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Personal exposure of children to formaldehyde in Perth, Western Australia

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USE OF THESIS

Personal Exposure of Children to Formaldehyde in Perth, Western Australia

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ABSTRACT

Formaldehyde is a common air pollutant that tends to be found in elevated concentrations in indoor air. Exposure to formaldehyde has the potential to impact on respiratory health, particularly amongst sensitive individuals and populations, including children. Children spend most of their time indoors at home, however, there are very little data on the contribution of formaldehyde concentrations in homes to personal exposure in children. The principal aim of this cross sectional study was to investigate whether the domestic environment is the most significant source of personal exposure of formaldehyde in children.

Forty-one primary school children (aged between 8 and 12) were recruited from two areas of Perth, Western Australia. Each child wore a personal passive formaldehyde sampler over a 24 hour period on two separate occasions, winter and summer. Samplers were also located indoors at home, outdoors at centralised locations and indoors at school for the corresponding period. A questionnaire about lifestyle and behaviour and a daily activity diary were completed for each participant. Passive samplers used filter papers impregnated with 2,4-dinitrophenylhadrazine (DNPH), with formaldehyde detected using high pressure liquid chromatography (HPLC).

In winter there was a wide range of personal exposure concentrations, with geometric mean concentrations of 9.7ppb at Duncraig and 11.5ppb at Calista. Indoor geometric mean concentrations at Duncraig were 10.1ppb, with outdoor and classroom concentrations below the analytical limit of detection (4ppb). At Calista, mean indoor concentrations were 14.2ppb. The outdoor concentrations were below the limit of detection and school concentrations were 8.0ppb.

Summer monitoring occurred during mild meteorological conditions and were very similar to winter results. Geometric mean personal exposure concentrations were 9.2ppb at Duncraig and 8.0ppb at Calista. Indoor geometric mean concentrations at Duncraig were 9.0ppb, with outdoor and classroom concentrations below the limit of detection (4ppb). At Calista, mean indoor concentrations were 9.9ppb, outdoor was below detection limit and school concentrations were 15.2ppb.

There were strong correlations between personal exposure and domestic concentrations at both Duncraig and Calista in winter (r^2 = 0.73 and 0.88, respectively) and in summer (r^2 = 0.67 and 0.84, respectively). The correlation for both seasons combined was significant, with a coefficient of r^2 = 0.78.

A time weighted model estimated personal exposure concentrations for each participant using stationary measures in combination with time activity data. These estimates of exposure correlated significantly with measured personal exposure concentrations, with a coefficient of r^2 = 0.80 for all data combined.

The indoor domestic environment was found to be the most important source of formaldehyde exposure for children. Time weighting was found to provide a stronger estimate of personal exposure than indoor air monitoring alone, although the time weighted model was not a significant improvement over the indoor measure alone.

DECLARATION

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TABLE OF CONTENTS

Figures

Tables

1.0 INTRODUCTION

1.1 Background

Formaldehyde is an air toxic that is produced from a variety of sources, resulting in its presence in both indoor and outdoor air. Classified as a priority air toxic as part of the Air Toxics Program (Environment Australia 2001), formaldehyde is an important contributor to air pollution. While ubiquitous, formaldehyde has been shown to be elevated in indoor air and this is recognised as the key environment for potential human exposure (WHO 2002). This is of particular relevance to people in the developed world as the majority of people spend over 90% of their time indoors (Wigle 2003).

Formaldehyde, or HCHO, is the simplest of the aldehyde class of chemicals. A gas at room temperature, yet readily soluble in water, it is more reactive than many other aldehydes. It will degrade readily in the atmosphere to form formic acid and carbon monoxide, usually within 24 hours (Atkinson 2000). Occurring naturally in the environment, it is a common compound in the synthesis of more complex compounds in industry (Lowe *et al* 1980). Formaldehyde is most often used to create polymers for resin production, with these resins often releasing formaldehyde gas for several years after production (Brown 2002).

There are a number of potential health impacts associated with inhalation exposure to formaldehyde. It is an irritant of the upper respiratory tract at relatively low concentrations and has been associated with asthma development and asthma symptom exacerbation, particularly in children (Garrett *et al* 1999; Arts *et al* 2008). It is also associated with occupational asthma in adults (Horvath *et al* 1988; Godish 1990). It is also classified as a human carcinogen by the International Agency for Research on Cancer based on toxicological data and longitudinal retrospective studies of occupational exposure (IARC 2004). It should be noted that the validity of the key study on which this classification was based has been queried (Marsh *et al* 2007), due to the findings being dependant on the data analyses methods utilised, with the findings not supported if different methods are applied.

In recent years, many epidemiological studies have focused on the respiratory health impacts associated with non-occupational exposure. These have included asthma development and exacerbation, increased atopy and sensitisation and irritation of the upper respiratory tract (Ritchie & Lehnen 1997; Godish 1990; Norbäck *et al* 1995; Garrett *et al* 1996; Suh *et al* 2000; Arts *et al* 2008).

Despite the number of sources of formaldehyde there is currently no Australian standard to regulate formaldehyde concentrations, either indoors or outdoors. To address this a National Environment Protection (Air Toxics) Measure (NEPM) has been developed to aid in gathering information for five priority air toxics, including formaldehyde, with the aim of developing national air quality standards (National Environment Protection Council 2004). There are, however, interim indoor air quality goals which have been suggested by various institutions. The National Health and Medical Research Council (NHMRC) recommended that indoor concentrations of formaldehyde do not exceed 100 parts per billion (ppb) (NHMRC 1982). Although this document has been rescinded, it was rescinded as it was no longer an area for which the NHMRC was responsible and not due to any errors or technical issues with the document (NHMRC 2005). The more recent National Industrial Chemicals Notification and Assessment Scheme (NICNAS) document suggests an indoor standard of 80ppb would be more appropriate (NICNAS 2006). Although aimed at information gathering, the NEPM suggests that for ambient concentrations a 24 hour average concentration should not exceed 40ppb (National Environment Protection Council 2004).

While further data collection within Australia is occurring as part of the NEPM, this focuses on outdoor air only. As formaldehyde is predominantly an indoor air quality issue, the NEPM does not target this key area of concern. Furthermore, there is limited research or monitoring within Australia for formaldehyde exposure, particularly in relation to children, who are particularly vulnerable to

the health impacts associated with exposure (Garrett *et al*1999; Rumchev *et al* 2002).

1.2 Formaldehyde Sources and Concentrations

1.2.1 Indoor Environment

1.2.1.1 Sources

The range of potential sources of formaldehyde is extensive due to the prevalence of formaldehyde as a chemical additive in many industrial processes, and its presence as a by-product of combustion (Lowe *et al* 1980; Bettelheim & March 1995). The primary use of formaldehyde is the production of resins which are used as adhesives in the production of particleboard, fibreboard and plywood, with these products common materials in almost all homes and indoor environments (McPhail 1991; Kelly 1999; Dingle *et al* 2000; Jiang 2002). Formaldehyde is used in moulding, paper treating, paper coating, textile treating and in surface coating (NICNAS 2006). The use of formaldehyde in the production of urea foam insulation is widespread, although production methodologies have improved since the 1980's to reduce emissions (USEPA 1997).

Formaldehyde is also an additive in a range of other chemical processes, such as a preservative in some paints, permanent pressing of fabrics, a preservative in cosmetics and as an additive in some household chemicals (Suh *et al* 2000; NICNAS 2006). It is also used in a range of medical applications for purposes such as embalming, skin disinfectants, cough drops, general disinfectants, and in industrial applications such as leather tanning, corrosion inhibition, gasoline stabilisation and as a chemical intermediate (NICNAS 2006).

While all of these applications are potential sources of formaldehyde, there are also a range of processes that create formaldehyde as a by-product. It is a product of fuel and wood combustion and is a compound in vehicular exhaust, wood fire smoke and exhaust from fuel burning appliances such as gas stoves

and heaters (Lowe *et* al 1980; Holgate *et al* 1999; WHO 2002; Reisen & Brown 2009).

As formaldehyde resins are used in the production of particleboard, which is widely used in housing, furniture and construction, there have been numerous studies which have assessed the relationship between particleboard and formaldehyde concentrations in indoor air. Brown (1999) undertook dynamic environmental chamber experiments to measure formaldehyde emissions from common building materials and office furniture. This study found that reconstituted wood based panels (RWP), such as particleboard and medium density fibreboard (MDF), emitted high concentrations of formaldehyde when new, above the then current NHMRC guidelines. The emission rates initially followed a first-order exponential decay which subsequently slowed, resulting in a constant emission source for extended periods. The study also found that office furniture emitted similar levels of formaldehyde to RWP despite laminate covers on RWP, with heat fusing adhesives the likely source. Increased ventilation was shown to increase formaldehyde emission rates from particle board and MDF (Brown 1999).

Hodgson *et al* (2002) undertook a small-scale chamber test of a range of materials used in manufactured homes, including particleboard countertops and cabinet cases, frame lumber, doors and plywood subfloors. Materials were placed in a small chamber for 48 hours and the chamber exhaust analysed to identify major formaldehyde emitters. The study found that, of the materials tested, cabinetry materials, passage doors and plywood subfloors were the most significant emitters of formaldehyde in new manufactured homes (Hodgson *et al* 2002).

