Environment Australia

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BTEX Personal Exposure Monitoring in Four Australian Cities

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Prepared by the Western Australian Department of Environmental Protection, The University of Western Australia, CSIRO Atmospheric Research, Monash University, Victorian Environment Protection Authority, New South Wales Health, NSW Environment Protection Authority, SA Environmental Protection Agency, Flinders University and Murdoch University.

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EXECUTIVE SUMMARY

Volatile organic compounds (VOCs) are emitted from a range of sources and some elevated levels have been monitored in Australian cities. There are many international studies that have investigated the concentrations of selected VOCs associated with specific activities and occupational environments. There are also studies which have examined personal exposure to selected VOCs among specific sample groups, such as occupationally exposed individuals. However, there are limited personal exposure monitoring studies of VOCs, internationally or in Australia, which focus on the general community setting. Given the number of sources of VOCs in urban airsheds, the potential public health significance of some of these VOCs needs to be determined.

In response to urban air quality issues, the Commonwealth Government developed the Living Cities – Air Toxics Program. As part of this program, the Department of Environmental Protection (WA) developed and coordinated a four city study which aimed to investigate the exposure of the urban population to selected VOCs, in non-industrial settings. This study was funded by Environment Australia and was conducted in collaboration with the University of Western Australia, CSIRO Atmospheric Research, Murdoch University, NSW Health, NSW Environment Protection Authority, Victorian Environment Protection Authority, Monash University, SA Environmental Protection Agency and Flinders University. The selected VOCs considered were benzene, toluene, ethylbenzene and xylene (BTEX). This report presents the results from a study investigating personal exposure monitoring of BTEX using passive sampling techniques.

A cross sectional study of personal exposure to BTEX of 207 randomly selected non-smoking, non-occupationally exposed participants was undertaken (individuals were from Perth, Sydney, Melbourne and Adelaide). Each participant was requested to wear a passive BTEX sampler over 24 hours to monitor exposure to BTEX for 5 consecutive days. Participants were ask to complete a questionnaire prior to monitoring their exposure and fill in a diary while wearing the personal samplers. Sampling was conducted during winter and summer, to take into account any seasonal differences in exposure patterns.

A wide range of BTEX concentrations were recorded for this study, however for the vast majority of participants, their exposures were considered to be low compared with Australian occupational standards and international environmental limits/guidelines. The mean personal exposure measurements recorded for this study (complete dataset) are summarised in Table ES1. The mean BTEX personal exposure results from this study were within the lower range of the personal exposure measurements reported in the international literature. One reason for these low exposure measurements may be that this study examined community exposures, whereas international studies have primarily focused on known sources or exposed sub-groups in the community. The lowest personal exposure measurements recorded for all the BTEX constituents were below the limit of detection. The most elevated exposure measurement recorded for each of the BTEX constituents was; 23.8 ppb for benzene, 2120 ppb for toluene, 119 ppb for ethylbenzene and 697 ppb for xylene, respectively. Elevated concentrations were found to be associated with non-occupational

activities such as the use of lacquer thinners, resins and house paints and exposure to spilt petrol.

Table ES1 Mean Personal Exposure Measurements (ppb) for the Winter and Summer Monitoring Campaigns

Air Pollutant	Mean exposure [winter] (ppb)	Mean exposure [summer] (ppb)
Benzene	1.25	1.25
Toluene	8.12	5.29
Ethylbenzene	1.13	0.81
Xylene	6.23	4.25

The information supplied in the participant questionnaires of each city were compared to determine if they were significantly different, which may help explain any differences in participant exposures which may be observed. The only significant differences found were that more participants in Sydney (90%) were employed compared to Perth (64%) participants during the summer monitoring campaign and the main type of home heater used in Melbourne (35%) and Perth (41%) was flued and unflued gas, respectively, where Sydney (29-35%) and Adelaide (44-45%) participants used electric.

Information from the participant activity diaries showed that overall the mean time participants spent outdoors (1.1-1.6 hours) over a day was significantly shorter than they spent indoors (19.1-20.3 hours), with the majority of this in their home (15.4-16.7 hours). There was little difference between the cities, when the mean reported total time spent indoors and in the various indoor locations were compared. There was also little difference between the participants of each city when the mean reported travelling time in a motor vehicle was examined (1.3-1.7 hours). Furthermore, time spent undertaking activities such as cooking (0.5-0.9 hours), cycling/walk/jogging (0.2-0.5 hours) and machinery repair/refuelling (0.005-0.2 hours) were similar when the means were compared for each city.

The participant diaries also collected information on refuelling, drive-through use, enclosed car park use, whether a smoker was nearby and heater/air conditioner use. Participants in Perth recorded the highest percentage of individual sampling periods during both winter and summer in which refuelling (13.6-16.8%) and drive-though use (5.6%) occurred. Sydney and Melbourne had the highest recorded percentage of individual sampling periods for both winter and summer in which an enclosed car park was used (15.3-18.4%) and periods in which a smoker was nearby (27.3-34.3%), respectively. Heater use was reported to occur most often by participants in Sydney during the winter (60.9%) monitoring campaign. Air conditioner use was reported to occur most often by participants in Perth during the summer (16.5%) monitoring campaign.

Generalized linear mixed models were used to investigate the significant risk factors for increased BTEX exposure associated with specific activities and behaviours. Activities and locations found to significantly (95% confidence interval) increase BTEX personal exposure included motor vehicle related activities such as vehicle repair and machinery use; refuelling of motor vehicles and time spent undertaking arts/crafts/woodwork.

Conversely, time spent outdoors (all activities) was found to decrease personal exposure to BTEX, even though specific outdoor activities such as cycling/running/walking were found to increase BTEX personal exposure for the complete dataset. This may be the result of where a person spends their time outdoors as this can affect their personal exposure. It is unknown whether the participants' time spent outdoors was in environments likely to contribute to BTEX exposure. Even in environments that could contribute to BTEX exposure, factors such as wind speed (which may affect personal sampler diffusion), dispersion of BTEX concentrations and proximity to BTEX sources may affect the personal exposure measurements. These differences could also be a modelling artefact.

For all of the BTEX constituents for both winter and summer, a highly significant difference was found between the mean exposure of participants in Perth and those in Adelaide, Melbourne and Sydney. Perth participant's BTEX exposures were significantly lower than the other three cities. This significant effect of city of residence on participant exposure to BTEX is thought to be linked to more stringent fuel quality regulation of benzene in Western Australia. There was no significant difference in the mean BTEX exposure of participants in Adelaide, Melbourne, and Sydney, except for xylene, where Melbourne was significantly different from the other two cities.

GLOSSARY

Air Toxics Gaseous, aerosol or particulate pollutants (other than the six criteria pollutants) which are present in the air at low concentrations with characteristics such as toxicity or persistence so as to be a hazard to human, plant or animal life.

Blank (field blank sample) An unexposed sampling medium used in an analytical procedure, in the absence of added analyte. The measured value of a field blank sample is the blank value and is used to set the 'zero' concentration of the measurements.

BTEX Benzene, toluene, ethylbenzene and xylene

Carcinogen Any substance that can cause or aggravate cancer.

Criteria Pollutants Identified in the National Environment Protection Measure for Ambient Air Quality and are carbon monoxide, ozone, sulfur dioxide, nitrogen dioxide, lead and particles (as PM_{10}).

CSIRO Commonwealth Scientific and Industrial Research Organisation

EA Environment Australia

ETS Environmental tobacco smoke

Exposure The amount of pollutant present in a given environment that represents a potential health threat to living organisms.

LOD Limit of detection; Calculated according to standard ISO 6879, which states that a zero sample has a 5% probability of causing a measured concentration above the detection limit

Mean (Arithmetic) The sum of all the measurements in a data set divided by the number of measurements in the data set.

Mean (Geometric) The nth root of the product of n values.

Personal monitoring Monitoring an individual's immediate environment using an active or passive device to collect the samples.

ppb parts per billion

QA Quality assurance; An integrated system of activities involving planning, quality control, quality assessment, reporting and quality improvement to ensure that a product or service meets defined standards of quality with a stated level of confidence.

QC Quality control; The overall system of technical activities whose purpose is to measure and control the quality of a product or service so that it meets the needs of its users. The aim is to provide quality that is satisfactory, adequate, dependable, and economical.

Sample A small unbiased representative group of something designed to exhibit the same characteristics and trends of the whole. Exposure-related measurements are usually samples of environmental or ambient media, exposures of a small subset of a population for a short time, or biological samples, all for the purpose of inferring the nature and quality or parameters important to evaluating exposure.

Statistical significance An inference that the probability is low that the observed difference in quantities being measured could be due to variability in the data rather than an actual difference in the quantities themselves. The inference that an observed difference is statistically significant is typically based on a test to reject one hypothesis and accept another.

Summa Canister Is an airtight, stainless-steel container with an inner surface that has been electropolished and chemically deactivated. This process of chemical deactivation is the “Summa” process. These canisters are used for ambient air monitoring

US EPA United States Environmental Protection Agency

VOCs volatile organic compounds. Organic compounds which participate in atmospheric photochemical reactions except those designated as having negligible photochemical reactivity.

Volatile Any substance that evaporates readily.

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1 INTRODUCTION

The Living Cities initiative was developed by the Commonwealth Government to address priority urban pollution issues. The Living Cities - Air Toxics Program was a core element of this initiative and aimed to address urban air quality issues by supporting the development of national approaches to the management of 'air toxics'. Air toxics were defined for the purpose of the Living Cities initiative (EA, 2000) as: "*gaseous, aerosol or particulate pollutants (other than the six criteria pollutants*[1]*) which are present in the air in low concentrations with characteristics such as toxicity or persistence so as to be a hazard to human, plant or animal life*."

A list of priority air toxics were identified under the Air Toxics Program, on the basis of their presence in air, emission estimates and potential health and environmental impacts. A total of 28 priority air toxics were identified including the volatile organic compounds benzene, toluene and xylene.

There are many international studies which have investigated concentrations of selected volatile organic compounds (VOCs) associated with specific activities and occupational environments. There are also studies which have examined personal exposure to selected VOCs among specific sample groups, including occupationally exposed individuals such as petrol station attendants for example. However, there are few personal exposure monitoring studies of VOCs, internationally or in Australia, which focus on exposures in the general community. Given the number of sources of VOCs, the potential public health significance of these compounds to the community needed to be determined.

In response to these issues, this study was developed to examine the exposure of the non-smoking urban population to selected VOCs, in non-industrial settings. The selected VOCs considered were air-borne benzene, toluene, ethylbenzene and o-, m- and p-xylenes (BTEX).

BTEX are chemical compounds which share certain similarities in their chemical structure and are often used for similar purposes (refer to Appendix A). The health effects of BTEX have been well established in the occupational setting. Studies of chronic exposure to BTEX constituents (by inhalation) have shown a range of potential health effects. These range from increased risk of myeloid leukaemia as a result of exposure to benzene, to a range of central nervous system disorders (headaches, dizziness, loss of balance or muscular control) and possible effects on blood, liver or kidneys associated with chronic exposure to benzene, toluene, ethylbenzene and xylene. Additional information on the health effects of BTEX, summarised from recent published studies, is presented in Appendix B.

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[1] The six criteria pollutants identified in the National Environment Protection Measure for Ambient Air Quality (the 'Air NEPM') are carbon monoxide, ozone, sulfur dioxide, nitrogen dioxide, lead and particles (as PM_{10}). Further information on the Air NEPM can be found on the internet at the following addresses:- http://www.ea.gov.au/atmosphere/airquality/nepm.html and http://www.ephc.gov.au.

1.1 Study phases

This study was conducted in several phases, to reflect the aims and objectives of the study and maximise the amount of information gathered.

Phase I identified the sources of BTEX which may contribute to personal exposure. This involved sampling a range of sources and locations identified from the literature as contributing high concentrations of VOCs to the environment. The term source is used to reflect both specific sources and locations.

The VOC source monitoring was undertaken in Perth using analytical procedures and protocols comparable with the US EPA method TO-15 to characterise BTEX concentrations in a range of environments (roadside, homes, cafes/nightclubs, inside cars, buses and trains, etc) (US EPA, 1997). This method involves the collection of air samples into stainless steel (SUMMA) canisters and analysis of the samples by gas chromatography and mass spectrometry (US EPA, 1997). The source monitoring found that BTEX constituents were present in all the ambient air samples, with toluene having the highest concentration. The maximum 12-hour toluene and benzene concentrations were obtained from a sample taken in a basement carpark, and were 24.7 parts per billion (ppb)[2] and 5.6 ppb, respectively. The source monitoring results showed that sites associated with motor vehicle emissions such as carparks and petrol stations had higher levels of the BTEX compounds. A sample recovered from a home using a wood heater also recorded high concentrations of these compounds, as did a sample from a nightclub which was probably a result of environmental tobacco smoke (ETS) being present. The source monitoring report submitted to Environment Australia is presented in Appendix C.

Phase II included the development of a Protocol to study personal exposure to selected VOCs. The Protocol was based on the results of phase I and a further literature review of the methods available to assess personal exposure to BTEX. Phase II of the study defined the recruitment, sampling, analytical and statistical methods to be employed. These methods are outlined in the Methods section of this report. The VOCs investigated in this project were limited to BTEX because of the cost, complexity and logistics associated with multiple sampling and analysis.

