	.12	.07	.08	.06	.07	.09
FT SASK RURAL	.07	-.11	-.12	-.07	-.01	-.02	-.01	.00	
BRUDERHEIM	-.01	-.03	-.04	-.02	.00	-.01	-.02	-.01	
REDWATER	-.06	-.32	-.33	-.32	-.27	-.27	-.21	-.21	
TRAILOR	.00	-.03	-.03	.00	-.02	-.02	.03		
MULT2	-.05	-.17	-.17	-.14	-.14	-.14	-.09		
NEW	.03	.09	.09	.09	.09	.09	.02		
MED	.00	.02	.02	.04	.04	.04	.04		
NFCDAIR	.01	.13	.13	.13	.09	.10	.10		
CARET	.02	.03	.02	.06	.04	.05	.04		
ATTG	-.15	-.36	-.36	-.40	-.41	-.40			
DETG	-.11	-.30	-.30	-.30	-.34	-.32			
UNPAVED	-.02	.09	.09	.08	.04	.04			
JOBFT	.04	-.06	-.06	-.01	.02				
JOBPT	.05	-.11	-.10	-.05	-.04				
SMKHOME	.01	.18	.18	.22					
SMKCAR	.09	-.07	-.08	-.07					
SMKAMT	-.04	-.03	-.02	-.04					
SMKEXP2	-.11	-.25	-.26	-.22					
IH	.04	-.08	-.08						
OH	.01	-.07	-.07						
IW	.01	-.05	-.04						
OW	-.02	-.06	-.06						
IA	.06	.04	.03						
OA	-.07	-.26	-.26						
T	.00	-.05	-.05						
OCON3	.02	.07							
ICON3	.80								
R	.87	.49	.49	.43	.35	.34	.27	.22	.09

8.8 Summary of Exposure Relationships for Passive Samplers

The previous sections have presented a large amount of information about a number of chemicals each analyzed separately. Within each analysis, careful examination of the tables can allow a sophisticated picture of causal influences to be postulated. However, little has yet been said about the manner in which the causal influences are similar across chemicals. In the following section, a higher order analysis is presented which can allow preliminary statements about the full domain of chemicals collected by passive samplers.

The starting point of this analysis is the regression coefficients for each of the independent variables included in the modeling process for each chemical. (These were presented in the column for the last step of the set of tables entitled, "Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations" for each analysis of personal exposure). Basically, these numbers were brought together into a single table (with a separate column for each chemical and separate row for each set of influences) for the current analysis.

Next, a principal component decomposition of this table was performed, and the largest two dimensions of this analysis were used for a single biplot representation displayed in Figure 80. With proper interpretation, this diagram summarizes the information present in the original table (to a substantial degree, though more dimensions would be required to allow complete reconstruction). The advantage of this analysis is that it can represent the relative importance of the causal influences across chemicals, and the relative similarity of chemicals with respect to their causal influence structure within a single graphic representation.

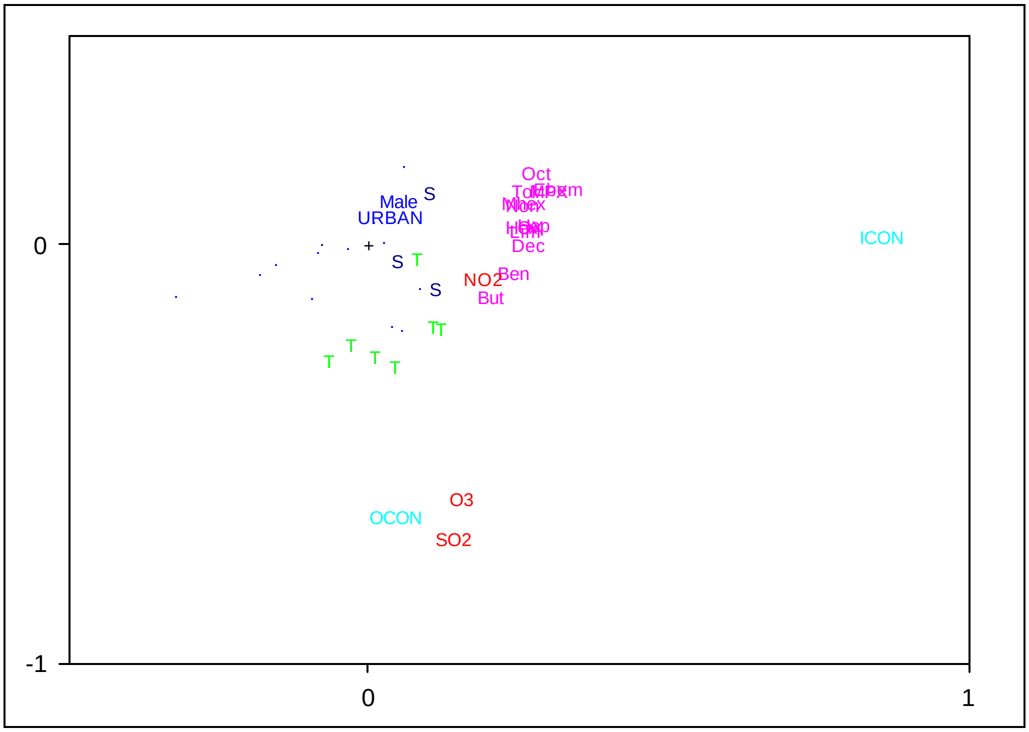
The interpretation of this diagram is as follows: each causal influence and each chemical has a co-ordinate in the two dimensional space. In absolute terms, the average size of the semi-partial multiple correlation coefficient across all chemicals considered together can be determined by the relative location of the points representing the causal influences on the first dimension. That is, the orderings of the coefficients on the first dimension gives the average ordering of the coefficient across all chemicals. In the current case, it can be seen that the influence of indoor concentrations is the single largest influence on the personal concentrations across this set of chemicals (because it has the highest positive value on the first dimension; it is located to the extreme right).

The inclusion of the second dimension on each of the diagrams allows chemicals to be separated based upon differences in the pattern and magnitude of the set of influences. To determine the nature of these differences, follow this basic procedure for each chemical point: mentally draw a line from its co-ordinate through the '+' located on the graph at the 0,0 point (the origin). Consider this line as a new dimension. Values of the causal influences are ordered on this dimension in terms of their order of magnitude in predicting the concentration of that chemical. (Mentally, the operation to determine the values of the influences on this new dimension requires that you draw a perpendicular line from the point to the new point to the axis dimension (technically, "orthogonally project"). This operation is entirely analogous to determining the value of a point on a labeled dimension, as was necessary to determine the magnitudes (described above). Notice that the actual pattern and ordering of the influences will differ for chemicals located in different quadrants of the space.

The analogous procedure can be performed for each set of influences to derive an ordering of chemicals for which this set of influences is relatively more or less important.

Finally, a global mode of interpretation is possible by combining all of this information as follows: chemicals in the same radial sector have similar patterns of influence, those farther from the origin (the '+' point) are more predictable than those nearer the origin. For personal concentration levels, this pattern is shown by SO_2 and O_3. Chemicals that are close together on the plot have similar patterns of influence and similar levels of predictability. For personal concentrations, this condition is clearly met for the VOCs.

Figure 80: Biplot Representation of Semi-Partial R for Determinant Sets of Chemicals (Personal Concentrations)



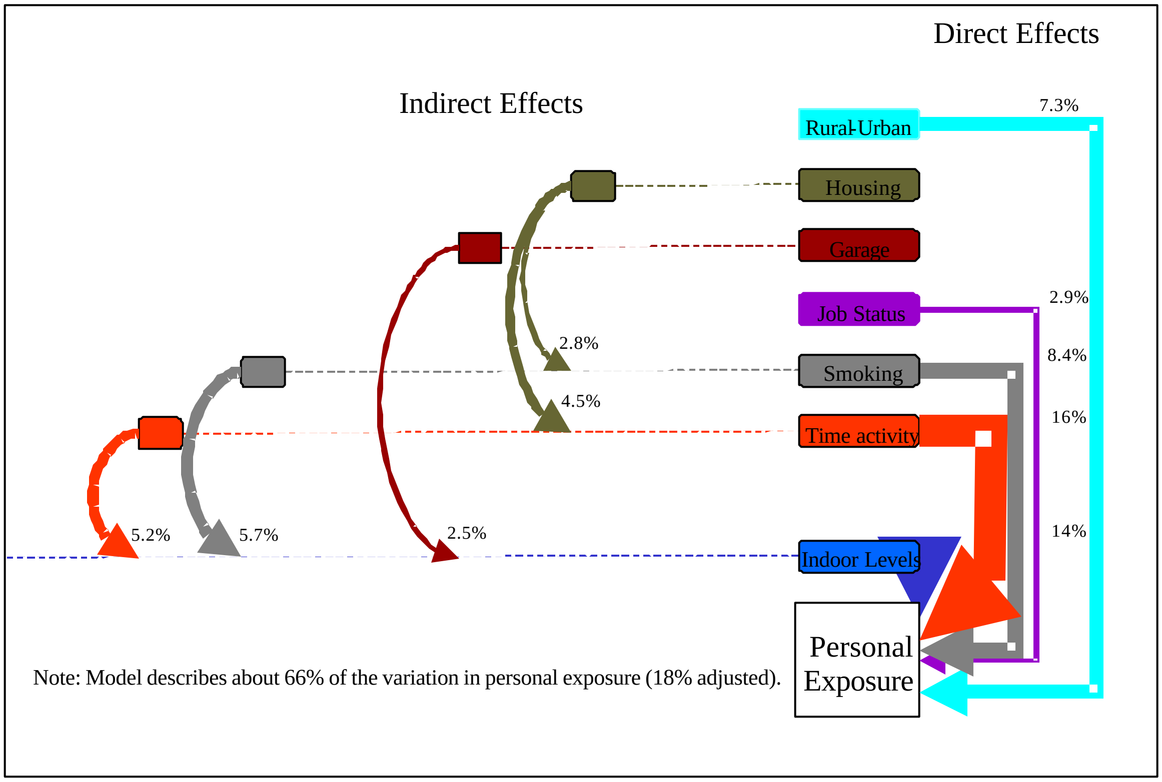
The overall impression that is left by this global mode of interpretation is as follows:

- For all chemicals, indoor levels are an important causal feature
- Outdoor concentrations are relatively more important for SO_2 and O_3 than for NO_2 and the VOCs.
- Time-activity patterns and smoking behavior are relatively more important for SO_2, O_3, and NO_2 than for (most of) the VOCs.

8.9 Particulate Analysis: $PM_{2.5}$

The results of the analysis of relationships between personal exposures and the factors that may affect exposure are presented pictorially in Figure 81. The model examined the relationship between the combined variability of all factors and the variation in personal exposure. The model accounted for about two-thirds of the variation in personal exposure. However, because the sample size is very small for this analysis, there is greater uncertainty associated with these estimates (adjusted variation is only 18%). The unexplained variation in personal exposure is likely due to sampler error and other factors that were not included in the model.

Figure 81: Results of Model of Personal Exposure to $PM_{2.5}$ Showing Direct and Indirect Effects of Factors



Important factors influencing variations in $PM_{2.5}$ exposures were as follows:

- ***Time activity,*** directly (16.0%)
- ***Indoor levels,*** directly (14.0%)
- ***Smoking characteristics,*** directly (8.4%)
- ***Rural-Urban,*** directly (7.3%)
- ***Smoking characteristics,*** operating indirectly through effects on indoor air (5.7%)
- ***Time activity,*** operating indirectly through effects on indoor air (5.2%)
- ***Housing characteristics,*** operating indirectly through effects on time activity (4.5%)
- ***Job Status,*** directly (2.9%)
- ***Housing characteristics,*** operating indirectly through effects on smoking (2.8%)
- ***Garage characteristics,*** operating indirectly through effects on indoor air (2.5%)

Variability in time activity, indoor levels, smoking, and rural-urban were the dominant factors explaining variation in personal exposure to $PM_{2.5}$ accounting for over two thirds of the variation explained by the model. Time activity had an important impact on personal exposures both directly (16%) and as a pathway through which for other factors act (about 15%). Variation in the time spent outdoors at work was the most important component of the time activity effect. In addition to smoking being an important factor alone (8.4), there was an important indirect effect on indoor air (5.7). Variations in outdoor concentrations were not important factors affecting variations in personal exposure to $PM_{2.5}$.

The two tables on which Figure 81 is based follow below (Table 45 and Table 46).

Table 45: Comparative Multiple Regression Coefficients for Variable Sets

Source	Total Effects	Model-Derived Total Effects	Direct Effects: Semi-Partial R
Gender	0.11	0.11	0.07
Rural-Urban	0.39	0.40	0.16
Housing Characteristics	0.33	0.22	0.13
Garage	0.35	0.11	0.06
Job Status	0.33	0.29	0.11
Smoking Characteristics	0.36	0.27	0.23
Time Activity	0.62	0.55	0.39
Outdoor Concentration	0.22	0.02	0.01
Indoor Concentration	0.74	0.35	0.35

Table 46: Beta Weights for Hierarchical Set Regression of Personal Exposure Concentrations

Source	Step 9	8	7	6	5	4	3	2	1
GENDER	-.09	-.16	-.16	.02	.05	.09	.10	.14	.11
FT SASK RURAL	.17	.21	.21	.06	.03	.04	.07	.15	
BRUDERHEIM	-.06	-.03	-.03	-.04	.01	.03	.06	.11	
REDWATER	.20	.53	.54	.38	.34	.36	.38	.41	
TRAILOR	-	-	-	-	-	-	-		
MULT2	-.07	-.06	-.06	-.10	-.10	.02	.03		
NEW	.00	-.19	-.18	.30	.27	-.01	.05		
MED	.04	-.11	-.10	.36	.27	.05	.19		
OLD	.00	-.24	-.23	.33	.25	.10	.27		
NFCDAIR	-.11	-.07	-.07	-.02	.17	.14	.11		
CARET	.08	.07	.07	-.05	-.04	-.01	-.03		
ATTG	.00	-.08	-.08	-.17	-.16	-.09			
DETG	.10	.05	.06	-.03	.05	.06			
UNPAVED	.00	-.06	-.07	.10	.07	.06			
JOBFT	-.23	-.22	-.23	-.33	-.37				
JOBPT	-.15	-.15	-.15	-.24	-.23				
SMKHOME	-.11	-.15	-.15	-.24					
SMKCAR	.26	.55	.55	.44					
SMKAMT	-.31	-.20	-.20	-.15					
SMKEXP2	-.06	-.20	-.20	.06					
IH	.03	.30	.31						
OH	.20	.40	.41						
IW	.07	.36	.37						
OW	.38	.56	.57						
IA	.24	.52	.53						
OA	-.05	.21	.21						
T	.10	.28	.28						
OCON3	-.01	.02							
ICON3	.57								
R	.91	.84	.84	.63	.57	.49	.47	.42	.11

9.0 Biomarkers of Exposure

Blood and urine samples were obtained during the assessment period for each participant.

The analysis of the blood samples included measures of nicotine, while the analysis of the urine samples included measures of BTEX compounds. The following table summarizes information from the blood and urine data analysis.

As shown by Table 47, only nicotine, muconic acid, and hippuric acid were above detection limits in some samples, but analysis did not reveal any relationship between personal exposure to benzene, toluene, or nicotine as measured by the passive monitors and their respective biomarker levels.

Table 47: Analysis of Metabolites

Biomarkers Measured in Blood	Number of Samples Analyzed	Number of Samples Above Detection Limit and Range	Detection Limit
Nicotine	131	8 (12.06 – 52.48 ng/mL)	5 ng/mL
Biomarkers Measured in Urine			
Muconic acid (metabolite of benzene)	130	28 (0.07 – 0.38 μg/mL)	0.05 μg/mL
Hippuric acid (metabolite of toluene)	130	129 (37.15 – 2145.80 μg/mL)	25 μg/mL
Mandelic acid (metabolite of ethylbenzene)	130	0	25 μg/mL
2-Methylhippuric acid (metabolite of o-xylene)	130	0	25 μg/mL
3-, 4- Methylhippuric acid (metabolite of m-xylene)	130	0	25 μg/mL

10.0 Biomarkers of Effect

The biomarkers of effect included in the Fort Saskatchewan and Area Community Exposure and Health Effects Assessment Program consisted of a neurocognitive assessment and a respiratory health assessment.

10.1 Autoantibodies

Autoantibodies are produced by the immune system and unlike most antibodies that are intended to protect the body, these are directed against normal components of the body. Autoantibodies are used to aid in the diagnosis and management of many disease states such as systemic lupus erythematosus, rheumatoid arthritis, vascultitis, primary biliary cirrhosis, and scleroderma. They do occur in the absence of disease, but this is usually at low concentrations or titers.[32] Environmental agents and xenobiotics are also known to induce autoimmune effects that include autoantibodies; examples include mercury, cadmium, iodine, and vinyl chloride.[33,34] In some of these cases, specific autoantibodies are a result of these exposures. For example, certain genetic strains of mice exposed to mercury or silver uniformly produce autoantibodies to an intracellular nucleolar component known as fibrillarin.

Autoantibody testing of a population sample allows the investigators to look for relationships between exposures and this immune response. Positive values must always be interpreted in view of clinical findings. Participants' blood serum samples were analyzed for a broad spectrum of autoantibodies.

A total of 128 samples were analyzed. The percentage of samples with significantly positive antinuclear autoantibodies (ANA) was 16% (20/128). This prevalence is comparable to the findings of Tan et al., who found that 13% of healthy individuals have antinuclear antibodies.[1] It is also similar to a study of other populations in Alberta (16-17% in The Alberta Oil Sands Community Exposure and Health Effects Assessment Program).[35] Sixty-eight samples underwent further testing with the results summarized in Table 48.

Table 48: Autoantibody Specificities

Autoantigen	Number
U1-RNP	1
SS-A/SS-B	1
SS-A only	2
dsDNA	1
CENP	1
Chromatin (ELISA)	19
Chromatin (confirmed On Luminex)	13 (13/19)

Antibodies to the above antigens are seen in conditions such as systemic lupus erythematosus, mixed connective tissue disease, drug or xenobiotic-induced lupus and Sjögren's syndrome. Presence of the autoantibody **does not** mean that disease is present, and therefore significance is hard to determine in population studies. These findings would need to be interpreted in combination with clinical data.

In summary, there is no increase in the prevalence of autoantibodies in this study group. Although some of the samples had specific autoantibodies, the significance of this finding is not known at this time.

10.2 Lung Function

The lung function component of the assessment included spirometry measures that were collected just prior to the beginning of the exposure-monitoring period as well as an interviewer-administered respiratory health survey.

Spirometry Test Results

The project co-ordinator attempted to obtain five completed spirometric sessions during the initial interview at the study office. When spirometry is performed, the results are compared with a set of normal or predicted values based upon a participant's age, height, and gender.[36] Reference values are calculated using prediction equations derived from previous epidemiologic studies involving healthy, non-smoking adult populations without a history of disease that could compromise their ventilatory function. Reference values come from studies that are conducted using both equipment and methods compatible with present standards.[37]

Two diagnostically important spirometric test measurements are forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1). Specifically, FVC refers to the maximal amount of air that can be forcefully exhaled after a full inhalation. FEV_1 is the volume of air exhaled during the first second of the FVC maneuver. The normal range for both FVC and FEV_1 is 80-120% of predicted values.

The average baseline FVC and FEV_1 values were determined by applying the prediction equations of Crapo et al. (1982).[38] Table 49 provides a summary of the findings.

Table 49: Summary of Spirometry Data

Lung Function Measurement	Percent of Predicted Value (%)	Standard Deviation
FVC	102.43	14.00
FEV_1	95.49	14.45

Note: These average values reflect normal lung function.

Respiratory Health Survey

Participants also completed the standardized, interviewer-administered European Community Respiratory Health Survey Questionnaire.[39] This questionnaire collected information on respiratory symptoms, smoking status, and past history of respiratory conditions and related medication use.

The percent of respondents in each community who responded "Yes" or "No" to specific questions were compared. Results for the 134 Fort Saskatchewan participants, 149 Fort McMurray participants, and 33 Lethbridge participants who completed the survey are summarized in Table 50.

Table 50: Differences in the Prevalence of Reported Respiratory Symptoms between Fort Saskatchewan, Fort McMurray and Lethbridge

Respiratory Symptom	Fort Saskatchewan n (%)	Fort McMurray n (%)	Lethbridge n (%)
Wheeze within the last 12 months	34 (25.4)	43 (28.9)	16 (48.5)
Wheeze in the absence of a cold	20 (14.9)	27 (18.2)	10 (30.3)
Waking with chest tightness in the last 12 months	17 (12.7)	27 (18.1)	8 (24.2)
Shortness of breath			
while at rest	12 (9.0)	21 (14.1)	6 (18.2)
while hurrying on level ground or walking up a slight hill	26 (19.4)	21 (14.1)	3 (11.5)
Woken by shortness of breath	11 (8.2)	10 (6.7)	5 (15.2)
Cough in the morning during winter	17 (12.7)	19 (12.8)	2 (6.3)
Phlegm in the morning during winter	19 (14.2)	25 (16.8)	6 (18.2)
Ever seen by a doctor for a breathing problem	56 (41.8)	41 (27.5)	13 (39.4)
Ever diagnosed by a physician as having asthma	24 (17.9)	20 (13.4)	10 (30.3)
Nasal allergies (e.g., hay fever)	51 (38.1)	59 (39.6)	15 (45.5)
Eczema/skin allergies	43 (32.1)	48 (32.2)	11 (33.3)
Parental asthma/allergy history			
Mother:			
Asthma	12 (9.0)	12 (8.3)	0 (0.0)
Skin allergies	23 (17.2)	30 (21.1)	8 (24.2)
Father:			
Asthma	8 (6.0)	7 (4.9)	0 (0.0)
Skin allergies	17 (12.7)	29 (20.9)	3 (9.4)
Serious respiratory infection before the age of 5	12 (9.0)	19 (13.3)	7 (21.2)
Hospitalized over night for breathing problem	15 (11.2)	9 (6.0)	2 (6.1)
Total Number of Participants	134	149	33

Apart from “wheeze within the last 12 months”, “wheeze in the absence of a cold” and “diagnosis of asthma by a physician”, the prevalence of each respiratory symptom reported in the three study populations was similar. It is important to note that “wheeze in the absence of a cold” is more suggestive of respiratory problems (e.g., asthma) than is “wheeze within the last 12 months”. With respect to the prevalence of asthma, respondents in Lethbridge were approximately twice as likely to indicate wheezing in the last twelve months and twice as likely to report having received a physician’s diagnosis of asthma.

10.3 Neurocognitive Functioning

Neuropsychological assessment was conducted to provide a non-invasive means of evaluating associations between exposure and effects in neurocognitive function. Participants completed the Neurobehavioral Evaluation System 2 (NES2), Neuropsychological Impairment Scale (NIS), the Verbal Digit Span section of the Wechsler Memory Scale – Revised (WMS-R), and the Weekly Stress Inventory (WSI). Comparisons were made between control groups of previous studies that have employed versions of the NES to that of the current study.

Neurobehavioral Evaluation System (NES2)

The NES2 is a computerized program that assesses a number of basic neurological and cognitive parameters, including finger tapping, continuous performance, hand-eye co-ordination, associate learning, simple reaction time, symbol-digit, pattern comparison, pattern memory, serial digit learning, switching attention, colour-word, and delayed associate recognition.

In order to determine whether the scores obtained from the sample population were any different than other unexposed populations, the sample population was compared to control populations obtained for a variety of other studies. Demographic data along with the description of the measures and control groups for each study is shown in Table 51. It should be noted that not every control group used for comparison administered the same set of activities to their subjects as the current sample; thus, different reference groups are used for different activities.

Table 51: Comparison between Study Sample and Other Study Populations

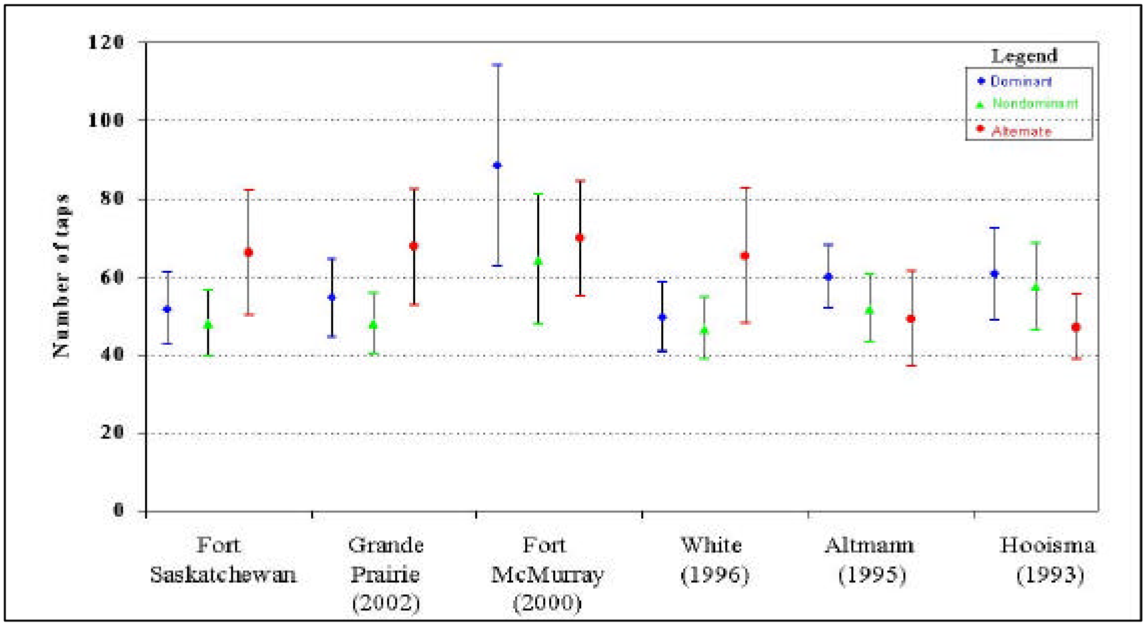
Study/ Author	Study Objectives	Source of Controls	N	Age Mean (SD)	Gender (% Male)	N	Education Mean (SD)
Fort Saskatchewan	Assess the impact of airborne contaminants on the health of the population	Other Alberta communities (i.e., Grande Prairie and Fort McMurray)	137	47.34 (11.48)	35 (25.4%)	137	13.52 (3.24)
Grande Prairie (2002)[40]	Assess the impact of airborne contaminants on the health of the population	Other Alberta communities (i.e., Fort Saskatchewan and Fort McMurray)	135	43.27 (11.32)	56 (40.0%)	135	14.02 (3.86)
Fort McMurray[41]	Fort McMurray community exposure to oil sands industry	Community of Lethbridge	300	39.96 (10.05)	135 (45%)	274	14.53 (2.19)
Lethbridge (2000)[42]			33	43.67 (14.14)	15 (45%)	29	14.90 (2.18)
Kilburn et al. (1998)[43]	Population-based prediction equations for neurobehavioral tests	Randomly, from different areas of the United States	264	44.2 (19.7)	121 (46%)	264	12.8 (2.2)
Colvin et al. (1993)[44]	Neurobehavioral effects of chronic solvent exposure on workers in a paint manufacturing plant	Unexposed internal group	24	43.52 (10.04)	24 (100%)	24	6.43 (3.87)

Table 51: Comparison between Study Sample and Other Study Populations (cont'd)

Tsai et al. (1997)[45]	Neurobehavioral effects of exposure to low-level organic solvents among Taiwanese workers in paint factories	Unexposed internal group	47	37.9 (14.8)	38 (81%)	47	10.46 (2.54)
Laire et al. (1997)[46]	Assessment of nocturnal oxygen desaturation in long-term solvent-exposed workers	Army personnel	21	38.1 (11)	20 (95%)	21	11 (2)
Tsai et al. (1996)[47]	Neurobehavioral effects of occupational exposure to low-level styrene	Unexposed internal group	45	35.9 (9.6)	31 (69%)	45	10.6 (2.2)
White et al. (1996)[48]	Validation of NES2 in patients with neurologic disorders	Spouses, friends, and family of patients	67	56.5 (12.2)	28 (42.4%)	67	45.5 (2.5)
Muijser et al. (1996)[49]	Behavioral effects of exposure to organic solvents in carpet layers	Cement floor layers	71	37.6 (9.6)	71 (100%)		
Broadwell et al. (1995)[50]	Clinical and neurobehavioral assessment of solvent-exposed microelectronic workers	Unexposed internal group	32	47.6 (9.0)	15 (47%)	32	13.9 (2.2)
Altmann et al. (1995)[51]	Outcome of chronic low-level tetrachloro-ethene exposure of dry cleaning shops	Unexposed personnel of Public Health Office and Medical Institute	23	37.2 (10.1)	9 (39%)		
Hooisma et al. (1993)[52]	Behavioral effects of exposure to organic solvents in Dutch painters	Carpenters and brick-layers	53	36.9 (3.2)	53 (100%)	53	9.4 (1.6)

The following graphs compare the performance of the Fort Saskatchewan cohort to previous Community Exposure and Health Effects Assessment findings as well as control groups of previous studies. Overall, there were no significant differences between the current study's participants and the other controls.