Studies measuring formaldehyde in the indoor air of portable buildings and caravans found that the use of large amounts of RWP in the construction resulted in elevated formaldehyde concentrations in these buildings (McPhail 1991; Scmidt 1991; Brown 1999; Hodgson *et al* 2002). McPhail (1991) found that

caravans and portable buildings had substantially elevated levels of indoor formaldehyde, compared with conventional homes, with the studies by Scmidt (1991) and Hodgson *et al* (2002) reporting similar findings.

A number of other studies which have measured formaldehyde in conventional buildings found significant relationships between certain dwelling characteristics and indoor formaldehyde concentrations. A study of 833 English homes by Raw *et al* (2004) measured formaldehyde in bedrooms for a 3 day sampling period, finding that newer homes and homes with particleboard flooring had significantly higher formaldehyde concentrations. Smedge & Norback (2001) measured formaldehyde in 181 classrooms in Sweden and found that classes with more fabric and more open shelves had higher formaldehyde concentrations. The possible relationship between the open shelves and formaldehyde concentrations is not discussed and is not clear, although it may be due to the use of greater amounts of particleboard for use in shelving in the classrooms.

Motor vehicle cabins can also contain significant concentrations of formaldehyde. Materials such as plastics used in vehicle fittings can emit significant concentrations of many volatile organic compounds (VOCs), including formaldehyde (Yoshida & Matsunga 2005). Closed vehicles parked in the sun can develop particularly elevated concentrations as emission rates from formaldehyde containing products increase at higher temperatures (Brown 1999). However, Fedoruk & Kerger (2003) reported elevated concentrations present in stationary hot cars were rapidly dissipated under normal working conditions, including when the air-conditioning was on recirculation mode. There is also potential for vehicle exhaust to be a contributor to in-cabin concentrations of formaldehyde (Yoshida & Matsunga 2005).

1.2.1.2 Indoor Concentrations

A number of international studies have been published which report indoor air concentrations of formaldehyde. Jurvelin *et al* (2001) reported low mean concentrations of formaldehyde in dwellings (12.8ppb) and in workplaces

(12.0ppb) in a study in Helsinki, although the study is limited by the small sample size of 15 individuals. Samples were collected over a 48 hour sampling period in the main living area of the participants dwelling. Gustafson *et al* (2005) measured formaldehyde in 65 bedrooms in Sweden, with the study collecting 24 hour samples in Campaign A (n=24) and 6 day samples in Campaign B (n=40), with the two campaigns undertaken in different cities. The study reported median indoor formaldehyde concentrations of 18.7ppb in Campaign A using a 24 hour sampling period, while Campaign B reported a median indoor concentration of 23.6ppb with a 6 day sampling period. As there are no reported differences in the dwelling characteristics between Campaign A and Campaign B, the difference in median concentrations between campaigns appears to be a result of the different sampling periods. The 6 day sampling periods included weekends and were started on random days, although the impact of weekday versus weekend activities on measured concentrations was not discussed. If any factors were identified that would cause the Campaign B indoor concentrations to be higher, these additional sources of formaldehyde are not discussed or evident in the data presented in the Gustafson *et al* (2005) study.

A study undertaken in Mexico City collected indoor air samples in 30 residences over a 24 hour sampling period, with a median formaldehyde concentration of 16.0ppb reported (Serrano-Trespalacios *et al* 2004). A comprehensive study conducted across three cities in the United States collected 48 hour passive samples of formaldehyde concentrations indoors in a number of homes, with a total of 398 indoor air samples collected (Weisel *et al* 2005). The study reported an average indoor concentration of 17.6ppb for all samples (Weisel *et al* 2005).

In Australia there have been very few studies that have measured indoor formaldehyde concentrations. Garrett *et al* (1997) measured formaldehyde in Victorian homes, with concentrations reported being quite low and largely below the 1982 NHMRC interim goal of 100ppb, with a median of 12.6ppb. Passive sampling techniques were used and sampling media were exposed for 4 days within the participant's home. There was a significant relationship between

formaldehyde indoor concentrations and the presence of fibreboard, particleboard, unvented gas heaters and age of home, with dwellings less than 10 years old having higher concentrations. The study measured concentrations in 80 homes with sampling repeated on four occasions, with this sample size large enough to ensure that there is statistical strength in the conclusions and data analyses.

Dingle & Franklin (2002) collected data on potential formaldehyde bearing materials and formaldehyde sources in 185 Perth homes, with formaldehyde measured in four indoor locations in each home. Sampling was undertaken using passive sampling techniques, with two rounds of sampling conducted and sampling media exposed for a three day sampling period. The study reported a geometric mean indoor air concentration of 22.8ppb for all homes and found that age of home and season were the only significant factors relating to indoor concentrations. Homes in this study tended to be newer than Perth homes on average (46% less than 10 years old in this study, compared with 30% of homes less than 10 years old across Perth on average) (Dingle & Franklin 2002).

A similar study was undertaken by Rumchev *et al* (2002) which monitored 192 Perth homes using passive sampling methods, with samples collected over 8 hrs from 9.00 am to 5.00 pm in both the living room and a child's bedroom. Rumchev *et al* (2002) reported mean concentrations of 24.5ppb in bedrooms and 22.4ppb in the living room. This study reported a significant relationship between indoor air concentrations and season, indoor air temperature, the presence of unflued gas heaters and new carpets (Rumchev *et al* 2002). However, the use of an 8 hour measure collected during the day has some limitations as it may not be representative of concentrations present during the evening and night time, which are generally the main periods when people are indoors at home. Concentrations of formaldehyde in a room may differ between day and night time due to variability in factors such as ventilation or use of sources such as gas stoves, gas heating, wood heating or smoking. Furthermore, many inhabitants would not be home at all during this period, so the results may

not be an accurate representative of indoor formaldehyde concentrations individuals may be exposed to.

1.2.2 Outdoor Environment

1.2.2.1 Sources

Naturally occurring formaldehyde in ambient air is emitted from sources such as forest fires, animal wastes and plant volatiles (Bettelheim & March 1995; Martin *et al* 1999; de Vos *et al* 2008; Reisen & Brown 2009). Most organisms will produce small amounts of formaldehyde as a metabolic intermediate (WHO 2002). It is also an intermediate in the process of oxidation, or combustion, of methane and other carbon compounds (Bettelheim & March 1995). Formaldehyde forms in the atmosphere as a result of photochemical oxidation of reactive organic gases in polluted atmospheres (Bettelheim & March 1995). Formaldehyde will degrade to carbon monoxide and formic acid quickly in ambient air, usually within 24 hours (Atkinson 2000).

Estimates of total emissions into the Australian ambient environment indicate that 69.5% is due to domestic solid fuel burning and motor vehicle emissions (NPI 2005).

Formaldehyde can form in water due to irradiation of humic substances by sunlight (Kieber *et al* 1990). It can also be present in water due to bacteria, algae plankton and vegetation emissions (Nuccio *et al* 1995). Formaldehyde has a longer half life when present in water, of between two to 20 twenty days (Howard *et al* 1991).

Other outdoor air sources include manufacturing plants that use or produce formaldehyde, industries and refineries which require fuel combustion of any sort, including boilers, furnaces, incinerators and engines, and smoking and tobacco products (United States Environmental Protection Agency 1997; Environment Australia 2001; NPI 2005).

1.2.2.2 Outdoor Concentrations

Outdoor concentrations of formaldehyde have been measured in a number of studies, with the concentrations reported much lower than indoor concentrations. Ambient air monitoring conducted by Australian government agencies have reported ambient concentrations of 1.4ppb in Perth (DEC 2006) and 0.9 – 4.1ppb in Melbourne (EPA Victoria 2008).

Outdoor monitoring conducted by Garrett *et al* (1997) in Victoria reported outdoor concentrations of 0.2 – 12.4ppb, with a median of 0.6ppb. Studies conducted overseas have also reported low outdoor concentrations, with Jurvelin *et al* (2001) reporting a mean of 2.6ppb in Helsinki, Gustafson *et al* (2005) reporting median outdoor concentrations of 3.3ppb in Sweden, Serrano-Trespalacios *et al* (2004) reporting a median of 4.2ppb in Mexico City, and Weisel *et al* (2005) reporting a median of 2.4 – 5.3ppb across several cities in the United States. Outdoor concentrations have been found to be higher in urban than in rural areas, and are even further elevated outdoors in high density urban areas with significant ambient sources, such as Seoul or Mexico City (Son *et al* 2002; Serrano-Trespalacios *et al* 2004). This elevation of ambient concentrations is likely a result of both an increase in number of primary sources, such as vehicles and heavy industry, and also due to secondary formation from photochemical smog (Lowe *et al* 1980; NICNAS 2006).

1.2.3 Microenvironmental variation

Air quality and concentrations of chemicals in ambient air can vary significantly over relatively short distances, resulting in the occurrence of different concentrations between microenvironments. Microenvironments are discrete areas which are distinguished by factors such as concentrations of chemicals present, physical barriers, proximity and strength of sources, ventilation rates or the activities undertaken in an area (Nieuwenuijsen 2003). These microenvironments can vary in size from quite small areas, such as the area around an operational gas stove, to quite large areas, such as a whole suburb.