During phase II a postal survey using questionnaires was also undertaken to obtain information on the behaviours and activities in 'urban' populations that may influence the level of personal exposure to VOCs. A sample of 12,000 individuals was randomly selected from the Australian Electoral Roll. The random selection was limited to individuals between the ages of 18 and 67, who lived in the 'urban' areas of Sydney, Adelaide, Melbourne, and Perth. The design of the behaviour-and-lifestyle questionnaire reflected the dominant VOC sources identified from the source monitoring and literature review conducted in phase I. The questionnaire consisted of demographic questions, targeted questions about activities in and around the home, transport, garden operations,

[2] Throughout this report, the concentration of the gases in air will be reported in mixing ratio units of parts per billion by volume, ppb ($=10^{-9}$v/v) equivalent to one nanomole per mole.

heater use, and household product use. Questions about smoking and employment were also included. Each person receiving a questionnaire was asked to provide contact details if they were interested in participating in the personal monitoring component of this study. A report on the background and results of this postal survey is presented in Appendix D.

Phase III included a personal exposure pilot study to determine whether the methodologies, documentation and analytical techniques to be used in the study were suitable. A few alterations to the protocol were made as a result of the pilot study. The personal exposure monitoring study was then undertaken to examine personal exposure to BTEX and identify which sources and activities significantly affected this exposure. Pilot study data were not combined with the personal exposure monitoring study data. This report presents the results of the personal exposure monitoring.

2 OVERALL STUDY OBJECTIVES

The principal objective of the BTEX personal exposure study was to identify the contribution of non-occupational sources of benzene, toluene, ethylbenzene and xylene to personal exposure in non-smokers.

The specific objectives of the study were to:

- Determine the concentrations of BTEX to which non-smoking, non-occupationally exposed individuals are exposed to during their 'normal' daily routine.
- Determine the length of time and/or frequency non-smoking individuals spend undertaking various behaviour and lifestyle activities.
- Identify how behaviour and lifestyle activities influence personal exposure to BTEX.

3 STUDY DESIGN

3.1 General

This research was a cross sectional study of personal exposure to BTEX in the community setting. Two hundred participants (50 individuals from Perth, Sydney, Melbourne and Adelaide selected from respondents to the randomly distributed postal questionnaire) were recruited to wear passive BTEX samplers over 5 consecutive 24 hour periods. Sampling was undertaken during both winter and summer to account for any seasonal differences in exposure patterns.

3.2 Study Location

The study was conducted in Perth, Adelaide, Melbourne and Sydney. Participants were recruited from the metropolitan area of each city.

3.3 Sample Size Calculation

This section describes the rationale underlying the proposed sample size of 200 participants.

To calculate the size of a sample big enough to detect differences in measured personal exposure, information was required on estimated BTEX concentrations and the variability of the measured concentrations. The objective was to detect a doubling of benzene exposure with a 95% probability allowing for samples below the analytical quantification limit of detection.

The sample size calculation was based on benzene only because there is usually less benzene in environmental BTEX samples than the other compounds so this is the most sensitive. In addition, the pilot study revealed that 90% of samples recorded benzene levels above the limit of detection so any sample size calculation would be conservative using benzene concentration as the outcome variable.

The variability of benzene concentrations could be estimated from the pilot data, but the small numbers of people sampled made linking exposure to any specific source difficult. To overcome this, the results from a study by Leung and Harrison (1999) were considered, where sorbent tubes were used both in-vehicles and out-of-vehicles to assess exposure. The mean roadside concentration of benzene was 6.30 ppb (sd 7.32 ppb) and the mean concentration while commuting in a car was 13.3 ppb (sd 8.29 ppb). The work of Torre *et al* (1998) reported similar results for exposure levels while walking compared to commuting in a car. These results were used in the sample size calculation.

The sample size calculation indicated that 32 participants would be required to detect differences in exposure with 95% power. The 95% power was chosen to strengthen the confidence of the study results and conclusions. To take into account the pilot trial results where 50% of participants recorded benzene concentrations below the analytical quantification limit, and to enable sub-group analyses (eg by State, wood heater use etc) approximately four times this number was required. Therefore a minimum sample size of 128 participants was required to detect a doubling of benzene concentrations at the 5% level with 95% probability. This number was increased to 200 because of the large number of exposure variables being considered, to allow for sample losses and for bias towards a lower difference arising from exposure misclassification.

3.4 Personal Samplers

There are two broad approaches normally used to estimate personal exposure. These are: direct and indirect techniques. The indirect approach incorporates modelling to estimate exposure using measurements from specific microenvironments[3], combined with activity data. This approach is often much less expensive and time consuming than the direct approach, however the data frequently need further validation (Klepeis, 1999). The direct approach involves the use of active or passive samplers, which the individual wears. It is the most accurate way to determine personal exposure (Klepeis, 1999).

The study design directly measured BTEX using a personal monitoring device to provide an integrated measure of daily BTEX exposure. The literature indicates personal exposure to BTEX can be measured over a 24 hour time period, which is an appropriate length of time to examine exposure in a range of environments such as home or work, or while a broad range of activities are being performed, both indoors and outdoors (Thomas *et al*., 1993; Miller *et al*., 1998; Freeman *et al*., 1999). It is also generally an adequate time period to collect sufficient sample of BTEX to quantify (Thomas *et al*., 1993; Miller *et al*., 1998; Freeman *et al*., 1999).

3.5 Use of a Time/ Activity Diary and Questionnaire

Many personal exposure studies conducted throughout the United States and Europe have incorporated the use of activity diaries and questionnaires in order to determine the factors that contribute to personal exposure (Gilli *et al*., 1994; Miller *et al*., 1998; Levsen *et al*., 1999). These studies have shown that human activities, especially those related to tobacco smoke and automobiles, play a critical role in personal exposure to BTEX (Freeman *et al*., 1999; Hoffmann *et al*., 2000).

The time/activity diary was designed after an evaluation of those used in overseas studies. It was modified following the pilot trial (Appendix H). The diaries identified the amount of time spent in specific locations such as indoors (at home and work) and outdoors, and the activities performed in each of these locations or microenvironments (Schwab *et al*., 1990; Freeman *et al*., 1999).

In addition, participants were asked to indicate the presence of a smoker, as a number of authors suggested that this influences the degree of personal exposure to BTEX (CONCAWE, 1994; Freeman *et al*., 1991; Klepeis *et al*., 1995; Freeman *et al*., 1999).

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[3] A microenvironment is defined as "a location of homogeneous pollutant concentration that a person occupies for some finite period of time" (Duan, 1982).

The diary included prompts to identify key activities (such as refuelling of motor vehicles, use of underground carparks and use of wood heaters) that occur, as the pilot trial revealed that this information may not have been reported on a daily basis.

4 STUDY METHODS

Participants were asked to wear passive BTEX samplers over 24 hour periods to monitor their exposure to BTEX for 5 consecutive days and to record their activities and locations while wearing the samplers. Additional information on each participant (such as occupation, use of tobacco products, use of household chemicals, use of transport, etc) was collected by an interview administered questionnaire at the start of the monitoring period. Sampling was conducted during winter and summer.

4.1 Study Population

Participants were initially recruited from the respondents who provided their contact details via a postal questionnaire sent out to 12,000 randomly chosen residents in Melbourne, Sydney, Adelaide and Perth during phase II.

Participants were excluded from participating if they:

- smoked;
- were under 18 years of age;
- were employed in occupations with known elevated BTEX exposure:
  - petroleum/oil industry
  - fuel distributor/ supplier
  - chemical manufacture
  - construction industry using adhesives
  - petrol attendant
  - tile or carpet layer
  - painter or paint maker
  - pharmaceutical manufacturers
  - other e.g. printers, car mechanics

Where there were not enough participants eligible on the initial response list from the postal questionnaire undertaken during phase II, opportunistic recruitment was used to recruit additional participants. This method of recruitment was also employed to replace participants who did not undertake the second monitoring campaign (summer). Results for participants who were opportunistically recruited were not tested for volunteer bias.

4.2 Data Collection

Prior to undertaking the personal exposure monitoring for the first time, each participant was provided with background information on this program and was asked to complete an informed consent form (Appendix E).

Participants were provided with instructions (Appendix F) a questionnaire that requested personal behaviour and lifestyle information (Appendix G); and a time/activity diary (Appendix H), which was designed to record the time spent at each location or/and activity performed during each day. Participants also received a personal sampling package, comprising a set of personal sampler diffusion tubes and a sample record form.

The sample record form was designed to be used as a record of the opening and closing times of the personal samplers (Appendix I).

During the second sampling campaign participants were supplied with a personal sampling package, a time activity diary and supplementary questionnaire. The supplementary questionnaire was used to determine whether the participant's behaviour and lifestyle information had changed since the first monitoring campaign (winter) (Appendix I).

4.2.1 Questionnaire

The questionnaire (Appendix F) was designed after reviewing a number of questionnaires from major overseas studies of personal exposure (Thomas *et al*., 1993; Jo and Moon, 1999; Hoffmann *et al*., 2000). It takes into account information from the source monitoring program. The following information was included in the questionnaire:

- demographic information
- the use of and exposure to organic solvents and other consumer products in the home
- use of underground car parks
- whether a garage is attached to the participant's house
- the types of floor coverings and heating systems used in the house
- whether any recent renovations have occurred in the participants home.
- burning of candles/ oils in the home
- amount of time spent using different modes of transport.
- use of dry cleaning
- use of air conditioning

4.2.2 Supplementary Questionnaire

A supplementary questionnaire was developed to identify changes in lifestyle and behaviour subsequent to the first monitoring campaign (Appendix J). This document requested information relating to changes in employment, transport use and home characteristics and location. The supplementary questionnaire was also used to clarify the type(s) of heater(s) present in the participant's home and the main type of heater used during the first (winter) monitoring campaign.

4.2.3 Time/Activity Diary

The time/activity diary (Appendix H) used was designed on the basis of a review of those used in other studies (Section 3.5). The diary allowed for entries of activities and locations over a 24 hour period and also asked participants whether they had:

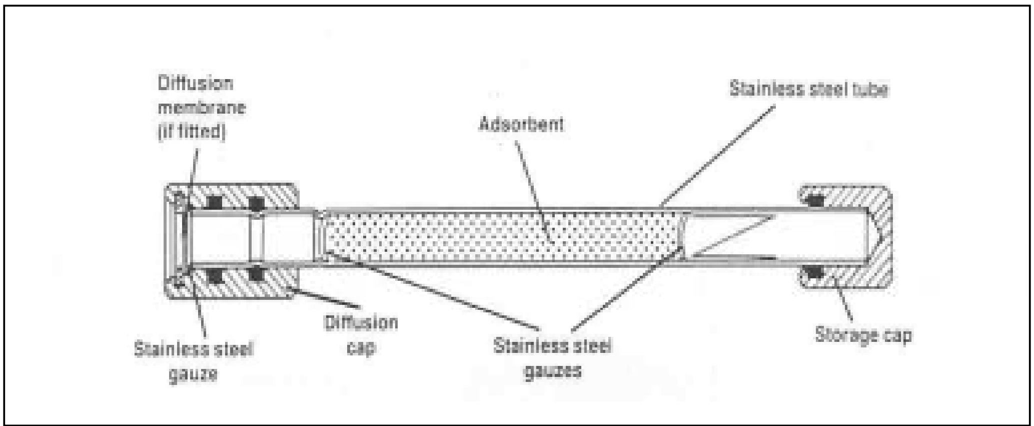
- been in the presence of a smoker
- refuelled a motor vehicle
- used a home air-conditioner or heater
- used an underground carpark
- used a drive-through facility.

The diaries were colour-coded by day for ease of use.

4.2.4 BTEX Personal Sampler Tubes

The personal sampling tubes used a passive diffusion method to sample the air. The adsorbent, Chromosorb 106 was packed into the stainless steel tube, 6.35 mm diameter (¼ inch OD) and 90 mm in length. During sampling the cap was removed from the marked end and a wire grill top was fitted to the end of the sampling tube. This protected the opening and allowed gases to diffuse to the adsorbent. Figure 1 shows a diagram of a personal sampling tube fitted with a diffusion cap.

Figure 1 Diagram of a personal sampling tube



Each participant was provided with 7 colour-coded personal sampling diffusion tubes (5 sample tubes, 1 field blank and 1 duplicate tube), for the winter and summer sampling campaigns.

4.2.5 Personal Sampler Tube Preparation and Transport

The BTEX personal sampler tubes were pre-cleaned before each sampling period by heating under a stream of ultra high purity helium in a *Perkin-Elmer* Automated Thermal Desorption (ATD) 400 System. In the winter phase, each tube was heated at 240°C for 15 minutes. In the summer phase, the protocol was changed to a two-stage cleaning process as shown in Table 4-1, where the sample tube was initially heated at 210°C for 10 minutes and subsequently heated at 180°C for 10 minutes. The first stage of the cleaning process is designed to remove any remaining species trapped on the adsorbent bed, whilst the second cleaning stage at lower temperatures reduces the amount of benzene artefact in the field blank.

Prior to, and following exposure, the BTEX passive sample tubes were sealed with *Swagelok* caps to a tightness greater than finger-strength using two spanners. The sample tubes were individually wrapped in aluminium foil that had been baked at 400°C for five hours. The foil provided a layer of protection against diffusion of BTEX gases onto the tube if a cap failed to seal. The wrapped sample tubes were packed in clean metal tins containing charcoal bags to adsorb any BTEX gases that might be present in the container. The tins were immediately sealed with metal lids capable of withstanding air cargo pressure changes during transport. Research associates were responsible for checking the tightness of all sample tubes prior to them being returned to CSIRO for analysis.