Figure 82: NES2 Finger Tapping Test (with 95% Confidence Intervals)



Note: Dominant, nondominant, and alternate refer to the hand that was used during that trial.

Figure 83: NES2 Associate Learning Test (with 95% Confidence Intervals)

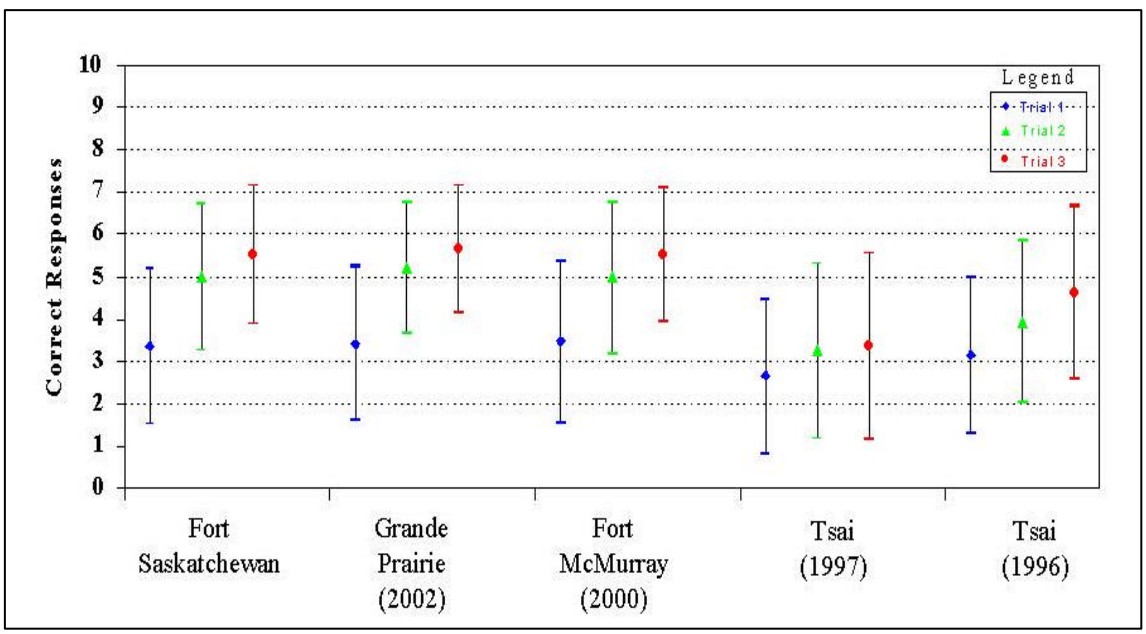
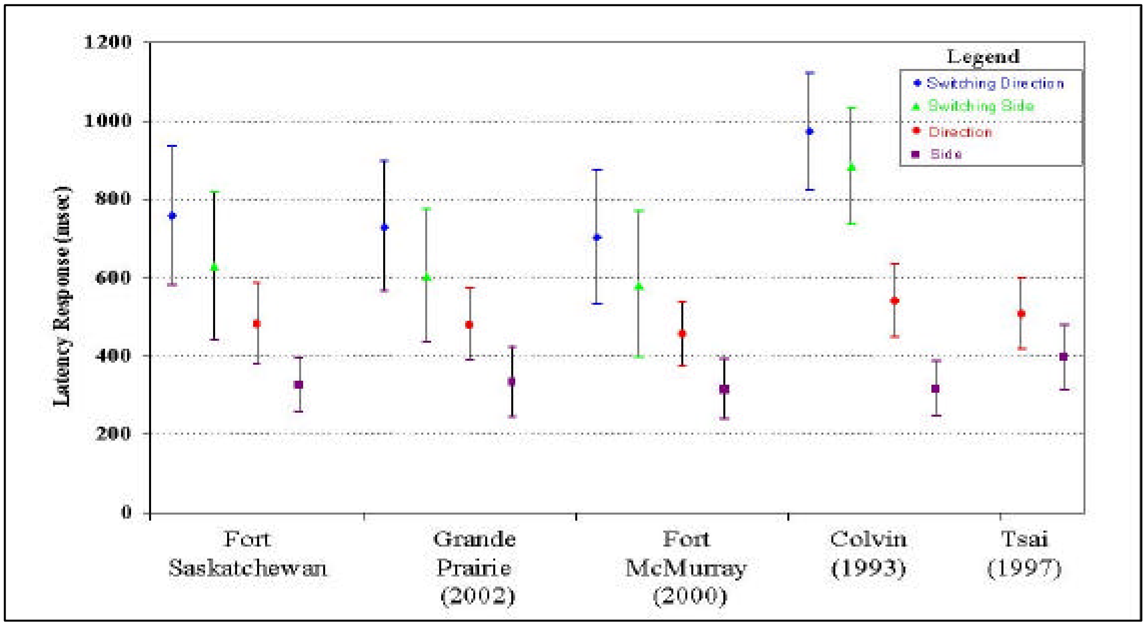
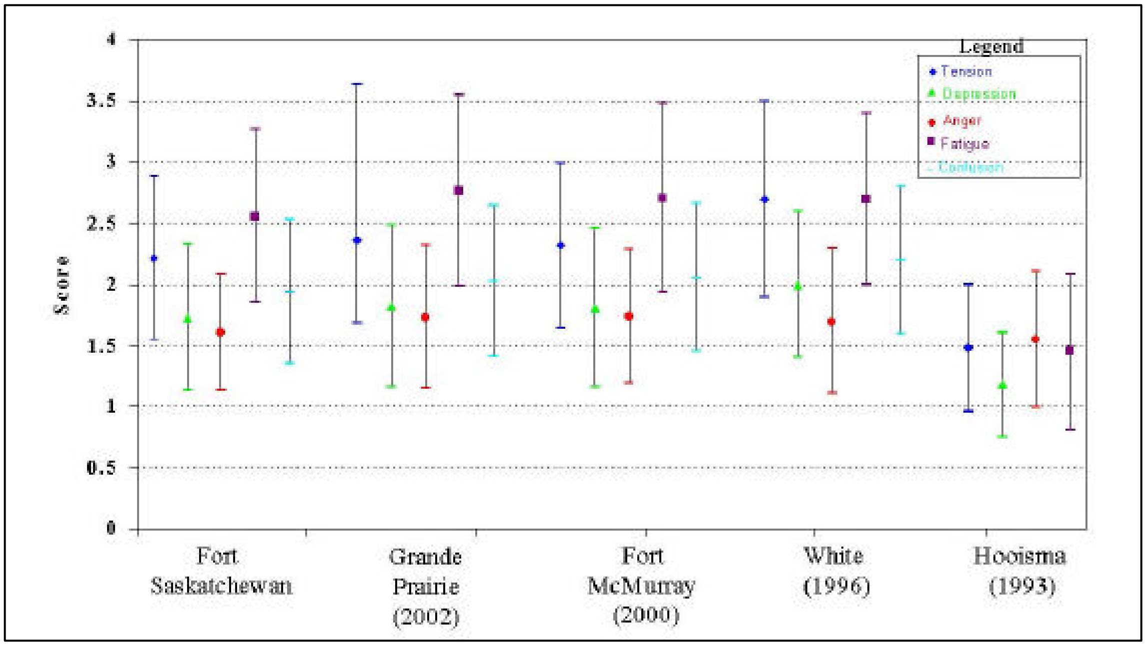


Figure 84: NES2 Switching Attention Test (with 95% Confidence Intervals)



Note: Participants responded to the side or direction a stimulus was presented on; in the switching trials the participant would be cued prior to the presentation of the stimulus to respond to either the side or the direction.

Figure 85: NES2 Mood Scales (with 95% Confidence Intervals)



Note: Mood scales were created based on grouping of the separate items that were responded to.

Figure 86: NES2 Continuous Performance Test (with 95% Confidence Intervals)

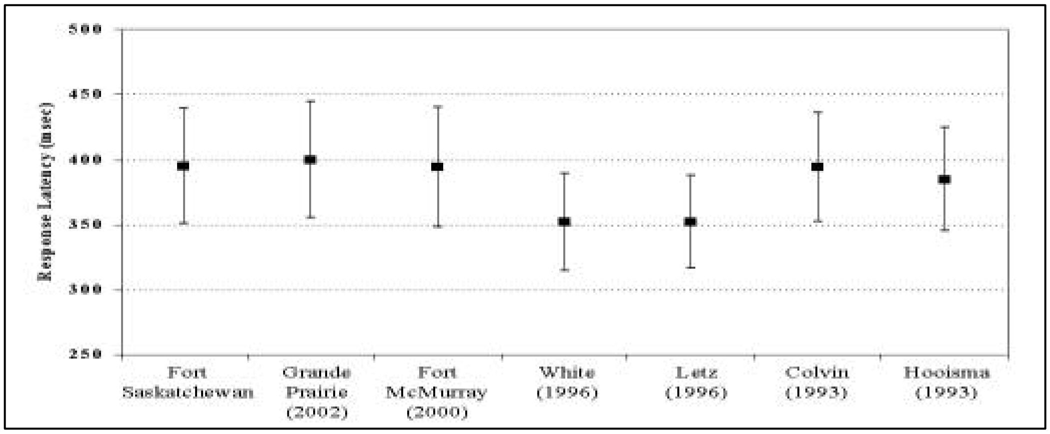


Figure 87: NES2 Hand-Eye Co-ordination Test (with 95% Confidence Intervals)

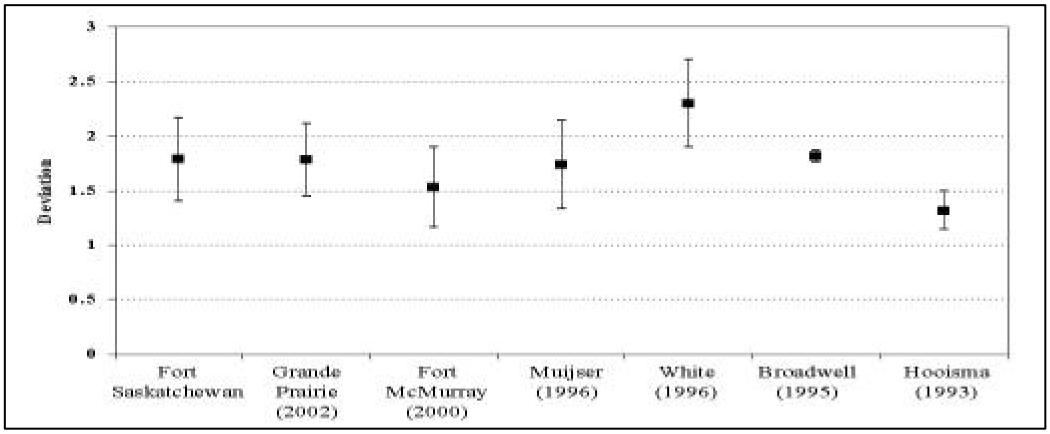


Figure 88: NES2 Simple Reaction Time Test (with 95% Confidence Intervals)

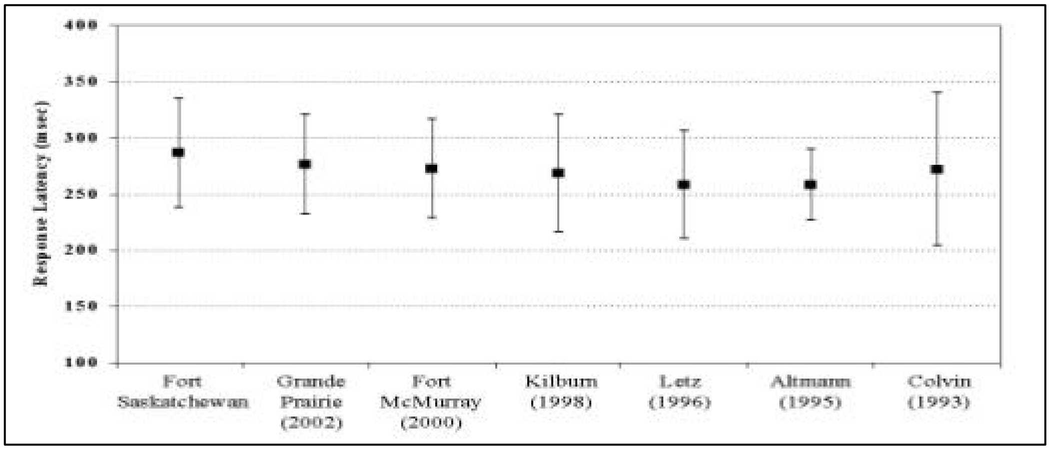


Figure 89: NES2 Symbol-Digit Test (with 95% Confidence Intervals)

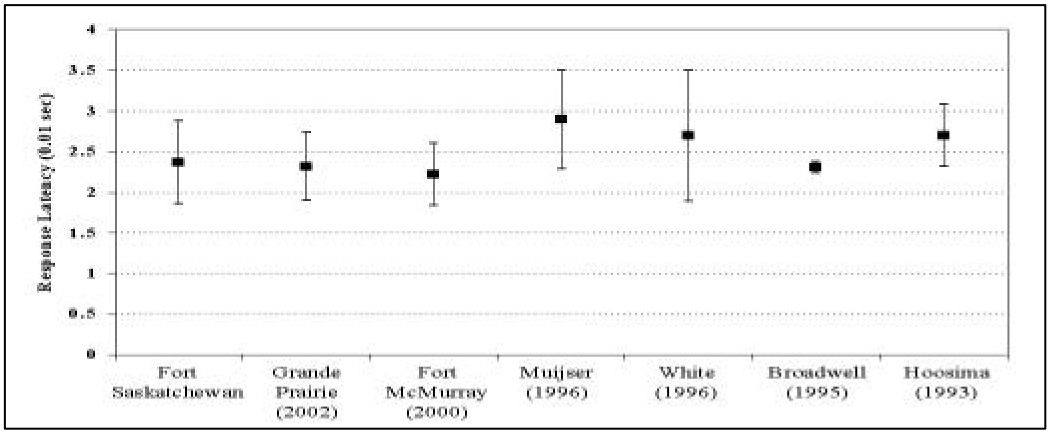


Figure 90: NES2 Pattern Comparison Test (with 95% Confidence Intervals)

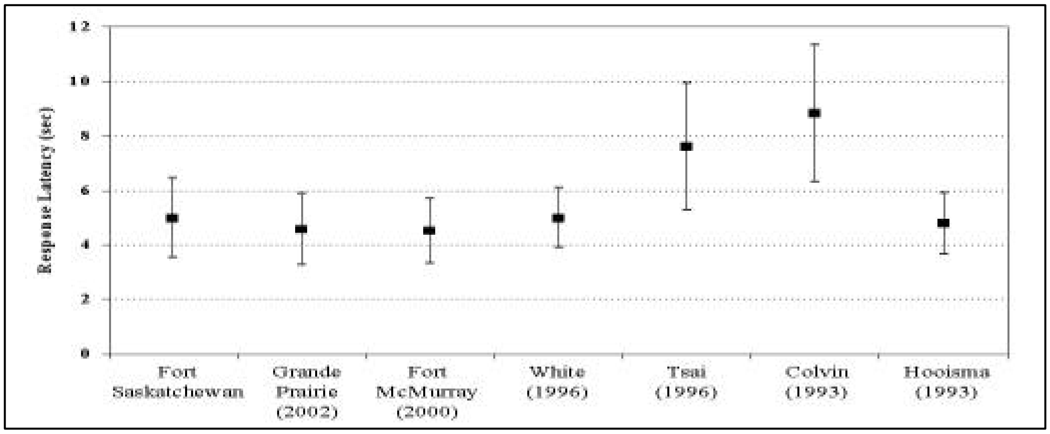


Figure 91: NES2 Pattern Memory Test (with 95% Confidence Intervals)

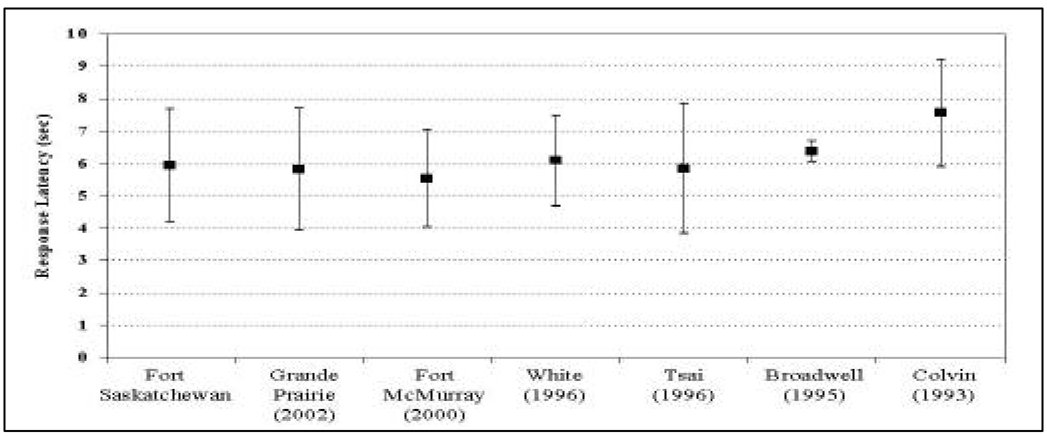


Figure 92: NES2 Serial Digit Learning Test (with 95% Confidence Intervals)

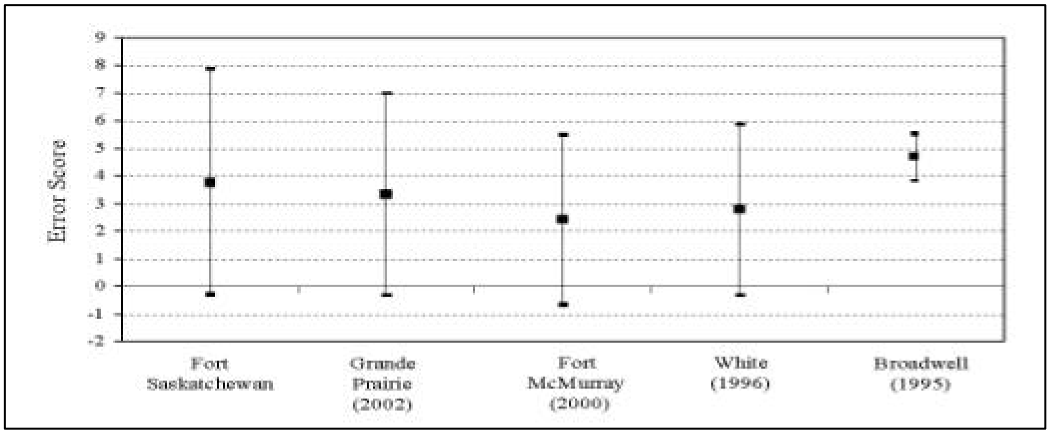


Figure 93: NES2 Colour-Word Test (with 95% Confidence Intervals)

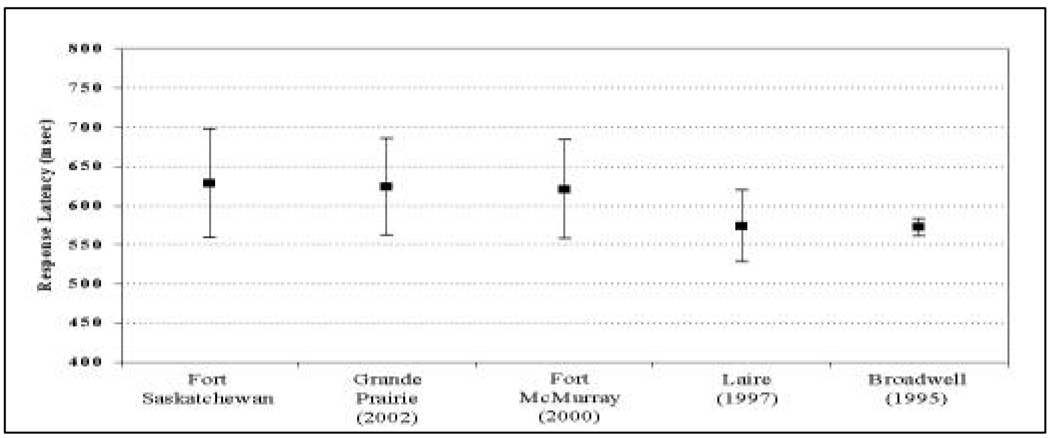


Figure 94: NES2 Vocabulary Test (with 95% Confidence Intervals)

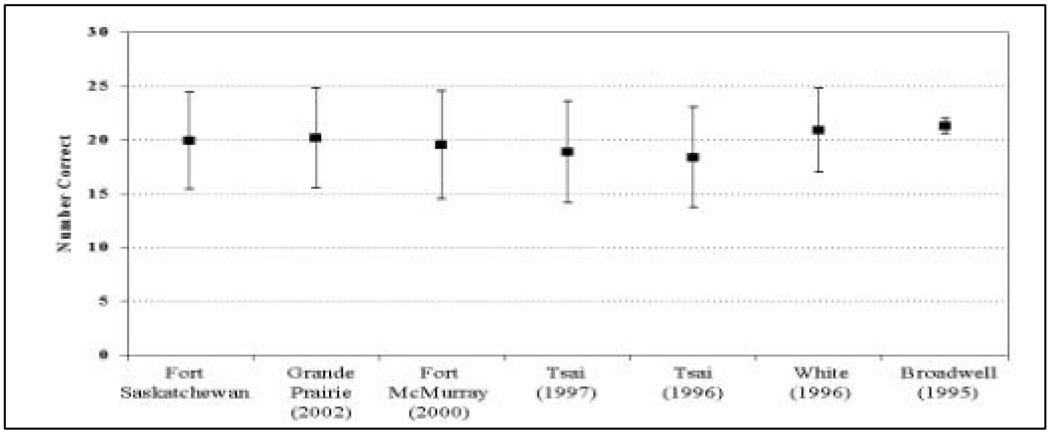
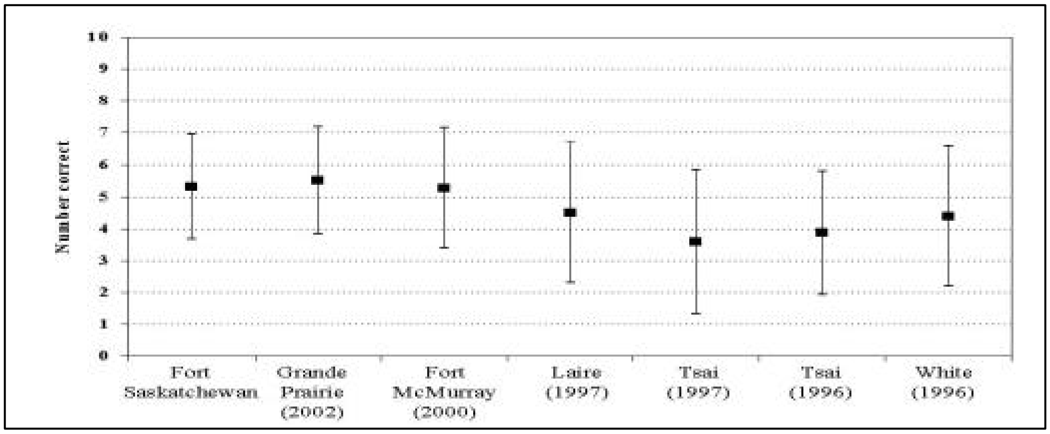


Figure 95: NES2 Delayed Associate Recognition Test (with 95% Confidence Intervals)



Symptoms Questionnaire

A symptom questionnaire was also included in the NES2 program to collect information on symptoms that are often associated with exposure to neurotoxic agents. The questionnaire requires participants to indicate how often they experienced each of the symptoms in the past month. The results of this questionnaire are displayed in the following table. A small percentage of Fort Saskatchewan participants indicated frequently experienced symptoms: feeling tired (15.4%), lack of sexual drive (12.5%) and having to make notes to remember (10.3%).