The variation in concentrations of pollutants between microenvironments can be significant, with this variation particularly evident for some chemicals, including formaldehyde. The reasons for these differences in concentrations are varied, but can be due to the large number of potential sources and their rates of emission, the type/s of sources present and physical characteristics such as ventilation and temperature. Microenvironments are often grouped into three broad categories based on the locations in which people spend the majority of their time, being indoors at home, outdoors and indoors at work or school (Lee *et al* 2000; Jurvelin *et al* 2001; Gustafson *et al* 2005).

Formaldehyde concentrations have been found to be highest indoors, particularly in homes (Jurvelin *et al* 2001; Garrett *et al* 2002; Serrano-Trespalacios *et al* 2004; Gustafson *et al* 2005; Weisel 2005). However, stationary monitoring in an indoor environment may not accurately reflect concentrations encountered indoors or even in a single room, due to small scale microenvironmental variation. Concentrations within a single room can fluctuate significantly over relatively small distances, with formaldehyde sources potentially creating microenvironments with elevated concentrations within a single room and/or building (Wolkoff *et al* 1991; Brown 2002; Glas *et al* 2004).

An investigation by Phillips *et al* (2005) was undertaken to develop generalised methods for estimating personal exposure to ambient air pollutants, with the study measuring indoor and outdoor VOC concentrations in 42 homes in Oklahoma. The study found that residential indoor concentrations of many VOCs, including formaldehyde, were higher than outdoor concentrations and were not correlated with the permeability of the residence. This was seen as an indication that indoor pollutant concentrations were representative of localised, short term emissions within the dwellings studied.

Using stationary measures to assess variation between outdoor and various indoor locations, Garrett *et al* (1997) found that season was a significant factor in microenvironmental variation, with higher levels recorded in summer than in

other seasons. The study also reported that concentrations were higher in bedrooms than in living areas and kitchens; however Dingle & Franklin (2002) found no significant difference between rooms. Both these studies used passive techniques, similar exposure times (3 to 4 days) and measured multiple rooms (4 to 5 rooms). However, Garrett *et al* (1997) undertook four rounds of sampling, compared to Dingle & Franklin's (2002) two rounds, and the larger dataset of the Garret *et al* (1997) study may have provided greater statistical strength to identify these differences.

A study by Sabin *et al* (2005) looking specifically at children's pollution exposure during school bus transport demonstrates some of the variation that can be present within a single environment. The study found higher concentrations of formaldehyde inside bus cabins than in the outdoor ambient air, with concentrations higher when the windows were closed than when partially open and also higher in buses fuelled by natural gas, which contains formaldehyde, than in diesel fuelled buses (Sabin *et al* 2005).

These studies indicate some of the variability experienced in airborne formaldehyde concentrations between microenvironments. While some microenvironments which are key to exposure have been identified, short term exposures to elevated source concentrations in a range of locations has also been identified as important to exposure, as they are potentially the key exposure periods during which health impacts may occur (Nieuwenhuijsen 2003; Sabin *et al* 2005; Phillips *et al* 2005).

1.3 Health Effects of Formaldehyde

1.3.1 Carcinogenicity and genotoxicity

The International Agency for Research on Cancer (IARC) released a monograph on formaldehyde which reviewed data from several retrospective cohort studies and case-control studies on occupational exposure and health impacts (IARC 2004). These studies reported a statistically significant increase in the number of deaths of exposed industrial workers by nasopharyngeal cancer. Based on the

research reviewed, IARC (2004) found sufficient evidence of the carcinogenicity of formaldehyde in humans to classify it as 'carcinogenic to humans'. This classification is solely based on toxicological data and occupational exposure studies, and there is no evidence that low concentrations in the domestic environment result in exposures resulting in carcinogenic impacts. Subsequent to this classification some articles have been published which state that the IARC classification may not be appropriate. This is based on other cohort studies which have not identified an increase in deaths from nasopharyngeal cancer in association with occupational exposure to formaldehyde (Marsh *et al* 2005) and due to increased uncertainty in the outcomes when the same cohort data is analysed in different ways (Marsh *et al* 2007).

Toxicological studies have also indicated that formaldehyde is genotoxic in bacterial and mammalian cells, by mechanisms including increased frequency of chromatid and chromosome aberrations, sister chromatid exchanges and gene mutations (Kligerman *et al* 1984; Kitaeva *et al* 1990; Cassee *et al* 1996). A recent study found that formaldehyde induced DNA-protein crosslinks and sister chromatid exchanges in human blood cells, causing gene aberrations in daughter cells (Schmid & Speit 2007).

A study by Titenko-Holland *et al* (1996) collected buccal and nasal cells from mortuary students exposed to embalming fluid containing formaldehyde. The study found an increased number of epithelial cells with chromosome fragments following exposure, a finding which is consistent with the reported genotoxic effects of formaldehyde, such as chromosome aberrations or sister chromatid exchanges (Titenko-Holland *et al* 1996).

1.3.2 Respiratory impacts

Formaldehyde's impact as a respiratory irritant is widely known, with these irritant effects on eyes, mucous membranes and the upper respiratory tract well documented when inhalation exposure occurs (Stenton & Hendrick 1994; Suh *et al* 2000; Thompson *et al* 2008). These impacts can occur with some severity

following acute exposures with concentrations above 100ppb shown to cause immediate irritation of the eyes, nose and throat (Suh *et al* 2000; Arts *et al* 2008). Concentrations of 100ppm or greater are immediately threatening to life and health (Suh *et al* 2000). Chronic exposures in occupational environments have been shown to irritate the eyes, nose and throat and to cause respiratory symptoms (WHO 2002; Aalto-Korte *et al* 2008; Arts *et al* 2008). Exposures to elevated domestic indoor concentrations, such as those experienced in portable dwellings, caravans and buildings with significant amounts of formaldehyde containing materials, can also cause chronic respiratory effects resulting from irritation of the upper respiratory tract (Ritchie & Lehnen 1987; Godish 1990; Ezratty *et al* 2007).

Godish (1990) measured a range of respiratory symptoms in conjunction with formaldehyde concentrations in both conventional and portable homes in the United States. This study found a significant relationship between indoor formaldehyde concentrations and the severity of 16 respiratory symptoms, including eye irritation, sore throat, headaches and sinus irritation. The health effects were measured based on the participants judgement and recall only, so may be subject to recall bias (Godish 1990). However, the formaldehyde concentrations were significantly higher than those reported in Australian studies, with medians of 120ppb in mobile homes and 70ppb conventional homes with particleboard subflooring (Godish 1990).

A relationship between chronic exposure to formaldehyde in the domestic environment and impacts on both the upper and lower respiratory tracts has also been identified. These impacts have included tightness of chest, increased asthma, and increased asthma-like symptoms (Thun *et al* 1982; Krzyzanowski *et al* 1990; Norbäck *et al* 1995; Garrett *et al* 1996; Franklin *et al* 2000; Venn *et al* 2003). This is potentially of concern for sensitive populations, such as children, the elderly and people with pre-existing respiratory concentrations (Arts *et al* 2008). In particular, the impact of formaldehyde exposure on the lower respiratory system in children, including the presence of asthma, has received

1.5 Personal Exposure to Air Toxics Studies

There have been few personal exposure studies undertaken in Australia and overseas which measured the personal exposure of individuals to a range of pollutants. Within Australia there have been no studies measuring personal exposure to formaldehyde in either adults or children. These studies generally follow the approach outlined above, with the collection of personal exposure measures, the collection of several stationary measures (i.e. indoors at home, outdoors at home, indoors at work) and completion of detailed questionnaires and time activity diaries.

The EXPOLIS program, measuring population exposures to key air pollutants in six cities across Europe, has provided significant research in this field since the late 1990's (Gauvin *et al* 1999; Rotko *et al* 2000; Jurvelin *et al* 2001; Edwards *et al* 2001; Lai *et al* 2004; Gustafson *et al* 2005). One research program from EXPOLIS measured personal exposure and microenvironmental concentrations of formaldehyde and acetaldehyde over two 48 hour periods in Finland (Jurvelin *et al* 2001). The study had a small sample size of 15 adults randomly selected from the population. Other contaminants, including $PM_{2.5}$, VOCs and NO_2 were also measured as part of the research undertaken as part of this study, although these results were reported elsewhere (National Public Health Institute of Finland 2007). Using active sampling with DNPH impregnated silica cartridges, the study collected personal exposure, indoor at home, outdoor at home and indoor at work measures. The study reported mean personal exposure concentrations of formaldehyde of 21.4pp, which significantly correlated with indoor residential formaldehyde concentrations. Indoor concentrations were slightly higher than personal exposure, and a time-weighted model did not improve indoor concentrations alone as an estimation technique. The study was limited by the small sample size (n=15), with factors such as smoking (27% of participants, or n=4, smoking), significantly impacting on results even though the actual numbers are small.

Gustafson *et al* (2005) undertook an investigation into formaldehyde exposures in Sweden as part of the EXPOLIS program. This study measured personal exposure along with simultaneous measures from indoors and outdoors at home, for 64 randomly selected adults. Passive samplers were deployed over 24 hours for a study in one city (Campaign A, n=24) and over 6 days in another city (Campaign B, n=40). The median personal exposure concentrations were 17.9ppb in Campaign A and 18.7ppb in Campaign B (Gustafson *et al* 2005). Indoor concentrations were higher than personal exposure, although the two measures were significantly correlated. The indoor concentrations from Campaign A (18.7ppb) were more closely correlated with the personal exposure concentrations for the 24 hour measure, with the indoor concentrations for the 6 day Campaign B measures (23.6ppb) not as closely correlated. This indicates that shorter duration weekday indoor sampling provides a more accurate measure of personal exposure than longer duration sampling.