Table 4-1 Conditions of the ATD 400 System used for tube cleaning.

Procedure 1st stage	Setting
Mode	1
Primary desorption	210°C
Primary desorption time	10 min
Valve temperature	210°C
Procedure 2nd stage	**Setting**
Mode	1
Primary desorption	180°C
Primary desorption time	10 min
Valve temperature	180°C

Upon return to CSIRO, all sample tubes were unpacked and the seal of each *Swagelok* cap was checked and where necessary, tightened. The sampling data were entered into an Excel spreadsheet and any sampling irregularities were recorded.

4.2.6 Data Collection Schedule

Data were collected from participants during five consecutive days. The starting day was randomised, usually including at least one day of the weekend during the sampling period. The day on which the duplicate sampler was opened was also randomised, using the participant recruitment order. The first recorded participant opened their duplicate sampler on day one, the second participant on day two and so on. The sixth recorded participant opened their duplicate on day one and the sequence was repeated. The documents supplied to the participant identified which day of the sampling period the duplicate should be opened.

A 2-3 week turn around period was allocated for the distribution, participant use and collection of the sample tubes and associated documents. A similar time period was allocated for the analysis and cleaning of the sample tubes by CSIRO. The schedules used for the first (winter) and second (summer) monitoring campaigns are presented in Appendix K.

4.3 Coding of Questionnaire and Time/Activity Diary

Codes were assigned for each question in the questionnaire to correspond to the individual responses to those questions. A separate coding system was established for the continuous and categorical variables in the time/activity diaries (Appendix L). For each day in the time/activity diary, the entries of activities and locations were coded separately. The amount of participant time associated with each of these categories was recorded in a database.

4.4 Analysis of BTEX Sample Tubes

Sample tubes were loaded into a *Perkin – Elmer* ATD 400 Gas Chromatography System. The tubes were heated to 190ºC to desorb the BTEX. The desorbed BTEX gases were transferred via a heated line to the gas chromatograph where they were separated in a SGE BP20 capillary column and detected with a flame ionisation detector.

The field blanks and limit of detection (LOD) for each sampling batch were considered separately, as they were slightly different for each batch. There are several definitions for the calculation of the LOD and limit of quantification (LOQ). This study followed Standards Australia which has adopted the International Standard *ISO 6879 Air quality – Performance characteristics and related concepts for air quality monitoring methods* and the associated definitions for LOD and LOQ. The LOD was calculated according to standard *ISO 6879*, which states that a zero sample has a 5% probability of causing a measured concentration above the detection limit. The concentrations in samples with an initial measured concentration below the LOD, were set to half the appropriate LOD.

The field blanks were used to set the zero concentration of the measurements of each batch, in accordance with *ISO 6879*. The formula used to estimate the concentration of BTEX on each sampling tube was:

$$Concentration\ (tube) = \left(\frac{Area_{raw} - (Area\ blank)_{batch}}{Calibration\ x\ Uptake\ rate\ x\ Sampling\ time} \right)$$

4.5 Quality Assurance and Control

Quality assurance and control (QA/QC) procedures were employed to help to prevent methodological and analytical errors occurring and to help ensure the data collected was accurate. This included the incorporation of additional questions in the supplementary questionnaire to verify information supplied in the first participant questionnaire. Another example was the use of colour-coded forms and sampling devices to reduce the risk of mismatching or mis-numbering sample tubes and associated record sheets. Sample duplicates and field blank samplers were used to verify the sampling methodology employed. The results of this analysis are presented in Section 5.4.

The methodologies used to analyse the BTEX personal sampling tubes incorporated conventional laboratory QA/QC procedures for verifying instrumental accuracy and maintaining data reliability. Furthermore, each 24-hour long analytical run consisted of flushing the system with at least two injections prior to performing two standard injections. A maximum of six sets of sampling tubes (42 samples) were analysed per run, with a flush (empty tube) between each set of seven sampling tubes, followed by two more flushes of the standard lines and two standard injections at the end of the run. The standard gas used for this calibration was a certified mixture purchased from Scott Specialty Gases, San Bernadino, CA, USA.

Chromatograms were acquired and integrated using Perkin Elmer Turbochrom software. Integrated areas were exported to a Microsoft Excel workbook and calculations were undertaken in systematic tables. All chromatograms were subsequently reviewed to confirm correct identification and a draft final dataset of exposures was prepared. The data processing procedure was then checked. The chromatograms for sixteen participants were reviewed for correct identification and integration. Fourteen sample concentrations were calculated from basic principles for comparison with the spreadsheet table results. As a result of these examinations the draft final data set was passed as the final data set.

4.6 Modification to Study

Modifications to the personal monitoring protocol were made after the study started, these are detailed below.

Analysis of a number of the earlier samplers showed high ethanol levels, which were found to be associated with the use of personal spray products such as deodorants or perfume. Ethanol eluted just before benzene in the analytical procedure used, so if the ethanol concentration was large it would interfere with the benzene concentration calculations. After this observation, participants were asked to either remove the personal sampler or cover the diffusion cap while personal spray products were applied. A longer gas chromatograph column was used for the summer analyses and this increased the separation between the ethanol and benzene peaks and no significant interference occurred in the summer results. Furthermore a two stage cleaning process was instigated before the summer sampling and this reduced the blank values and the limit of detection.

Some participants indicated they had trouble using the name badge supplied as a suitable method for attaching the personal sampler when it could not be attached to their clothing. A few participants also expressed their concern about attaching the personal samplers to summer clothing, which may be made from a more light weight material. To resolve this concern a necklace made of ribbon was provided so the sampler could be worn outside the participants clothing without damaging it.

Participants overtightened approximately 30 of the tubes, which reduced the diffusion path surface area. This was thought to have occurred after the sample had been collected so the sample results were used but these tubes were not re-useable. Researchers were asked to advise participants not to overtighten the tubes.

4.7 Statistical Analysis

Univariate statistics were used to examine demographic variables. T-tests and ANOVA's were used to compare means, for example the means of duplicate samples to the original samples and mean participant exposures for each city. Chi-square and Kruskal-Wallis tests were used to examine distributional differences between categorical variables, such as gender. These analyses were performed using the microcomputer statistical software package SPSS (SPSS Inc., 1998) and SAS (SAS Institute, version 8.2).

To effectively utilize all the recorded data, a generalized linear mixed model was used. The within-subject correlation was assumed to be equally correlated between occasions for each individual. This is commonly referred to as a compound symmetry structure. The results were tested at the 95% confidence level. This analysis was done using PROC MIXED from SAS (SAS Institute, version 8.2).

The data were modelled using a repeated measures approach (generalized linear mixed models), which refers to data on subjects measured repeatedly at different times. In this case, the observations are clustered or grouped within subjects, so the model has to handle the between and within-subject variability in the data. In the first instance, all the variables listed below were included in the model. A reduced model was then run using those variables found to be significant (95% confidence level) in the complete model.

Exposure concentration results of participants who withdrew were not included in the final analysis. The exposure data were examined to determine if there were any ‘extreme’ individual exposure results which may have affected the statistical results. The inclusion of ‘extreme’ exposure results could significantly affect the mean values and the estimates of the fixed effects model. To identify extreme exposure measurements for each pollutant, the 5 lowest and 5 highest exposure observations were considered. The elevated exposure results were cross-checked with diary information to determine if they were associated with activities or locations which are known to increase exposure.

To focus on the important questions and reduce the number of input variables into the model, many of the variable codes for the questionnaire and diary were combined. Selected questionnaire data were used and the continuous (time) diary variable codes were collapsed into 6 variables with associated codes in relation to various location-and-activity scenarios and are shown below. The categorical diary data was also included in the statistical analysis.

The questionnaire data considered in the statistical analysis included:

- Which city the participant lives in? (Adelaide/Melbourne/Perth/Sydney)
- The participant’s gender? (male/female)
- Was the participant in paid employment? (yes/no)
- Was the participant’s home located within 300m of industry? (yes/no)
- The presence of an attached garage at home? (yes/no)
- What type of heater was used by the participant during winter? (type 0-9)
- How old is the participant? (age)
- The distance the participants home was to nearest highway or arterial road? (metres)

The 6 collapsed continuous and 5 categorical diary variables considered were:

- Time in transport - motor vehicle, public transport and cycling/walking/etc (min)
- Time inside buildings - home, work and other [smoker present/not present] (min)

- Time outdoors (this variable included all locations identified outdoors, such as the beach, a park and golf course) (min)
- Time cooking (min)
- Time undertaking art/woodwork/decorating/craft (min)
- Time undertaking motor vehicle repair/refuelling/ using petrol machinery (min)
- Was the participant near a smoker? (yes/no)
- Did the participant refuel? (yes/no)
- Did the participant enter a underground carpark? (yes/no)
- Did the participant enter a drive-through facility? (yes/no)
- Was the main home heater used? (yes/no)

5 STUDY RESULTS

5.1 Comparison of the Responses from the Participant and Postal Questionnaires

The responses supplied in the participant questionnaires were compared to the responses from the postal questionnaires, with each city compared separately. This was performed to identify if there were significant differences in the results from the two samples populations. For categorical and continuous variables, Mann-Whitney analysis and t-tests were used, respectively.

Some specific questions could not be considered in the comparison of the two questionnaires as they were not asked in both questionnaires. The questions which were compared are summarised in Table 5-1, with the significantly different responses summarised in Table 5-2. Of the 36 questions compared, 11 were found to have significantly different responses by the participants of this study compared to the respondents of the postal questionnaire. For these 11 questions, significant differences between the two sample populations were generally only found for a single city. For example, Victorian participants reported more frequent use of glues and adhesives compared with the postal survey respondents.

Table 5-1 Questions which were compared from the participant and postal questionnaires.

Question Compared
Age of participant
Sex of participant
Main floor covering in bedrooms
Main floor covering in living room
Main floor covering in kitchen
Are you currently renovating or have done renovations in the last 12 months?
Have you painted indoors recently (within the last 12 months)?
Have you painted outdoors recently (within the last 12 months)?
What type of fuel/energy do you use to operate your hot-plate?
Is a range hood (with external flue) or ventilation fan normally used when the hot plate is used?
What type of fuel/energy do you use to operate your oven?
Average weekday hours spent travelling in a car/ute
Average weekday hours spent travelling on a motorcycle
Average weekday hours spent travelling on a bus
Average weekday hours spent travelling on a train
Average weekday hours spent travelling on a bicycle
Average weekday hours spent walking/running/jogging
Average weekday hours spent travelling in 'other' mode
Average weekend day hours spent travelling in a car/ute
Average weekend day hours spent travelling on a motorcycle
Average weekend day hours spent travelling on a bus
Average weekend day hours spent travelling on a train
Average weekend day hours spent travelling on a bicycle
Average weekend day hours walking/running/jogging
Average weekend day hours spent travelling in 'other' mode
Do you ever refuel a motor vehicle?
How many times per week do you refuel (on average)?
How often do you park in an underground/multistorey car park?
Do you use a heater at home in winter?
What is your main type of home heater?
How often do you use glues/adhesives in and around your home?
How often do you use nail polish/remover in and around your home?
How often do you burn candles in your home?
How often do you burn essential/aromatherapy oils in your home?
Do smokers live in your house?
Are you employed?

Table 5-2 Summary of significantly different responses from the participants of this study and respondents of the postal questionnaire.

Question	Significantly Different Responses		
	State	Participant Questionnaire Responses	Postal Questionnaire Responses
Age of participant	WA	48.2years (Significant for females only)	40.3 years (Significant for females only)
Have you painted indoors recently (within the last 12 months)? (y=1, n=2)	NSW	1=50.9%	1=38.1%
What type of fuel/energy do you use to operate your hot-plate? (gas=1, electric=2, wood=3, other=4, do not know=5)	NSW	1=58.5%, 2=41.5%	1=44.2%, 2=55.5%
What type of fuel/energy do you use to operate your oven? (gas=1, electric=2, wood=3, other=4, do not know=5)	NSW	1=37.7%, 2=62.3%	1=25.8%, 2=73.7%
Average weekday hours spent travelling in a car/ute (data converted into minutes)*	VIC WA	1=61.8%, 2=23.6%, 3=5.5%, 4=9.1% 1=72%, 2=18%, 3=2%, 4=8%	1=49.9%, 2=22.6% 3=8.4%, 4=19.1% 1=55.8%, 2=21.1% 3=7.2%, 4=15.9%
Average weekend day hours spent travelling in a car/ute (data converted into minutes)*	WA	1=68%, 2=20%, 3=6%, 4=6%	1=50%, 2=29.2% 3=9%, 4=11.8%
Average weekend day hours spent travelling on a motorcycle (data converted into minutes)*	SA	(participant no motorcycle used)	
How often do you use glues/adhesives in and around your home? (once a day=1, once per week=2, once per month=3, never/infrequently=4)	VIC	1=1.8%, 2=14.56%, 3=29.1%, 4=54.5%	1=0.9%, 2=7.2%, 3=21.9%, 4=70.4%
How often do you burn essential/aromatherapy oils in your home? (once a day=1, once per week=2, once per month=3, never/infrequently=4)	VIC NSW	1=1.8%, 2=20%, 3=23.6%, 4=54.5% 1=3.8%, 2=18.9%, 3=18.9%, 4=58.5%	1=3.8%, 2=10.7%, 3=9.3%, 4=76.3% 1=4.5%, 2=6.9%, 3=7.3%, 4=81.3%
Smokers in house (y=1, n=2)	NSW SA VIC	2=92.5% 2=93.2% 2=89.1%	2=80.7% 2=80.2% 2=76.8%
Are you employed? (y=1, n=2)	NSW	1=86.8%	1=74.3%

* 1-60min=1, 61-120min=2, 121-180min=3, 181min-onwards=4

5.2 Descriptive Analysis: Selected Demographic Data from the Participant Questionnaire

Selected demographic information of the study participants obtained via the questionnaire (Appendix G) is shown in Table 5-3. It was considered that this demographic information would not be provided via the participant diary and may affect the potential for exposure to BTEX and should be considered. This information may also help in interpreting whether the exposure information can be generalised to the rest of the urban population. The demographic variables summarised correspond to the variables considered in the statistical analysis (Section 4.7). Information from the questionnaire relating to vehicle use and other activities have not been summarised in this report as this information was obtained via the participant diaries and is summarised in Section 5.3.