Table 52: Frequency of Experiencing Symptoms (NES2)

Symptoms	Fort Saskatchewan (N = 136, %)			
	Not at all	A little	Fair	A lot
Feeling tired	5.9	55.1	23.5	15.4
Difficulty concentrating	33.1	51.5	13.2	2.2
Difficulty remembering things	26.5	53.7	17.6	2.2
Seizures	99.3	0.7	0	0
Headaches	54.4	34.6	9.6	1.5
Difficulty falling asleep	49.3	31.6	16.2	2.9
Lack of sexual drive	38.2	34.6	14.7	12.5
Tingling in my fingers or toes	64.7	20.6	9.6	5.1
Loss of appetite	85.3	12.5	0	2.2
Diarrhea	72.1	22.8	4.4	0.7
Dry mouth	62.5	27.9	5.9	3.7
Feeling depressed for no reason	68.4	27.2	2.9	1.5
Confusion	68.4	30.1	1.5	0
Having to make notes to remember	21.3	50.7	17.6	10.3
Hallucinations	97.1	2.9	0	0
Heart palpitations	86.8	11.8	0.7	0.7
Lack of co-ordination	77.9	17.6	3.7	0.7
Sleeping more than usual	77.2	18.4	3.7	0.7
Perspiring for no reason	86.0	11.8	1.5	0.7
Skin dryness	55.1	34.6	6.6	3.7
Unexplained weight loss	97.1	2.2	0	0.7
Indigestion	63.2	28.7	5.9	2.2
Excessive salivation	97.8	1.5	0.7	0
Feeling irritable	35.3	56.6	7.4	0.7
Feeling light-headed or “high”	77.9	19.9	2.2	0
Lack of muscle strength	59.6	29.4	6.6	4.4
Tightness in my chest	86.0	13.2	0.7	0
Feeling excitable	54.4	40.4	4.4	0.7
Nausea	80.9	16.2	1.5	1.5
Inflamed gums	91.2	7.4	1.5	0
Feeling anxious	48.5	43.4	8.1	0
Tremor in my fingers	87.5	8.1	2.9	1.5
Loose teeth	98.5	1.5	0	0
Trembling eyelids, lips or tongue	94.1	4.4	1.5	0
Difficulty buttoning clothes	92.6	5.1	1.5	0.7

The items of the symptom questionnaire can be further combined to form seven scales, which are displayed in Table 53. The values reflect the average responses, based on the 4-point scale, of all the symptoms corresponding to their respective categories. These composite scales measure lassitude (weariness), neurasthenia (experience of physical symptoms such as tiredness or exhaustion with no physical justification), memory, confusion, co-ordination, neurological impairment ("neurologic"), and physical health ("physical"). The memory score, which has the highest mean in all study results, reflected "a little" experience with symptoms associated with a memory deficit. There are no significant differences between study results; the memory scale holds the highest score within all study results, followed by the lassitude scale.

Table 53: Symptom Composite Scales (NES2)

Scale	Fort Saskatchewan Mean (SD)	Grande Prairie Mean (SD)	Fort McMurray Mean (SD)	Lethbridge Mean (SD)
Lassitude	2.02 (0.66)	2.06 (0.62)	1.99 (0.63)	1.98 (0.57)
Neurasthenia	1.47 (0.38)	1.54 (0.40)	1.53 (0.40)	1.55 (0.35)
Memory	2.06 (0.71)	2.06 (0.66)	2.04 (0.69)	2.14 (0.7)
Confusion	1.54 (0.50)	1.5 (0.46)	1.53 (0.49)	1.53 (0.47)
Co-ordination	1.19 (0.40)	1.17 (0.38)	1.15 (0.35)	1.21 (0.28)
Neurologic	1.24 (0.30)	1.22 (0.28)	1.20 (0.22)	1.19 (0.18)
Physical	1.29 (0.26)	1.33 (0.25)	1.28 (0.24)	1.35 (0.23)
Symptom Mean Intensity	1.42 (0.29)	1.47 (0.38)	1.41 (0.26)	1.45 (0.22)

Neuropsychological Impairment Scale (NIS)

The Neuropsychological Impairment Scale (NIS) was developed as a self-reported questionnaire consisting of 50 items which measure potential neuropsychological symptoms concerned with language usage, memory, sensory capabilities, head injuries, motor capabilities, frustration tolerance, and mental alertness. The NIS can be used to identify general neurocognitive deficits and as a useful research tool for evaluating neurocognitive impairments in the general population.

The NIS was developed to produce eight separate scores. A measure of test-taking attitude (LIE) is obtained from the answers to five independent items not included in any of the other scales. A raw score sum of the 45 items yields a Global Measure of Impairment (GMI) which indicates the patient's self-perceived adaptive deficiencies. The Total Items Checked (TIC) provides an additional index of symptom presence. The Symptom Intensity Measure (SIM) is a gauge of symptom severity calculated by dividing GMI by TIC. The General Impairment Scale (PAT) identifies previous diagnosis of symptoms such as seizures, head injury, paralysis or other physical problems that may lead to possible neurocognitive deficits. The Learning-Verbal Scale (L-V) is a scale of verbal ability. The Frustration Scale (FRU) identifies behavioral signs of anger, frustration, and resentment.

The NIS scores of Fort Saskatchewan were compared to norms used in previous studies. The study by Errico et al. (1990) involved screening for neuropsychological impairment in alcoholics. His control group included subjects with no history of neurological disorders or alcohol abuse. O'Donnell et al. (1983) included thorough normative data from a heterogeneous population base. In the following graphs, the results from the Fort Saskatchewan population are compared to the control groups of other studies. As shown by Figures 96-103, there are no statistically significant differences between Fort Saskatchewan and other study results.

Figure 96: NIS General Measure of Impairment (GMI)

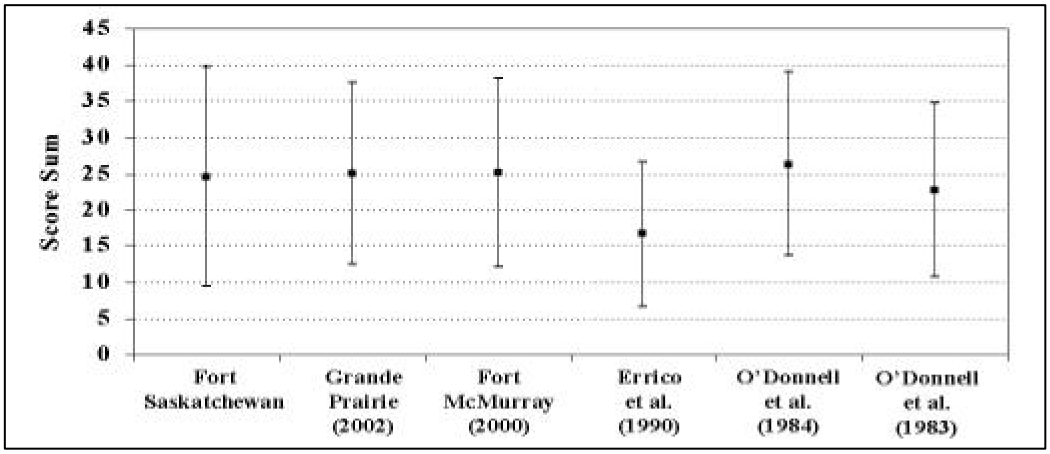


Figure 97: NIS Total Items Checked (TIC)

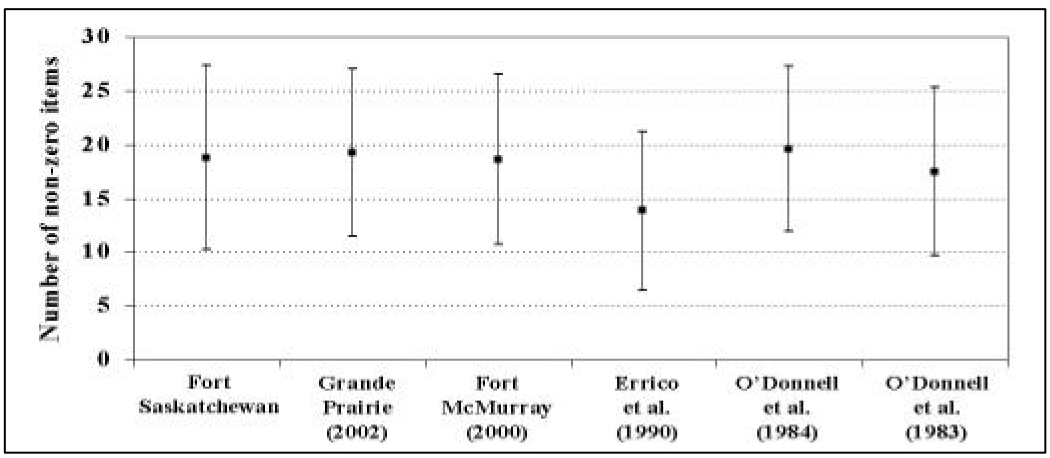


Figure 98: NIS Symptom Intensity Measure (SIM)

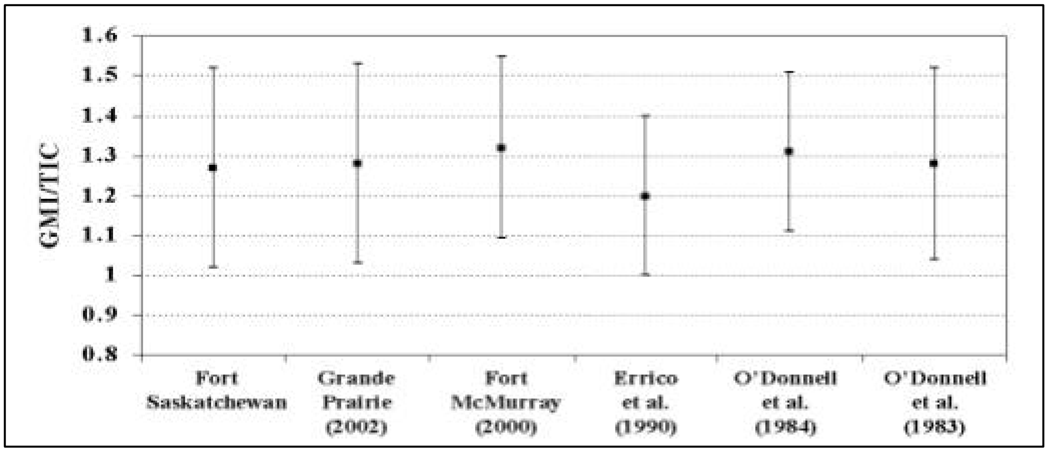


Figure 99: NIS General Scale (GEN)

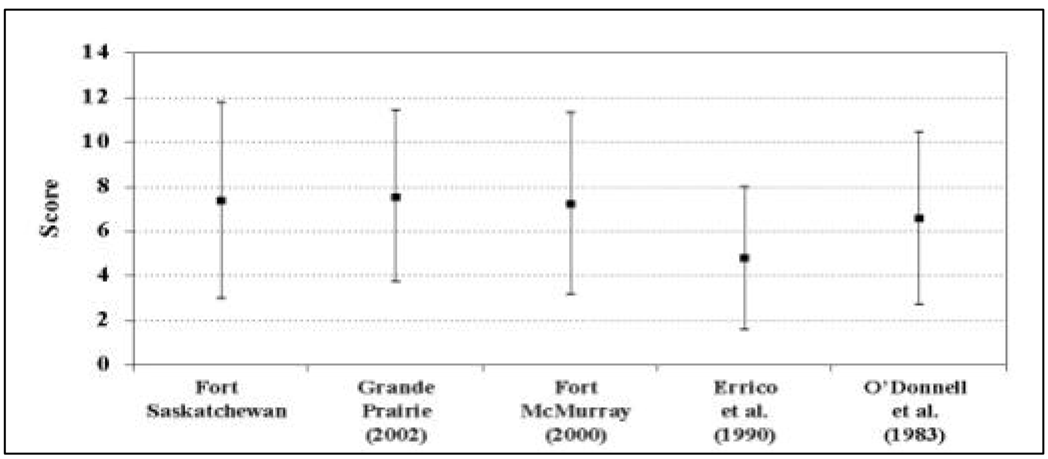


Figure 100: NIS Pathognomic Scale (PAT)

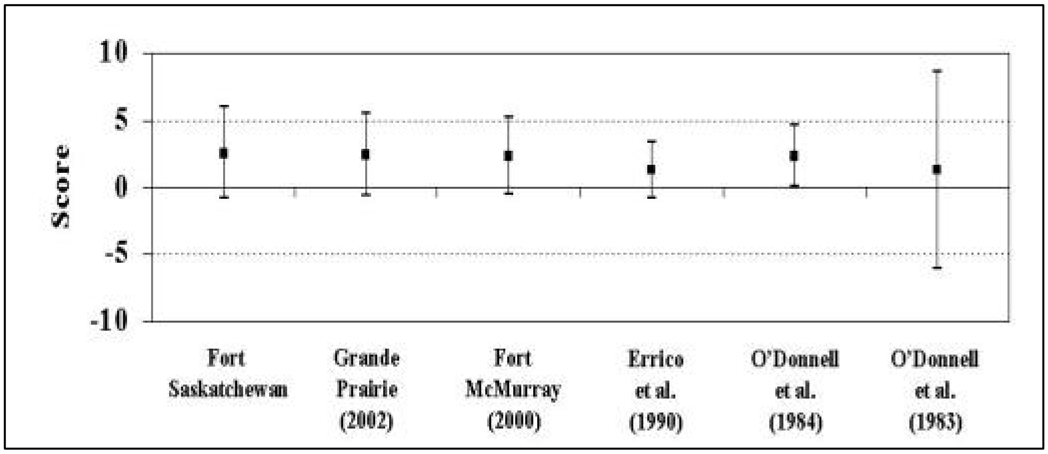


Figure 101: NIS Frustration Scale (FRU)

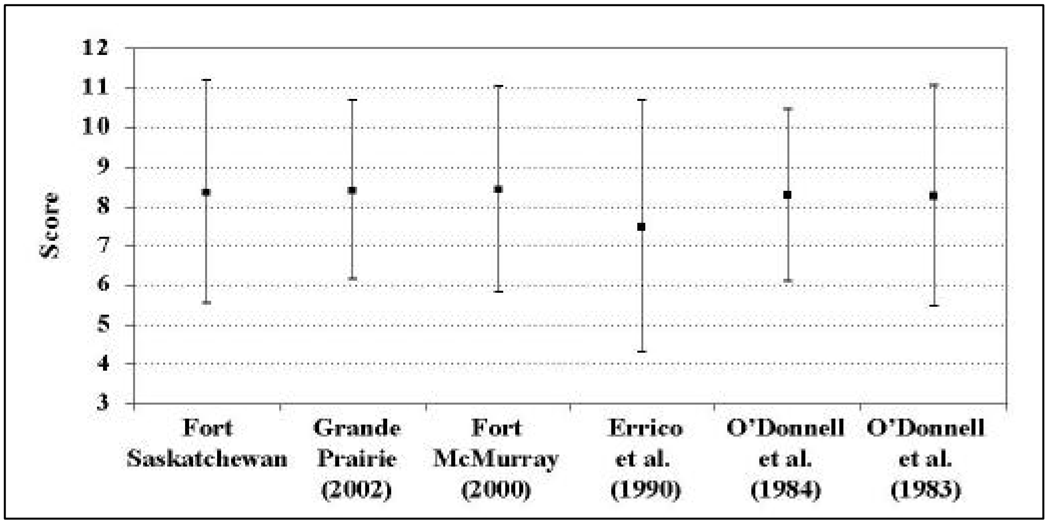


Figure 102: NIS Learning-Verbal Scale (L-V)

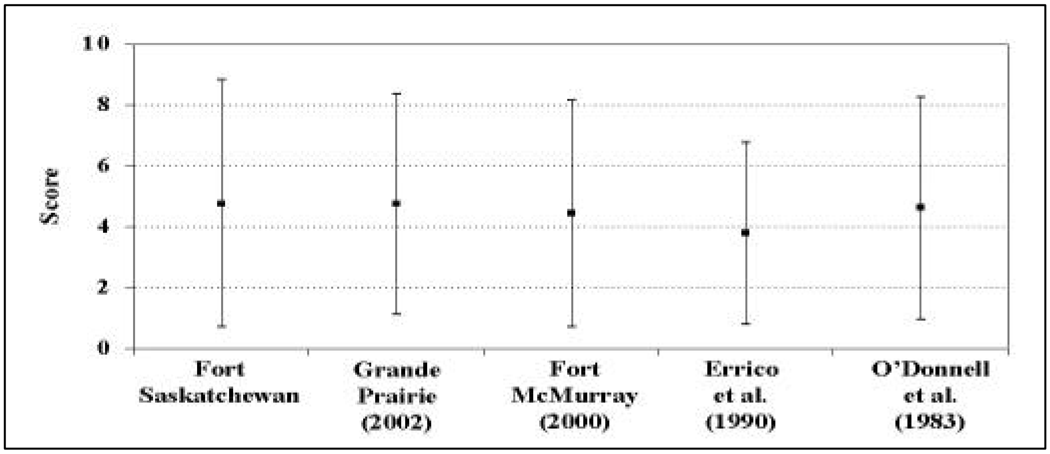
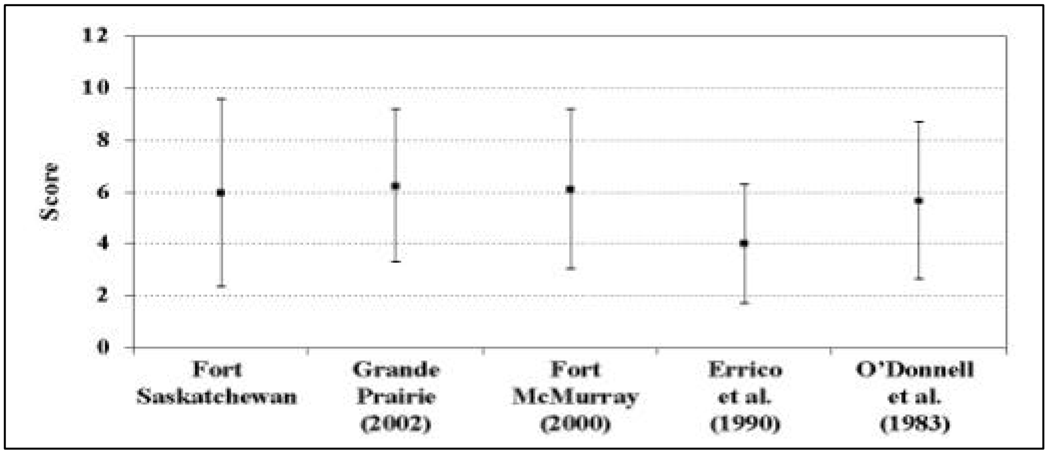


Figure 103: NIS Lie Scale (LIE)



Verbal Digit Span (VDS)

The Verbal Digit Span is a section of the Wechsler Memory Scale – Revised (WMS-R) [53] and was administered to each participant as an assessment of auditory processing. The WMS-R version of the Verbal Digit Span is composed of two parts, the Digits Forward and the Digits Backward, which are administered separately. During administration of both sections of the test, the participants are required to repeat increasingly long strings of numbers, either forward or backward, which provide a measurement of the participants' long-term memory.

The following table shows the Verbal Digit Span results for both Digits Forward and Digits Backward. The results of the Fort Saskatchewan study were comparable to the results of other researchers, including the previous Health Effects and Assessment Programs within Grande Prairie [54] and Fort McMurray.[55] In a study conducted by Amitai et al. (1988), control group participants were young (average age = 22.2

years), healthy university students.[56] Fastenau (1996) used a comparable group of healthy adults with a mean age of 43.5 years.[57]

Table 54: Verbal Digit Span Results

	N	Digits Forward	Digits Backward
Fort Saskatchewan	138	8.23 (1.71)	6.20 (2.02)
Grande Prairie (2002)	140	8.34 (1.87)	6.64 (2.21)
Fort McMurray (2000)	334	8.46 (1.94)	6.66 (2.18)
Amitai et al. (1998)	47	8.98 (1.80)	7.83 (2.00)
Fastenau et al. (1996)	47	7.50 (2.10)	NA

Weekly Stress Inventory (WSI)

The Weekly Stress Inventory (WSI) was developed as a self-report questionnaire consisting of a variety of examples of daily stressors. Each respondent was asked to identify events that occurred during the previous week, and rate the perceived stressfulness of the event on a scale from 1 (occurred, but was not stressful) to 7 (extremely stressful). The items of the WSI were selected to represent relatively minor events having a high potential of occurring in any given week. The items were also chosen to describe observable events with a discrete beginning and end. The questions focus on such events as arguments with loved ones or co-workers, problems at work, financial situations, and other social events that commonly occur. Two measures are calculated from the inventory: the WSI-Event scale, which measures the number of stressful events that occurred each week; and the WSI-Impact scale, which estimates the impact of the events for each participant.

Table 55 presents the mean scale score for Fort Saskatchewan respondents and compares it to the mean score of Grande Prairie residents and the reference study from Jones and Brantley.[58] Differences between the three populations are not statistically significant.

Table 55: Average Number and Impact of Weekly Stressful Events

	Number of Events Mean (S.D.)	Stress Impact Mean (S.D.)
Fort Saskatchewan	21.9 (10.4)	51.4 (42.5)
Grande Prairie	25.53 (12.55)	60.16 (41.13)
Jones and Brantley (1989)	32.16 (19.46)	105.38 (84.74)

11.0 Measures of Health

Several standardized questionnaires were included to obtain measures of the participant's perceived health, as well as measures of mental and psychosocial health. The data collected using the three questionnaires are discussed in the following sections.

11.1 Occupational Health Questionnaire

A standard occupational health questionnaire was used to measure symptoms typically associated with the work environment. The Ontario Ministry of the Environment originally adopted it for the Windsor Winter 1992 Personal Exposure Pilot (PEP) Study. The questionnaire uses a standard list of symptoms, which are characteristically associated with indoor air quality, and requires the respondent to specify the environmental location where the physical symptom is felt. Respondents were allowed to specify multiple locations.

Table 56 identifies the percentage of respondents from the Fort Saskatchewan sample who reported experiencing the specified symptoms in the past year, which are then divided into the specified locations. The symptoms reported most frequently were physical fatigue, colds and flu, back pain, dry skin, headaches, eye irritation, scratchy throats, aching joints and dry, itching and tearing eyes. Participants reported experiencing physical fatigue, dry skin, colds and flu, back pain and dry, itching and tearing eyes as occurring most frequently at home while the most common symptoms at work were nose irritation, strained eyes or focusing difficulties and throat irritation. Nausea and dizziness occurred most frequently while commuting.

Table 56: Frequency of Experiencing Symptoms

Symptom	None	Home	Work	Commuting	Combination
Eye irritation	45.2	22.2	4.8	0.0	27.8
Nose irritation	54.8	15.9	7.9	0.0	21.4
Throat irritation	54.8	16.7	6.3	0.0	20.6
Dry mucous membranes	62.7	14.3	4.8	0.0	18.3
Dry skin	39.7	31.0	2.4	0.0	27.0
Erythema	84.1	7.1	1.6	0.0	7.1
Mental fatigue	54.0	18.3	4.8	0.0	23.0
Physical fatigue	37.3	31.7	4.8	0.0	26.2
Headaches	44.4	22.2	4.8	0.0	28.6
Unspecified airway infections	87.3	4.8	0.8	0.0	7.1
Scratchy throats or coughs	47.6	19.0	2.4	0.0	31.0
Colds and flu	38.9	27.8	2.4	0.0	31.0
Nausea	77.0	11.9	1.6	0.8	8.7
Dizziness	71.4	15.1	1.6	0.8	11.1
Dry, itching or tearing eyes	49.2	25.4	1.6	0.0	23.0
Strained eyes or focusing difficulties	60.3	17.5	7.9	0.0	14.3
Chest tightness	83.3	9.5	1.6	0.0	7.9
Unspecified hyper-sensitivity	95.2	2.4	0.0	0.0	2.4
Feeling heavy headed	81.7	7.9	1.6	0.0	7.9
Difficulty concentrating	65.9	8.7	4.0	0.0	20.6
Dry facial skin	67.5	15.9	0.0	0.0	16.7
Aching joints	47.6	23.8	3.2	0.0	24.6
Muscle twitching	68.3	18.3	0.8	0.0	12.7
Back pain	38.9	26.2	4.0	0.0	31.0

11.2 General Health Questionnaire (GHQ)

The General Health Questionnaire (GHQ) is a self-administered screening questionnaire designed to detect current, diagnosable psychiatric disorders.[59] The tool does not identify severe illness, but can identify individuals who feel they are unable to carry out their normal daily functions, focusing on changes in normal functioning rather than lifelong traits. Respondents who report 12 or more complaints are considered to have a psychosomatic disorder.[60]

The mean sum of reported symptoms was 4.4. Over 80% of the respondents scored lower than 12 (refer to Table 57); 13% scored between 12 and 24; and almost 3% scored over 25. Contrary to typical findings with this measure, female respondents were somewhat less likely to report experiencing complaints or difficulties than the male respondents.

Table 57: GHQ Score - Percentage of Respondents by Gender

Score	Percentage		
	Males	Females	Total
0 - 11	70.4	88.6	84.0
12 - 24	25.9	8.9	13.2
25 +	3.7	2.5	2.8

11.3 Medical Outcomes Study Short Form (SF-36)

The Medical Outcomes Study, conducted by the Rand Corporation in the 1970's, developed a standard questionnaire intended to provide a general indicator of health status for use in population health surveys referred to as the 36-item Short Form (SF-36). The SF-36 includes a variety of questions designed to assess limitations in usual role activities due to physical or emotional problems, limitations in physical activities, limitations in social activities, general mental health, vitality, bodily pain, and general health perceptions. The questionnaire has been used extensively and has been proven reliable and valid.

Table 58 compares the mean scale score for Fort Saskatchewan respondents with values from Grande Prairie and a reference population.[61] Differences in most cases are likely due to small sub-sample sizes. Differences between the sample population and the reference population were also not significant.