Using time-weighting provided a slight improvement on indoor measures alone as an estimation technique, although outdoor measures were only collected for 20 participants in Campaign B (Gustafson *et al* 2005). The study design for this investigation is complex, with sampling from two separate towns, different sampling periods in each town, sampling in different locations (outdoors samples collected at 50% of Campaign B homes only) and repeated measures only on 50% of individuals from each campaign. This makes it difficult to identify if the conclusions being drawn are appropriate for the whole study population. Furthermore, the 6 day sampling period (Campaign B) would reduce the ability of the study to assess time activity impacts. This is due to potential for increased errors and recall bias in the completion of diaries, and the overall averaging out of weekdays and weekend days. Short duration activities that may result in elevated exposure, such as time in vehicles or in proximity to tobacco smoke, may also be 'lost' in the 6 day sampling period. The impacts of these short but potentially elevated exposures can be more readily distinguished from a shorter sampling period such as 24 hours.

The Relationship of Indoor, Outdoor and Personal Air (RIOPA) Study collected microenvironmental and personal exposure data on a range of chemicals across four cities in the United States (Weisel *et al* 2005). The study collected data on VOCs, carbonyls and $PM_{2.5}$ using both active and sampling techniques, with personal exposure monitoring of both adults and children (Weisel *et al* 2005). Forty-eight hour simultaneous passive measures of formaldehyde indoors, outdoors and of personal exposure were collected, with concentrations of 16.4, 5.3 and 16.7ppb recorded for adult participants, respectively (Weisel *et al* 2005). These measures were also repeated using active sampling methods, with indoor, outdoor and adult personal exposure concentrations of 19.1, 2.4 and 19.1 ppb, respectively (Weisel *et al* 2005). The personal exposure concentrations for children were 16.4ppb using passive methods and 15.3ppb using active methods (Weisel *et al* 2005). These results indicate that the children participants experienced lower personal exposures, despite them being exposed to the same indoor air concentrations as the adults. As all participating households were non-smoking, impacts from sources such as gas cooking, vehicles or at work are possible sources of more elevated exposures for the adults. This was a comprehensive investigation that would have required significant resources and planning. The resulting dataset is suited to the subsequent detailed analyses to identify suitable estimation techniques, as well as potential sources of the pollutants measured. The study also reported passive samplers to be as effective as active samplers.

Serrano-Trespalacios *et al* (2004) conducted a study measuring microenvironmental and personal exposure concentrations for a number of VOCs, including formaldehyde. Personal exposure concentrations were monitored for a 24 hour sampling period, along with indoors at home, outdoors at home and central area outdoor locations. 90 adults from 30 households across Mexico City participated in the study. Significant correlations between indoor and personal exposure concentrations were reported for a number of VOCs, including formaldehyde. Personal exposure concentrations were relatively low compared with other investigations, at 12.7ppb (Serrano-Trespalacios *et al*

2004). As this study reported more elevated outdoor concentrations than have been reported in many other investigations (Section 1.2.2.2), although still relatively low at 4.2ppb, the importance of indoor sources to exposure rather than outdoor sources is evident.

A study measuring personal exposure to benzene, toluene, ethylbenzene and xylenes (BTEX) was undertaken across four cities in Australia (Hinwood *et al* 2007). This study passively monitored personal exposure to BTEX using thermal desorption tubes (TDT) for a 5 day sampling period over two seasons, with questionnaires and daily diaries completed by participants. Mean exposure concentrations were relatively low compared with guideline values and international studies. However, TDT are generally used for active sampling, with air pumped through the sorbent packed inside the stainless steel tube, which measures approximately 10cm long with a 0.7cm diameter. The use of TDT for passive personal exposure monitoring may be problematic as air flow into and through the sorbent material inside the tube may be limited, particularly when the tube is hanging close to or against a person. While this may have resulted in concentrations which are lower than actual exposures, information on time activity patterns and sources of exposure are still valid. Participants spent the majority of their time indoors at home (15.4-16.7 hrs per day) and BTEX personal exposure was found to significantly increase with motor vehicle related activities, including repair and machinery use, and time spent undertaking craft and woodwork activities (Hinwood *et al* 2007).

A study conducted in Korea measured personal exposure to BTEX and 6 other VOCs, in combination with indoor and outdoor sampling, across two cities (Son *et al* 2002). Passive sampling was undertaken over 24 hours, with 30 participants recruited from the two cities. Although the study did not report formaldehyde concentrations, the VOCs data had similar patterns to those reported in other studies on VOCs which have reported formaldehyde concentrations (Serrano-Trespalacios *et al* 2004; Weisel *et al* 2005). Significantly higher indoor and outdoor concentrations of VOCs were reported in

the larger city, Seoul, and time activity modelling was found to underestimate measured personal exposure concentrations. Although this study had a small sample size and no repeat measures, it does report expected patterns and occurrence of these pollutants, with the more urbanised centres experiencing more elevated pollution levels. This pattern supports the expectation that much of Australia will report lower VOC concentrations than those found in Korea or other highly urbanised areas (NPI 2007; Hinwood *et al* 2008)

A study by Sexton *et al* (2004) was conducted to determine the value of estimation techniques versus personal exposure monitoring of VOCs. Personal exposure measures for 14 volatile organic compounds (VOCs) were collected from adults along with indoor at home and outdoor in central neighbourhood location measures. The samples were collected using passive charcoal based samplers, for 48 hour periods and repeated over three seasons. Questionnaire data and time activity diaries were collected to identify the importance of demographic, household characteristics and different environments to personal exposure. Personal exposure was significantly correlated with indoor concentrations, although indoor concentrations were generally lower. As with previous studies (Jurvelin *et al* 2001; Gustafson *et al* 2005) a time-weighted model did not significantly improve over indoor measures alone as a method for estimating exposure.

Glas *et al* (2004) conducted a study looking at inter-building and inter-individual variation in personal exposure to a number of pollutants for office workers in Sweden. The study measured personal exposure concentrations of 79 participants working in eight buildings, with sampling occurring only while the individual was in the office. The active sampling was conducted for a range of pollutants, being VOCs, ozone, aldehydes, particles, NO_2 and amines. The study found that inter-individual differences in personal exposure concentrations accounted for the large majority of variance in exposure to VOCs and aldehydes, including formaldehyde, with large differences in exposures among individuals working within the same building. This inter-individual variation is reflective of

the range of microenvironments with different concentrations encountered within a single building.

The majority of personal exposure studies have assessed exposure of adults to the pollutant of interest. There is very little available research which has measured personal exposure in children, despite the fact that they are likely to be more susceptible to the health effects of air pollution (Wigle 2003). The study by Weisel *et al* (2005) discussed above is the only currently available publication with any personal exposure data for children and formaldehyde, and there is limited data available for personal exposure of children to other VOCs or air toxics.

A study specifically assessing children's exposures to VOCs was undertaken in the United States by Adgate *et al* (2004), although formaldehyde was not measured in this study. Personal exposure measures of 15 VOCs were collected from 113 participants, with corresponding measures collected indoors at home and school and outdoors at school. Monitoring was undertaken once in summer and once in winter using charcoal based passive samplers. Generally, indoor domestic concentrations were the highest, with outdoor and school concentrations relatively low and having the least impact on personal exposure. A time-weighted model did not significantly improve on the use of indoor at home measures as an estimation technique for exposure.

1.6 Conclusion and Rationale for Study

There are significant health impacts associated with inhalation exposure to formaldehyde. The effects range from mild irritative effects of the upper respiratory tract at low concentrations, through to carcinogenic and genotoxic impacts associated with high concentrations and long term exposures. These impacts have been well documented in toxicological and epidemiological studies, with the majority of epidemiological studies focusing on occupational exposures and adult populations. However, respiratory impacts, which can occur at concentrations experienced in some domestic environments, are of particular

concern due to the ubiquitous nature of formaldehyde. This is particularly relevant for children's health, due to their potentially increased sensitivity to respiratory irritants (Wigle 2003) and due to the large amount of time they potentially spend in microenvironments associated with elevated concentrations of formaldehyde (Wigle 2003).

There has been some limited research undertaken in the field of children's health and formaldehyde, with some useful research undertaken within Australia (Garrett *et al* 1999; Franklin *et al* 2000; Rumchev *et al* 2002). These studies, which investigated children's respiratory health in relation to formaldehyde exposures based on stationary indoor measures, have indicated that respiratory impacts can occur at relatively low concentrations, as are found in conventional Australia homes (Garrett *et al* 1999; Franklin *et al* 2000). This further supports the need to more directly quantify the actual concentrations of formaldehyde children are being exposed to. This will aid in identifying if children are being exposed to concentrations of formaldehyde that may be harmful to their health, during their normal day to day activities.