A total of 197 and 193 recruits participated in the winter and summer sampling campaigns, respectively. Of the winter campaign participants, four each from Adelaide and Sydney and three from Melbourne withdrew before the summer campaign. All of the winter campaign participants from Perth participated in the summer campaign. Additional participants were recruited for the summer campaign for Adelaide (n=1), Sydney (n=2) and Melbourne (n=4). There was no significant difference between the number of female and male participants in the sample population as a whole or in the individual sample populations for each city with the exception of Sydney, where there were more females than males (Table 5-3).

The participants' ages ranged from 20 to 68 years for the entire sample, with a mean age of 45 years (Table 5-3). There was little difference in the mean age of participants between cities. The highest mean age was 49 years (Perth) and the lowest was 42 years (Sydney).

Approximately three-quarters of the participants in both the winter and summer campaigns were employed. Sydney had the highest proportion of participants who were employed (90%), while the Perth had the lowest (64%). This difference was found to be statistically significant for the summer campaign (Table 5-3).

The mean distance to the nearest arterial road or highway from all of the participants' residences was 862m (range: 0 - 10km) for the winter campaign and 840m for the summer campaign. Melbourne had longest mean distance to the nearest arterial road or highway (993m [winter] (range: 2m - 10km)). Adelaide had the shortest mean distance to the nearest arterial road or highway (642m [summer] (range: 0 - 4km)) (Table 5-3). The distances reported to the nearest arterial road or highway by participants may be influenced by their interpretation of these road types.

Table 5-3 Selected demographic information

	Sydney		Adelaide		Melbourne		Perth		All	
	Winter	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
Sample size	52	49	43	42	51	52	50	50	197	193
Age (Years)										
Mean	43	42	46	47	43	43	49	49	45	45
(Min, Max)	(20, 68)	(20,63)	(22, 66)	(22,66)	(20, 65)	(20,65)	(27, 68)	(27, 68)	(20,68)	(20,68)
Gender (%)										
Male	35	35	47	45	49	50	50	50	45	45
Female	65	65	53	55	51	50	50	50	55	55
% Employed	86	90	72	71	74	77	64	64	74	76
Distance to nearest highway/arterial road (Metres)	(n=50)	(n=47)	(n=41)	(n=41)	(n=51)	(n=52)	(n=46)	(n=46)	(n=189)	(n=186)
Mean	860	879	747	642	993	962	841	841	862	840
(Min, Max)	(1,5000)	(1,5000)	(25,4000)	(0,4000)	(2,10000)	(2,10000)	(10,5000)	(10,5000)	(0,10000)	(0,10000)
% of homes near industry (within 300m)	17	14	12	17	28	29	10	10	17	18
% of homes with an attached garage	19	20	14	12	8	10	18	18	15	14
% of main heater type used at home										
Unflued gas	29	26	9	7	*	0	37	37	18	18
Flued gas	8	8	23	21	35	35	4	4	17	17
Pot belly stove	0	0	2	2	6	6	6	6	4	4
Open fire	0	0	0	0	0	0	2	2	0	0
Electric	35	29	44	45	2	6	26	26	26	25
Oil/column	14	14	2	2	2	2	2	2	5	5
Kerosene	0	0	0	0	0	0	4	4	1	1
Slow combustion	6	6	19	19	4	4	8	8	9	9
Gas ducting	6	6	0	0	45	42	0	0	13	13
Other	0	0	0	0	0	0	4	4	1	1
(No response)	(2.0)	(4)	(0)	(0)	(6)	(6)	(6)	(6)	(4)	(4)

n = number of participants who responded to the question
* As unflued gas heaters are prohibited in Melbourne, participants who reportedly used unflued gas heaters have been included with those participants using flued gas heaters.

The most common heater type used in the home reported by participants was gas (flued and unflued) and electric. There was a statistically significant difference in the types of main heaters used in different cities. For Sydney and Adelaide, electric heating was the most common source of heating, while for Melbourne and Perth, gas heating was more commonly used (gas fired ducted heating in Melbourne and unflued gas heaters in Perth). Adelaide had the largest percentage of participants using potbelly stoves, open fires, or slow combustion heaters (21%)(Table 5-3).

5.3 Descriptive Analysis: Time/Activity Diary Data

The period of time each individual personal sampler was worn varied considerably, with a few participants sampling for over 48 hours at a time. The percentage of sampling time accounted for by the diaries ranged from 3% to 100% (Table 5-4). However on average participants accounted for over 90% of the time they wore the personal samplers in their diary.

Table 5-4 Percentage of sampling time accounted for by the diaries

	Sydney		Adelaide		Melbourne		Perth	
	Winter	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
Mean	94	98	100	97	92	96	96	95
Median	100	100	100	100	100	100	100	100
(Min,Max)	(26,100)	(47,100)	(33,100)	(38,100)	(3,100)	(3,100)	(36,100)	(17,100)

Results are presented for those locations and activities reported in the diaries which were considered in the statistical analysis, as described in Section 4.7. For ease of comparison within the report, these results were limited to diaries which reported individual sampling periods between 22.8 and 24 hours in length. The mean reported times and ranges calculated per individual sampling period[4] are summarised in Appendix M.

The reported amount of time spent inside the home, place of employment (indoors) and all other buildings are summarised in Table 5-5. The total time spent indoors and total time spent outdoors are also presented in this table. There was little difference between the cities in the mean reported time spent in the various indoor locations and total time spent indoors. No significant seasonal differences in the mean times were observed. Overall, participants spent significantly more time indoors than outdoors, and the majority of this was at home. The mean reported time spent at home (indoors) for all of the cities was 16.3 hours for the winter campaign and 15.9 hours for the summer campaign. The shortest mean times for the locations summarised were for time in all other buildings and total time outdoors, with 1.3 hours and 1.5 hours for the winter and summer campaigns, respectively.

The reported amount of time spent near a smoker while inside the home, a work building or any other building is summarised in Table 5-6. The mean reported time spent near a

[4] An 'individual sampling period' is defined as the period in which a participant wore one specific personal sampler. Although participants were instructed to wear each personal sampler for 24 hours, this time often varied with some participants wearing a single personal sampler for over 48 hours.

smoker at work was less than 0.2 hours per day, time near a smoker in 'other' locations ranged from 0.04 to 0.4 hour and in the home, 0.03 to 0.6 hours. No seasonal differences were observed. The amount of time spent near a smoker varied between cities. The longest reported time spent near a smoker inside the home was over 18 hours for a participant in Sydney (summer). The longest reported time spent near a smoker at work and in all other locations was over 10 hours and 16 hours, respectively. These were recorded by participants from Perth (summer).

The long reported times spent near a smoker may be overestimated by the manner in which the information was recorded by the participants. That is, participants identified they were in a specific location undertaking a specific activity and noted a smoker was nearby. However, it was unclear if the smoker was near the participant for the entire time they were in that location, or if a smoker was nearby only for a portion of the designated time. It is most probable that the time near a smoker is actually less than that reported in the diary.

Table 5-7 summarises the amount of time (in hours) spent undertaking selected activities. Overall, the greatest mean time spent undertaking one activity was motor vehicle use, with 1.6 hours for the winter campaign and 1.4 hours for the summer campaign. The shortest mean time was for public transport use for the winter campaign and arts/crafts/woodwork and machinery repair and refuelling for the summer campaign. The shortest mean time for these activities was 0.1 hours.

There was no significant difference in the mean times for the various activities between the summer and winter campaigns summarised in Table 5-7. There was little difference between the cities in the mean reported travelling time in a motor vehicle. Perth participants spent the least amount of time on public transport, while Adelaide participants spent the greatest amount of time on public transport. The mean reported time spent cooking was similar for all four cities, with a range from 0.5 to 0.9 hours. The highest mean reported time spent repairing vehicles/machinery was 0.2 hours for Adelaide during the summer monitoring campaign.

Participants were asked to note in the diary whether they undertook particular activities and whether they were near a smoker while they wore each personal sampler. The results of these questions are summarised in Table 5-8. However, as these were 'yes/no' questions it was not always possible to determine how many times or how long the participant performed these activities or were near a smoker while each specific monitor was worn. The results are expressed as a percentage of the total number of personal samplers worn per State during each season, to allow a more representative comparison to occur.

Heater/air conditioner use was the most reported potential source of BTEX for the winter campaign (56.9%), whereas proximity to a smoker was the most reported variable for the summer campaign (23.4%). The least reported variable for both the winter and summer campaigns was the use of a drive-through (1.8% and 3.0%, respectively).

Table 5-5 Summary of the average reported time (hours) and range spent inside the home, work building or other building, total time indoors and total time outside for personal diaries between 22.8- 24.0 hours only.

	Sydney		Adelaide		Melbourne		Perth		All	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
At home (indoor) Mean (Mean % of sampling period) (Min, Max)	15.7(67%) (0,23.8)	15.4(65%) (0,24.0)	16.6(69%) (1.3,24.0)	16.0(67%) (2.5,24.0)	16.2(68%) (0,24.0)	15.5(65%) (0.5,24.0)	16.7(70%) (0,24.0)	16.8(71%) (1.8,24.0)	16.3(69%) (0, 24.0)	15.9(67%) (0,24.0)
At work (indoor) Mean (Mean % of sampling period) (Min, Max)	3.4(14%) (0,12.2)	4.3(18%) (0,13.4)	2.8(12%) (0,10.3)	2.8(12%) (0,11.0)	3.1(13%) (0,12.3)	3.5(15%) (0,14.0)	2.4(10%) (0,13.3)	2.7(11%) (0,13.0)	2.9(12%) (0,13.3)	3.3(14%) (0,14.0)
Other buildings Mean (Mean % of sampling period) (Min, Max)	1.7(7%) (0,12.3)	1.9(8%) (0,12.4)	0.9(4%) (0,10.0)	1.1(5%) (0,15.0)	1.3(5%) (0,8.0)	1.6(7%) (0,20.8)	1.5(6%) (0,23.0)	1.5(6%) (0,16.7)	1.3(6%) (0,23.0)	1.5(6%) (0,20.8)
Total Time Indoors Mean (Mean % of sampling period) (Min, Max)	19.8(83%) (1.8,24.0)	20.3(85%) (8.0,24.0)	19.8(83%) (3.3,24.0)	19.1(80%) (9.5,24.0)	19.8(83%) (0,24.0)	19.8(83%) (9.8,24.0)	19.5(82%) (0,24.0)	19.8(83%) (10,24.0)	19.7(83%) (0,24.0)	19.8(83%) (8.0,24.0)
Outdoors Mean (Mean % of sampling period) (Min, Max)	1.3(6%) (0,8.1)	1.1(5%) (0,6.8)	1.4(6%) (0,9.0)	1.6(7%) (0,10.9)	1.4(6%) (0,10.5)	1.6(7%) (0,14.8)	1.2(5%) (0,8.7)	1.6(7%) (0,12.3)	1.3(6%) (0,10.5)	1.5(6%) (0,14.8)

Table 5-6 Summary of the average reported time (hours) and range spent inside the home, a work building or other building during (smoker nearby/not nearby) for personal samplers opened between 22.8- 24 hours only.