Table 58: Role Limitations, Vitality, Pain, and General Health Perceptions

	Age Category						
	18-24	**25-34**	**35-44**	**45-54**	**55-64**	**65+**	**Total**
Role Limitations, Emotional Health: Males							
Fort Saskatchewan	50.0 (0.0)	50.0 (0.0)	44.4 (9.6)	39.3 (16.8)	45.8 (11.8)	N/A	43.5 (13.4)
Grande Prairie	N/A	66.7 (44.4)	88.1 (24.8)	81.5 (33.8)	70.0 (42.9)	66.7 (57.7)	76.8 (37.1)
Reference	82.9 (31.1)	87.1 (27.9)	86.0 (28.6)	87.5 (29.5)	85.8 (29.9)	N/A	N/A
Role Limitations, Emotional Health: Females							
Fort Saskatchewan	50.0 (-)	45.0 (11.2)	45.7 (11.9)	44.0 (14.5)	45.6 (12.2)	40.5 (16.3)	44.7 (12.8)
Grande Prairie	100.0 (0.0)	82.4 (29.1)	78.8 (36.4)	85.7 (24.9)	78.8 (27.0)	N/A	81.9 (29.6)
Reference	78.8 (33.0)	80.6 (34.0)	80.3 (33.6)	80.8 (33.6)	83.3 (32.5)	N/A	N/A
Role Limitations, Physical Health: Males							
Fort Saskatchewan	50.0 (0.0)	50.0 (0.0)	29.2 (26.0)	43.8 (14.5)	23.4 (20.5)	N/A	38.3 (18.5)
Grande Prairie	N/A	100.0(0.0)	91.1 (21.0)	40.0 (39.4)	52.5 (43.2)	50.0 (0.0)	71.3 (39.0)
Reference	91.8 (22.6)	92.0 (23.2)	89.5 (25.5)	87.6 (28.3)	78.8 (36.1)	N/A	N/A
Role Limitations, Physical Health: Females							
Fort Saskatchewan	50.0 (-)	36.3 (20.8)	40.3 (18.1)	40.6 (17.9)	35.5 (19.2)	35.7 (24.4)	38.7 (18.7)
Grande Prairie	100.0 (0.0)	72.1 (40.4)	78.4 (32.1)	75.0 (37.1)	50.0 (41.9)	N/A	71.9 (37.5)
Reference	88.6 (25.5)	86.9 (29.2)	84.0 (32.0)	82.4 (32.0)	76.6 (36.9)	N/A	N/A
Physical Functioning: Males							
Fort Saskatchewan	66.7 (0.0)	56.7 (20.0)	53.3 (11.5)	52.3 (19.8)	36.3 (14.2)	N/A	49.7 (18.5)
Grande Prairie	N/A	90.0 (9.7)	96.1 (4.9)	74.0 (25.3)	74.5 (24.5)	60.0 (39.7)	83.0 (21.7)
Reference	92.8 (16.8)	93.9 (14.2)	91.9 (14.5)	87.9 (17.4)	80.0 (22.1)	N/A	N/A
Physical Functioning: Females							
Fort Saskatchewan	66.7 (-)	52.3 (13.8)	56.5 (11.4)	52.7 (16.2)	48.4 (16.3)	52.9 (13.5)	53.1 (14.4)
Grande Prairie	95.0 (0.0)	93.3 (9.5)	90.0 (16.5)	83.6 (16.7)	74.0 (22.9)	N/A	86.5 (17.0)
Reference	90.1 (16.4)	92.9 (13.3)	89.4 (16.1)	84.8 (18.3)	74.8 (23.5)	N/A	N/A
Social Functioning: Males							
Fort Saskatchewan	50.0 (0.0)	41.7 (16.7)	25.0 (22.0)	30.4 (20.6)	27.1 (19.3)	N/A	31.7 (19.4)
Grande Prairie	N/A	46.2 (8.4)	48.2 (6.7)	47.5 (12.9)	50.0 (10.2)	50.0 (0.0)	48.1 (9.0)
Reference	90.2 (16.4)	91.3 (16.3)	90.5 (17.0)	89.8 (18.7)	86.9 (22.6)	N/A	N/A
Social Functioning: Females							
Fort Saskatchewan	50.0 (-)	33.3 (18.4)	44.4 (15.5)	43.2 (15.4)	38.4 (17.7)	41.7 (16.7)	41.5 (16.3)
Grande Prairie	50.0 (0.0)	49.3 (6.9)	49.4 (7.2)	43.4 (12.3)	53.4 (9.8)	N/A	48.3 (9.7)
Reference	85.7 (19.7)	87.1 (18.9)	86.7 (20.5)	87.0 (20.8)	85.9 (22.6)	N/A	N/A
Mental Health: Males							
Fort Saskatchewan	65.0 (21.2)	62.5 (15.2)	45.6 (12.6)	56.9 (15.2)	53.3 (18.3)	N/A	56.1 (15.9)
Grande Prairie	N/A	66.8 (6.0)	67.1 (10.7)	71.6 (7.4)	65.4 (9.8)	58.7 (12.8)	6.71 (9.3)
Reference	74.8 (15.4)	75.8 (15.2)	75.0 (16.1)	76.0 (16.7)	78.0 (17.3)	N/A	N/A
Mental Health: Females							
Fort Saskatchewan	50.0 (-)	62.3 (13.4)	62.3 (16.1)	64.0 (10.3)	67.1 (18.0)	67.1 (18.0)	62.7 (13.7)
Grande Prairie	68.0 (0.0)	65.4 (9.9)	65.4 (10.6)	66.3 (8.7)	665 (9.6)	N/A	65.9 (9.5)
Reference	70.2 (17.4)	71.6 (15.2)	71.6 (17.8)	73.2 (18.2)	74.4 (18.5)	N/A	N/A
Vitality – Males							
Fort Saskatchewan	41.7 (5.9)	46.9 (4.0)	44.4 (10.5)	55.4 (9.4)	45.3 (7.2)	NA	49.7 (9.4)
Grande Prairie	N/A	56.5 (5.3)	60.0 (14.3)	62.5 (10.1)	57.7 (5.2)	53.3 (5.8)	58.8 (9.7)
Reference	66.4 (17.1)	64.5 (17.3)	63.5 (18.6)	62.9 (19.9)	62.9 (20.3)	N/A	N/A
Vitality – Females							
Fort Saskatchewan	50.0 (-)	54.2 (11.3)	48.3 (9.4)	46.0 (12.9)	52.4 (9.2)	50.0 (6.4)	49.2 (10.7)
Grande Prairie	55.0 (0.0)	56.5 (10.4)	50.2 (11.0)	57.1 (10.7)	58.6 (7.1)	N/A	55.1 (10.5)
Reference	59.8 (19.4)	58.3 (19.5)	58.2 (19.9)	59.4 (20.3)	59.0 (21.4)	N/A	N/A

Table 58: Role Limitations, Vitality, Pain, and General Health Perceptions (cont'd)

Bodily Pain: Males							
Fort Saskatchewan	42.0 (0.0)	53.3 (15.6)	52.0 (11.1)	52.7 (16.7)	56.5 (10.6)	N/A	53.0 (13.7)
Grande Prairie	N/A	83.2 (13.5)	85.1 (16.6)	593 (22.9)	67.6 (22.8)	75.0 (30.5)	74.8 (21.7)
Reference	86.6 (17.9)	87.5 (17.7)	85.6 (19.7)	81.8 (22.2)	78.8 (23.6)	N/A	N/A
Bodily Pain: Females							
Fort Saskatchewan	42.0 (-)	52.4 (11.8)	49.1 (13.9)	51.1 (14.0)	57.4 (17.8)	49.4 (16.3)	51.7 (14.8)
Grande Prairie	100.0 (0.0)	67.5 (19.2)	71.3 (17.7)	70.0 (21.6)	52.6 (22.3)	N/A	67.6 (20.8)
Reference	81.7 (20.8)	82.1 (21.1)	79.4 (22.0)	77.4 (22.3)	75.0 (25.1)	N/A	N/A
General Health Perceptions: Males							
Fort Saskatchewan	50.0 (2.8)	40.6 (2.0)	41.6 (4.0)	45.0 (5.7)	43.7 (10.9)	N/A	44.1 (7.0)
Grande Prairie	N/A	55.7 (10.7)	58.6 (7.4)	52.7 (5.5)	55.1 (9.0)	43.0 (20.1)	55.0 (9.5)
Reference	72.0 (20.1)	76.7 (17.7)	74.1 (18.5)	72.0 (20.1)	68.1 (22.9)	N/A	N/A
General Health Perceptions: Females							
Fort Saskatchewan	45.6 (-)	45.4 (8.1)	43.9 (6.6)	44.5 (5.7)	47.1 (7.7)	44.3 (6.4)	45.0 (6.6)
Grande Prairie	52.0 (0.0)	49.5 (11.0)	54.9 (9.3)	55.4 (7.3)	53.2 (7.0)	N/A	53.4 (9.0)
Reference	72.1 (20.3)	77.3 (18.5)	74.1 (20.3)	73.1 (19.9)	68.0 (22.0)	N/A	N/A

11.4 Previous Diagnoses

Study participants were asked to indicate which of a series of chronic diseases they have had diagnosed by a physician. Table 59 shows the percentage of the sample population who have been diagnosed with each specified chronic condition.

Statistical analysis indicates that the three communities displayed in Table 59 cannot be distinguished by differing rates of chronic disorders among the participants.

Back problems and allergies (both at 29%) were diagnosed most frequently for Fort Saskatchewan residents. Twenty-four percent of the respondents indicated they had been diagnosed with arthritis, and more than 10% had been diagnosed with food allergies, sinusitis, acne, high blood pressure and asthma. None of the respondents had been diagnosed with Alzheimer's disease, other forms of dementia, epilepsy or glaucoma and less than 1% of the respondents in Fort Saskatchewan indicated that they had been diagnosed with cataracts. Five percent of the Fort Saskatchewan sample indicated they had been diagnosed with some form of cancer.

Table 59: Percentage of Respondents with Previously Diagnosed Condition

Diagnosis	Location		
	Fort Saskatchewan (N = 121)	Grande Prairie (N = 121)	Fort McMurray (N = 274)
Food Allergies	14.0	17.4	12.8
Other Allergies	28.9	33.9	33.2
Asthma	19.0	15.7	13.1
Bronchitis/Emphysema	3.3	6.6	3.6
Sinusitis	14.9	15.7	12.8
Arthritis	24.0	19.8	14.2
Back Problems	28.9	34.7	22.3
Diabetes	3.3	5.8	2.6
Epilepsy	0.0	0.8	2.2
High Blood Pressure	16.5	11.6	9.5
Heart Disease	3.3	2.5	1.1
Effects of Stroke	2.5	0.0	0.7
Cancer	5.0	5.0	1.8
Alcoholism	1.7	1.7	1.1
Urinary Incontinence	4.1	5.0	1.8
Kidney Failure/Disease	1.7	0.8	0.7
Acne requiring medication	10.7	7.4	5.5
Cataracts	0.8	4.1	0.4
Glaucoma	0.0	0.8	0.4
Migraine	9.1	16.5	10.9
Head Injury	4.1	6.6	5.8
Alzheimer's Disease	0.0	0.0	0.0
Dementia	0.0	0.0	0.0
Emotional Illness	8.3	6.6	4.0
Mental Health Condition	2.5	7.4	2.9
Nervous System Disease	4.1	2.5	1.5
None of the Diagnoses	21.5	13.0	21.5

12.0 Analysis of Health Records

One of the objectives of the Fort Saskatchewan Community Exposure and Health Effects Assessment was to describe the distribution of human health outcomes potentially associated with exposure to airborne contaminants. This section of the report, reports a population-based study, using health records as a proxy measure of health outcomes to compare residents of Fort Saskatchewan with residents of Lethbridge on selected morbidity and mortality measures.

The analysis addressed two questions:

1. Is there an increased health risk for residents of Fort Saskatchewan?
2. Were the health care services obtained by the study participants representative of the services obtained by the population of Fort Saskatchewan?

A population cohort from the two communities was created from the Alberta Health Care Insurance Plan (AHCIP) Stakeholder Registry. Records for the members of the cohort were added from January 1, 1995 or thereafter, until either December 31, 2001 or until the individual died or moved out of the area. Records from the Alberta Fee-For-Service (FFS) Claims File and the Alberta In-Patient Hospital Morbidity File were linked to this file for each individual. The resulting database included demographic, socio-economic, residential history information, physician visits, and hospital stays. Overall, there were 23,687 people residing in Fort Saskatchewan and 100,817 people residing in the Lethbridge between January, 1995 and December, 2001. Of these, 10,230 (43.2%) from Fort Saskatchewan and 46,066 (45.7%) from Lethbridge were included for all seven years. An annual postal code-based population from 1984 to 2001 was also generated for comparison between communities over time.

A cohort design was used for morbidity measures, focusing on the period prevalence over 7 years (1995-2001) of measurement. A cross-sectional approach was applied for analysis of overall illness (January to December 2001) and mortality (1984-2001). The 3-year combined mortality was calculated to minimize the potential instability of rates due to small numbers. To control for confounding effects due to differences in the age distribution across communities and time period, the mortality rate and prevalence were adjusted to the age distribution of the 1996 Canadian census population. The standard error and 95% confidence interval of the age-adjusted rate were calculated.[62] When the 95% CI do not overlap, the differences are statistically significant, though slightly overlapping CIs might also be statistically significant (at a p-value of 0.05). Multivariate logistic regression was used to control for the effect of potential confounding from age, sex, First Nations treaty status, and socio-economic status in the analysis of the morbidity measures. Since the residence was used as a proxy measure of exposure, the final assessment of the cohort study was limited to permanent residents only. This included 7,777 individuals from Fort Saskatchewan and 29,125 individuals from Lethbridge.

Characteristics of the Population

A comparison of the population living in Fort Saskatchewan with the population living in Lethbridge indicates a number of differences (refer to Table 59). Overall, Fort Saskatchewan had slightly more male residents (51.5% compared to 49.3%), but fewer seniors (6.8% vs. 10.9%), fewer First Nations people (0.8% vs. 3.2%), and fewer individuals of low (12.6% vs. 17.4%) or lower (2.0% vs. 4.2%) socio-economic status. In addition, a smaller percentage of the population remained in the community for the complete seven-year period compared to the Lethbridge. Of those with complete seven-year observation, 76.0% of Fort Saskatchewan residents and 63.2% of Lethbridge residents stayed in the same residence postal code area over the 7-year period.

Table 60: Demographic and Socio-economic Characteristics of Community Populations, 1995-2001

Demographic and Socio-economic Factors	Category	Fort Saskatchewan (n=23 687) N	Fort Saskatchewan (n=23 687) %	Lethbridge (N=100 817) N	Lethbridge (N=100 817) %	*p*-value
Sex	Male	12,209	51.5	49,673	49.3	$p < 0.001$
	Female	11,478	48.5	51,144	50.7	
Age Group	0-14	6,487	27.4	25,061	24.9	$p < 0.001$
	15-64	15,594	65.9	64,752	64.3	
	65+	1,599	6.8	10,957	10.9	
First Nations Status [1]	Yes	189	0.8	3,209	3.2	$p < 0.001$
	No	23,498	99.2	97,608	96.8	
Socio-economic Status (SES) Surrogate Indicator	Lower[2]	483	2.0	4,283	4.2	$p < 0.001$
	Low[3]	2,978	12.6	17,564	17.4	
	Average[4]	20,226	85.4	78,970	78.3	
Complete 7-Year Observation[5]	Yes	10,230	43.2	46,066	45.7	$p < 0.001$
	No	13,457	56.8	54,751	54.3	
Mobility Status, 1995-2001	Moved[6]	2,453	24.0	16,941	36.8	$p < 0.001$
	Not Moved[7]	7,777	76.0	29,125	63.2	

[1] *Individuals registered with AHCIP had a treaty status at the time of registration and/o r updating.*

[2] *Lower: Receiving both social assistance and AHCIP subsidy.*

[3] *Low: receiving AHCIP subsidy only.*

[4] *Average: Non-AHCIP subsidy and non-social assistance recipient.*

[5] *Entered into the population cohort in January 1995 and still registered with AHCIP by December 31, 2001.*

[6] *Changed the residence postal code over a 7-year period of observation.*

[7] *Individuals with a complete 7-year follow-up who had the same residence postal code reported from 1995 through 2001.*

12.1 Morbidity of Respiratory Disorders

Respiratory disorders, particularly asthma, have received significant attention in studies of the potential impact of ambient air quality on human health. For example, several studies have reported a positive association between ambient air pollution and hospital admissions for asthma and other respiratory disorders.[63] For the purposes of this evaluation, the analysis focused on measures of morbidity due to asthma, bronchitis, COPD, and all respiratory disorders combined.

Proportion of Fee for Service (FFS) Practitioner Visits, Hospitalizations, and Both

The age-adjusted proportion of individuals who had visited a physician (FFS practitioner), had been hospitalized, or both were calculated for the permanent residents of Fort Saskatchewan and Lethbridge from 1995 through 2001.

As Table 61 shows, compared to the residents of Lethbridge, a smaller proportion of residents of Fort Saskatchewan visit a physician or a hospital for asthma (12.6% vs. 13.8%), bronchitis (10.2% vs. 13.6%), and COPD (11.7% vs. 15.8%) during the 7-year period. However, residents of Fort Saskatchewan were more likely to visit a physician or hospital for all respiratory disorders combined (82.5% vs. 78.1%), probably due to more common cold and other upper respiratory infections in this community. It has been reported that women who work inside the home have a higher rate of respiratory illness than women who work outside the home.[64] As well, rhinovirus and respiratory syncytial virus (RSV) – the major causes of common cold and other upper respiratory infections are primarily transmitted through close and perhaps prolonged contact - the conditions more prevalent at geographic areas of higher latitude with lower temperature.[65,66] Compared to Lethbridge, the residents of Fort Saskatchewan were more likely to be hospitalized for bronchitis, COPD, and all respiratory disorders combined. This difference may well be due to the difference in hospital admissions policies between the two communities.

Table 61: Proportion of Residents Visiting a Physician and/or Hospital for Respiratory Disorders

Diagnostic category (ICD-9)	Visit Group[1]	Fort Saskatchewan (n=7 777) N	%[2]	Lethbridge (n=29 125) N	%[2]	Group Comparison Ratio[3]	p-value[4]
Asthma (493)	Both	81	1.1	279	0.9	1.16	
	HV only	8	0.1	39	0.1	0.90	
	PV only	919	11.4	3,777	12.7	0.90	0.043
	No visit	6,769	87.4	25,030	86.2	1.01	
Bronchitis (490, 491)	Both	27	0.4	66	0.2	2.30	
	HV only	21	0.3	63	0.2	2.01	
	PV only	725	9.4	3,911	13.2	0.71	0.001
	No visit	7,004	89.8	25,085	86.4	1.04	
COPD (490-492,494, 496)	Both	51	0.8	239	0.7	1.25	
	HV only	32	0.5	49	0.1	3.69	0.001
	PV only	792	10.4	4,455	15.0	0.69	
	No visit	6,902	88.3	24,382	84.2	1.05	
All Respiratory Disorders (460-519)	Both	346	4.8	1,288	4.0	1.21	
	HV only	8	0.1	38	0.1	1.11	
	PV only	6,131	77.6	21,492	74.0	1.05	0.001
	No visit	1,292	17.5	6,307	21.9	0.80	

1 **Both** : *An individual had at least one visit to a physician and one hospitalization for a given diagnosis between January 1995 and December 2001;* **HV only** *: an individual had been hospitalized but had not visited a physician during the study period;* **PV only** *: an individual had visited a physician but had not been hospitalized during the study period.*

2 *The age-adjusted proportion according to the age distribution of 1996 Canadian census.*

3 *Poportion for residents of Fort Saskatchewan divided by the proportion for residents of Lethbridge.*

4 *Chi-square test for the difference in proportion between the residents of two communities.*

The Frequency of Visits for Selected Respiratory Disorders by Community

One of the questions raised is whether residents of Fort Saskatchewan visit a physician or a hospital more frequently for a given disease; Table 62 shows the mean and median number of days of visits for asthma, bronchitis, COPD, and all respiratory disorders in the permanent residents of Fort Saskatchewan and Lethbridge during the 7-year period of observation.

As shown, there is no significant difference in the adjusted mean days of visit for asthma, bronchitis, and COPD between the two communities. On average, the residents of Fort Saskatchewan visited a physician or a hospital for all respiratory disorders combined more frequently (7.2 days, SD=9) than the residents of Lethbridge (6.3 days, SD=8.4) due to common cold and upper respiratory infections.

Table 62: Mean and Median Number of Visits for Selected Respiratory Disorders by Community, 1995 Population Cohort during a 7-Year Observation

Diagnostic Category	Comparison Group	# Cases[1]	Mean[2]		Median	p-value[3]
			# days of visit	SD	# days of visit	
Asthma	Fort Saskatchewan	1,008	4.3	6.4	2	0.776
	Lethbridge	4,095	4.4	8.2	2	
Bronchitis	Fort Saskatchewan	773	1.9	2.6	1	0.438
	Lethbridge	4,040	1.8	2	1	
COPD	Fort Saskatchewan	875	2.3	3.9	1	0.071
	Lethbridge	4,743	2.6	5.2	1	
All respiratory disorders	Fort Saskatchewan	6,485	7.2	9	4	<0.001
	Lethbridge	22,818	6.3	8.4	4	

[1] *The number of individuals with a given diagnosis of respiratory disorders who are registered with AHCIP from January 1995 through December 2001and with a same residence postal code reported over 7 years.*

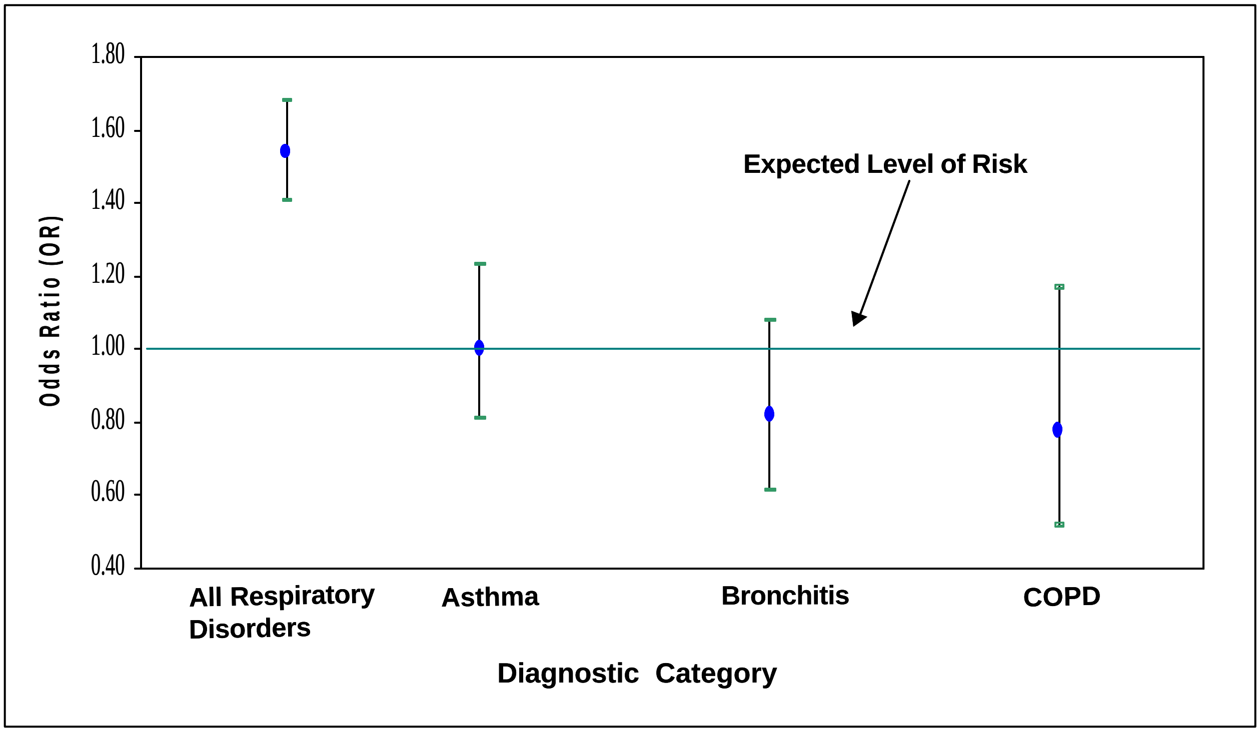
[2] *The adjusted average number of days of visit for a given diagnosis over seven years (1995-2001) in regression model, including age, sex, First Nations status, and SES status marker.*

[3] *The p-value of the F test for the statistical inference.*

Comparison of Prevalence of Asthma, Bronchitis, COPD, and Respiratory Disorders

Overall, during the seven-year period, the prevalence of visits to a physician and/or a hospital at least once in the residents of Fort Saskatchewan was lower than Lethbridge for asthma (13.0% vs. 14.1%), bronchitis (9.9% vs. 13.9%), and COPD (11.3% vs. 16.3%), but was higher for all respiratory disorders combined (83.4% vs. 78.3%). After adjusting for the effects from age, sex, First Nations status and socio-economic status, the pattern of difference remained, but to a much lesser degree and was not statistically significant. As stated previously, the remaining difference is most likely due to more common cold and other upper respiratory infections in this community. Figure 104 shows the adjusted odds ratio – no difference was found between the two communities for asthma, bronchitis, and COPD.

Figure 104: Estimated Relative Risk for Prevalence of Selected Respiratory Disorders: Fort Saskatchewan Compared to Lethbridge, 1995-2001



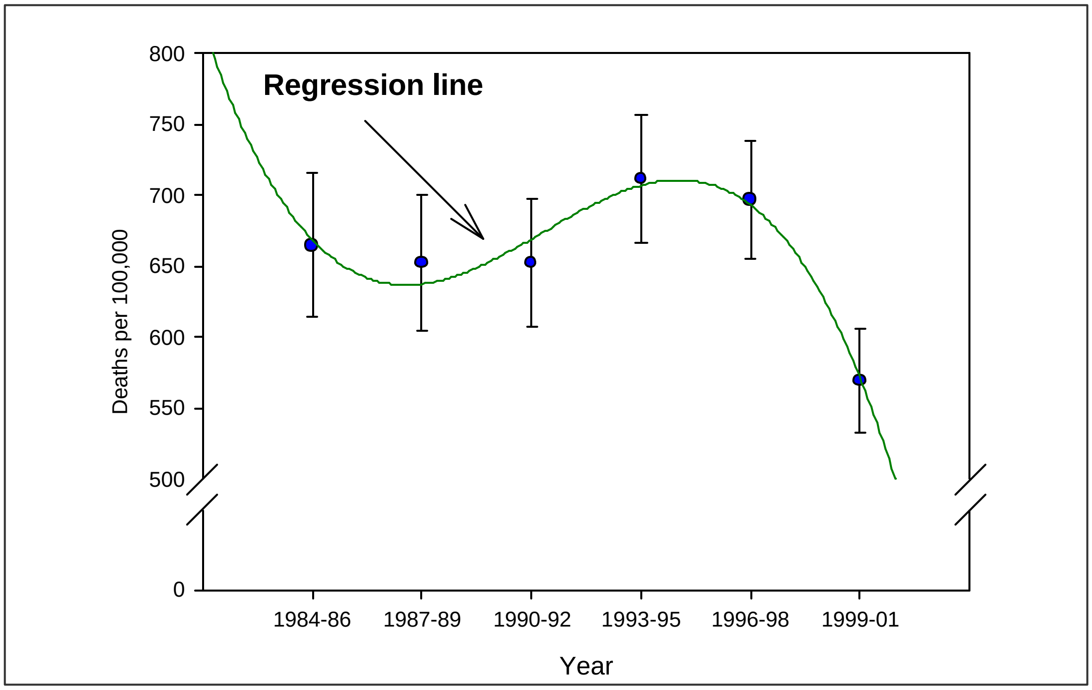
Note: Adjusted for the effects of sex, age, treaty status, and SES.

12.2 Mortality of Selected Causes of Death

Mortality rates have frequently been used as an outcome measure in environmental epidemiological studies. Several studies have examined the relationship between the ambient air quality and mortality due to cardiovascular disease,[67, 68] lung cancer,[69] or death from any cause.[70, 71, 72.]

Figure 105 shows the 3-year combined age standardized mortality rate from all causes of death for the residents of Fort Saskatchewan, 1984-2001. There was no increase in the standardized mortality rate for all causes of death in Fort Saskatchewan over an 18-year period (although the mortality rate was lower in 1999-2001 and slightly higher in 1993-1995 and 1996-1998).