While some data collection measuring formaldehyde concentrations in homes has occurred, these studies have focused on using stationary indoor measures as a surrogate for exposure. Exposure studies conducted on adults have indicated that, despite a strong correlation between indoor and personal exposure concentrations for a range of pollutants, including formaldehyde, personal exposure monitoring is a more accurate method of quantifying inhalation exposures to air pollution than stationary measures. Hence, there is a need to more accurately determine children's exposure to formaldehyde to better assess the risks of exposure.

To date there have been no studies published which measure personal exposure formaldehyde concentrations for children in Australia. While certain patterns are evident in a number of exposure studies conducted on adults and overseas, a comprehensive formaldehyde exposure study has not been conducted with

children. This lack of information extends to data on microenvironmental concentrations and children's time activity patterns.

Furthermore, exposure concentrations of children are likely to be different than those experienced by adults, particularly due to different behaviour patterns such as their potentially increased proportion of time spent indoors at home. Due to the potential for increased sensitivity of children to health impacts from formaldehyde, the need to gather information directly relating to children's exposure is evident. This study will aid in addressing this knowledge gap, as well as identifying potential surrogates for personal exposure measures.

1.7 Aims

The principal aim of this study was to determine whether the domestic environment is the most significant source of personal exposure to formaldehyde in children. The study used passive sampling techniques to measure personal exposure and microenvironmental concentrations of formaldehyde, as experienced by children. With this data, the study aims to identify the relationship between the concentrations measured and the proportion of time spent indoors and outdoors. This was assessed through comparison of personal exposure concentrations with:

1. Activities undertaken on different days and during different seasons; and
2. Microenvironmental characteristics and variation.

The specific aims of this study were to:

1. Determine formaldehyde personal exposure concentrations in children.
2. Determine whether the indoor home environment is the most significant source of personal exposure to formaldehyde in children.
3. Investigate whether other measures of formaldehyde exposure provide a good estimate of personal exposure.

Secondary aims:

4. Investigate seasonal variations in personal exposure
5. Determine indoor and outdoor factors that contribute to increased concentrations of formaldehyde.

2.0 STUDY DESIGN AND METHODOLOGY

2.1 Study Design

The project was a cross sectional study of formaldehyde exposure in children aged 9 to 12 years living in Perth, Western Australia. The study was conducted over two seasons, summer and winter, to investigate seasonal variations in exposure. The study measured personal exposure as well as indoor and outdoor formaldehyde concentrations using passive sampling techniques. During the sampling period children completed a time activity diary and a questionnaire to collect information about the indoor and outdoor environment.

Microenvironmental measurements were taken to coincide with the personal exposure measures, with samplers located in the main indoor living area of homes, outdoors at central neighbourhood locations and indoors at school.

2.2 Study Population

Children aged between 9 and 12 were the target age group for the study due to the susceptibility of children to health impacts from air pollution. The aim was to recruit 40 children in this age group (see sample size calculation in Section 2.8). This age group was considered appropriate as similar health studies have been conducted in this age group (Norback *et al* 2000; Weisel *et al* 2005). Furthermore, children this age are old enough to operate and maintain the personal exposure monitors but are still primary school aged. Personal exposures to formaldehyde have not been previously assessed in this age group.

2.3 Study Location

The study was undertaken in two suburbs of Perth, Calista and Duncraig. These areas were selected as they are representative of different outdoor pollution sources, being heavy industry in Calista and traffic emissions and domestic wood smoke in Duncraig.

Calista is situated approximately 40km south of the Perth CBD near the Kwinana industrial strip (*Figure 2.1*). The Kwinana industrial strip is the location of many of the key heavy industries in Perth, such as power generation, alumina refining and industrial chemical production. These industries produce a range of pollutants, including formaldehyde (NPI 2007).

Duncraig is situated approximately 15km north of the Perth CBD (*Figure 2.1*), with the suburb situated beside a major freeway and experiencing wood smoke related air quality issues in winter due to a large number of domestic wood fires (DEP 2000). The Department of Environment and Conservation (DEC) monitoring station and much of the suburb are located in a depression in the landscape, with the local topography exacerbating the air quality impacts resulting from the wood smoke haze and traffic pollution (DEP 2000).

Figure 2.1 Location map of Duncraig and Calista in Perth, Western Australia

2.4 Recruitment

A centrally located primary school was identified in each of the two target areas. The school principal was approached in each area to request the involvement of children from their school in the study. This approach was chosen as it was considered an efficient method of recruiting children of similar ages in similar areas. To facilitate this process, approval was obtained from the Department of Education and Training (DET) to recruit participants through primary schools in Western Australia, with police clearance also obtained (Appendix A.1).

Glengarry Primary School in Duncraig was selected as it was located directly next to the Department of Environment and Conservation (DEC) air quality monitoring station and was in close proximity to the freeway. The school's principal was contacted in September 2005 and was provided with a range of information, including a copy of all of the written materials to be provided to the students, as well as all documents relating to approvals from the DET and the Edith Cowan University Human Research Ethics Committee (ECU HREC) (Appendix A.2). Upon the principal providing a signed consent form, students in years 4, 5 and 6 were provided with an information package, which included an introductory letter, an information sheet with further detail and a consent form (Appendix B). If both parent and child were interested in participating the consent form, signed by both parent and child, was returned and the parents were contacted directly.

A total of 128 children were spoken to at Duncraig and from those students, 24 contact details forms were returned, with a subsequent 20 individuals' agreeing to participate in the study, giving a final recruitment rate of 15.6%. The questionnaire was completed and instructions provided on the use of the samplers through one-on-one meetings at the participant's home.

The process of recruiting in the Calista area varied from the method utilised in Duncraig. Several schools declined involvement when initially approached; however Calista Primary School expressed an interest in participating in the

study when approached in February 2006. The school agreed to run the project as a class science project for selected year 6 and 7 students, however, minor changes to the data collection methods and instructions were required due to the wariness of some parents to home visits from an unknown individual. Children were still required to provide a consent form signed by both the child and their parent, but all instructions regarding questionnaire completion, sampler use and diary completion were provided to the children as a school group. A science teacher was present to facilitate and to provide assistance at school when the sampling was conducted. The recruitment rate was much higher at Calista due to this approach, with 21 participants recruited from the 34 year 6 and 7 students who were addressed (61.8%).

2.5 Data Collection

2.5.1 Formaldehyde Passive Sampling

The formaldehyde monitoring was undertaken for two 24 hour periods over two seasons, winter (June) and summer (November) in 2006. While previous studies have measured exposure to pollutants for periods ranging from 8 hours to 6 days (Rumchev *et al* 2002; Gustafson *et al* 2005), a 24 hour sampling period was preferred due to the practicalities of dealing with children who are more likely to overlook completing the diary for an extended period, and to minimise recall bias. This sampling period was also chosen to aid in creating stronger associations between measured formaldehyde concentrations and daily activities. Passive sampling was the preferred methodology due to the potential constraints of dealing with children, in particular the difficulties children may face in wearing and operating active sampling equipment.

Monitoring was undertaken simultaneously for personal exposure, indoors at home and outdoors at central neighbourhood locations for each 24 hour period. Sampling was also conducted for 8 hours indoors at school. The number of samples collected in each location for both suburbs and seasons is presented in *Table 2.1*.

Table 2-1 Number of passive formaldehyde samples collected for each season of sampling

		Number of passive samplers deployed			
		Personal Exposure	**Indoor – Domestic**	**Outdoor – Central**	**Indoor – School**
Winter	Duncraig	20	20	5	2
	Calista	21	21	5	2
Summer	Duncraig	17	17	3	1
	Calista	16	16	5	2

The personal exposure samples were collected from within the breathing zone of the participant, with the sampler attached to the participant's collar during the day, and placed next to their bed as they slept. The indoor sample from their home was collected from the main living area, with samplers located towards the centre of the room, in a well ventilated location away from any direct sources such as heaters. The school samples were collected from a location towards the centre of the room, also in a well ventilated location away from any direct sources.

The outdoor samples were collected from backyards of selected participants homes. Approximately 5 outdoor samples were collected from each area for each sampling round. The number of samples collected from outdoor locations was reduced from an initial plan to sample every participant's domestic outdoor environment, to sampling selected central neighbourhood outdoor locations. This was based on the results from the DEC air quality monitoring station results, which indicated very low concentrations of formaldehyde were present in the ambient air (approximately 1.4ppb). This would result in very little variation between household outdoor concentrations due to the low concentrations present. The houses where outdoor samples were collected were chosen based on their being central to several participants' homes, with the 5 locations spread across the target suburb. Locations were at least 2m away from the dwelling in a well ventilated, shaded area.

Both personal and stationary sampling was undertaken using SKC UMEx100 passive formaldehyde personal samplers. These samplers consist of a silica gel filter paper, treated with 2,4-dinitrophenylhydrazine (DNPH), housed in a polypropylene case (*Figure 2.2*). The sampler's dimensions were 86mm x 28mm x 9mm and they weighed 10.8grams each. Samplers were stored below minus 20° Celsius before use and below 4° Celsius after use, with analyses required within three weeks of use. These samplers were considered appropriate due to the relatively high levels of accuracy of the SKC samplers, which are produced in a controlled laboratory environment and have been validated by the US OSHA and the Swedish Institute (SKC 2007). These samplers are small, lightweight and easy to wear and therefore easier for children to use.