	Sydney		Adelaide		Melbourne		Perth		All	
	Winter	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
Near Smoker										
At home Mean (Mean % of sampling period) (Min, Max)	0.1(0.4%) (0,6.3)	0.2(0.8%) (0,18.9)	0.03(0.1%) (0,3.5)	0.1(0.6%) (0,15.0)	0.2(0.7%) (0,7.6)	0.1(0.5%) (0,5.0)	0.1(0.3%) (0,4.8)	0.6(2%) (0,13.5)	0.1(0.4%) (0,7.6)	0.3(1%) (0,18.9)
At work Mean (Mean % of sampling period) (Min, Max)	0.2(0.8%) (0,9.0)	0.1(0.3%) (0,6.4)	0.03(0.1%) (0,3.3)	0.2 (0,9.3)	0.1(0.4%) (0,7.6)	0 (0,0)	0.2(0.7%) (0,8.3)	0.1(0.5%) (0,10.3)	0.1(0.6%) (0,9.0)	0.1(0.4%) (0,10.3)
Other place Mean (Mean % of sampling period) (Min, Max)	0.2(0.9%) (0,4.3)	0.2(0.8%) (0,3.8)	0.04(0.2%) (0,2.8)	0.1(0.4%) (0,5.0)	0.3(1%) (0,6.8)	0.4(1%) (0,7.0)	0.2(0.6%) (0,5.5)	0.3(1%) (0,16.7)	0.2(0.8%) (0,6.8)	0.2(1%) (0,16.7)
Not Near Smoker										
At home Mean (Mean % of sampling period) (Min, Max)	15.6(66%) (0,23.8)	15.2(64%) (0,24.0)	16.5(69%) (1.3,24.0)	15.9(66%) (0,23.3)	16.0(67%) (0,24.0)	15.3(64%) (0.5,24.0)	16.7(70%) (0,24.0)	16.3(68%) (0,24.0)	16.2(68%) (0,24.0)	15.7(66%) (0,24.0)
At work Mean (Mean % of sampling period) (Min, Max)	3.2(13%) (0,12.2)	4.2(18%) (0,13.4)	2.8(12%) (0,10.3)	2.6(11%) (0,11.0)	3.0(13%) (0,12.3)	3.5(15%) (0,14.0)	2.3(9%) (0,13.3)	2.6(11%) (0,13.0)	2.8(12%) (0,13.3)	3.3(14%) (0,14.0)
Other place Mean (Mean % of sampling period) (Min, Max)	1.5(6%) (0,12.3)	1.7(7%) (0,12.4)	0.9(4%) (0,10.0)	1.0(4%) (0,15.0)	0.9(4%) (0,8.0)	1.2(5%) (0,20.8)	1.3(6%) (0,23.0)	1.2(5%) (0,9.5)	1.2(5%) (0,23.0)	1.3(5%) (0,20.8)

Table 5-7 Summary of the average reported time (hours) and range spent undertaking selected activities for personal diaries between 22.8- 24 hours only

	Sydney		Adelaide		Melbourne		Perth		All	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Motor vehicle use Mean (Mean % of sampling period) (Min, Max)	1.4(6%) (0,13.0)	1.3(6%) (0,15.0)	1.4(6%) (0,9.8)	1.4(6%) (0,12.3)	1.7(7%) (0,9.4)	1.3(5%) (0,9.0)	1.7(7%) (0,11.8)	1.6(7%) (0,12.0)	1.6(7%) (0,13.0)	1.4(6%) (0,15.0)
Public transport use Mean (Mean % of sampling period) (Min, Max)	0.2(0.8%) (0,4.5)	0.2(1%) (0,2.5)	0.2(1%) (0,10.0)	0.4(2%) (0,8.6)	0.1(0.4%) (0,2.0)	0.1(0.5%) (0,1.8)	0.02(0.1%) (0,1.6)	0.03(0.1%) (0,1.3)	0.1(0.6%) (0,10.0)	0.2(0.8%) (0,8.6)
Cycling/walking/jogging Mean (Mean % of sampling period) (Min, Max)	0.5(2%) (0,3.5)	0.5(2%) (0,3.5)	0.4(1%) (0,3.3)	0.4(1%) (0,4.8)	0.5(2%) (0,6.0)	0.3(1%) (0,5.8)	0.2(1%) (0,2.0)	0.2(0.9%) (0,2.8)	0.4(2%) (0,6.0)	0.3(1%) (0,5.8)
Cooking Mean (Mean % of sampling period) (Min, Max)	0.8(3%) (0,6.0)	0.5(2%) (0,7.3)	0.6(3%) (0,8.9)	0.5(2%) (0,9.5)	0.5(2%) (0,5.8)	0.5(2%) (0,6.0)	0.9(4%) (0,6.0)	0.7(3%) (0,8.0)	0.7(3%) (0,8.9)	0.6(2%) (0,9.5)
Art/craft/woodwork Mean (Mean % of sampling period) (Min, Max)	0.1(0.5%) (0,4.8)	0.1(0.3%) (0,5.8)	0.03(0.1%) (0,2.3)	0.1(0.4%) (0,3.6)	0.5(0.7%) (0,10.8)	0.3(1%) (0,8.8)	0.06(0.3%) (0,5.3)	0.1(0.6%) (0,8.0)	0.2(0.7%) (0,10.8)	0.1(0.6%) (0,8.8)
Machinery repair/refuel (includes vehicles) Mean (Mean % of sampling period) (Min, Max)	0.04(0.2%) (0,1.9)	0.005(0.02%) (0,0.6)	0.06(0.3%) (0,4.5)	0.2(0.8%) (0,7.0)	0.1(0.5%) (0,3.0)	0.1(0.3%) (0,2.7)	0.1(0.3%) (0,2.5)	0.1(0.3%) (0,3.0)	0.07(0.3%) (0,4.5)	0.1(0.3%) (0,7.0)

Table 5-8 Summary of the frequency of individual sampling periods in which selected activities and locations were recorded for winter and summer

	Sydney		Adelaide		Melbourne		Perth		All	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Refuelling	(n=27) 10.3%	(n=31) 12.6%	(n=27) 12.6%	(n=23) 11.2%	(n=29) 11.7%	(n=24) 9.4%	(n=42) 16.8%	(n=34) 13.6%	(n=125) 12.9%	(n=112) 11.7%
Drive-through	(n=0) 0.0%	(n=3) 1.2%	(n=0) 0.0%	(n=3) 1.5%	(n=3) 1.2%	(n=9) 3.5%	(n=14) 5.6%	(n=14) 5.6%	(n=17) 1.8%	(n=29) 3.0%
Car park	(n=40) 15.3%	(n=45) 18.4%	(n=18) 8.4%	(n=15) 7.3%	(n=37) 14.9%	(n=34) 13.3%	(n=19) 7.6%	(n=13) 5.2%	(n=114) 11.7%	(n=107) 11.2%
Smoker nearby	(n=77) 29.5%	(n=58) 23.7%	(n=31) 14.5%	(n=29) 14.1%	(n=85) 34.3%	(n=70) 27.3%	(n=62) 24.8%	(n=67) 26.9%	(n=255) 26.2%	(n=224) 23.4%
Heater or air conditioner use	(n=159) 60.9%	(n=9) 3.7%	(n=110) 51.4%	(n=26) 12.6%	(n=138) 55.7%	(n=27) 10.6%	(n=147) 58.8%	(n=41) 16.5%	(n=554) 56.9%	(n=103) 10.8%

Note: An 'individual sampling period' is defined as the period in which a participant wore one specific personal sampler.
n = no. of individual sampling periods in which a selected activity was recorded;
% = no. of individual sampling periods in which a selected activity was recorded divided by the total number of individual sampling periods.
Participants may have undertaken an activity more than once during an individual sampling period.

Refuelling was reported to occur between 11.7% and 12.9% of the total number of individual sampling periods. Participants in Perth recorded the highest percentage of individual sampling periods during both winter and summer in which refuelling and drive-though use occurred. Sydney and Melbourne had the highest recorded percentage of individual sampling periods for both winter and summer in which an enclosed car park was used and periods in which a smoker was nearby, respectively. Heater use was reported to occur most often by participants in Sydney during the winter monitoring campaign. Air conditioner use was reported to occur most often by participants in Perth during the summer monitoring campaign.

5.4 Analysis of Passive Sampler Field Blanks and Duplicates

Sample duplicates and blank samplers were used to verify the sampling methodology employed. The field blanks were analysed to determine the limit of detection (LOD). The precision (repeatability) of the sampling methodology was examined through the analysis of the duplicate samples.

5.4.1 Field Blanks

The mass of the BTEX constituents on each sample tube was measured. The average masses measured on the summer field blanks were 30 to 65% lower than the masses recorded on the winter field blanks as shown in Table 5-9. The limits of detection for the BTEX constituents are presented in Table 5-10. The changes made to the summer sampling preparation (2-stage cleaning process) and analysis (a longer column was used in the Gas Chromatography System) reduced the limit of detection, which increased the percentage of samples able to be quantified, as shown in Table 5-10. The LOD was calculated according to the ISO 6879 standard.

Table 5-9 Mean and standard deviation of masses (ng) of BTEX on the field blank samples.

	Winter (n=198)	Summer (n=190)
Benzene	0.73±0.30	0.30±0.13
Toluene	0.28±0.34	0.17±0.09
Ethylbenzene	0.20±0.19	0.14±0.09
p-Xylene	0.09±0.15	0.03±0.04
m-Xylene	0.11±0.23	0.07±0.07
o-Xylene	0.15±0.20	0.05±0.05

Table 5-10 Limits of Detection for summer and winter sampling.

	Winter		Summer	
	LOD (ppb)	Samples>LOD	LOD (ppb)	Samples>LOD
Benzene	0.16	92.2%	0.08	98.4%
Toluene	0.14	96.9%	0.05	98.4%
Ethylbenzene	0.12	94.2%	0.05	97.4%
p-Xylene	0.07	93.8%	0.02	98.5%
m-Xylene	0.09	96.8%	0.03	98.4%
o-Xylene	0.09	96.9%	0.02	98.8%

5.4.2 Duplicate comparison

The influence of sampling precision of the BTEX concentrations in winter relative to summer was assessed on a statistical basis using the difference between logarithmic transformed duplicate concentrations. The data set consisted of a large range of BTEX exposure measurements. The absolute differences between duplicate concentrations increased as the sample exposure measurements increased. The variation in duplicate samples between the summer and winter sampling periods is shown in **Table 5-11**.

The precision between winter and summer was tested at the 95% confidence level using the F statistic which tests if there is a difference between one or more means. There was no statistically significant change in precision for benzene, ethylbenzene and o-xylene. However, there was a statistically significant decrease in precision from winter to summer samples for toluene, p-xylene and m-xylene.

Table 5-11 Comparison of the precision of duplicate samples in winter and summer.

	Standard deviation of differences between $\log_{10}$ duplicate pairs	
	Winter (n = 198)	**Summer (n = 190)**
Benzene	0.13	0.13
Toluene	0.06	0.13
Ethylbenzene	0.20	0.17
p-Xylene	0.13	0.17
m-Xylene	0.09	0.13
o-Xylene	0.15	0.16

The reason for the reduced precision for toluene, p-xylene and m-xylene in the summer samples is unknown. Changes between winter and summer which may have influenced the precision of the personal samplers were:

- cleaning protocol
- sampler exposure protocol
- analytical process
- ambient concentrations
- coelutions from other pollutants adsorbed onto the sampler

An examination of these factors suggested only ambient concentrations and coelutions could contribute to the observed changes. The altered cleaning protocol and analytical process improved the limit of detection and the separation of the BTEX peaks on the chromatograms, respectively. The change to the sampler exposure protocol was to limit the interference from ethanol.

5.5 Descriptive Analysis: Participant BTEX Concentrations

The BTEX concentrations are summarised as a mean and range for the participants in each city and are presented in Table 5-12. The mean concentrations for each city were often heavily influenced by elevated exposures from one or two individual participant exposures. The personal exposure measurement are presented as box plots, of which the components are defined in Figure 2. The range of participants' exposures is presented for winter and summer in Figure 3 and Figure 4.

Table 5-12 Summary of personal exposure monitoring results (ppb) per individual sampling period (nominally 24 hours*)

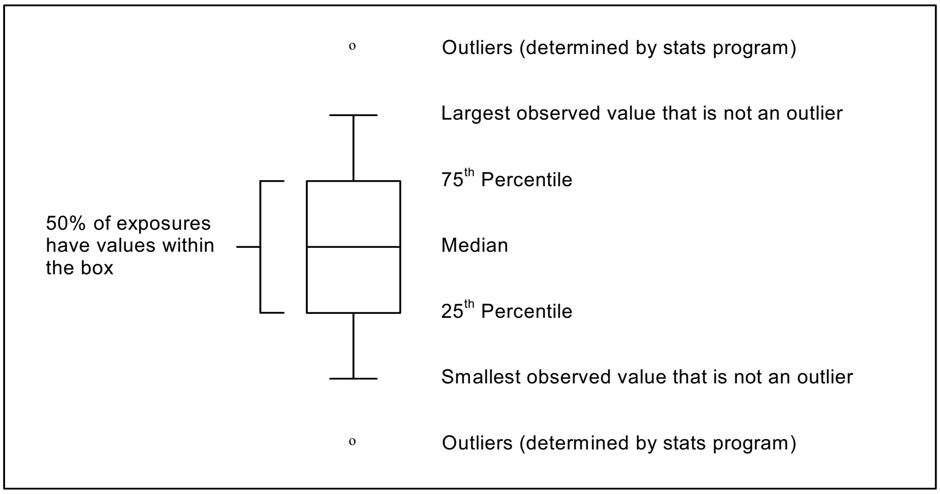
	Sydney		Adelaide		Melbourne		Perth		All	
	Winter (n=252)	**Summer** (n=243)	**Winter** (n=211)	**Summer** (n=203)	**Winter** (n=242)	**Summer** (n=243)	**Winter** (n=249)	**Summer** (n=243)	**Winter** (n=954	**Summer** (n=932)
Benzene	(n=251) [1]		(n=209) [1]				(n=246) [1]	(n=242) [1]	(n=948) [1]	(n=931) [1]
Mean	1.43	1.56	1.32	1.66	1.63	1.32	0.62	0.55	1.25	1.25
Geometric Mean	1.05	1.11	0.90	1.00	1.10	1.01	0.40	0.40	0.80	0.81
(Min,Max)	(0.08,13.5)	(0.10,15.0)	(0.08,9.6)	(0.04,23.8)	(0.08,19.2)	(0.16,14.0)	(0.08,8.6)	(0.04,3.7)	(0.08,19.2)	(0.04,23.8)
Toluene										
Mean	4.66	4.66	10.2	5.75	15.0	7.96	3.20	2.86	8.12	5.29
Geometric Mean	3.64	3.24	3.23	3.13	3.04	3.14	2.05	1.85	2.91	2.75
(Min,Max)	(0.07,43.1)	(0.45,126)	(0.07,1040)	(0.43,129)	(0.07,2120)	(0.39,538)	(0.07,58.0)	(0.03,28.0)	(0.07,2120)	(0.03,538)
Ethylbenzene										
Mean	0.96	0.78	1.29	1.48	1.49	0.68	0.81	0.40	1.13	0.81
Geometric Mean	0.67	0.53	0.76	0.50	0.77	0.47	0.50	0.26	0.66	0.42
(Min,Max)	(0.06,8.8)	(0.10,7.6)	(0.06,26.6)	(0.03,91.9)	(0.06,119)	(0.03,19.7)	(0.06,7.4)	(0.03,3.6)	(0.06,119)	(0.03,91.9)
Xylene								(n=242) [1]		(n=931) [1]
Mean	7.19	3.79	7.40	9.45	6.39	2.79	4.12	1.83	6.23	4.25
Geometric Mean	3.55	1.10	3.26	2.41	2.64	2.04	2.19	1.24	2.85	1.94
(Min,Max)	(0.12,463.6)	(0.04,69.8)	(0.12,141.1)	(0.31,697.0)	(0.12,640.4)	(0.35,32.5)	(0.12,100.8)	(0.15,17.2)	(0.12,640.4)	(0.04,697.0)

* The actual sampling times varied from 6.2 hours to 50.5 hours.
[1] The total number of samples considered for these cells are lower due to personal samplers appearing to have 'sampling errors and analytical problems'.