Figure 105: Age-Standardized Mortality Rate of All Causes of Death, Fort Saskatchewan, 1984-2001

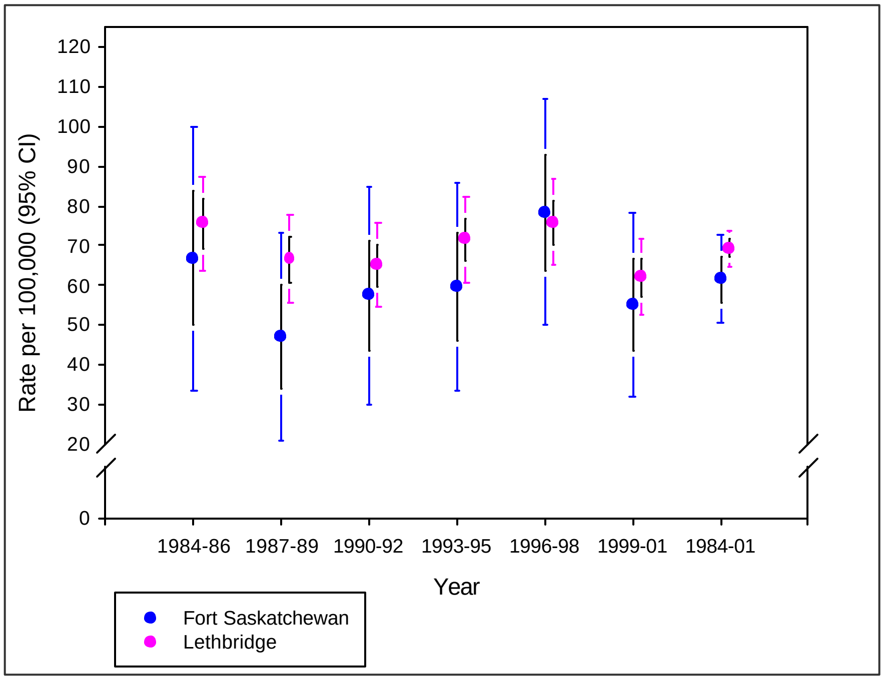


Note: 1) Adjusted to 1996 Canadian Census age distribution.
2) All causes of death of underlying disease: ICD-9 = 001-999

The rate of mortality from respiratory disorders, COPD, and all causes combined between the years 1984 to 2001 were compared for the residents of Fort Saskatchewan and the residents of Lethbridge. There was no evidence of an increased risk of death for residents of Fort Saskatchewan from respiratory disorders, COPD, pneumonia, or all causes of death combined for any of the 3-year period examined during 1984 and 2001 (Figures 106A, 106B, and 106C).

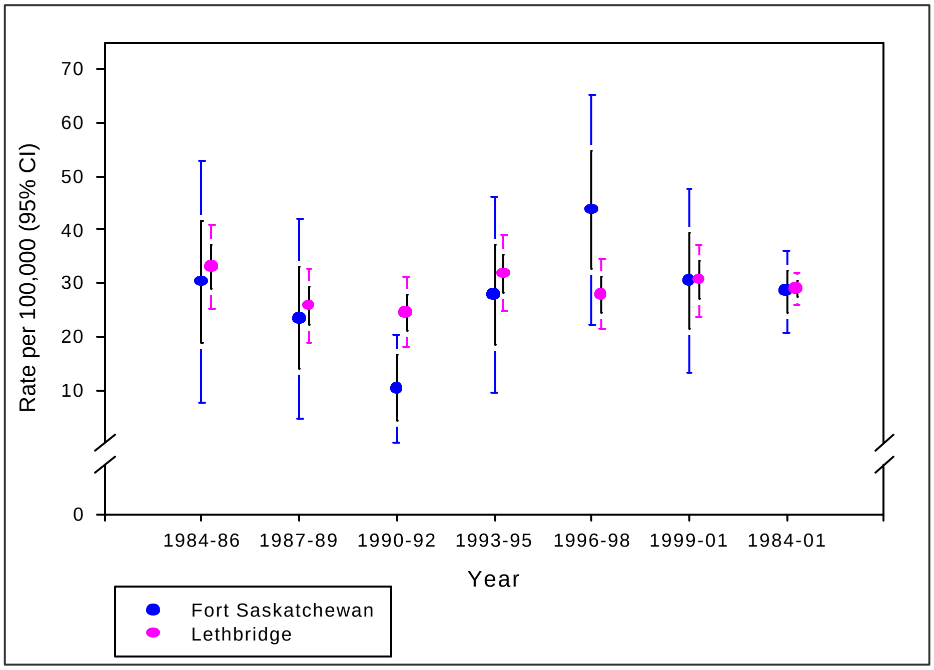
Figure 106: Comparison of Age Standardized Mortality Rates of Selected Causes of Death Between Fort Saskatchewan and Lethbridge, 1984-2001 (with 95% Confidence Interval)

A. Respiratory Disorders



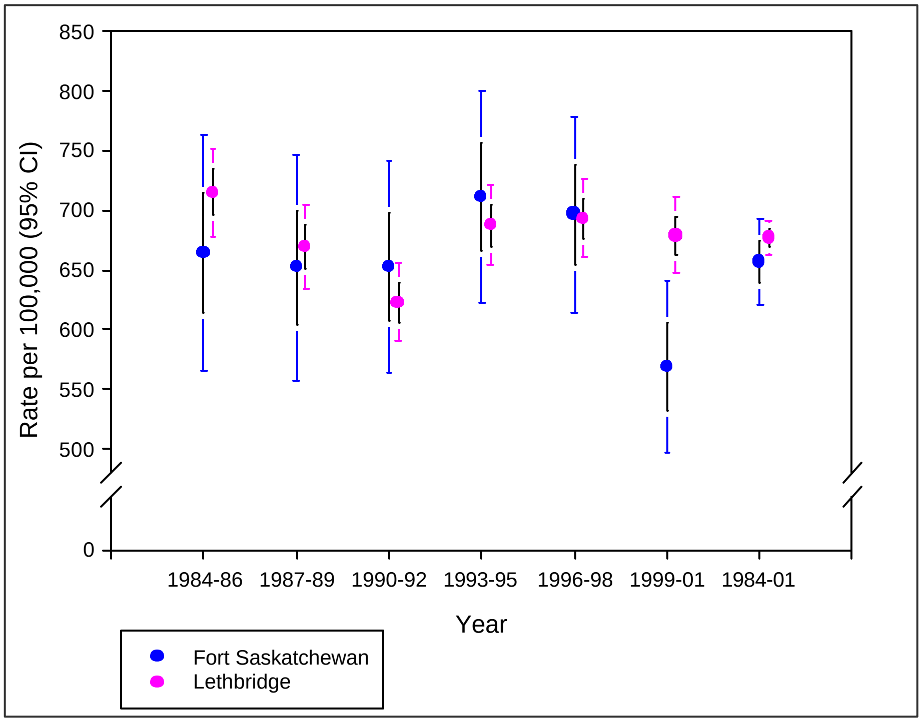
Note: 1) Adjusted to 1996 Canadian Census age distribution.
2) Respiratory Disorders: ICD-9 = 460-519.

B. COPD



Note: 1) Adjusted to 1996 Canadian Census age distribution.
2) Chronic Obstructive Pulmonary Disorders (COPD): ICD-9 = 490-492, 494, 496.

C. All Causes of Death



Note: 1) Adjusted to 1996 Canadian Census age distribution.
2) All causes of death of underlying disease: ICD-9 = 001-999

12.3 Comparison of Overall Illness: Participants vs. the General Population

Health records from Fee-For-Service claims between January and December 2001 were used to compare study participants with the general population of Fort Saskatchewan to determine if the study participants accessed health care services differently than the resident population of the community.

Of 138 study participants, 94.9% (n=131) visited a Fee-For-Service (FFS) health care practitioner between January and December 2001. Overall, this proportion is higher than the proportion (87.9%) for the general population of the community (refer to Table 63). However, the proportion is lower for younger and older participants. The average number of visits per year was also higher for study participants (14.3 visits per year) compared to resident population of the community (8.5 visits per year).

Table 63: Proportion Visiting a Healthcare Provider and Average Number of Visits for Any Illness by Age Group, Fort Saskatchewan, January to December 2001

Age Group	Participants (n=138)		General Population (n=16,442)	
	Proportion[1] (%)	Mean[2] Visit/Case-Year	Proportion[1] (%)	Mean[2] Visit/Case-Year
18-24	75.0	8.7	83.1	6.6
25-34	88.2	12.4	84.6	8.4
35-44	94.4	11.8	82.7	8.1
45-54	95.5	10.6	87.6	9.2
55-64	100.0	21.5	91.1	11.0
65+	85.7	28.8	97.7	16.3
Total	**94.9**	**14.3**	**87.9**	**8.5**

[1] The number of individuals who visited a Fee-For-Service practitioner at least once for any illness per 100 person-year under observation.
[2] The average number of visits per person with illness of a given age group, January to December, 2001.

12.4 Summary of Analysis of Health Records

Findings from the analysis of health records suggest the following:

- There is no evidence of either a significantly higher morbidity (period prevalence, frequency of visits) of asthma, bronchitis, and COPD in Fort Saskatchewan, nor an increased risk of death from all causes, respiratory disorders, and COPD in this area.
- There is a difference in the Fee-For-Service physician visits between the study participants and non-participants.
- There is evidence of an increased prevalence and frequency of visits for all respiratory disorders combined in Fort Saskatchewan. This is likely due to increased common cold and upper respiratory infections in this area. Continued surveillance is recommended.

Community variations in the rate of hospitalization for a given disease may be a reflection of differences in hospital practice across communities. Given that records of hospitalization account for only a small proportion of total morbidity records for most diseases, a combination of health records from both Fee-For-Service claims and In-Patient Hospital Morbidity data may allow a better estimation and more valid comparison of morbidity measures and inter-community differences.

13.0 Exposure Sources

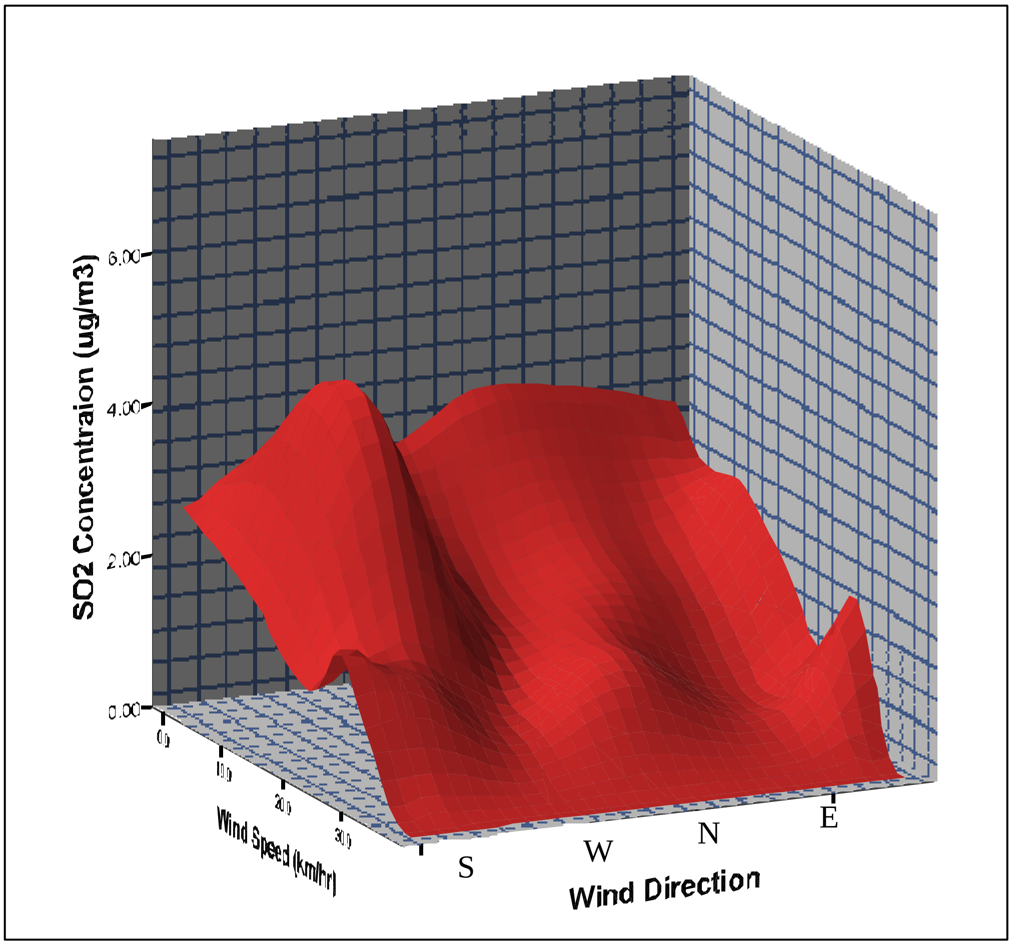
An objective of the Study was to quantify the relative contributions of various exposure sources and pathways to airborne chemicals. This section of the report will discuss sources of exposure drawing on an analysis of wind and ambient air quality data and some of findings of the previous section that addressed exposure pathways. This assessment qualitatively compares the relative contributions of indoor vs. outdoor exposure sources and further categorizes the outdoor sources as local (urban emissions), regional (oil sands industry), and background (levels not due to regional industry or the city).

In exploring the impacts of regional contaminant sources, hourly data from the AENV Fort Saskatchewan monitoring station was analyzed for the time period of the study.

13.1 Sulfur Dioxide (SO_2)

Figure 107 shows a surface that represents the average of hourly SO_2 readings taken with the Alberta Environment (AENV) monitors at the Fort Saskatchewan ambient station. As the figure shows, there were significantly higher average levels of SO_2 in the city of Fort Saskatchewan when the wind was from the south-southwest at moderate wind speeds. The increase in SO_2 levels in the city when winds are from the south-southwest is likely due to SO_2 emissions from the industries and the city of Edmonton, which are located in that direction. The significant impact of local emissions of SO_2 is defined in the part of the figure that shows the wind from the east at lower speeds. The impact of background levels was very low as is shown by the low concentration in the area of the figure with high wind speeds.

Figure 107: Average SO_2 Levels at Fort Saskatchewan Measured by AENV During (January 2000 to December 2001) Plotted by Wind Speed and Wind Direction



The impact of the regional SO_2 sources south-southwest of the city on the average SO_2 levels in Fort Saskatchewan was estimated. The estimate is based on an overlay of the SO_2 surface in Figure 107 and the wind diagram in Figure 12 (refer to section 6.14). As the wind diagram shows the predominant wind direction during the study was from south-southwest.

Estimates of SO_2 levels, unrelated to regional sources to the north of Fort Saskatchewan, were based on average levels when the wind was from eastern directions. Estimates of SO_2 levels attributable to the City of Edmonton and industries south-southwest of town were based on the difference between estimated levels from eastern sources and the estimated levels from south-southwest sources. Estimates of the proportion of SO_2 contributed by source are as follows:

- Portion of SO_2 levels due to south-southwest sources = 21% = (time weighted SO_2 levels due to south-southwest sources) / (time weighted total SO_2 levels).
- Portion of SO_2 levels due to local or non-northern sources = 79% = (time weighted SO_2 levels due to non- south-southwest sources) / (time weighted total SO_2 levels).

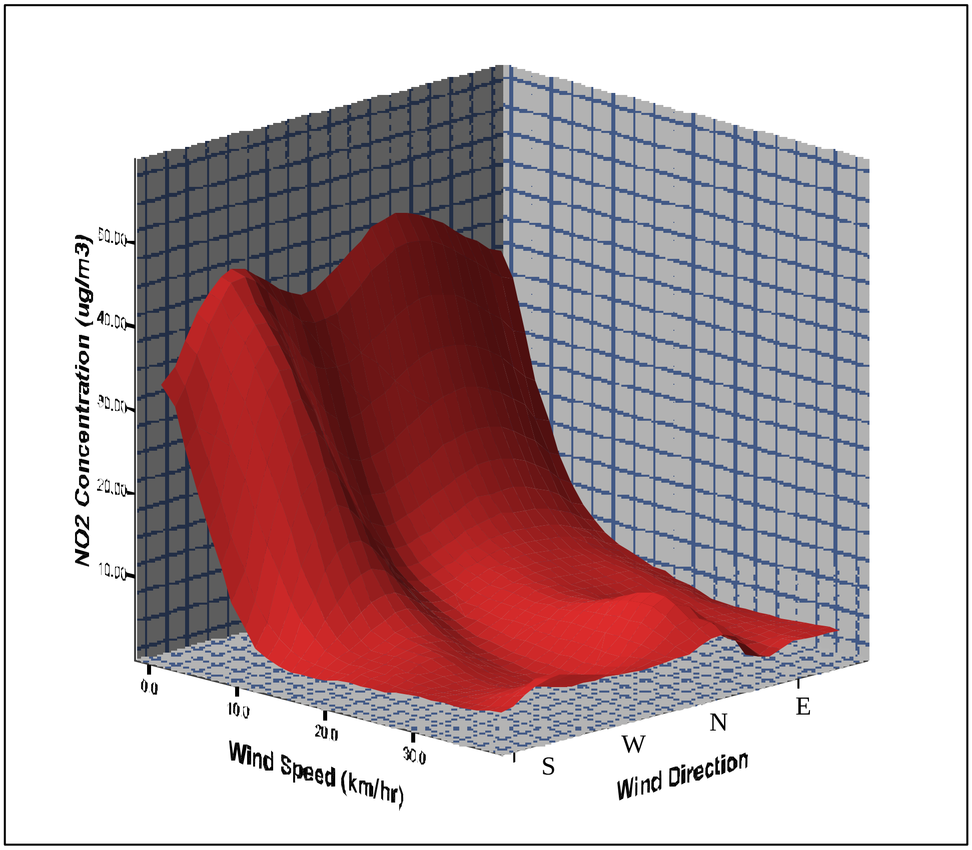
The SO_2 levels in Fort Saskatchewan are significantly higher when influenced by south-southwestern sources. Based on wind speed and direction data, 21% of the average SO_2 concentrations in Fort Saskatchewan were attributable to south-southwestern sources. This result is sensitive to wind direction. It should be kept in mind that these SO_2 levels are considered low.

Section 8.5 identified outdoor levels of SO_2 as an important driver of personal exposure both directly and through indoor air. This analysis indicates that local urban emissions and emissions south-southwest of town have a significant impact on the ambient SO_2 levels in Fort Saskatchewan. Based on these findings, the most important exposure source identified during this study was local sources followed by regional sources while background influences could not be identified.

13.2 Nitrogen Dioxide (NO_2)

Figure 108 shows the average NO_2 levels during the period of study with the highest concentration of NO_2 occurring at low wind speeds relatively consistent for all directions. The NO_2 concentrations in the figure indicate that ambient NO_2 levels in Fort Saskatchewan are dominated by local sources with little influence of regional or background sources being evident.

Figure 108: Average NO_2 Levels at Fort Saskatchewan Measured by AENV During (January 2000 to December 2001) Plotted by Wind Speed and Wind Direction



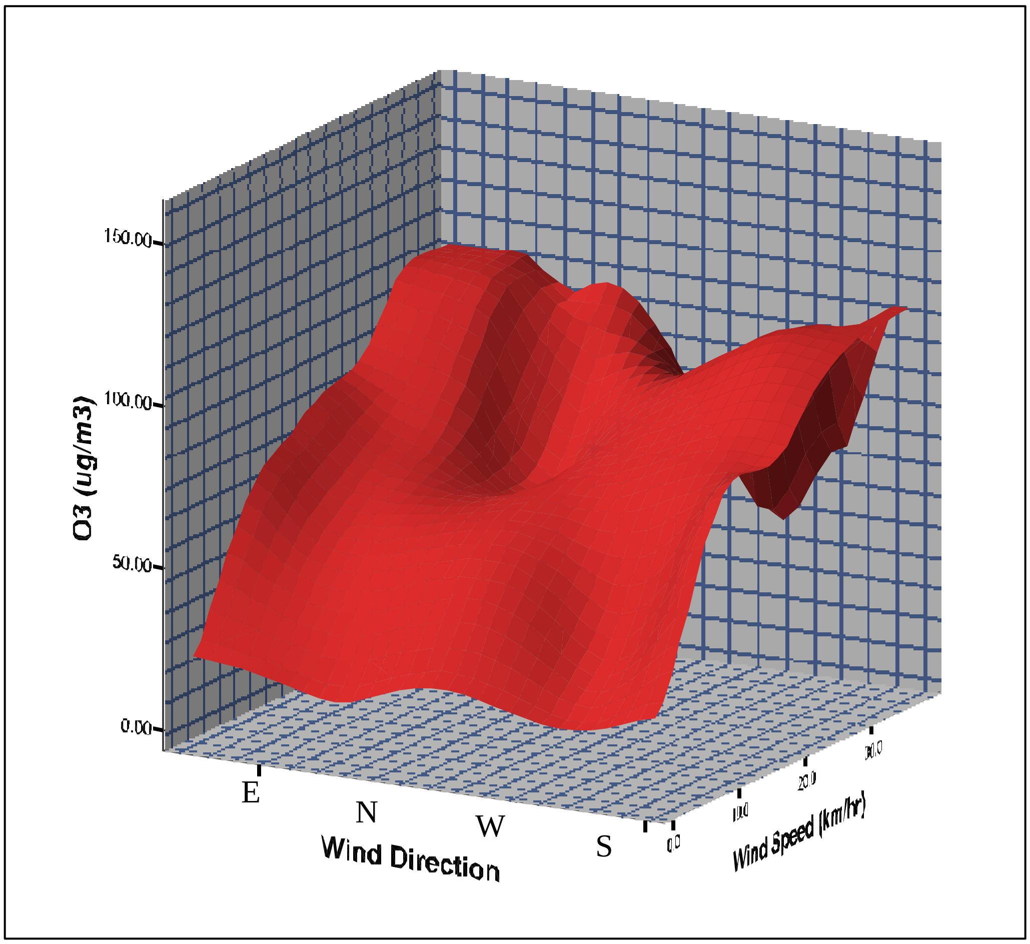
The analysis of NO_2 exposure pathways (refer to section 8.4) showed both indoor and outdoor impacts on personal NO_2 exposures. The results identified outdoor levels of NO_2 as the more important driver and pathway of personal exposure. Based on these findings, local emissions of NO_2 were the largest exposure source identified while the influence of regional or background sources was not detected.

13.3 Ozone

Figure 109 shows the surface representing the average ozone levels during the study with the highest levels of ozone occurring during higher wind speeds. These ambient levels did not predict personal exposures well (refer to section 8.6). This figure demonstrates the classic characteristics of ozone in urban areas where there are lower concentrations of ozone due to scavenging by urban pollutants during low wind speeds (low winds coincides with higher pollutant concentrations) and higher concentrations of ozone coincidental with lower urban pollution during high wind speeds. The figure does not demonstrate that the levels of ozone in Fort Saskatchewan are significantly impacted by regional pollution sources, but it does suggest that local urban pollution was an important influence on the ozone levels.

The behaviour of ozone in the environment is very complex making it difficult to draw succinct conclusions as to important exposure sources. This analysis indicates that outdoor air is the source of ozone in personal exposure and background sources are the most important relative source with regional and local sources not increasing personal exposure to ozone.

Figure 109: Average O_3 Levels at Fort Saskatchewan Measured by AENV During (January 2000 to December 2001) Plotted by Wind Speed and Wind Direction



14.0 Conclusions

The goal of the Fort Saskatchewan and Area Community Exposure and Health Effects Assessment Program was designed to explore the relationship between air quality and human health outcomes. The study collected a wide range of measures of health using both self-reported information and quantitative measures of health. Exposure levels to airborne chemicals and particulates were measured in a variety of locations and the relative contribution of various exposure sources and pathways to airborne chemicals was estimated. Finally, associations between the exposure data and human health effects were described. The key findings of the study are presented in the following sections.

14.1 The Study Sample

Despite an aggressive recruitment campaign, only 138 individuals volunteered for participation, and of these, only 126 provided a complete set of measures to complete the required analysis. The study sample reflected the population in terms of age, but a larger percentage of the study sample were female, had a higher education, and a greater average annual income compared to the rest of the population in the study area. In addition, the study sample included fewer smokers than expected.

Study participants indicated that they consumed fewer than the recommended number of servings of grain products, and more than the recommended number of non-nutritious foods each day. The sample also had a higher average body mass index (27.4) compared to the Canadian average of 25.4, indicating more obesity in the sample population than expected. In addition, the sample population indicated that a large portion of the sample barely meets the amount of exercise recommended by Health Canada.

14.2 Measures of Exposure

An exposure model was developed to describe the effects of nine factors on personal exposure. These nine factors were: 1) gender; 2) urban-rural location; 3) housing characteristics; 4) ownership of a garage; 5) job status; 6) smoking characteristics; 7) time activity pattern; 8) outdoor concentration levels; and 9) indoor concentration levels.

The following describes the major findings of the air quality investigation both in terms of the concentrations measured and the factors affecting the variations in personal exposure.

Nitrogen Dioxide (NO_2)

Levels were low compared to existing guidelines and were comparable to other similar studies. Median concentrations were 13.7 $\mu g/m^3$ (personal), 10.0 $\mu g/m^3$ (indoor), and 10.4 $\mu g/m^3$ (outdoor). The final model predicted about 67% of the variation in personal NO_2 exposure across individuals. Indoor variation accounted for over one-half of the variation in personal NO_2 exposure described by the model. Time activity was also an important driver of personal exposure while smoking and housing characteristics had smaller effects. The most important factor within time activity appears to be the amount of time spent indoors at work; higher exposure is associated with more indoor work time.

Sulfur Dioxide (SO_2)

Indoor and outdoor levels were very low compared to existing guidelines. Median concentrations were 0.70 $\mu g/m^3$ (personal), 0.34 $\mu g/m^3$ (indoor), and 2.30 $\mu g/m^3$ (outdoor). The final model predicted about 59% of the variation in personal SO_2 exposure across individuals. Overall, variations in activity patterns accounted for almost half the variation in personal exposure. Time spent indoors at home resulted in reduced SO_2 exposure while time spent outside at work increased exposure. Indoor variation had important effects on personal exposure. Smoking in the car was an important variable affecting SO_2 exposure.

Ozone (O_3)

Indoor and personal levels of ozone were very low. Outdoor levels were an order of magnitude higher. This suggests that ambient measures are an inadequate measure of personal exposure. Median concentrations were 6.1 µg/m^3 (personal), 4.0 µg/m^3 (indoor), and 47.4 µg/m^3 (outdoor). The final model predicted about 81% of the variation in personal O_3 exposure across individuals. The variation in personal exposure described by the model was mostly due to time activity acting directly and indirectly through indoor levels related to time spent indoors at home. Variations in indoor concentrations were also an important factor as well as outdoor levels acting directly and indirectly through indoor air.

Volatile Organic Compounds (VOCs)

Levels of measured VOCs were low. The final models for each VOC contaminant predicted between 56-81% of variation in personal VOC exposure across individuals. For example, the benzene model predicted about 56% of variation and median concentrations were 1.55 µg/m^3 (personal), 0.29 µg/m^3 (indoor), and 0.61 µg/m^3 (outdoor). For the rest of the VOCs, variation in indoor concentrations is the predominant factor affecting personal exposure; the other factors were of minor importance. Outdoor concentrations did not have a significant direct effect on personal exposure.

Particulate Matter 2.5mm ($PM_{2.5}$)

$PM_{2.5}$ outdoor concentrations measured in Fort Saskatchewan were similar with that found in other communities in that they were well below guidelines. Median concentrations were personal (15.1 µg/m^3), indoor (7.0 µg/m^3), and outdoor (6.6 µg/m^3). Variations in outdoor concentrations were not important as a predictor of variations in personal exposure within this community while variations in indoor levels, time activity, and smoking were found to be more important.