Figure 2.2 SKC UMEx100 passive formaldehyde sampler

These samplers have been validated by Levin *et al* (1986) for a period of 15 minutes to 24 hours with a detection range of 2ppb to 5ppm for a 24 hour sampling period. The sampling rate is 28.6ml/min with an accuracy of ±25%. The samplers uptake rate is likely to be impacted at temperatures greater than 30° Celsius, in wind speeds greater than 1.0m/s and if ozone concentrations are greater than 0.5ppm (Levin *et al* 1986).

2.5.1.1 Meteorological Data

Meteorological data was collected by the Bureau of Meteorology from stations in the Perth central business district and Jandakot area, these being the closest

locations to Duncraig and Calista, respectively. This data is accessible via their website (www.bom.gov.au) for each day of the year, and data accessed includes maximum and minimum temperature, humidity, wind speed at 9am and 3pm and precipitation.

2.5.2 Questionnaire

Questionnaires are a common tool in exposure assessment and epidemiological studies as they allow information relating to exposure, such as where the participant spends their time, to be collected (Niewenhuisen 2003). They are particularly useful when used in combination with a range of techniques such as diaries and personal exposure monitoring. Other air pollution exposure studies which have been undertaken have successfully used a combination of these techniques to estimate exposure (Jurvelin *et al* 2001; Jurvelin *et al* 2003; Environment Australia 2003; Serrano-Trespalacios *et al* 2004; Adgate *et al* 2004; Gustafson *et al* 2005).

The aim of the questionnaire was to identify potential sources of formaldehyde that the participant may be exposed to, as well as to gather information on the amount of time spent in various microenvironments. For this study a questionnaire was designed using a combination of questions from an existing study on BTEX personal exposure (Environment Australia 2003) and newly designed items (Appendix C). The newly designed items aimed to collect information on potential known sources of formaldehyde in the home. These included questions regarding furnishings, dwelling construction materials, type and use of cooling, distance to four-lane road and time activity pattern information. These items were included due to their potential to influence formaldehyde concentrations (NICNAS 2006).

The questionnaire addressed four main areas; demographics, dwelling characteristics, transport methods and activity patterns. Basic demographic information was collected, including age and gender, while more detailed information on dwelling characteristics and potential formaldehyde sources was

collected, including age of home, types of flooring and wall coverings, types of furniture, methods of heating and cooling, use of household chemicals and the presence of smokers in the house. The transport usage and activity pattern questions required the participants to estimate their time spent travelling and in each microenvironment, with this information to provide some validation for the diary data (Section 2.5.3).

To test the clarity of the questionnaire prior to the commencement of the study, it was tested on a sample population of 10 people. These people ranged in age from 10 to 58 years as the questionnaire was to be answered by both participants and their parents. All of the test group were from non-scientific backgrounds and were asked to complete the questionnaire unassisted while noting any problems they had in the margins of the questionnaire. The returned test questionnaires were analysed to identify inconsistencies in the answers or any mistakes in interpreting the questions. A few minor problems were identified, such as clarifying that time activity questions required information for a full 24 hour period, and these were remedied before the questionnaire was provided to study participants.

The questionnaire was designed to be interview administered to the participant and their parent at the commencement of the study. However, as the questionnaire was tested by unassisted individuals, it was also suited for completion by unaided participants.

2.5.3 Daily Activity Diary

A daily activity diary was utilised, which was based on the diary developed for the EXPOLIS studies (Niewenhuisen 2003). Diaries are an important aspect in personal exposure monitoring as they provide key information on participants movement and activities, and therefore potential exposure sources.

The diary (Appendix D) collected information in 15 minute intervals for each 24 hour monitoring period for each participant. The 15 minute time interval was

necessary to ensure that transport time, which can be a source of significant yet short term exposure, was identified by the participants. The diary required the participant to note any comments on key activities completed and also the times of opening and closing of samplers. Participants were required to mark their location (indoors at home, outdoors at home, school, indoors other and outdoors other), their transport (walking, driving, bus or train) and whether they were near potential key sources (cigarette smoke, gas heating or gas cooking).

2.6 Chemical Analyses

All analyses of the DNPH impregnated filter papers were completed using high performance liquid chromatography (HPLC) technology using the U.S. Environmental Protection Authority 'Determination of formaldehyde in ambient air using adsorbent cartridge followed by high performance liquid chromatography (HPLC)' (USEPA 1999).

The formaldehyde 2,4-dinitrophenylhydrazone was extracted from the filter papers by shaking for one minute with 3.0ml of acetonitrile-190 in a polypropylene tube. The extracted sample was injected into a HPLC vial for analyses in a Varian Star HPLC system. The hydrozone was detected at 365nm, with a run time of 4.9 minutes, with an analytical detection limit of 4ppb.

Standard solutions of known concentrations were made and run through the HPLC to create a calibration curve for each new run of the HPLC. Standard solutions were made from a 36% formaldehyde solution, diluted to create a 100ppm formaldehyde solution. Volumes of the 100pm solution were placed into 50ml volumetric flasks, along with 7ml of adsorbing reagent and acetonitrile-190, to make standard solutions ranging from 0.01ppm to 5.0ppm. A summary of the standards made and the calibration curve for each round of analyses is provided in *Table 2.2* below.

Table 2-2 Formaldehyde standards used for calibration in HPLC analyses

Sampling Round		Standards (ppm)	Calibration curve (r^2)
Winter	Duncraig	0.01, 0.1, 1.0, 5.0, blank	0.99
	Calista	0.01, 0.1, 0.5, 1.0, 5.0, blank	0.99
Summer	Combined	0.01, 0.05, 0.1, 1.0, 5.0, blank	0.99

2.6.1 Quality Assurance and Quality Control

A minimum of 5% duplicates and blanks were collected during all field and laboratory work, with a minimum of one blank and one duplicate for each 20 samples collected and analysed. The quality control measures for each group of measurements are summarised in *Table 2.3.*

Table 2-3 Summary of Field and Laboratory QA/QC – Number of blanks and duplicates analysed per sampling round

			Field QA/QC		Laboratory QA/QC	
		n	Blanks	Duplicates	Blanks	Duplicates
Winter	Duncraig	46	7	3	3	6
	Calista	47	5	4	3	8
Summer	Duncraig	39	3	1	2	6
	Calista	38	4	2	2	6

n = all personal exposure, indoor, outdoor and school samples collected

The minimum target of 5% (2 samples) was not obtained for field duplicates in Duncraig in summer as one classroom duplicate sample was lost and one indoor duplicate sample was not returned by a participant. All field duplicates varied less than 15% from the original sample. Field blanks were analysed using the internal blank provided with each SKC UMEx100 passive formaldehyde sampler, with approximately 10% randomly chosen for analysis.

Laboratory duplicates were obtained by re-sampling the 1.0ppm known concentration formaldehyde sample after approximately every 10th sample. All laboratory duplicates varied less than 8% from the 1.0ppm laboratory control sample. Laboratory blanks consisted of analysing a sample from a 50ml solution of acetonitrile-190 with 7ml of adsorbing reagent only.

2.7 Data Handling

Each participant was allocated an individual code to protect their identity, with this code applied to each questionnaire, diary and sampler. All analyses and data handling were undertaken using this unique code as the identifier.

Questionnaire and daily diary data for each participant was entered into a Microsoft Access database. Questionnaire data was coded according to the coding scheme on the questionnaire. Diary data was numbered based on the sum of 15 minute intervals spent in each microenvironment. Data entry was validated by a random check of a minimum of 10% of data, undertaken by an environmental science postgraduate student.

Due to the low outdoor concentrations recorded and the fewer number of outdoor sampling locations, the 'outdoor home' and 'outdoor other' categories were collapsed into a single 'outdoor' category. Non-detects were allocated the analytical detection limit of 4ppb for inclusion in statistical analyses (Newman *et* al 1989; Childress *et al* 1999).

2.8 Statistical Analyses

2.8.1 Sample Size

The study aimed to recruit 40 participants from schools within the two target areas. This number is based on a sample size calculation utilising indoor air concentrations (19.7ppb ± 8.4) and outdoor air concentrations (3.8ppb ± 1.2) from Gustafson *et al* (2005), to enable a comparison with indoor concentrations and outdoor concentrations. There are no data available using personal exposure measurements to distinguish indoor from outdoor formaldehyde concentrations,

so data has been taken from the Gustfson *et al* (2005) EXPOLIS study utilising stationary passive samplers. For these concentrations at 90% power at the 5% confidence level, the population required is only five. To allow for the potential differences in environments between Europe and Australia, the nature of sampling being undertaken in this study and to enable other factors such as season, day of week and school and residence location to be taken into account, the sample size has been increased to a total of 40 children across two schools.

The sample size for a population required to detect significant differences between indoor and outdoor concentrations was calculated using the following formula:

$$n = \left[\frac{z_{a/2}\sigma}{E} \right]^2$$

Where E is the margin of error, $z_{a/2}$ is the critical value, σ is the population standard deviation and n is the sample size (Winkler & Hays 1975).

2.8.2 Analyses and Interpretation of Results

The questionnaire, diary and monitoring data were imported into SPSS for Windows version 15.0 for all data manipulation within and between datasets. These included calculations such as significance testing, multivariate analyses (ANOVAs), correlations and multiple linear regression models. Student t-tests were performed between the two populations for the questionnaire, daily diary and formaldehyde monitoring datasets to identify differences between populations. Spearmans correlations were performed on the formaldehyde monitoring results to identify relationships between microenvironmental and personal exposure monitoring results.