The concentrations of benzene ranged from below the limit of detection to 23.8 ppb. The highest mean benzene concentrations were found for Melbourne participants during the winter campaign (1.63 ppb) and for Adelaide during the summer campaign (1.66 ppb). The lowest mean benzene concentrations were found for Perth for both the winter and summer campaigns (0.62 and 0.55 ppb, respectively). There was no significant difference between the average benzene concentrations of Adelaide, Melbourne and Sydney. However, for both seasons, Perth's average benzene concentrations was significantly lower than those of the other cities.

Concentrations of toluene ranged from below the limit of detection to 2120 ppb. The highest toluene concentrations were found for Melbourne and Adelaide participants during the winter campaign (2120 and 1040 ppb, respectively). At least one participant in each of the cities recorded a toluene concentration below the limit of detection during winter. During summer, only participants from Perth recorded toluene concentrations below the limit of detection.

Figure 2 Components of a box plot



The highest ethylbenzene concentration was recorded by a participant in Melbourne during the winter campaign (119 ppb) and in Adelaide during the summer campaign (91.9 ppb). Participants from each city recorded ethylbenzene concentrations below the limit of detection during the winter and summer monitoring campaigns, except for Sydney where the lowest recorded concentration was 0.10 pp

The concentration range of exposure to xylene was from 0.04 to 697 ppb. The highest total xylene concentration was found for Melbourne during the winter campaign (640 ppb) and for Adelaide during the summer campaign (697 ppb). The lowest xylene concentrations were 0.12 ppb during the winter campaign (all cities) and 0.04 ppb during the summer campaign (Sydney).

Figure 3 Personal exposure monitoring results for the winter sampling campaign ((a) box plots summarises raw data; (b) box plots summarises log transformed data)

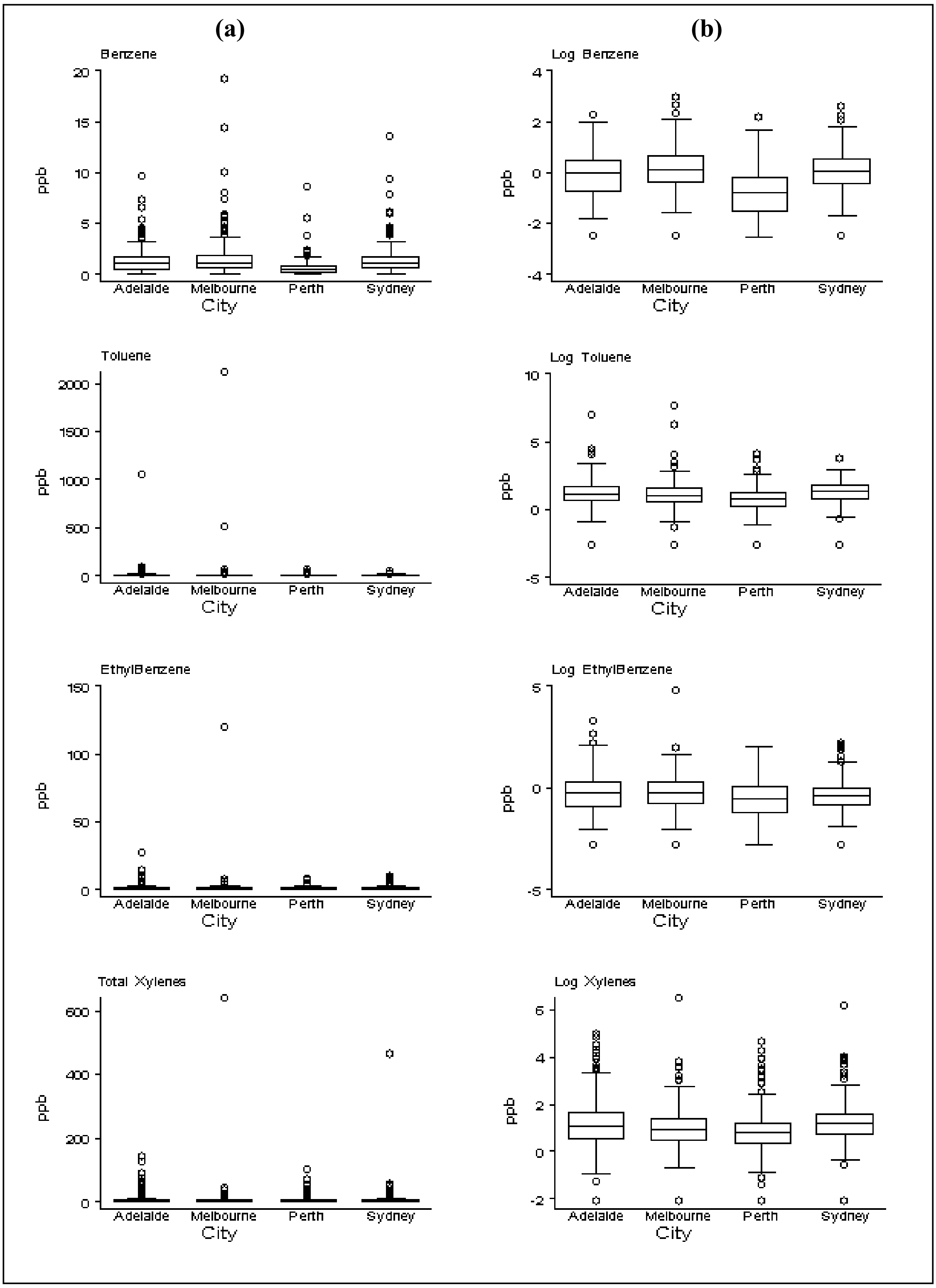
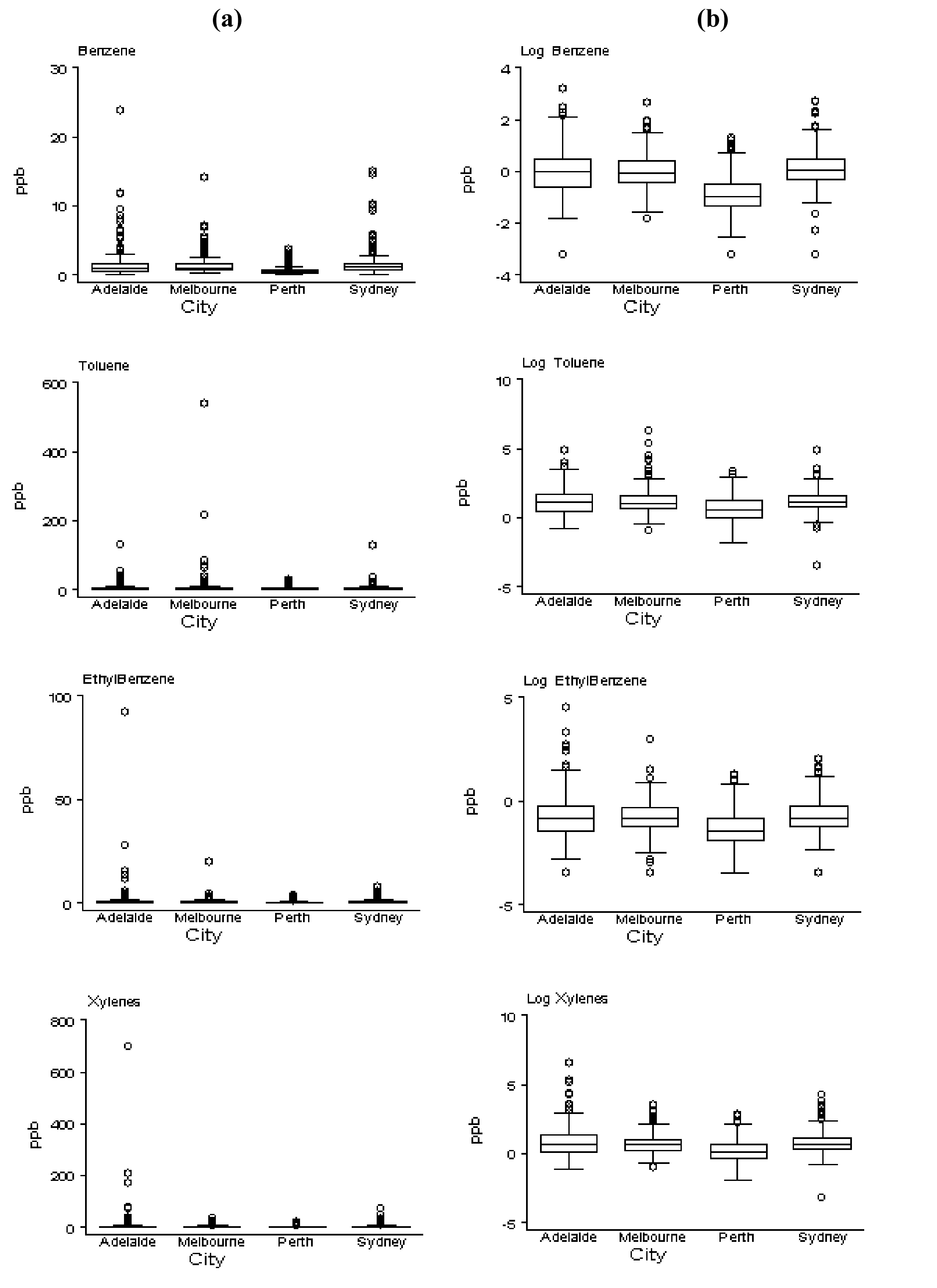


Figure 4 Personal exposure monitoring results for the summer sampling campaign ((a) box plots summarises raw data; (b) box plots summarises log transformed data)



For all of the BTEX constituents for both winter and summer, a highly significant difference was found between the mean exposure of participants in Perth and those in Adelaide, Melbourne and Sydney. Perth participants' BTEX exposures were significantly lower than the other three cities. However, there was no significant difference in the mean BTEX exposure of participants in Adelaide, Melbourne, and Sydney, except for xylene, where Melbourne was significantly different from the other two cities.

5.5.1 Descriptive Analysis: Exclusion of Outlying Elevated Personal Exposure Measurements

In order to examine the typical exposure of most people, a separate analysis was done in which a limited number of outlying elevated personal exposure measurements were excluded from the dataset. It was thought these outlying exposures may unduly influence the identification and estimates of exposure sources for the majority of the participants. Systematic checks for the five highest and lowest values were done and values idetified. If the difference between any of the five highest or lowest values was found to be more that twice the previous value then the values were marked as an outlier. All subsequent analysis was done including and excluding these outliers. The elevated personal exposure measurements (n=8) that were excluded are tabulated in Appendix N.

The outlying elevated personal exposure measurements were cross-checked with the participants' diaries to determine if there were any information to explain the elevated levels and whether the results were 'real' exposures measurements or compromised or suspect exposure measurements.

For all of the elevated personal exposure measurements, diary entries indicated the participants' exposure was likely to be associated with an activity or source which are known to have elevated BTEX concentrations. Specifically, these participants were exposed to lacquer thinners, resins and house paints for several hours, or to spilt petrol which may explain the elevated exposures.

The BTEX concentrations without the outlying elevated personal measurements were tabulated a mean and range for each city in Table 5-13. Benzene exposure results summarised in this table are the same as shown in Table 5-12, as no elevated exposures were excluded for either sampling campaigns. Adelaide participants recorded the highest mean concentrations for all the BTEX constituents except benzene during the winter sampling campaign and toluene during the summer sampling campaign. Melbourne participants recorded the highest mean concentrations for benzene during winter and toluene during the summer.

Personal exposure (excluding outlying elevated exposures) measurements for winter and summer were categorised based on selected categorical diary and questionnaire variables and are summarised in Figure 5. Increased mean participant exposures to most of the BTEX constituents were associated with refuelling a motor vehicle, heater use, being employed and using a carpark. The results show that the mean exposure to most of the

BTEX constituents of male participants were higher than female participants. Similar results were found for both winter and summer.

5.6 Statistical Analysis: Significance of Sources and Activities to Personal Exposure

The influence of sources and activities on measured personal BTEX exposure were investigated using generalized linear mixed models, as outlined in Section 4.7. These models were performed on the entire personal exposure dataset, as well as the personal exposure dataset with the elevated outliers excluded. The winter and summer monitoring campaigns were examined separately and then combined, with season considered as a variable.