Personal exposure to PAHs bound to $PM_{2.5}$ is completely driven by outdoor levels except where smoking occurs (refer to *Appendix A*).

Exposure Sources

- Ambient concentrations were not a good predictor of personal exposures.
- The most important exposure source of nitrogen dioxide (NO_2) was identified as local sources. Influences from background and regional sources were not detected. The presence of indoor sources could not be confirmed.
- The most important exposure source of sulfur dioxide (SO_2) identified was local sources (urban emissions such as vehicle exhaust) followed by regional sources from the south-southwest (City of Edmonton and industries). An influence from background sources and indoor sources was not detected.
- The most important exposure source for ozone (O_3) was background sources. Indoor, local, and regional influences that increase exposure were not detected.

14.3 Measures of Health

Biomarkers of Exposure

The biomarkers of exposure were included to provide evidence of exposure to a variety of contaminants. Biomarkers for benzene, toluene, and nicotine were measurable (i.e., above detection limits), but all levels were unassociated with exposures measured using personal monitors.

Biomarkers of Effect

No statistically significant differences in neurocognitive functioning were found between the samples or in comparison to reference populations.

Self-Reported Health

Several standardized questionnaires were included to obtain measures of the participant's perceived health, as well as measures of mental and psychosocial health. No statistically significant differences between the samples were identified on any of the self-reported health questionnaires. The most common diagnoses in Fort Saskatchewan included back problems and other allergies (both reported by 29% of the sample).

Health Records

Findings from the analysis of health records suggest the following:

- There is no evidence of either a significantly higher morbidity (period prevalence, frequency of visits) of asthma, bronchitis, and COPD in Fort Saskatchewan, nor an increased risk of death from all causes, respiratory disorders and COPD in this area.
- There is a difference in the Fee-For-Service physician visits between the study participants and non-participants.
- There is evidence of an increased prevalence and frequency of visits for all respiratory disorders combined in Fort Saskatchewan. This is likely attributed to the increased common cold and upper respiratory infections in this area. Continued surveillance is recommended.

15.0 Discussion

> "A series of new studies over the past decade have demonstrated a link between ambient air pollution and several adverse human health effects…"[73]
>
> "It is critical to our understanding of health and the environment that we have credible information. Continuing to improve our exposure assessment is the key to understanding this relationship … the goal of such studies (i.e., personal exposure) is to gather sound scientific evidence based on the best possible technology." (Gabos, 1998)

There is ample evidence in the peer-reviewed literature that epidemiological studies (i.e., ecological studies) have been used to establish a correlation between ambient air quality and human health outcomes. However, there is little evidence of a causal relationship.[4] Furthermore, there is very little conclusive evidence that demonstrates the contribution to personal exposure from indoor and outdoor sources.

Many previous exposure studies have relied on data from static ambient air monitoring stations to represent population exposure contaminants. It is clear from the Alberta Oil Sands Community Exposure and Health Effects Assessment Program, the Grande Prairie and Area Community Exposure and Health Effects Assessment, and most recently, the Fort Saskatchewan and Area Community Exposure and Health Effects Assessment experience that air quality data recorded at static ambient air monitoring stations does not represent, and should not be interpreted as representing, personal exposure to the contaminants being monitored. If we are to better understand the relationship between air quality and human health outcomes, it is clear that personal exposure monitoring must become part of an enhanced long-term air monitoring strategy.

This approach (i.e., personal exposure monitoring) has been recognized by the Clean Air Strategic Alliance* (CASA), and by the Alberta Multi-Stakeholder Group on Particulate Matter and Ozone** (MSG-PM/O_3). CASA's Human Health Project Team developed a comprehensive air quality and human health monitoring framework that recognizes and supports establishing a long-term, systematic approach to data gathering, focused on improving our knowledge about the link between air quality and human health. The components of the comprehensive human health and air quality monitoring system include:

- Symptoms and public health complaints;
- Known human health effects of air contaminants;
- Information about relevant event occurrences;
- Ambient air quality monitoring data; and
- Human health effects monitoring data.

Recommendations from the MSG-PM/O_3 to Alberta Environment included the recommendation that: "personal exposure monitoring should become part of a long-term air monitoring strategy in any region within the country and these efforts should be encouraged and supported. Personal exposure monitoring data will help us better understand the relationship between air quality and human health outcomes."

These initiatives, together with the Community Exposure and Health Effects Assessment Programs completed in Fort McMurray, Grande Prairie, and Fort Saskatchewan, recognize that data gaps currently exist that limit our understanding of the relationship between air quality and human health outcome. These include:

- Identification of the responsible component(s) of air quality that is/are causally associated with adverse health effects;
- A description of the population and personal distribution of exposure to airborne chemicals and particulates; and
- An understanding of the relative contribution of various exposure sources and pathways to airborne chemicals (i.e., the relative contribution of outdoor and indoor air to the total exposure).

Recently, the National Environmental Respiratory Center (NERC) indicated support for addressing these data gaps. It states that, "environmental air quality research and regulatory strategies have focused largely on single pollutants and sources, but it is unlikely that the health effects observed in individuals or

[4] The strength of these ecological studies is that they provide evidence of an association between ambient air quality and human health. However, their weakness relates to judgements regarding causality; they lack the direct link between personal exposure to a contaminant and the resulting human health outcome. They also fail to tell us anything about individual exposure or individual risk.

populations are caused solely by single pollutants or sources. Indeed, as levels of most air pollutants are reduced, it is unlikely that the residual effects observed in populations are attributable to a single pollutant species or sources. There is an increasing need to know more about the contributions of individual pollutants and families of pollutants to the total effects of exposure to complex mixtures of air contaminants from man-made and natural sources. There is also a great need to better understand the health risks caused by interactions between exposures to environmental pollutants and to airborne materials encountered in the home and workplace."[74]

There is clearly a need to encourage others to develop and participate in activities that are consistent with the terms of reference and experience of the Community Exposure and Health Effects Assessment Programs completed in Fort McMurray, Grande Prairie, and Fort Saskatchewan. These are:

- Describe the population and personal distribution of exposure to airborne chemicals and particulates:
  - estimate the population distribution of selected airborne chemicals and particulates;
  - estimate the seasonal variation of exposure; and
  - characterize the personal variation of exposure as a function of individual activity patterns.
- Quantify the relative contribution of various exposure sources and pathways to airborne chemicals:
  - quantify the relative contribution of outdoor and indoor air to the total exposure.
- Describe associations between exposure to airborne chemicals and human health effects:
  - analyze occurrence relationships between selected exposures, biomarkers and health outcomes.

***** The mandate of the Clean Air Strategic Alliance is to bring together diverse stakeholder groups to solve air quality problems on a consensus, rather than adversarial, basis.
****** The Multi-Stakeholder Group on Particulate Matter and Ozone provided recommendations to Alberta Environment related to the Canada Wide Standard process addressing Particulate Matter and Ozone.

16.0 Abbreviations

AENV – Alberta Environment

AHCIP – Alberta Health Care Insurance Plan

BTEX – benzene, toluene, ethylbenzene, and xylenes

BMI – body mass index

CASA – Clean Air Strategic Alliance

COPD – chronic obstructive pulmonary disease

DNA – deoxyribonucleic acid

FFS – Fee-for-Service

GHQ – General Health Questionnaire

I/O – ratio of indoor exposure to outdoor exposure

L – litres

MDL – method detection limit

MSG-PM/O_3 – Alberta Multi-Stakeholder Group on Particulate Matter and Ozone

N – number of cases overall

NES2 – Neurobehavioral Evaluation System

NIS – Neuropsychological Impairment Scale

NO_2 – nitrogen dioxide

O_3 – ozone

P/I – ratio of personal exposure to indoor exposure

$PM_{2.5}$ – particulate matter of 2.5 microns or less (approximately 1/20 the diameter of a human hair); also called fine particles

P/O – ratio of personal exposure to outdoor exposure

RHA – Regional Health Authority

SD – standard deviation

SES – socio-economic status

SO_2 – sulfur dioxide

TEAM – Total Exposure Assessment Methodology

UK – United Kingdom

USEPA – United States Environmental Protection Agency

VOCs – volatile organic compounds

WMS-R – Wechsler Memory Scale – Revised

17.0 Definitions

Benzene[75]

- a water-soluble volatile organic compound (VOC) which at normal temperatures is a liquid, but readily evaporates and small amounts are detectable in the atmosphere.
- important sources are the combustion of petroleum fuels by motor vehicle engines and emissions associated with many industrial activities such as ore mining, wood processing, coal mining, textile manufacture, and processes used in the oil and gas industry.
- other sources, of which cigarette smoking is a major one, make important contributions to the exposure of individuals.
- benzene is a known carcinogen and appears on Health Canada's First Priority Substances List.

Biomarker

- a specific biochemical in the body which has a particular molecular feature that makes it useful for indicating environmental exposure, the progress of disease, or the effects of treatment.

Body Mass Index (BMI)

- a measure of body mass; it has the highest correlation with skinfold thickness or body density.

BTEX compounds

- the BTEX chemicals (benzene, toluene, ethylbenzene, and xylenes) are volatile organic compounds (VOCs) which are commonly found together in crude petroleum and petroleum products such as gasoline.
- they are also produced as bulk chemicals for industrial use as solvents and starting materials for the manufacture of pesticides, plastics, and synthetic fibres.

Empirical

- based on observation and experiment.

Ethylbenzene

- a water-soluble volatile organic compound (VOC)
- ethylbenzene is used primarily in the production of styrene; other uses include solvents in paints and varnishes, as products in synthetic rubber, household cleaning products, gasoline, pesticides, carpet glues, asphalt, and tobacco smoke.
- ethylbenzene will enter the atmosphere primarily from emissions and exhaust connected with its use in gasoline; more localized sources will be emissions, waste water, and spills from its production and industrial use.

Median

- the value halfway through an ordered data set, below and above which there lies an equal number of samples.

Method Detection Limit (MDL)

- the minimum concentration that can be measured and reported with confidence that the value is above zero -- that is, that the contaminant is actually present
- in this study, three standard deviations above the mean method blank levels were used as the MDL.

Morbidity

- the condition of being diseased or sick; a state of ill-health.

Nitrogen Dioxide (NO_2)[76]

- for the purposes of air quality monitoring, oxides of nitrogen (NO_X) is considered to be the sum of nitric oxide and nitrogen dioxide; most oxides of nitrogen are emitted in the form of nitric oxide which will rapidly react with ozone in the atmosphere to form nitrogen dioxide.
- in Alberta, about 43% of oxides of nitrogen emissions are produced by transportation (primarily by vehicles), while 37% are due to industrial sources (oil and gas industries) and 18% as a result of power plants (based on 1990 emission estimates).
- smaller sources of oxides of nitrogen include natural gas combustion, heating fuel combustion, and forest fires.

Odds Ratio

- Odds are the number of times an event is expected to occur *(a)* divided by the number of times it is expected not to occur *(b)* or *a/b*. This contrasts with the probability of an event defined as the number of times an event is expected to occur divided by the number of times it could have occurred, or *a/(a+b)*.
- An ***odds ratio*** is a ratio of the odds of an event occurring in one group divided by the odds of it occurring in another group. As the odds ratio deviates from 1.0 (indicating equal odds in the two groups), the larger is the disparity between the groups.

Ozone (O_3)[77, 78]

- ozone is both a naturally occurring gas, generated in the higher layers of the atmosphere and a major constituent of photochemical smog.
- unlike other pollutants, ground-level ozone is not emitted directly by man's activities, but is generated by a photochemical reaction of oxides of nitrogen (NO_X) and volatile organic compounds (VOCs) in the presence of sunlight.
- in Alberta, ozone concentrations are generally lower at urban locations than at rural locations due to the destruction of ozone by nitric oxide which is emitted by vehicles.
- in Alberta, maximum ozone values are generally recorded during the spring and summer months.

Particulate Matter (PM)[79]

- particulate matter consists of a mixture of particles of varying size and chemical composition.
- most man-made particles are in the range of 1 to 10 microns in diameter; particles less than 10 micrometers in diameter (PM_{10}) are considered to be inhalable particulates and are suspended in the air for an indefinite period of time.
- PM_{10} sources, which can be inhaled into the nose and throat but do not normally penetrate into the lungs, include windblown soil, road dust, dust resulting from other activities (e.g. harvest), and industrial processes, generally created during burning processes, consisting of fly ash from power plants, carbon black from diesel and gasoline engines, and soot from wood-burning.
- the fine particles ($PM_{2.5}$ and less), which can penetrate into the lungs (respirable particulates), are typically secondary aerosols that form when chemical reactions occur between sulfate (from power plants) or nitrate (from motor vehicles and industry such as oil and gas plants) and ammonia or from sources such as compressor stations, household heating appliances, and forest fires.

Relative Risk

- ratio of at-risk individuals to those not at risk in a group; ratio of a disease rate in the study population to the rate in the reference population.
- **adjusted relative risk:** ratio of a disease rate in the study population to the rate in the reference population when effects of confounding are taken into consideration.

Sulfur Dioxide (SO_2)[80,81]

- a water-soluble irritant gas and a major pollutant in the atmosphere formed during the processing and combustion of fossil fuels containing sulfur, for example from gas plant flares, oil refineries, pulp and paper mills, fertilizer plants, coal-fired power plants, power generating stations, metal smelters, and heating boilers.
- sulfur dioxide (along with NO_X) has a number of other environmental effects including lake acidification due to acid rain, and associated corrosion of stone and metalwork.
- sulfur reacts in the atmosphere to form sulfuric acid and acidic aerosols which contribute to acid rain; combines with other gases to produce aerosols which may reduce visibility causing haze over large regions.
- in Alberta, it is estimated that 42% of sulfur dioxide emissions are emitted by natural gas processing plants while oil sands and power plants produce 26% and 18%, respectively, based on 1990 emission inventory.

TEAM

- method developed by the USEPA to determine exposures of the general population to certain pollutants.

Toluene

- a water-soluble volatile organic compound (VOC).
- the largest chemical use for toluene is in the production of benzene and urethane; also used as a solvent, gasoline additive, and in the manufacture of explosives, dyes, cements, spot removers, cosmetics, antifreezes, asphalt, and detergent.
- toluene is released into the atmosphere principally from the volatilization of petroleum fuels and toluene-based solvents and thinners, and from motor vehicle exhaust.
- toluene appears on Health Canada's First Priority Substances List.

Volatile Organic Compounds (VOCs)

- VOCs are chemicals that contain the element carbon.
- VOCs produce vapors readily; at room temperature and normal atmospheric pressure, vapors escape easily from volatile liquid chemicals.
- VOCs include gasoline, industrial chemicals such as benzene, solvents such as toluene and xylene, and tetrachloroethylene (perchloroethylene, the principal dry cleaning solvent).
- VOCs can be emitted naturally or as by-products of industrial processes.

Xylene

- a water-soluble volatile organic compound (VOC)
- found in coal and wood tar, and crude wood spirit; used primarily as solvents for which their use is increasing as a replacement for benzene and in gasoline.
- major environmental releases of xylenes are due to emissions from petroleum refining, gasoline, and diesel engines.
- xylene appears on Health Canada's First Priority Substances List.

18.0 Endnotes

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Appendix A

Measuring Exposure to Polycyclic Aromatic Hydrocarbons in Fort Saskatchewan, Alberta

May 2003

By
Health Surveillance, Alberta Health and Wellness

Executive Summary

This is a report of a study to measure exposure to polycyclic aromatic hydrocarbons (PAHs) as an indicator of products of incomplete combustion. This work was done as a sub-study of the "The Fort Saskatchewan and Area Community Exposure and Health Effects Assessment".

Public concern over the health and environmental effects of products of incomplete combustion has been increasing. In addition to outdoor anthropogenic sources of incomplete combustion including gas flaring in the oil industry, "teepee" burners in the forest industry, automobile exhaust in urban centers, controlled burning on farmland, and controlled or natural forest fires, there are also many indoor sources including fireplaces, cigarette smoking, and cooking. Understanding personal exposures to products of incomplete combustion is important to adequately address public health concerns associated with the emission of these pollutants. Information on the levels of personal exposure to products of incomplete combustion is needed to understand the human health implications. Additional information on the relative contribution of the various emission sources is valuable in identifying high impact emissions and can provide evidence for decision-making in support of public policies affecting emissions of health concern.

The two measurement techniques used were "integrated sampling" and "real-time monitoring". Integrated sampling involves collecting PAHs on filter media over a period of time, shipping of the filters to the laboratory where the samples are extracted and analyzed using gas chromatography and mass spectrometry (GC/MS). Real-time monitoring captures and analyzes samples in the field using a device that provides moment-to-moment results. This real-time monitor differentiates between outdoor and indoor sources of PAHs and can characterize the temporal variations in air quality. The monitor effectively differentiated between relative levels changing over time at one site but was only predictive of absolute measures compared at different sites when high PAH levels, due to indoor smoking, were encountered. The real-time PAH measures combined with wind speed and direction may prove effective in apportioning outdoor PAH levels between local and regional sources. Integrated samples were effective in comparing 7-day average absolute levels indoors, outdoors, and personally. The impact of indoor and outdoor levels on the personal exposure to PAHs was characterized by using the "fingerprint" of individual PAH compounds in the personal, indoor, and outdoor samples.

Levels of PAHs were higher in the town of Fort Saskatchewan when compared with the surrounding areas and the City of Grande Prairie but lower than large urban centers. These increased levels are due to the regional sources (industries and the City of Edmonton). Outdoor levels and sources drive exposure to the heavier (larger molecular weight) PAHs when there is no apparent or known contact with cigarette smoking. Smoking was the only indoor source of the heavier group of PAH compounds identified in the study. Indoor levels and sources drive exposure to the lighter group of PAH compounds and while smoking appears to be a source of these compounds, there are other sources that appear to be more significant.

An examination of PAH levels with wind speed and direction data determined that local emission in the town, background levels, and regional sources from the south-southwest (Edmonton and industries) each had a similar impact on the average PAH concentration during the study. Emissions from regional sources to the north-northeast of the city have roughly half of the impact of the other sources due to the fact the wind seldom blows from that direction.

Table of Contents

1.0 Introduction

Public concern over the health and environmental effects of products of incomplete combustion has been increasing. In addition to outdoor anthropogenic sources of incomplete combustion including gas flaring in the oil industry, "teepee" burners in the forest industry, automobile exhaust in urban centers, controlled burning on farm land, and controlled or natural forest fires, there are also many indoor sources including fireplaces, cigarette smoking, and cooking. Understanding personal exposures to products of incomplete combustion is important to adequately address public health concerns associated with the emission of these pollutants. Information on the levels of personal exposure to products of incomplete combustion is needed to understand the human health implications. Additional information on the relative contribution of the various emission sources is valuable in identifying high impact emissions and can provide evidence for decision-making in support of public policies affecting emissions of health concern.

This study investigated levels of exposure to incomplete combustion products by measuring the concentration of polycyclic aromatic hydrocarbons (PAHs). PAHs are multi-ringed compounds that can be formed by incomplete combustion processes. Some PAH compounds exhibit carcinogenic effects in humans (IARC, 1983-1985), the earliest documentation dates back over 200 years, when an increase in scrotal cancer was noted among chimney sweeps in London (Pott, 1963).

The current study involved measuring PAH levels indoors, outdoors, and in the personal breathing zone of nine individuals, each for one consecutive 7-day period. The two complementary measurement techniques used were integrated samples and real-time monitoring. Integrated samples with laboratory analysis can provide concentrations of individual PAH compounds, but the short-term fluctuations in the levels cannot be identified. Real-time monitoring identifies short-term fluctuations in total PAHs but no information on individual PAH compounds is provided. These techniques have been widely used and are recommended by others to investigate air contamination due to products of incomplete combustion (Chuang *et al.*, 1999).

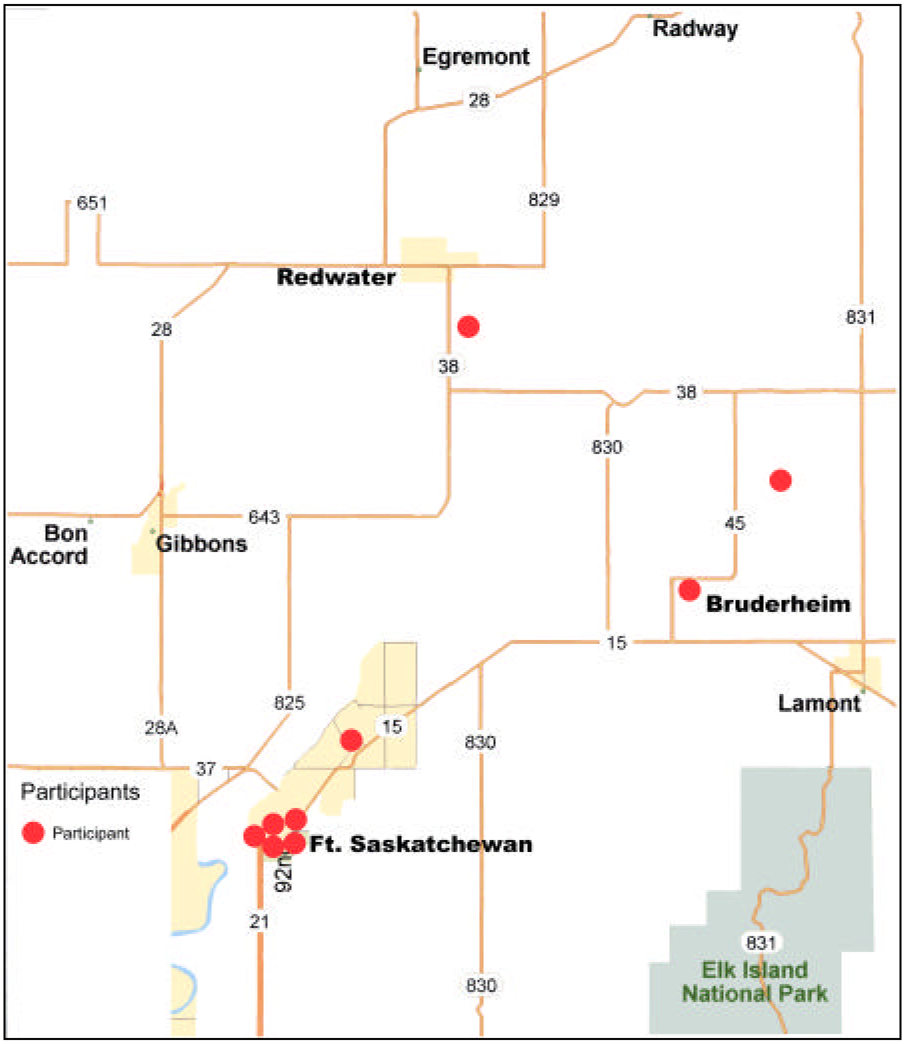
2.0 Objective

The main study objective was to gather data on the levels of PAHs in Fort Saskatchewan and area.

3.0 Methods

Volunteers in Fort Saskatchewan, Alberta were monitored over a consecutive 7-day period for personal, indoor, and outdoor air concentrations of PAHs between August and October 2001. Measurements of PAHs were taken using 7-day integrated samples and real-time monitoring using the PAS 2000 CE PAH monitor (Ecochem Analytics Inc.). In addition to the PAH samples, 7-day integrated samples of SO_2, NO_2, VOCs, and O_3, were also collected outdoors, indoors, and in the participants' breathing zone (see Fort Saskatchewan and Area Community Exposure and Health Effects Assessment Program: Final Report for results). The study involved nine participants: 5 from the community of Fort Saskatchewan and four from surrounding areas. The map in Figure 1 shows the locations of the participants.

Figure 1: Map of Locations of Urban Volunteers' Residences



3.1 Real-time Monitored PAH

PAHs were monitored nearly continuously indoors and outdoors at the residence of each participant for the 7-day period. The sampling method consisted of a PAS 2000 CE PAH (Ecochem Analytics Inc.) monitor that estimates the total concentration of PAHs with four or more aromatic rings using a photo-ionization detector. The monitor was connected to a manifold and valve system that alternated, continuously drawing a sample from the indoors for a five minute period and then from the outdoors for a five minute period. A data logger was used for data collection and for timing the alterations of the valve. Average readings over a 30-second time period were recorded with the first reading of each five minute-sampling interval discarded, resulting in nine usable measures of both indoor and outdoor air every ten-minute cycle. The data plots developed from these data used one hour running averages to minimize the noise in the data.

The detection of PAH by the PAS 2000 CE monitor is based on the measurement of small electric charges induced by the photoelectric ionization of PAH adsorbed on the surface of carbon aerosols (Agnesod *et. al*, 1996). The monitor has a demonstrated ability to detect PAH compounds containing four or more aromatic rings like benzo(a)pyrene (Ramamurthi *et al.*, 1997). The PAS 2000 was not considered to be specific for individual PAH compounds but has proved effective as a total PAH aerosol monitor for a given combustion source (Wall, 1996). Evaluations of the performance of this monitor have recommended its use in estimating human exposure related to various activities that may generate PAH (Wilson *et al.*, 1994). This monitor provided a good comparison of the changes in particulate-bound PAH over time, although caution should be used when interpreting absolute levels as they may vary depending on combustion sources.

The instrument response to PAHs seems to have changed compared with an earlier study in Grande Prairie the previous year. The output from the two studies cannot be compared quantitatively.

3.2 Integrated PAH Samples

Seven-day integrated samples of PAHs in the personal, indoor, and outdoor environments were collected at the residence of each volunteer. The sample method for the personal, indoor, and outdoor samples consisted of a particulate matter (PM) sampler to capture particulate-bound PAH followed by a polyurethane foam (PUF) filter to capture PAH in the vapor or gaseous phase. Generally, under normal temperatures the heaviest PAHs (least volatile) occur in the environment bound to the fine particulates in air while the lightest PAHs (most volatile) occur entirely in the vapor phase with the compounds between (semi-volatile) occurring in both media. A size selective impactor head with a cut-size of 2.5 μm (MSP Corporation and Airmetrics) containing a glass fiber filter was used as the PM sampler. The samples were analyzed for the list of PAHs in Table 1 at the Centre for Toxicology at the University of Calgary, Alberta. The Centre for Toxicology is a public health laboratory. The Centre for Toxicology analyzed a complete set of personal, indoor, blank, and outdoor samples from each participant using a GC/MS method.