Graphical displays of data, such as scatter graphs and histograms, were created to aid in visual interpretations.

Formaldehyde concentrations from personal exposure and indoor monitoring were non-parametric, so tests were performed to determine if transformation would normalise the data, or if non-parametric analyses on the untransformed data would be required. To test the data, a linear mixed model was run on both transformed and untransformed data, with covariates, such as age and gender, being modelled against personal exposure as the dependant variable. The residuals and predicted values from this model, for both transformed and untransformed personal exposure, were presented in a scatter graph. As the spread of the residuals against the predicted values for the transformed data was close to being evenly spread, the transformed data was considered appropriate for use with parametric analysis methods. Further confirmation of this was undertaken by performing ANOVAs on a selection of variables with both the transformed and untransformed data, and Kruskal-Wallis tests with the untransformed data. As the ANOVAs on the transformed data provided similar results to the Kruskal-Wallis results, this provided further support for using parametric tests on the transformed data. The formaldehyde monitoring data for personal exposure and indoor measures were therefore transformed by natural logarithm to normalise the distribution.

Significance tests suited for parametric datasets were then applied, using one-way analysis of variance (ANOVA's) to identify significant relationships ($P < 0.05$) between demographic, dwelling and time activity characteristics. Those characteristics identified as being significant at less than $p = 0.25$ were then input into a multiple linear regression model. The value of 0.25 was used as, although high, it permitted for a broader range of variables to be included. Only these variables were identified for inclusion in the model for a number of reasons; to simplify the model by not including every variable for which data was collected; the relatively small sample size would potentially weaken the ANOVA significance value for certain characteristics; and, certain key characteristics that were identified in other studies as formaldehyde sources were not significant at $P < 0.05$. After the initial run of multiple linear regression, the model was re-run multiple times, each time removing variables with negative beta coefficients,

negative confidence interval ranges and high significance values, as these factors did not correlate with personal exposure concentrations.

Personal exposure modelling was conducted via time-weighted calculations. These were undertaken for each individual using microenvironmental concentrations and diary data for comparison with personal exposure concentrations. The predicted exposure concentration was calculated using the equation, as applied by Jurvelin *et al* (2002):

$$E = \frac{(C_I T_I + C_O T_O + C_S T_S)}{(T_I + T_O + T_S)}$$

Where E is exposure concentration, C is concentration, T is time, I is indoor, O is outdoor and S is school. This calculated concentration was then correlated with personal exposure and indoor concentrations using Spearman's correlation coefficient.

2.9 Ethics Approvals and Confidentiality

Ethics approval for the study was required and obtained through the Edith Cowan University Human Research Ethics Committee (ECU HREC). To obtain this approval an application was made to the HREC providing details of the study, outlining how all data would be managed, how confidentiality would be addressed and providing a copy of all documentation to be provided to the schools and participants through the recruitment process. The HREC suggested minor changes to the initial application, including the requirement for both the participant and their parent to sign the consent form, before providing approval for the research to be undertaken (Appendix A.1). Recruitment did not commence until final ethics approval was obtained.

The confidentiality of participants was maintained throughout the project via a number of steps. Each participant was provided with a unique identifying code, with all questionnaire, diary and monitoring results identified only via this code.

The cover pages of questionnaires, which contained both the participants name and code, were removed from the questionnaires and kept separately in a locked filing cabinet, accessible only to the researcher. For ease of access, contact details were also maintained in an Excel spreadsheet, which was password protected and accessible only to the researcher.

2.10 Feedback to Participants

The results of the formaldehyde monitoring were provided to the participants in the form of a general letter stating the average and range of results for their area. The results were compared against international guideline values and a brief qualitative discussion presented some general conclusions regarding the low nature of the concentrations recorded. Contact details were provided if any individuals wished to obtain more detailed information or their specific results, however no participants responded.

3.0 RESULTS

3.1 Demographics, Behavioural and Dwelling Characteristics of Study Population

A range of demographic, dwelling, transport and estimated time activity characteristics data was collected from all participants via the questionnaire at the commencement of the study and is shown below. The full results of the analysis of responses to the questionnaire are presented in Appendix E.1. A selection of the key dwelling and transport data, identified as being potentially significant in terms of formaldehyde exposure through previous investigations is presented below in *Table 3-1a, 3-1b* and *3-1c.*

Table 3-1a Demographics of study population (%)

Characteristic		**Duncraig (n=20) (%)**	**Calista (n=21) (%)**
Age*	9 years	70	0
	10 years	20	10
	11 years	10	48
	12 years	0	42
Sex	Male	40	38
Smoker in house	Yes	25	48
Location of smoking*	Indoors	0	0
	Outdoors	100	76
	Both	0	24
Transport method to school	Car	55	71
	Walk/cycle	45	29

* = Significantly different between Calista and Duncraig

Table 3-1b Dwelling characteristics of study population (%)

Characteristic		Duncraig (n=20) (%)	Calista (n=21) (%)
Age of Home*	1-3 years	0	5
	4-10 years	0	14
	10-20 years	5	33
	>20 years	95	48
Renovations within last year	Yes	50	29
Hotplate fuel	Gas	50	67
	Electric	50	33
Oven fuel*	Gas	0	33
	Electric	100	67
Heating fuel: Primary	None	5	0
	Gas	60	71
	Electric	0	14
	Wood	5	10
	Reverse cycle	30	5
Heating Use in Winter	< Once week	5	5
	None	5	10
	1-4 a week	40	10
	> 4 a week	15	19
	Every day	35	56
Cooling Type: Primary	Reverse cycle	35	24
	Ceiling fans	5	24
	Portable fans	10	5
	Evaporative	45	37
	Open Windows	5	10
Cooling Use in Summer	< Once week	10	0
	1-4 a week	20	19
	> 4 a week	35	38
	Every day	35	43
Furniture Materials[1]:	Cotton	100	100
	Vinyl	30	57
	Leather	30	19
Distance to 4 lane road*	<50m	5	5
	50-200m	60	19
	201-500m	15	14
	>500m	20	62

* = Significantly different between Calista and Duncraig

[1] = Reponses total greater than 100%, based on percentage of participants with each type of furniture materials

Table 3-1c Chemical use in households of participants (%)

Characteristic		Duncraig (n=20) (%)	Calista (n=21) (%)
Glue Use:	Daily	0	0
	Weekly	65	19
	Monthly	15	33
	A few times a year	20	38
	Never	0	10
Deodoriser Use:	Daily	20	42
	Weekly	20	28
	Monthly	5	10
	A few times a year	10	10
	Never	45	10
Disinfectant Use:	Daily	10	19
	Weekly	50	76
	Monthly	10	0
	A few times a year	10	0
	Never	20	5

* = Significantly different between Calista and Duncraig

More females (61%) were recruited than males in both areas. There was significant variation evident for some demographic and dwelling characteristics between the study populations at Duncraig and Calista. Comparisons between the two areas using Student T-tests showed significant differences ($p<0.05$) in the age profiles of the groups, location of smoking, age of home, oven fuel used and distance to four lane road. Calista participants were slightly, but significantly, older, which is due to the slightly different recruitment approach for this area (Section 2.4). Calista had a higher percentage of households where smoking occurred indoors and resided in newer homes on average (*Table 3-1a*). Calista students also had a higher percentage of gas ovens and a lower percentage of participants living within 500m of a four lane road (*Table 3-1b*). Although not significantly different, the questionnaire responses indicated that Duncraig participants tended to walk to school more than Calista participants (refer to Appendix E.1). Most of these differences were expected due to the recruitment process.

Table 3-2 Characteristics between Duncraig and Calista participants identified as being significantly different using Students T-test (SPSS)

Characteristic	Duncraig (n=20)	Calista (n=21)	T-test (p)
Age (median years)	9	11	0.000
Location of Smoking			
% Outdoors Only	100	76	0.019
Age of Home (years)[1]	>20	11-20	0.001
Oven: Fuel Used			
% Electric	100	67	0.004
Distance to 4 Lane Road (metres)[2]	50-200	>500	0.007

[1] = age of home is shown as a range of years, as per the questionnaire response
[2] = distance to 4 lane road shown as a range of years, as per the questionnaire response

3.2 Time Activity Patterns

The results of the completed time activity diaries indicate the key locations where participants spent their time, as well as potential sources of exposure (*Table 3-3*). An average time was calculated for the time spent in each microenvironment and is expressed as a percentage of the 24 hour monitoring period. The categories were largely divided between indoor and outdoor locations, with information also collected on proximity to key sources such as heating or stovetops. For the winter monitoring period 37 participants kept diaries (90%), with 3 of these diaries only partially completed (average 31% complete) and the remaining 34 diaries 100% complete. For the summer sampling period 94% (n=31) of participants completed diaries, and all diaries were 100% complete. Incomplete diaries were not included in the analysis. The time spent in 'outdoor home' and 'outdoor other' categories were grouped together as a result of the limited amount of time spent in the 'outdoor other' category.