5.6.1 Entire Personal Exposure Dataset (Elevated Outlying Exposures Included)

The activities and sources which were found to be significantly associated with BTEX exposure by the reduced model are summarised in Table 5-14. The statistically significant sources and activities are identified by the shaded cells. The output tables from the complete model and the reduced model are provided in Appendix O.

Benzene

City of residence, gender, time spent doing vehicle repairs or using machinery, and refuelling were found to result in a statistically significant increase in benzene exposure for participants in the winter campaign (Table 5-14).

In addition to the factors associated with increased benzene concentrations in winter, carpark use and time spent inside a building were also found to be statistically significant for increased benzene exposure in summer. In the summer samples, significantly lower benzene exposures were found for participants who were employed compared with those who were unemployed or retired. When winter and summer samples were combined, employment was not shown to significantly reduce exposure.

Toluene

For the summer campaign, doing art/woodwork/craft and undertaking vehicle repairs or using machinery were found to result in a highly significant increase in the participants' exposure to toluene (Table 5-14). Time spent cycling/walking/running and doing art/woodwork/craft were found to result in a highly significant increase in participant toluene exposure in the winter campaign. These variables were also significant for the combined winter and summer analysis. In addition to these variables, the presence of a smoker was found to be just significant for increased toluene exposure. No significant difference in toluene exposures was observed for the participants in the different cities.

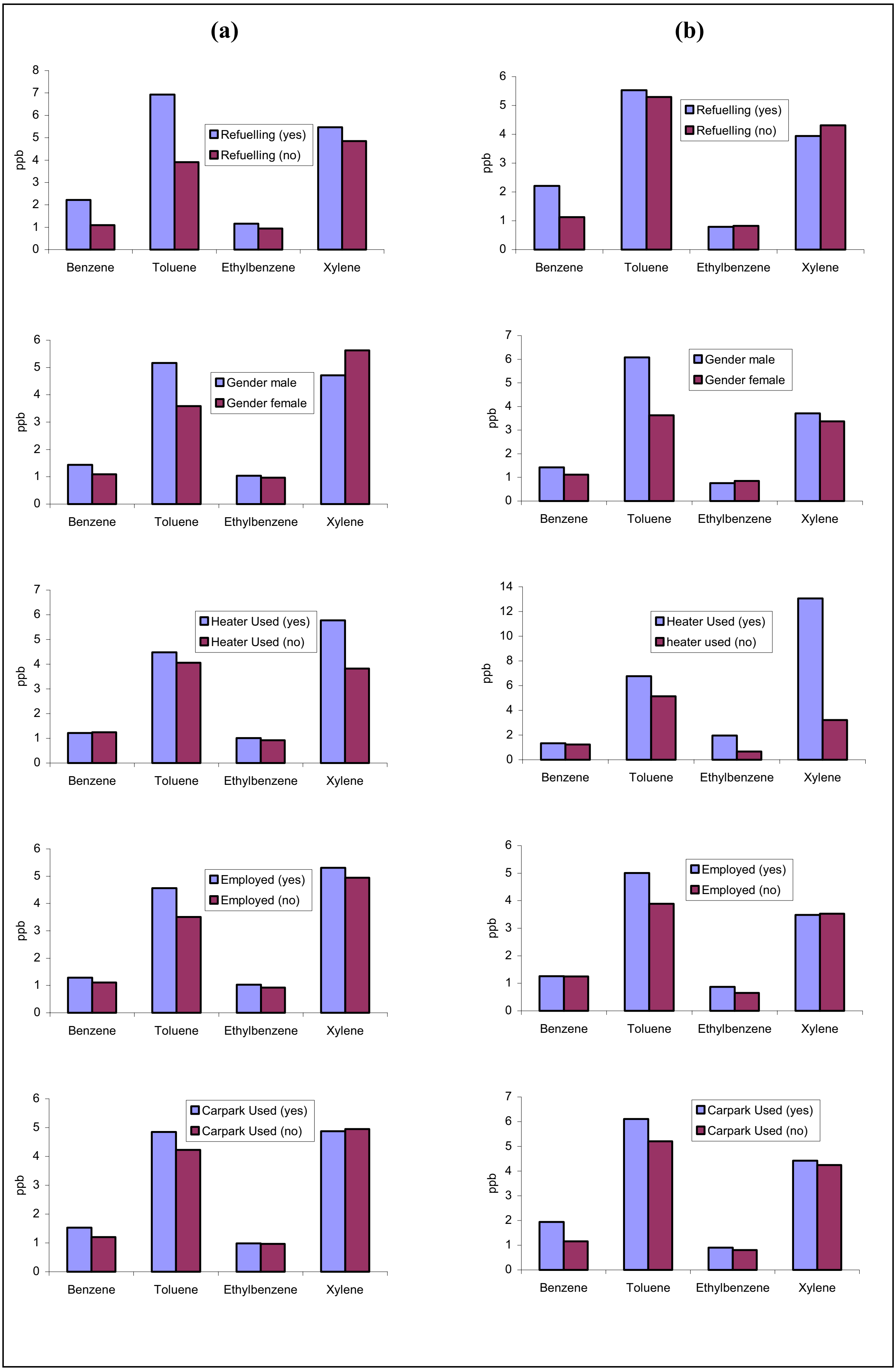
Table 5-13 Summary of personal exposure monitoring results (ppb) with outlying elevated exposure measurements excluded per individual sampling period (nominally 24 hours*)

	Sydney		Adelaide		Melbourne		Perth		All	
	Winter (n=252)	**Summer** (n=243)	**Winter** (n=211)	**Summer** (n=203)	**Winter** (n=242)	**Summer** (n=243)	**Winter** (n=249)	**Summer** (n=243)	**Winter** (n=954)	**Summer** (n=932)
Benzene	(n=251) [1]		(n=209) [1]				(n=246) [1]	(n=242) [1]	(n=948) [1]	(n=931) [1]
Mean	1.43	1.56	1.32	1.66	1.63	1.32	0.62	0.55	1.25	1.25
Geometric Mean	1.05	1.11	0.90	1.00	1.10	1.01	0.40	0.40	0.80	0.81
(Min,Max)	(0.08,13.5)	(0.10,15.0)	(0.08,9.6)	(0.04,23.8)	(0.08,19.2)	(0.16,14.0)	(0.08,8.6)	(0.04,3.7)	(0.08,19.2)	(0.04,23.8)
Toluene			(n=210) [1]		(n=240) [1]	(n=242) [1]				(n=931) [1]
Mean	4.66	4.66	5.30	5.75	4.18	5.76	3.20	2.86	4.30	4.71
Geometric Mean	3.64	3.24	3.15	3.13	2.90	3.08	2.05	1.85	2.86	2.74
(Min,Max)	(0.07,43.1)	(0.45,126)	(0.07,81.4)	(0.43,129)	(0.07,57.6)	(0.39,215)	(0.07,58.0)	(0.03,28.0)	(0.07,81.4)	(0.03,215)
Ethylbenzene					(n=241) [1]				(n=953) [1]	
Mean	0.96	0.78	1.29	1.48	1.00	0.68	0.81	0.40	1.00	0.81
Geometric Mean	0.67	0.53	0.76	0.50	0.75	0.47	0.50	0.26	0.66	0.42
(Min,Max)	(0.06,8.8)	(0.10,7.6)	(0.06,26.6)	(0.03,91.9)	(0.06,7.0)	(0.03,19.7)	(0.06,7.4)	(0.03,3.6)	(0.06,26.6)	(0.03,91.9)
Xylene	(n=251) [1]			(n=202) [1]	(n=241) [1]			(n=242) [1]	(n=952) [1]	(n=930) [1]
Mean	5.37	3.79	7.40	6.05	3.76	2.79	4.12	1.83	5.09	3.51
Geometric Mean	3.48	2.37	3.26	2.34	2.58	2.05	2.19	1.24	2.82	1.92
(Min,Max)	(0.12,52.2)	(0.04,69.8)	(0.12,141.1)	(0.31,207.7)	(0.12,42.8)	(0.35,32.5)	(0.12,100.8)	(0.15,17.18)	(0.12,141.1)	(0.04,207.7)

* The actual sampling times varied from 6.2 hours to 50.5 hours.

[1] The total number of samples considered for these cells are lower due to personal samplers appearing to have 'sampling errors and analytical problems' or the removal of elevated exposure measurements.

Figure 5 Personal exposure results with specific reference to selected categorical diary and questionnaire variables ((a) Winter; (b) Summer)



Ethylbenzene
Time spent cycling/walking/running and doing art/woodwork/craft were found to be highly significant for increased participant exposure to ethylbenzene during the winter sampling campaign.

For the summer campaign, undertaking vehicle repairs/using machinery and heater/air conditioner use were found to be significant predictors of increased participant exposure to ethylbenzene. The length of time spent outdoors was significantly associated with a decrease in the ethylbenzene personal exposure measurements of participants during summer (Table 5-14).

For the summer sampling campaign a significant difference was found between the ethylbenzene exposures of participants in Perth and those in Adelaide, Melbourne, and Sydney, with Perth's participants recording significantly lower ethylbenzene personal exposure measurements. No significant difference between the ethylbenzene exposure measurements of participants from Adelaide, Melbourne, and Sydney were found.

Time spent cycling/walking/running, doing art/woodwork/craft and undertaking vehicle repairs/using machinery were found to significantly increase participants' exposure to ethylbenzene when the data from the winter and summer sampling campaigns were combined.

Xylene
Results from the winter sampling campaign showed that doing art/woodwork/craft and the length of time spent cycling/walking/running were significantly associated with an increase in participant xylene exposure measurements (Table 5-14).

In the summer, time spent cycling/walking/running, undertaking vehicle repairs/using machinery and using a home heater/air conditioner were shown to significantly increase participant personal exposures to xylene. Conversely, lower xylene exposure measurements were significantly associated with the amount of time participants spent outdoors.

When the winter and summer sampling campaigns data were combined, time spent cycling/walking/running, doing art/woodwork/craft, undertaking vehicle repairs/using machinery and using a home heater/air conditioner significantly increased participant exposure measurements to xylene.

5.6.2 Personal Exposure Dataset with Elevated Outlying Exposures Excluded

In order to examine the usual daily exposure of the population sampled, a separate analysis was undertaken where the elevated exposure measurements discussed in Section 5.5.1 and outlined in Appendix N were excluded. Benzene was not included in this analysis as there were no elevated outliers, therefore the result would be exactly the same as presented in Section 5.6.1.

Table 5-14 Significant (Pr > |t|)[1] sources and activities associated with BTEX exposure (entire personal exposure dataset)

Variables Considered in Model	**Benzene**			**Toluene**			**Ethylbenzene**			**Xylenes**		
(Number represents significance value)	**Winter**	**Summer**	**Combined**	**Winter**	**Summer**	**Combined**	**Winter**	**Summer**	**Combined**	**Winter**	**Summer**	**Combined**
Season												
Gender	0.02	0.05	0.0142									
Age												
City of residence	<0.0001	<0.0001	<0.0001					0.02				
Employed		0.03										
Inside Building Home Smoker Nearby												
Inside Building Home No Smoker Nearby												
Inside Building Work Smoker Nearby												
Inside Building Work No Smoker Nearby												
Inside Building Other Smoker Nearby												
Inside Building Other No Smoker Nearby		<0.0001	0.0011									
Motor vehicle time												
Public transport time												
Cycling/walking/etc time				<0.0001		<0.0001	<0.0001		<0.0001	<0.0001	0.03	<0.0001
Outdoors All (time)								0.05			0.04	
Cooking All (time)												
Art/woodwork/craft All (time)				<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001		0.002
Vehicle repair/refuel/machinery time	0.008	<0.0001	<0.0001		<0.0001			<0.0001	0.001		<0.0001	0.0003
Refuelling	<0.0001	<0.0001	<0.0001									
Drive-through												
Enclosed car park		0.0009	0.0003									
Home within 300m of industry												
Attached garage at home												
Near smoker during sampler period						0.05						
Distance to nearest highway/arterial road												
Heater/ AC use during sampler period								0.002			0.002	0.005
Specific heater type												

[1] Pr > |t|: Significance value for the reduced model at the 95% confidence level. The smaller the number the more significant the variable.
Note: Blank cells correspond to sources or activities not found to be significant by the model.

The activities and sources which were found to be significantly associated with BTEX exposure, using the reduced models (excluding outlying elevated exposure measurements) are summarised in Table 5-15. The statistically significant sources and activities are identified by the shaded cells in the table. The output tables from the complete model and the reduced model are provided in Appendix O.

Toluene
City of residence, gender, refuelling and time spent doing vehicle repairs or using machinery were found to result in a statistically significant increase in toluene exposure in the winter samples (Table 5-15). In addition, lower toluene exposures were found to be associated with increased time outdoors. In the summer, city of residence, use of drive-through facilities, heater/air-conditioner use and time spent undertaking vehicle repairs/using machinery were associated with a statistically significant increase in the toluene exposure of participants. When the winter and summer data were combined, season was identified as significantly affecting participant exposure to toluene, with summer exposures more elevated than winter exposure measurements.

Ethylbenzene
Refuelling was the only factor that was found to be statistically significant for increased ethylbenzene exposure in the winter sample (Table 5-15). For the summer sample, city of residence, heater/air-conditioner use and time spent doing vehicle repairs or using machinery were found to be statistically significant for increased ethylbenzene exposure. Time spent outdoors was found to be just significant for decreased ethylbenzene exposure.