Table 1: Individual PAH Compounds Analyzed in Integrated Samples

1	Naphthalene
2	Acenaphthylene
3	Acenaphthene
4	Fluorene
5	Phenanthrene
6	Anthracene
7	Fluoranthene
8	Pyrene
9	Benzo(a)anthracene
10	Chrysene
11	Benzofluoranthenes
12	Benzo(e)pyrene
13	Benzo(a)pyrene
14	Perylene
15	Dibenzo(a.h)anthracene
16	Indeno(1,2,3-cd)pyrene
17	Benzo(ghi)perylene

4.0 Results

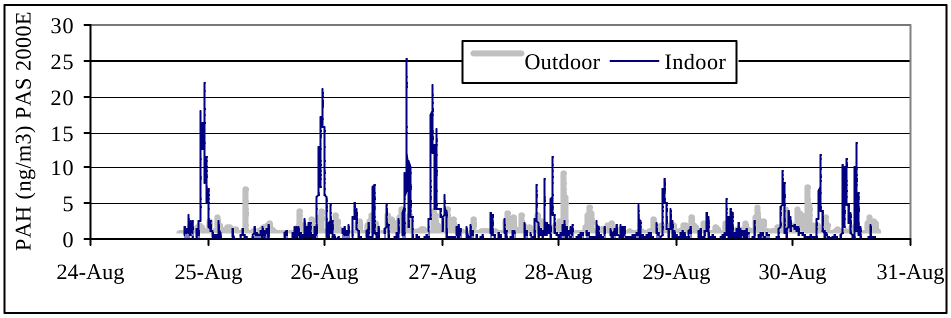
The results of the two measurement techniques are provided with a brief discussion demonstrating the insights gained from the different data.

4.1 Real-time PAHs

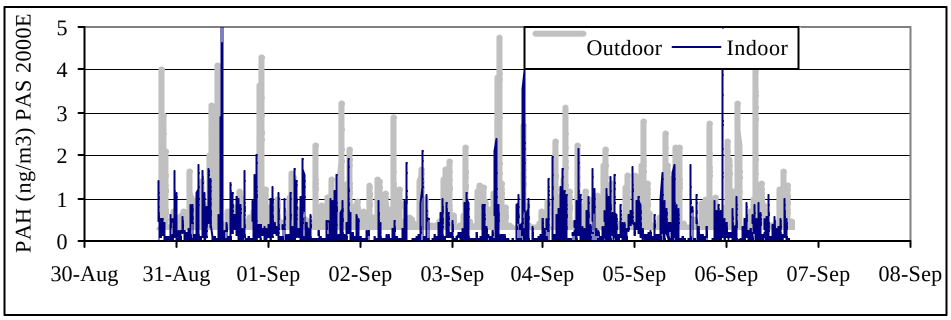
Eight of the 9 participants were successfully monitored for PAHs using the PAS 2000 CE. Patterns of PAH levels from the houses monitored are shown in Figures 2A to 2H. In these figures a blue line and a pink line represent the concentration of PAHs measured with the PAS 2000 CE indoors and outdoors, respectively. Generally, the PAH level indoors followed closely the outdoor levels, except when indoor exposure sources occur, mainly cigarette smoking indoors, as shown in Figures 2A and 2C. Table 2 shows the average levels, a ratio of indoor over outdoor levels. Clearly, the highest ratios of indoor over outdoor occurred in the house where smoking took place.

Figure 2: Real-Time Measures of PAH Level Indoors and Outdoors at the House of Participants

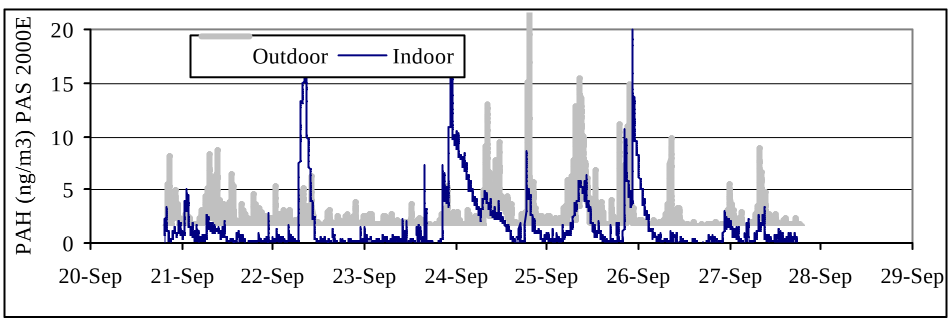
A. Participant #22



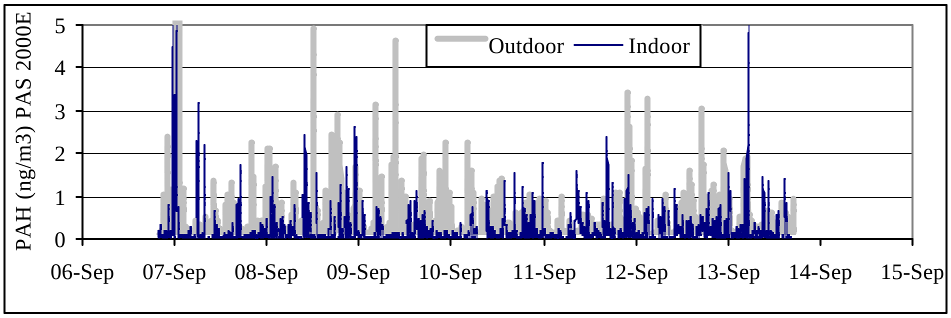
B. Participant #23



C. Participant #24



D. Participant #25



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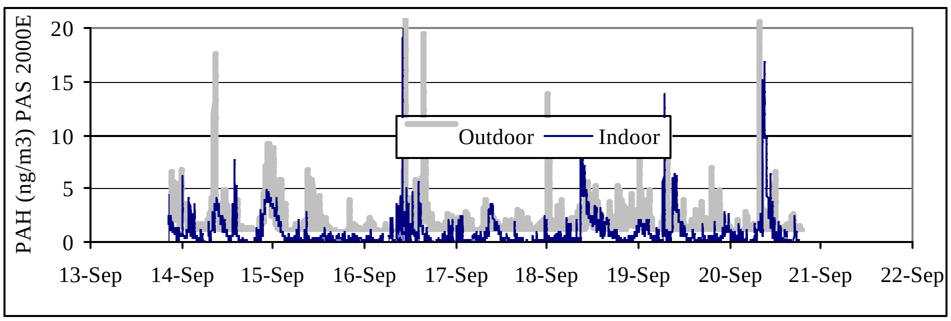
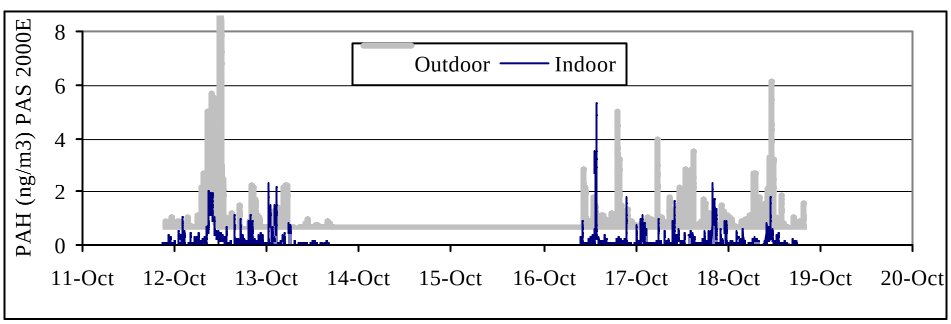
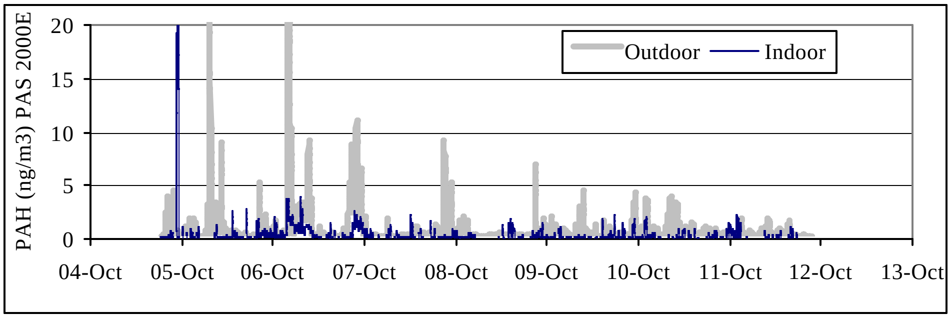


F. Participant #27



G. Participant #28



H. Participant #29

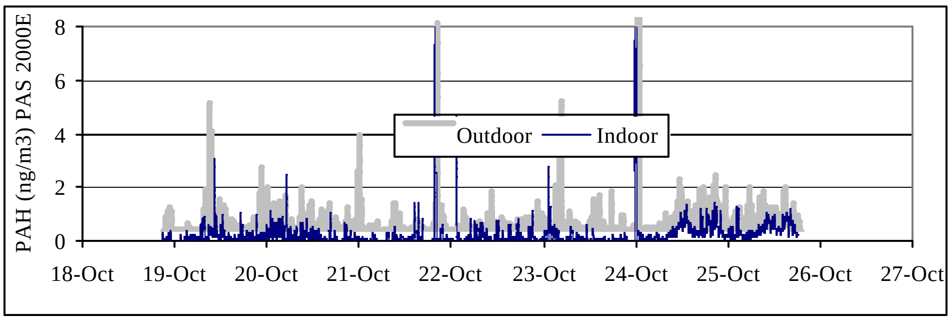


Table 2: Summary of Real-Time PAH Data From Houses in the Study

Participant #	Smoking	Rural	Indoor Average	Outdoor Average	in/out Ratio
21		yes	-	-	-
22	yes	yes	1.30	0.28	460%
23		yes	0.23	0.23	103%
24			1.58	0.80	196%
25		yes	0.21	0.25	86%
26			0.93	0.86	108%
27			0.17	0.31	54%
28			0.25	0.59	43%
29			0.26	0.28	92%

These data suggest that outdoor levels of PAHs have an important impact on indoor levels. Increases in outdoor levels lead to increases in indoor levels after a brief lag period. Important information on the time of day the outdoor increases occur can be used to speculate on the exposure sources.

4.1.1 Local and regional sources

Studies have shown that weak air movements or calm conditions over cities are correlated with poorer air quality due to pollution from local sources not being effectively dispersed (Delaney *et al*, 1998). A study in Fort McMurray, Alberta revealed that the relative impact of pollution sources in the city (local) compared with an industry 50km away (regional) could be quantified by plotting hourly contaminant levels with wind speed and direction (see The Alberta Oil Sands Community Exposure and Health Effects Assessment: Summary Report). Two views of a surface representing the mean of the real-time PAH data collected in Fort Saskatchewan are shown in Figures 3 and 4. Two views are presented to provide a good perspective of the dominant features of the figure. The surface is based on only 8 weeks of monitoring, which is not adequate to draw firm conclusions and accordingly these results are preliminary findings.

Figure 3: First View of Surface Representing Mean Real-Time Measures of PAH Levels Outdoors Compared to Wind Speed and Direction

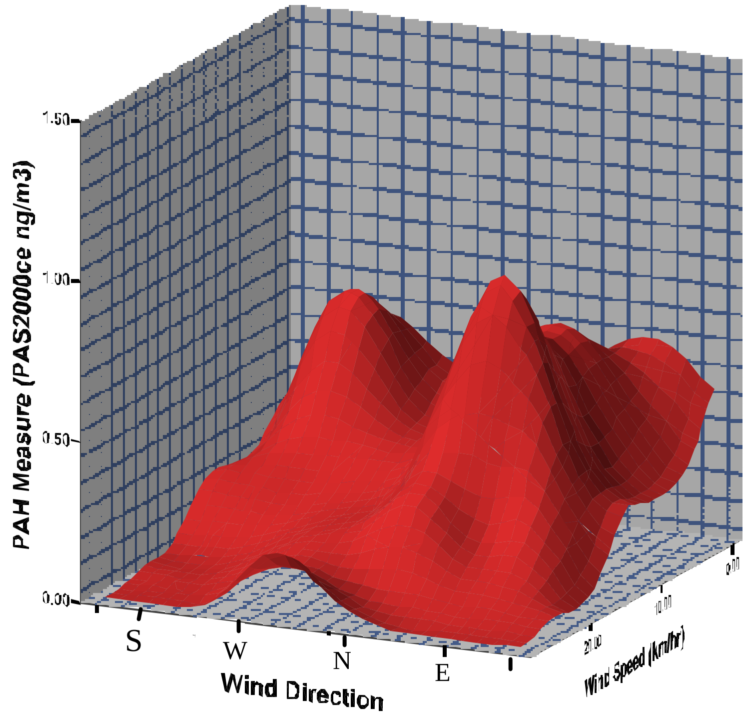
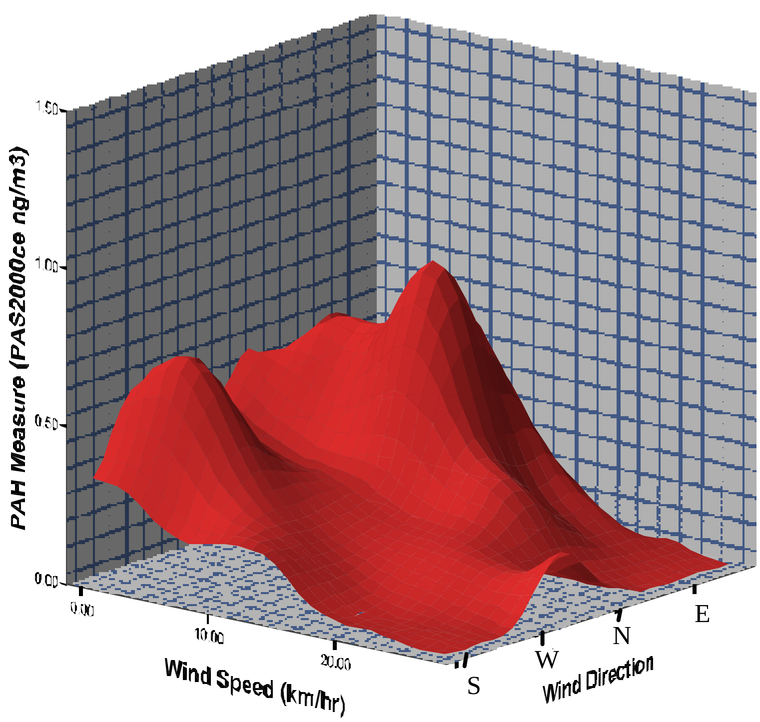


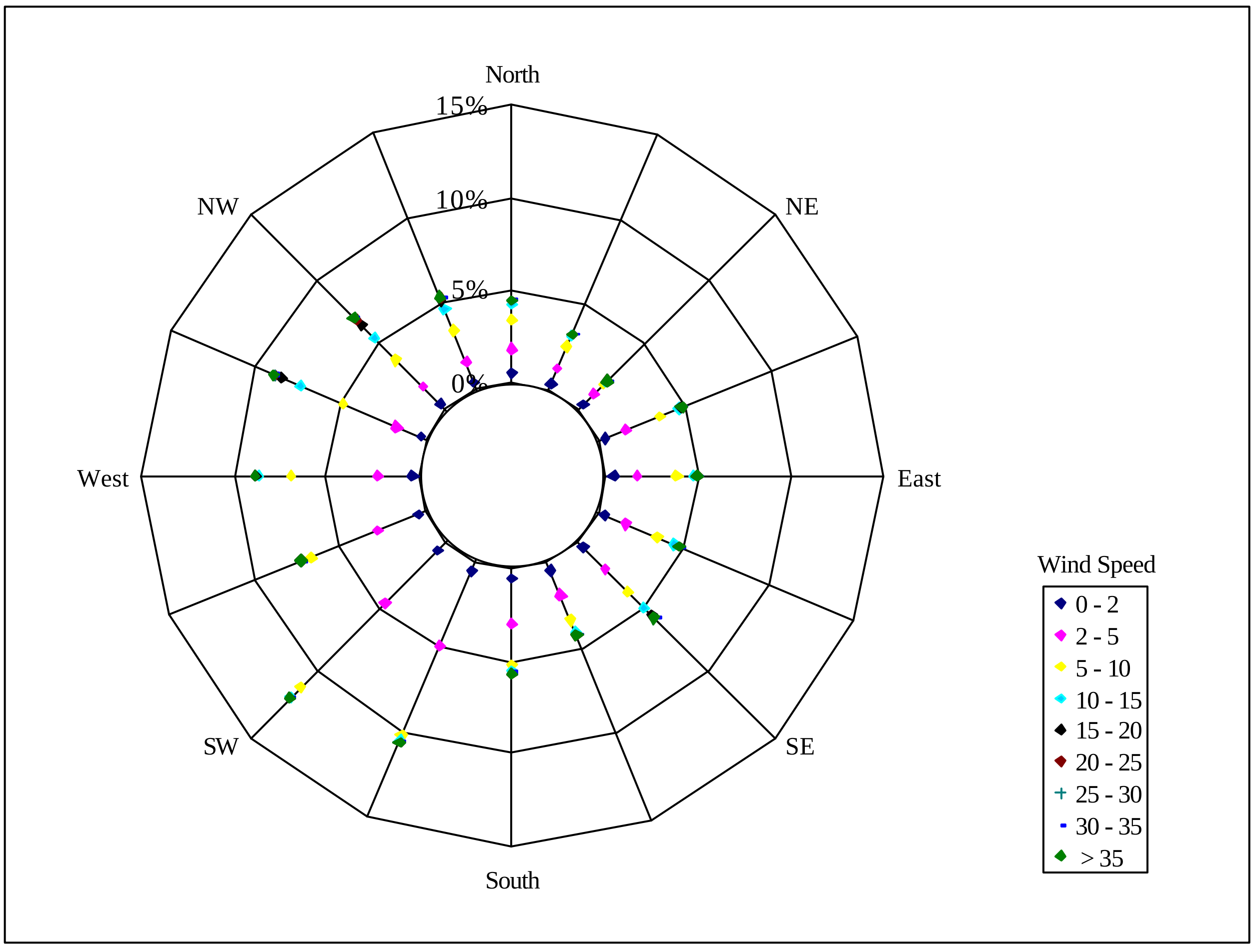
Figure 4: Second View of Surface Representing Mean Real-Time Measures of PAH Levels Outdoors Compared to Wind Speed and Direction



As Figures 3 and 4 show, there were significantly higher average levels of PAHs in the town of Fort Saskatchewan when the wind was from the SSW (south-southwest) at low wind speeds and when the wind was from the NNE (north-northeast) at low to moderate wind speeds. The increase in PAH levels in the town when winds are from the SSW are likely due to PAH emissions from the City of Edmonton and industries that are located SSW of town. The increase in PAH levels in the town when winds are from the NNE is likely due to PAH emissions from the industries that are located NNE of town. The impact of local town PAH emissions are defined in the part of the figure that shows the wind from the east at low speeds. The impact of background levels is shown by the low concentration in the area of the figure with high wind speeds.

The impact of the regional PAH sources NNE and SSW of the city on the average PAH levels in Fort Saskatchewan was estimated. The estimate is based on an overlay of the SO_2 surface in Figures 3 and 4 and the wind diagram in Figure 5. The wind diagram describes the percent of time the wind blows from various directions and speeds. As the wind diagram shows, the predominant wind direction in Fort Saskatchewan was from the SSW.

Figure 5: Summary of Wind Patterns in Fort Saskatchewan



Estimates of PAH level from local sources were based on average levels when the wind was from the east at low to moderate wind speed. PAH levels attributed to background sources were based on average PAH levels with wind from the east over 20km/hr. PAH levels attributable to the regional sources were estimated by subtracting the spikes in the surface at NNE and SWW directions from the background and local levels. Estimates of the proportion of PAH contributed by sources are as follows:

- Portion of PAH levels due to industries north-northeast of town = 14% = (time weighted PAH levels due to northern sources) / (time weighted total PAH levels).
- Portion of PAH levels due to City of Edmonton and industries south-southwest of town = 31% = (time weighted PAH levels due to south-southwest sources) / (time weighted total PAH levels).
- Portion of PAH levels due to local sources = 28% = (time weighted PAH levels due to local sources) / (time weighted total PAH levels).
- Portion of PAH levels due to background = 27% = (time weighted PAH levels due to background sources) / (time weighted total PAH levels).

The PAH levels in Fort Saskatchewan are significantly higher when influenced by northern and southern regional sources. Background levels, local sources, and regional sources south-southeast each have a similar impact on the PAH levels while regional sources to the north-northeast have roughly half of that impact. The regional sources north-northeast have a lesser effect because the wind seldom blows from that direction.

A fire at the BP Canada fractionation plant northeast of Fort Saskatchewan, August 26 to September 3, did not have a measurable effect on the PAH levels in the town because the wind did not blow toward the town during that time period.

4.2 Integrated Sampling PAHs

The results of the integrated samples of PAHs in the outdoor, indoor, and personal air is shown in Tables 3A to 3C. The table presents the air concentrations (ng/m^3) of the PAHs measured and lists the PAH compounds measured in order of ascending molecular weights (lightest to heaviest). As expected, the average levels measured in Fort Saskatchewan are lower than the minimum levels measured in other studies in larger centers (Brown *et al.*, 1996; Chuang *et al.*, 1991). The outdoor levels in the rural areas of Fort Saskatchewan are similar to levels measured in other rural areas of Alberta (Alberta Environment, 1998) while the levels measured in the town were slightly higher than measures taken in Grande Prairie.

Table 3: Results of Integrated PAH Samples

A. Participants #21 to #23

PAH Compound	Participant # 21			Participant # 22			Participant # 23		
	Personal	Outdoor	Indoor	Personal	Outdoor	Indoor	Personal	Outdoor	Indoor
Naphthalene	2.62	0.24	2.07	2.03	0.33	1.46	2.69	0.49	2.48
Acenaphthylene	0.10	0.00	0.00	0.72	0.03	0.45	0.61	0.00	0.00
Acenaphthene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36
Fluorene	2.86	0.17	0.61	2.75	0.36	1.85	1.87	0.43	2.45
Phenanthrene	5.26	1.46	6.60	10.80	2.51	15.47	6.44	3.02	9.07
Anthracene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluoranthene	0.18	0.22	0.33	0.00	0.28	0.55	0.52	0.91	0.33
Pyrene	0.21	0.48	0.00	0.07	0.27	0.00	0.84	1.51	0.00
Benz[a]anthracene	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
Chrysene	0.00	0.00	0.00	0.19	0.00	0.08	0.00	0.00	0.00
Benzo[j]fluoranthene	0.00	0.03	0.00	0.41	0.04	0.23	0.08	0.00	0.00
Benzo[e]pyrene	0.00	0.02	0.04	0.19	0.02	0.11	0.13	0.00	0.00
Benzo[a]pyrene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Perylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indeno[1,2,3-cd]pyrene	0.00	0.02	0.05	0.15	0.03	0.10	0.14	0.00	0.00
Dibenz[a,h]anthracene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzo[ghi]perylene	0.05	0.03	0.05	0.16	0.03	0.10	0.36	0.00	0.00
Total	11.29	2.66	9.75	17.56	3.89	20.40	13.69	6.35	15.69
Total of last eight	0.05	0.10	0.14	1.10	0.12	0.62	0.71	0.00	0.00
Total of first seven	11.03	2.08	9.61	16.30	3.51	19.78	12.13	4.84	15.69

B. Participants #24 to #26

PAH Compound	Participant # 24			Participant # 25			Participant # 26		
	Personal	Outdoor	Indoor	Personal	Outdoor	Indoor	Personal	Outdoor	Indoor
Naphthalene	0.37	0.36	0.78	1.12	0.20	1.56	0.83	0.32	0.76
Acenaphthylene	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00
Acenaphthene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluorene	3.92	0.72	2.01	1.28	0.00	1.25	3.29	1.13	3.07
Phenanthrene	11.54	3.97	5.83	5.45	0.58	5.09	13.17	5.38	7.10
Anthracene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluoranthene	0.00	0.70	0.47	0.00	0.10	0.00	0.51	0.89	0.69
Pyrene	0.00	0.83	0.73	0.00	0.11	0.00	0.80	1.07	0.59
Benz[a]anthracene	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Chrysene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00
Benzo[j]fluoranthene	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.08	0.00
Benzo[e]pyrene	0.05	0.04	0.05	0.00	0.00	0.00	0.06	0.05	0.05
Benzo[a]pyrene	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.00
Perylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Indeno[1,2,3-cd]pyrene	0.00	0.04	0.05	0.00	0.00	0.00	0.07	0.04	0.06
Dibenz[a,h]anthracene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzo[ghi]perylene	0.08	0.06	0.07	0.00	0.00	0.00	0.10	0.07	0.08
Total	15.96	6.88	10.00	7.85	0.99	8.07	18.84	9.27	12.41
Total of last eight	0.13	0.23	0.17	0.00	0.00	0.00	0.23	0.42	0.19
Total of first seven	15.83	5.74	9.10	7.85	0.87	8.07	17.81	7.72	11.62

C. Participants #27 to #29

PAH Compound	Participant # 27			Participant # 28			Participant # 29		
	Personal	Outdoor	Indoor	Personal	Outdoor	Indoor	Personal	Outdoor	Indoor
Naphthalene	2.69	0.98	3.99	2.53	0.45	2.61	0.88	2.25	0.67
Acenaphthylene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.07	0.00
Acenaphthene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluorene	3.70	1.31	3.44	4.16	1.35	3.44	3.26	2.21	3.41
Phenanthrene	9.52	2.51	9.77	9.88	3.79	5.63	7.74	3.26	5.70
Anthracene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluoranthene	0.37	0.47	0.27	0.00	0.83	0.31	0.26	0.55	0.37
Pyrene	0.43	0.57	0.35	0.32	0.86	0.39	0.35	0.64	0.42
Benz[a]anthracene	0.00	0.02	0.00	0.00	0.06	0.00	0.00	0.03	0.00
Chrysene	0.00	0.10	0.03	0.00	0.16	0.00	0.00	0.06	0.00
Benzo[j]fluoranthene	0.00	0.11	0.00	0.00	0.17	0.00	0.00	0.12	0.00
Benzo[e]pyrene	0.06	0.05	0.00	0.06	0.08	0.05	0.04	0.07	0.04
Benzo[a]pyrene	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.04	0.00
Perylene	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Indeno[1,2,3-cd]pyrene	0.08	0.04	0.05	0.08	0.08	0.06	0.00	0.05	0.05
Dibenz[a,h]anthracene	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Benzo[ghi]perylene	0.10	0.06	0.05	0.09	0.10	0.07	0.07	0.08	0.05
Total	16.95	6.23	17.96	17.12	7.99	12.55	12.60	11.43	10.70
Total of last eight	0.24	0.36	0.13	0.23	0.65	0.17	0.11	0.42	0.13
Total of first seven	16.28	5.28	17.48	16.57	6.41	11.98	12.13	10.34	10.15

The concentrations of the PAHs measured are shown pictorially for outdoor, indoor, and personal air in Figures 6 to 8. Note that the scale on the outdoor figure is much different than those for indoor and personal figures. The figures show the concentration of lighter PAH compounds were higher than the heavier compounds. In all cases the compound with the highest concentration was phenanthrene.

Figure 6: Summary of PAH Levels Measured With Personal Integrated Samplers

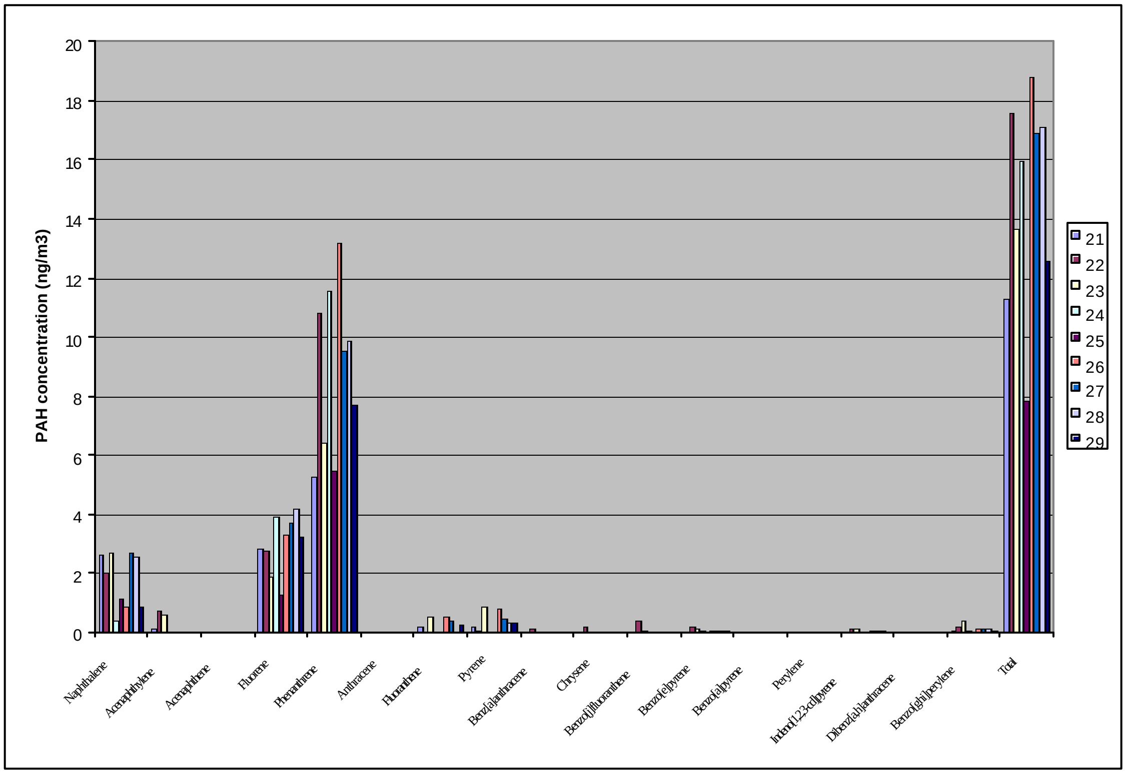


Figure 7: Summary of PAH Levels Measured With Indoor Integrated Samplers

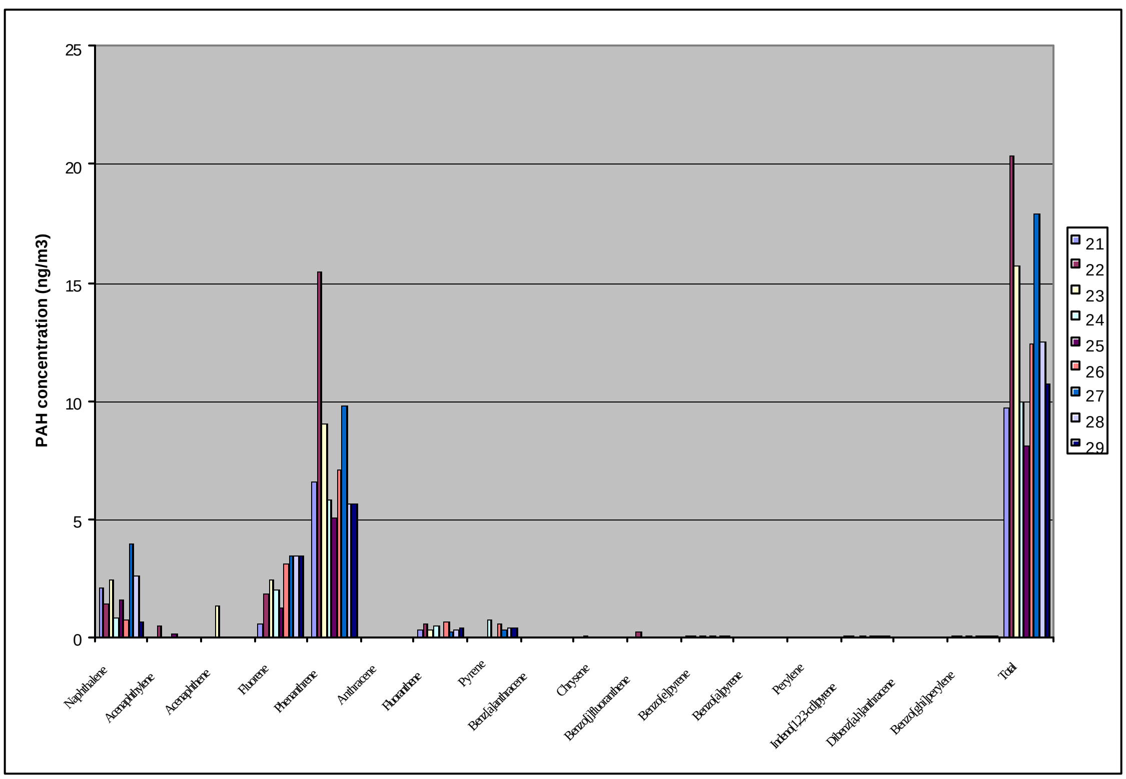


Figure 8: Summary of PAH Levels Measured With Outdoor Integrated Samplers

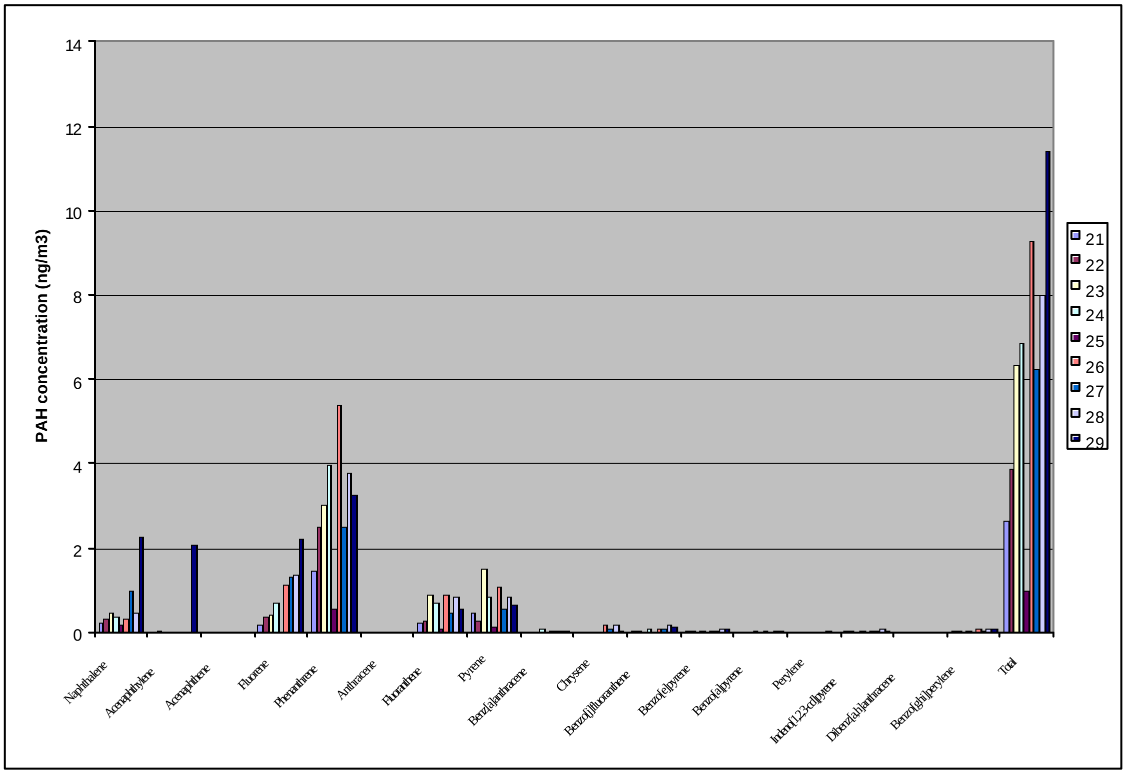
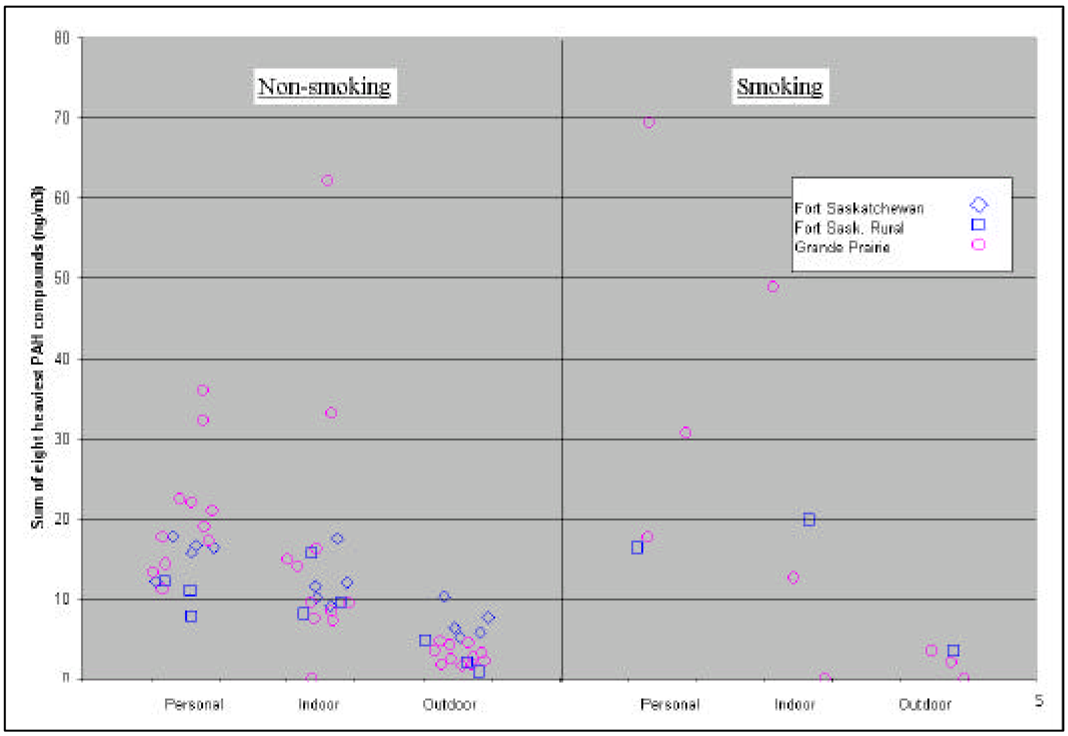


Figure 9 compares the sum of the seven lighter PAH compounds from Fort Saskatchewan and Grande Prairie indoor, outdoor, and personal air concentrations. The figures show that the two communities have a similar pattern in smoking and non-smoking households with similar indoor and personal levels that were much higher than outdoor levels. The explanation for higher indoor and personal levels in one of the smoking households is not clear since it does not appear to be related to the amount of smoking. This figure suggests that there are significant indoor sources of these more volatile PAH compounds. These indoor sources were not identified in this study, although it appears that smoking is not the most important source. The outdoor levels within the town of Fort Saskatchewan were slightly higher than Grande Prairie and the rural areas.

Figure 9: Comparison of Personal, Indoor, and Outdoor Levels of the Lightest PAHs



Similarly, Figure 10 compares the sum of the eight heaviest PAH compounds from Fort Saskatchewan and Grande Prairie indoor, outdoor, and personal air concentrations. The two communities are similar except outdoor levels within the town of Fort Saskatchewan were slightly higher than Grande Prairie and the rural areas. The figure shows that the highest levels were measured outdoors and the lowest measured indoors at the non-smoking households. Figure 11 shows the positive correlation between indoor and outdoor levels at the non-smoking houses. These results point to outdoor concentrations as being the driver of indoor and personal levels in non-smoking households. The only indoor source of these PAH compounds identified was smoking, with the levels increasing with the amount smoked.

Figure 10: Comparison of Personal, Indoor and Outdoor Levels of the Heaviest PAHs Measured

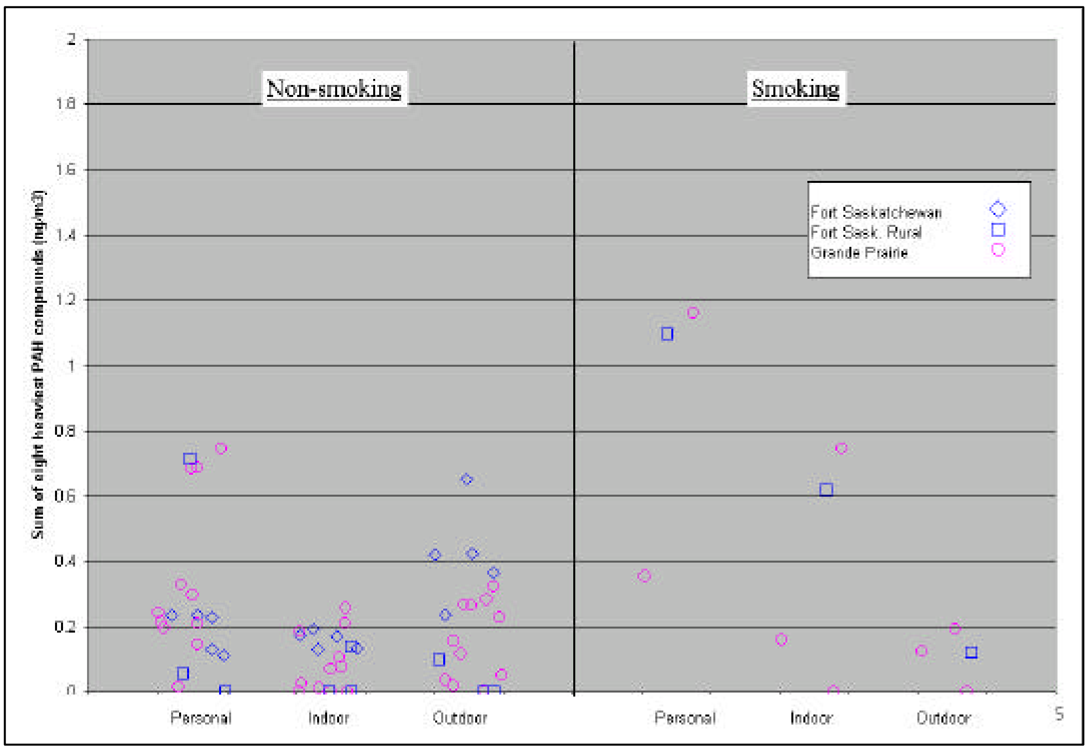
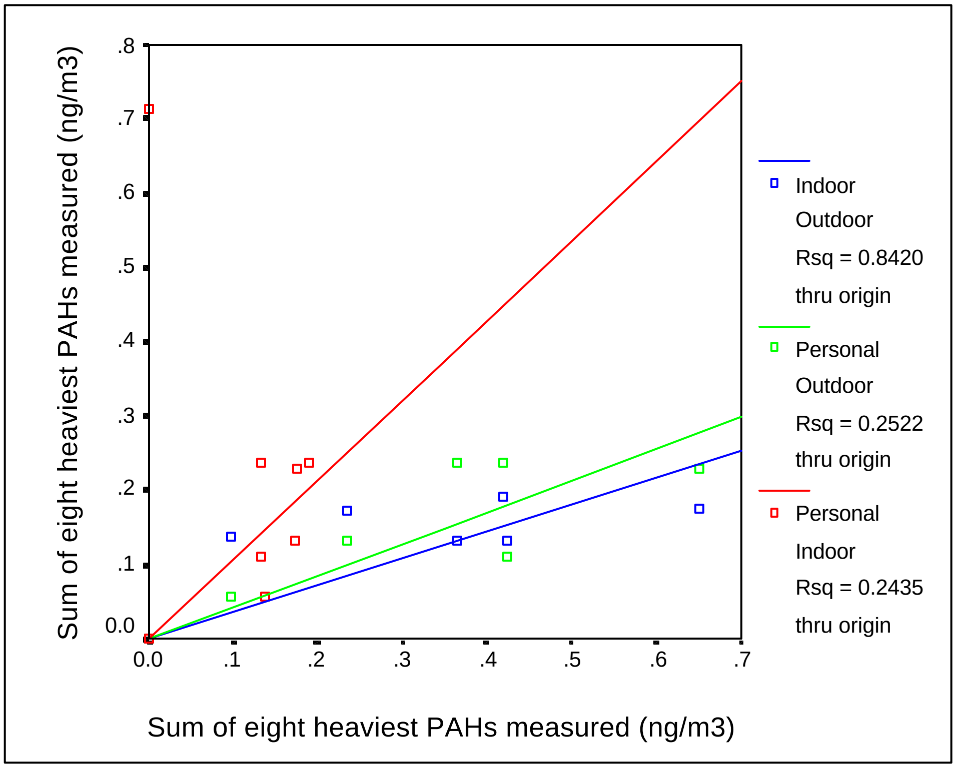


Figure 11: Correlation of Personal, Indoor, and Outdoor Levels (Non-Smokers Only)



4.2.1 Analysis of the PAH Fingerprint

A summary of these findings are elegantly displayed in a biplot (Figure 12) which allows a comparison of the distribution of the PAH compounds measured at each sample location relative to the average distribution. The blue numbers represent the PAH compounds numbered 1 to 17 (smallest to largest), while the black, green, and red numbers represent the personal, indoor, and outdoor sample locations of each participant, respectively. Black, green, and red dots in the figure represent Grande Prairie data. The diagram allows the comparison by sample location of the differences in the pattern and magnitude of air concentrations of the set of PAH compounds. To determine the nature of these differences, follow this basic procedure for each sample location: mentally draw a line from its co-ordinate through the '+' located on the graph at the 0,0 point (the origin). Consider this line as a new dimension with the positive direction being from the origin outward to the sample location number. The magnitude of the deviation from the average PAH compound distribution are ordered along this dimension. Notice that the actual PAH compound distribution will differ for sample location numbers located in different quadrants of the space. Additionally, a global mode of interpretation is possible by combining all of this information as follows: sampling locations in the same radial sector have similar distributions of PAH compounds; those farther from the origin (the '+' point) have less scatter than those nearer the origin. Compounds that are very close together on the plot have similar patterns of influence and similar levels of scatter.

Figure 12: Biplot Showing Distribution of PAH Compounds at the Sampling Sites

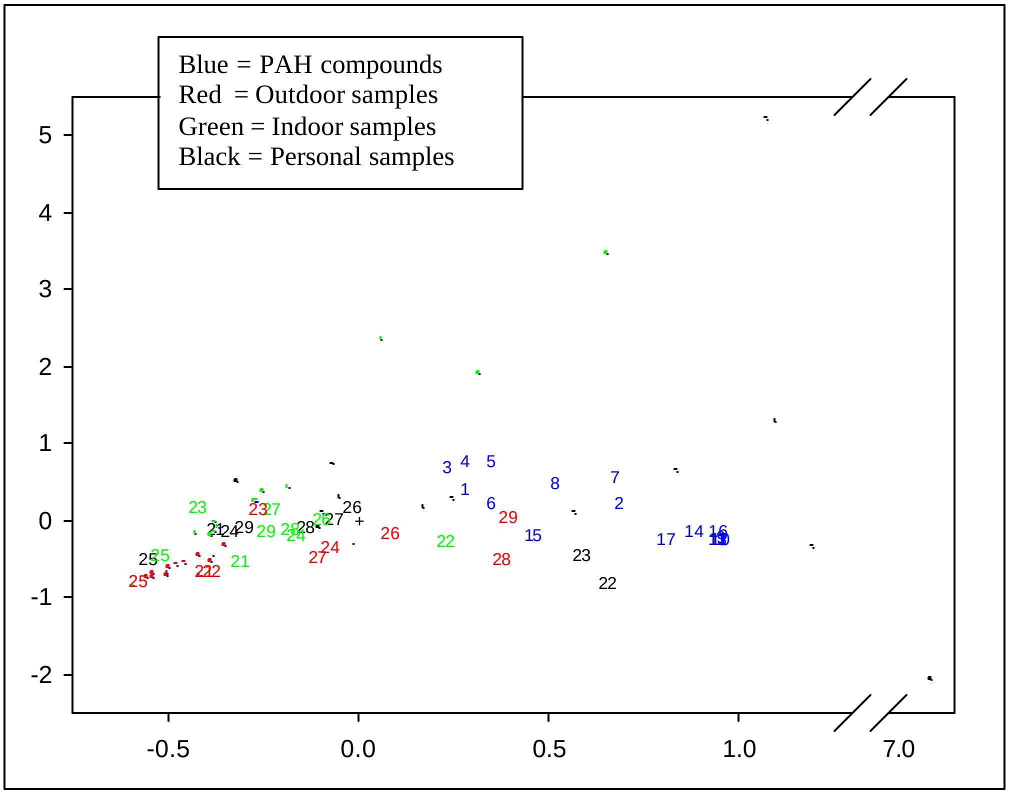


Figure 12 shows two distinct clusters of the blue PAH compound markers with numbers 9 through 17 except 15 tightly grouped, while the others are more loosely grouped in another location. These results are similar with earlier analysis, which showed that the lighter PAHs occur very differently than the heavier PAHs.

Figure 12 shows that all outdoor samples of the rural Fort Saskatchewan locations (indicated by red numbers 21,22,23, and 25) are in the same radial quadrant to the lower left of the origin as the red dots representing the Grande Prairie data. This suggests a similar distribution of the PAH compounds at all sites with lower levels than the average of both the heavy and light PAH compounds. The five outdoor samples taken within the town of Fort Saskatchewan (red numbers 24 and 26 to 29) have higher PAH levels than the rural and Grande Prairie sites indicated by a shift to the right in the figure. Just above the cluster of outdoor sites but still roughly in the same pattern are all of the indoor sites (in green), except number 22 which is shifted right due to smoking indoors. The location of this cluster indicates that the indoor levels are similarly in the heavy PAH group but higher in the lighter group compared to the outdoor sites. The personal sites (black numbers) are all very similar to the indoor pattern except for participant 23, which had much higher levels likely due to PAH exposure away from the home. It is interesting to note that for these participants, the pattern of the PAH compounds is the same indoors, outdoors, and personal but the outdoor levels of the lighter fraction were roughly one quarter the indoor and personal level.

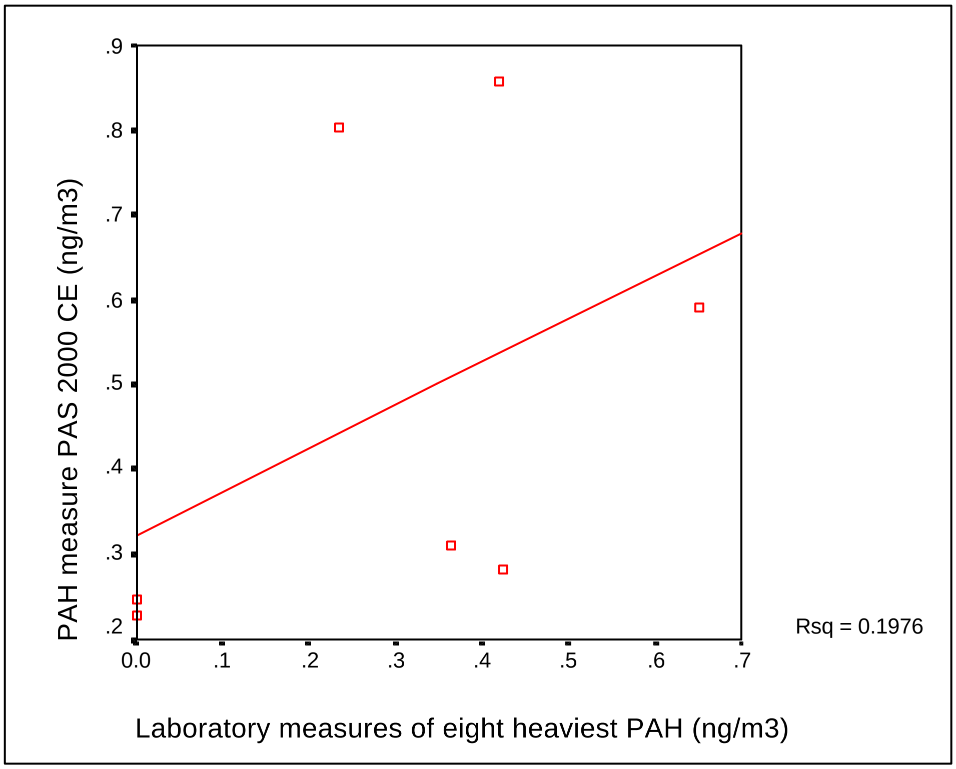
This confirms earlier predictions that smoking was an important indoor exposure source for both heavier and lighter PAH groups. The elevated indoor levels of the lighter PAH compounds at the non-smoking households indicates that there must be other unidentified indoor exposure sources that appear more important than smoking.

4.3 Comparison of the PAH measurement techniques

The two measurement techniques for PAHs provided different perspectives on the concentrations of the contaminants. The integrated samples provide the individual concentrations of the PAH compounds averaged over the sampling period which allows comparison of the changes in the profile of the PAH compounds as well as the average levels for different locations. The PAS 2000CE provides real-time readings of the total concentration of the PAH compounds with four or more aromatic rings which allows identification of short-term spikes and may indicate whether the sources were indoors or outdoors.

Figure 13 shows a scatter plot of the sum of the heavier PAH compounds (8 to 17) versus the average PAS 2000 CE measures which illustrates the correlation. The figure shows weak correlation between the two measurement techniques. The literature on the PAS 2000 advises that the instrument output is a good relative measure of PAHs, useful for comparing changing levels at one site, but may not be a good absolute measure comparable from one site to another.

Figure 13: Comparison of PAS 2000 CE and Laboratory Measures



5.0 Discussion and Conclusions

This study measured personal, indoor, and outdoor levels of PAHs that can be used to characterize exposure to products of incomplete combustion.

Levels of PAHs were higher in the town of Fort Saskatchewan when compared with the surrounding areas and the City of Grande Prairie but lower than large urban centers. These increased levels are due to the regional sources (industries and the City of Edmonton). Outdoor levels and sources drive exposure to the heavier (larger molecular weight) PAHs when there is no apparent or known contact with cigarette smoking. Smoking was the only indoor source of the heavier group of PAH compounds identified in the study. Indoor levels and sources drive exposure to the lighter group of PAH compounds and while smoking appears to be a source of these compounds, there are other sources that appear to be more significant.

An examination of PAH levels with wind speed and direction data determined that local emissions in the town, background levels, and regional sources from the south-southwest (Edmonton and industries) each had a similar impact on the average PAH concentration during the study. Emissions from regional sources to the north-northeast of the city have roughly half of the impact of the other sources due to the fact the wind seldom blows from that direction.

6.0 References

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