Season was identified as significantly affecting participant exposure to ethylbenzene when the winter and summer data were combined, with winter exposures more elevated than summer exposure measurements. Moreover, time in a motor vehicle and doing art/woodwork/craft were associated with a significant increase in ethylbenzene exposure when the combined data were analysed.

Xylene
Results from the winter sampling campaign showed that none of the variables considered in the model were found to be significantly associated with participant xylene exposure measurements (Table 5-15). During the summer sampling campaign however, time spent undertaking vehicle repairs/using machinery and using a home heater/air conditioner were shown to significantly increase participant personal exposures to xylene. Moreover, lower xylene exposure measurements were significantly associated with the amount of time participants spent outdoors.

In addition to the variables identified as being significant for the summer sampling campaign, city of residence was found to be significantly associated with xylene exposure. Lower xylene exposure measurements were significantly associated with the amount of time participants spent inside a work building (no smoker nearby).

Table 5-15 Significant (Pr > |t|)[1] sources and activities associated with BTEX exposure (personal exposure dataset with the elevated outliers excluded)

Variables Considered in Model	Benzene			Toluene			Ethylbenzene			Xylenes		
(Number represents significance value)	Winter	Summer	Combined	Winter	Summer	Combined	Winter	Summer	Combined	Winter	Summer	Combined
Season						0.05			<0.0001			
Gender	0.02	0.05	0.01	0.02		0.01						
Age												
City of residence	<0.0001	<0.0001	<0.0001	0.01		0.004		0.02	0.0002			0.0003
Employed		0.03										
Inside Building Home Smoker Nearby												
Inside Building Home No Smoker Nearby												
Inside Building Work Smoker Nearby												
Inside Building Work No Smoker Nearby												0.03
Inside Building Other Smoker Nearby												
Inside Building Other No Smoker Nearby		<0.0001	0.001									
Motor vehicle time									0.03			
Public transport time												
Cycling/walking/etc time												
Outdoors All (time)				0.01				0.05			0.01	0.03
Cooking All (time)												
Art/woodwork/craft All (time)									0.008			
Vehicle repair/refuel/machinery time	0.008	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		<0.0001	<0.0001		<0.0001	<0.0001
Refuelling	<0.0001	<0.0001	<0.0001	<0.0001		0.03	0.005					
Drive-through					<0.0001	<0.0001						
Enclosed car park		0.0009	0.0003									
Home within 300m of industry												
Attached garage at home												
Near smoker during sampler period												
Distance to nearest highway/arterial road												
Heater/ AC use during sampler period					0.04			0.002			0.01	<0.0001
Specific heater type												

[1] Pr > |t|: Significance value for the reduced model at the 95% confidence level. The smaller the number the more significant the variable.
Note: Blank cells correspond to sources or activities not found to be significant by the model.

6 DISCUSSION

The results of this study are based on 207 participants who ranged from 20 to 68 years in age. One hundred and eighty six (186) participants wore personal samplers in both the winter and summer monitoring campaigns.

A large range of participant exposures were recorded for all of the BTEX constituents. The lowest personal exposure measurements recorded for all the BTEX constituents was below the limit of detection. The most elevated exposure measurement recorded for each of the BTEX constituents was; 23.8 ppb for benzene, 2120 ppb for toluene, 119 ppb for ethylbenzene and 697 ppb for xylene, respectively.

The mean exposure measurements of participants in this study were well below these maximum exposures and are low compared with international air quality objectives/guidelines and Australian occupational exposure standards for BTEX (Table 6-1). It should be noted however, a comparison of the personal exposure measurements from this study with air quality objectives/guidelines is not simple. Different countries adopt different objectives/guidelines, depending mainly on the sample collection or averaging time, ranging from as short as 3 minutes to as long as 1 year. The participants of this study were nominally sampled for 24 hours, but short term excursions to higher concentrations would have been experienced within this period. The table below shows comparable environmental standards that may apply to each of these pollutants, together with the Australian occupational exposure standard.

Table 6-1 International environmental and occupational exposure (ppb) standards for BTEX.

Air Pollutant	Air Quality UK objective/WHO guidelines (averaging time)	Source	Australian Occupational standard	Mean exposures in this study (winter/summer)
Benzene	5 (1 year)	DEFRA (2001)	5,000	1.25/1.25
Toluene	67.8 (1 week)	WHO (1999a)	100,000	8.12/5.29
Ethylbenzene	4,978 (1 year)	WHO (1996)	100,000	1.13/0.81
Xylene	1,086 (24 hours)	WHO (1997)	80,000	6.23/4.25

Note: Workplace standards are those to which nearly all workers may be repeatedly exposed for 8 hours per day, 5 days per week, for a working lifetime without ill effect. World Health Organisation (WHO) guidelines presented above were referenced in the *Guidelines for Air Quality* (WHO, 1999b).

The BTEX personal exposure results measured by this study are comparable to personal exposures reported elsewhere (Appendix Q). It is difficult to accurately compare 'real' differences in the exposures measured, as different sampling methodologies were employed and the sampling periods varied. Differences in the sample population will also result in different means and ranges of exposure. Taking this into consideration, the BTEX personal exposure results from this study were within the lower range of the personal exposure measurements reported by the other research summarised in Appendix Q.

The average personal monitoring results were similar to the ambient BTEX concentrations measured in phase I of this study and previous ambient studies conducted in Australia (Appendix P). However some participant exposures were much higher than ambient measurements, suggesting the need for personal monitoring which takes account of all exposures rather than sampling ambient air or a single microenvironment (Edwards *et al*., 2001).

Comparisons were drawn between the information supplied in the questionnaires by the participants of each city to determine if they were significantly different. This was done to help explain any differences in participant exposures which may be observed. It was determined that significantly more participants in Sydney were employed compared to Perth participants during the summer monitoring campaign. There were also significant differences between the main type of home heater used, with Melbourne and Perth using gas and Sydney and Adelaide using electric.

Information from the activity diaries indicated participants overall spent significantly more time indoors than outdoors, the majority of the indoor time was spent at home. There was little difference between the cities, when the mean reported total time spent indoors and in the various indoor locations were compared. These results are similar to those found by Langley *et al*. (1992) who reported Australians spent between 68% to nearly 90% of their time at home. There was also little difference between the participants of each city when the mean reported travelling time in a motor vehicle were examined. Furthermore, time spent undertaking activities such as cooking, cycling/walk/jogging and machinery repair/refuelling were similar when the means were compared for each city.

The results from the generalized linear mixed models found that city of residence significantly affected personal exposure to BTEX, despite there being few differences in behaviour and lifestyle between the participants from different cities as reported in the questionnaire and diaries. The mean participant BTEX exposures recorded in Perth were significantly lower than those of the other cities. The most probable reason for these differences is the variation in fuel quality between the States. Western Australia has regulated fuel to 1% benzene, where as the other States in this study have petrol containing typically 2 to 3.5% benzene. Furthermore, even though refuelling was reported more frequently in Perth, the average exposure was less than half that of the other cities.

Motor vehicle and petrol related activities such as vehicle repair, motor vehicle use, petrol machinery use and refuelling were found to be significantly associated with an increase in BTEX personal exposure. Previous studies have reported similar findings (Edwards and Jantunen, 2001; Ilgen *et al*., 2001). Emissions from motor vehicles result from incomplete combustion (exhaust) and fugitive emissions. Results from this study confirm that time spent repairing vehicles and using and refuelling handheld petrol machinery, carpark use and drive-through use are significantly associated with elevated BTEX exposure during the summer. One explanation may be the potential increase in fugitive emissions i.e. hot soak losses from vehicles as a result of increased ambient temperatures during the summer monitoring campaign. In this study benzene and toluene were the only constituents found to have a significant association with motor vehicle related activities during winter.

Refuelling motor vehicles was found to significantly increase BTEX personal exposure, during winter (when the elevated exposures were not considered by the model). Benzene was the only BTEX constituent to show a significant increase in exposure associated with refuelling motor vehicles during summer. Vayghani and Weisel (1999) suggested that refuelling is an activity during which individuals can be exposed to very high petrol vapour concentrations. In their opinion a number of factors such as the type of fuel used, the duration of refuelling and the number of vehicles refuelling influence the degree of personal exposure. Other research has drawn similar conclusions (Leung and Harrison, 1999; Romieu *et al*., 1999; Lindstrom and Pleil, 1996; NESCAUM, 1989).

When the complete personal exposure dataset was considered using the generalized linear mixed models, time spent undertaking arts, crafts and woodwork were found to significantly increase exposure to BTEX. Previous studies have found that household products such as paint, paint stripper, varnish, varnish remover, rubber cements, adhesives and degreasing agents may all emit constituents of BTEX when used (US EPA, 1993a; US EPA, 1995a US EPA, 1995b; Zhang and Smith, 1996; Chattopadhyay *et al*., 1997). Many of the elevated exposures measured in this study appear to be associated with these activities, as indicated in these participants' diaries. When the outlying elevated exposures were removed from the personal exposure dataset, arts and craft activities were not found to significantly increase personal exposure, except for ethylbenzene (when the winter and summer data were combined). This suggests that a few people doing some high BTEX exposure activities will influence the overall results for the group.

Time spent outdoors (all activities) was found to decrease personal exposure to BTEX, even though specific outdoor activities such as cycling/running/walking were found to increase BTEX personal exposure for the complete dataset. However, when the elevated outlying exposures were excluded, specific outdoor activities such as cycling/running/ walking were no longer found to significantly increase personal exposure. These results differ from international research. These differences may be a result of where a person spends their time outdoors as this can affect their personal exposure. It is unknown whether the participants' time spent outdoors was in environments likely to contribute to BTEX exposure. Even in environments that could contribute to BTEX exposure, factors such as wind speed (which may affect personal sampler diffusion), dispersion of BTEX and proximity to BTEX sources may reduced the personal exposure measurements. These differences could also be a modelling artefact.

Environmental tobacco smoke (ETS) has been shown to be another important source of BTEX exposure (ATSDR, 1991; Wallace, 1987, Wallace *et al*., 1989; Brown *et al*., 1994). ETS was not found to significantly increase exposure to BTEX by the generalized linear mixed models. This may be a result of the participant selection criteria, which excluded active smokers from this study to prevent personal smoking habits influencing the exposure measurements. Furthermore, the diaries for the majority of the participants demonstrated that the participants spent little time near smokers or otherwise exposed to ETS. The low mean exposure time for the workplace is probably due to no smoking policies in many buildings.

One limitation of this study was the lack of information on the time spent refuelling, in the presence of a smoker, using a home heater or air conditioner, using a drive-through and using an enclosed carpark. Categorical (yes/no) questions were asked for these variables at the beginning of each day's diary. Participants frequently provided little information regarding the length of time linked to each of these variables. Another limitation was the reporting of multiple activities for a single time period, particularly for household activities, such as cooking, cleaning and gardening. This was also the case for commuting and other transport, which was often incorporated with other activities, such as shopping.

Caution should be exercised in the interpretation of the results from this study. The sample of participants was primarily chosen from a pool of self-selected respondents from phase II (survey) of this Project. As a result, the selected participants may not truly represent the populations of these Australian cities. Results from the participant questionnaire were compared to the responses from the postal questionnaire sent out in phase II of this project, to determine if the two sample populations were statistically significantly different. For 11 of the 36 questions analysed, significant differences between the two sample populations were found. In most cases the significant differences were generally only found for one city. These results suggest the participants of this study were similar in behaviour and lifestyle to the respondents of the postal questionnaire. Further work is required to determine this. However, in terms of factors which increase personal exposure to participants in this study, the results are valid.

7 CONCLUSIONS

Australian urban personal exposures to BTEX measured in this study are comparable to exposures reported in the international literature. For the most part these exposures are near the lower bounds of those measured elsewhere and were well below environmental exposure guidelines. One reason for these low exposure measurements may be that this study examined community exposures, whereas international studies have primarily focused on known sources or exposed sub-groups in the community. Elevated personal exposure measurements were found to be associated with various non-occupational locations and activities known to increase BTEX exposure. This range of contributing sources outlines the usefulness of personal monitoring compared with fixed location monitoring.

The activities and locations found to significantly increase BTEX personal exposure included motor vehicle related activities such as vehicle repair and machinery use; refuelling of motor vehicles; time spent undertaking arts, crafts and woodwork; and city of residence. The results suggest that most of the significant sources of personal exposure to BTEX were associated with specific localized indoor and outdoor activities and locations. These results are confirmed by research conducted internationally.

Perth participants had significantly lower mean personal exposure measurements than the participants in the other States. This significant effect of city of residence on participant exposure to BTEX is thought to be linked to more stringent fuel quality regulation of benzene in Western Australia. There was no significant difference in the mean BTEX exposure of participants in Adelaide, Melbourne, and Sydney, except for xylene, where Melbourne was significantly different from the other two cities.

The risk factors shown to increase BTEX exposure require further investigation to confirm the results of this study and the impact of reducing BTEX concentrations. This study could only provide information on the relative importance of sources and/or activities which have been identified in this report. The consideration of factors such as traffic density could strengthen the study results. Additional activity and location monitoring specific to the participants, would assist in resolving the interrelationships between the various sources and personal exposures. Furthermore, the personal exposure monitoring conducted during this study did not consider the amount of BTEX entering the body. Measuring urinary metabolites, for example, may be an extension of this project to confirm the extent of uptake of BTEX into the body.

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