The time activity diaries show that the majority of children spent over 90% of their time indoors over the 24 hour monitoring periods. This time includes time spent indoors at home, indoors at school and indoors at other locations. The time spent at school was classified as 'indoors at school'. Proportion of time spent in nearly all microenvironments was consistent across both areas for both seasons, although Duncraig children spent slightly more time outdoors (*Table 3-3*). Many

of the activities, particularly when averaged across the entire population, account for a very small proportion of time. The Duncraig participants were never in proximity to cigarette smoking, although some of the Calista participants were for short periods of time (approximately 5 minutes per day on average) (*Table 3-3*).

Table 3-3 Percentage of time in a 24 hour period spent in key microenvironments

Microenvironments	**Duncraig**		**Calista**	
	Winter (%) (n=19)	**Summer (%) (n=16)**	**Winter (%) (n=18)**	**Summer (%) (n=15)**
Walking*	0.94	1.05	0.14	0.71
Car	2.27	2.01	2.85	2.92
Bus	0.20	0.07	0	0
Indoors – Home	64.9	65.2	67.6	64.6
Indoors – Other	0.73	1.75	0.75	3.81
School	26.3	25.7	26.7	25.1
Outdoors	4.25	4.04	1.81	3.07
Near Smoking*	0	0	0.36	0.35

n.b. One 15 minute time interval on the daily activity diary equals approximately 1% of a day

* = Significantly different between Calista and Duncraig in winter

A comparison between the two areas activities showed significant differences in the time spent walking, and near smoking in winter, with Duncraig participants spending on average slightly more time walking and less time near smoking (*Table 3-3*). The increased amount of time walking is consistent with questionnaire responses. There were no significant differences in any of the daily activities between the two areas in summer. The lack of any significant differences between activities in summer, and the very few number of significant differences in winter (which are based on very small proportions of time), indicate the similar time activity patterns of the participants across both areas at the time periods during which sampling occurred.

3.3 Meteorological Data

The meteorological data for the days of sampling is presented in *Table 3-4*, with the data collected from the Perth station approximately 15 kms south of Duncraig and from the Jandakot station approximately 13 kms north-east of Calista.

Although the target was for winter and summer periods, the potential sampling dates for summer sampling were restricted due to the end of the school year approaching, resulting in summer sampling occurring in late November before the summer season had commenced. The meteorological conditions on the summer sampling days were cooler than average temperatures for that time of year (*Table 3-5*).

Table 3-4 Meteorological data for each sampling day, with data from the meteorological stations at Perth and Jandakot

Meteorological Data		**Perth (Duncraig)**		**Jandakot (Calista)**	
		1 June	**29 Nov**	**27 June**	**30 Nov**
Temperature (°C)	Max	19.0	22.7	20.5	22.2
	Min	4.5	12.8	6.7	14.9
Rainfall to 9am (mm)		0	7	4	2.2
Humidity (%)	9am	82	50	99	51
	3pm	46	51	83	46
Wind Speed (km/h)	9am	5	22	15	26
	3pm	9	21	26	28

Table 3-5 Mean monthly meteorological data from Perth and Jandakot meteorological stations

Meteorological Data		**Perth (Duncraig)**		**Jandakot (Calista)**	
		June	**Nov**	**June**	**Nov**
Temperature (°C)	Max	19.2	26.3	18.8	26
	Min	8.5	14.2	7.4	12.4
Monthly Rainfall (mm)		134.3	20.7	164.1	28.7
Humidity (%)	9am	79	52	80	52
	3pm	57	44	58	44

3.4 Measured Formaldehyde Concentrations

Passive formaldehyde sampling was conducted for personal exposure and in microenvironments where children are known to spend their time; indoor at home, outdoor in neighbourhood and indoor at school (Section 2.6). This data, including geometric means (GM), is summarised in *Table 3-6* and *3-7*.

Table 3-6 Summary of passive formaldehyde monitoring results by area and season (ppb)

Monitoring	Duncraig		Calista	
	Winter	**Summer**	**Winter**	**Summer**
Personal exposure (ppb)				
n	20	16	21	17
Mean	10.9	11.0	13.4	9.2
Min, Max	<4.0, 23.6	<4.0, 26.3	<4.0, 27.9	<4.0, 24.2
GM	9.7	9.2	11.5	8.0
Indoor domestic (ppb)				
n	20	16	21	17
Mean	11.6	10.2	16.8	11.8
Min, Max	4.1, 21.9	<4.0, 18.7	<4.0, 37.5	<4.0, 26.4
GM	10.1	9.0	14.2	9.9
Outdoor domestic (ppb)				
n	5	3	5	5
Mean	<4.0	<4.0	4.6	<4.0
School indoors(ppb)				
n	2	1	2	2
Mean	<4.0	<4.0	8.0	15.2

Personal exposure concentrations were relatively low, ranging between <4ppb to 27.9ppb, with indoor concentrations ranging from <4ppb to 37.5ppb. Outdoor concentrations were very low, with most samples being below the limit of reporting (4ppb). School indoor concentrations, although limited in number, were also low, although Calista reported significantly higher concentrations than Duncraig. The formaldehyde concentrations measured were left skewed, as indicated in the histograms of the personal exposure and indoor formaldehyde concentrations (Appendix E.2). Kurtosis for personal exposure concentrations was -0.105 and for indoor concentrations was 1.054, while skewness for personal exposure was 0.980 and for indoor was 0.961. When the data was transformed, the histograms were of a more normal distribution (Appendix E.2).

A comparison between Duncraig and Calista indicated that the only significant difference between the two areas was for the winter indoor domestic concentrations and the school indoor concentrations (using both seasons combined to increase the number of samples), with Calista significantly higher than Duncraig. Due to sample size and the similarities in all other concentrations

reported the data have been considered in combination for further analyses (*Table 3-7*).

A comparison of the winter and summer results indicates no significant difference in personal exposure and outdoor concentrations between winter and summer. Scatter graphs of the summer and winter sampling results are presented in Appendix E.3.

Table 3-7 Summary of all passive formaldehyde monitoring results by season (ppb)

Monitoring	**Winter**	**Summer**	**All Results**
Personal exposure (ppb)			
n	41	33	74
Mean	12.2	10.1	11.2
Min, Max	<4.0, 27.9	<4.0, 26.3	<4.0, 27.9
GM	10.5	8.6	9.6
Indoor domestic (ppb)			
n	41	33	74
Mean	14.3	11.0	12.8
Min, Max	<4.0, 37.5	<4.0, 26.4	<4.0, 37.5
GM	12.0	9.5	10.8
Outdoor domestic (ppb)			
n	10	8	18
Mean	4.3	<4.0	4.2
School indoors(ppb)			
n	4	3	7
Mean	6.0	11.5	8.4

3.5 Factors Influencing Residential Formaldehyde Concentrations

3.5.1 Dwelling Characteristics and Indoor Concentrations

The relationship between various dwelling characteristics and indoor formaldehyde concentrations was investigated, with the results of these tabulated in full in Appendix E.4. *Table 3-8* presents the results for the characteristics for which significant relationships at $P<0.10$ with indoor concentrations were observed. Some factors which were not statistically significant have also been presented as they are characteristics identified in previous studies as being important in terms of human exposure.

Table 3-8 Significance values of key dwelling characteristics on indoor formaldehyde concentrations, using ANOVA

Characteristic	**Significance (P)**
	Indoor (n = 74)
School/ Suburb	0.094
Smoker in house	0.056
Flooring	
Bedroom	0.077
Heating	
Primary	0.145
Secondary	0.167
Use	0.067
Furniture	
Vinyl	0.041*
Household Chemical Use	
Deodoriser	0.122
Disinfectant	0.025*

* = significantly impacts on personal exposure formaldehyde concentrations at $P<0.05$

These results indicate that the presence of vinyl furniture and disinfectant use are the only factors to significantly (<0.05) impact on indoor formaldehyde concentrations.

3.6. Factors Influencing Personal Formaldehyde Concentrations

3.6.1 Time Activity Patterns and Personal Exposure Concentrations

3.6.1.1 Questionnaire Responses for Time Activity Patterns

ANOVA's were performed on the estimated transport characteristics and time activity patterns, as identified in the questionnaire, and the combined personal exposure formaldehyde concentrations. These analyses (presented in full in Appendix E.4) identified some significant factors, with some of the key results presented in *Table 3-9*.

Table 3-9 Significance values of questionnaire estimates of key transport and time activity characteristics on personal exposure formaldehyde concentrations, using ANOVA for full dataset

Characteristic	**Significance (P)**
Transport method to:	
School	0.065
Friends	0.037*
Weekday transport time estimates:	
Driving	0.001*
Walking	0.065
Weekend transport time estimates:	
Driving	0.043*
Walking	0.083
Weekday estimates of time spent at/in:	
Kitchen	0.034*
Living Room	0.053
Inside home – other rooms	0.002*
Outside home	0.043*
Weekend estimates of time spent at/in:	
Kitchen	0.012*
Inside home – other rooms	0.001*
Outside home	0.021*
Doing sports indoors	0.000*
At shops	0.053

* = significantly impacts on personal exposure formaldehyde concentrations at $P<0.05$

These results indicate that the method of transport used to travel to friend's homes marginally impacts on personal exposure, with participants who drive to friend's homes tending to experience higher exposure concentrations. Estimates of time spent driving on weekdays and weekends are the only transport estimate factors that are significantly correlated with personal exposure concentrations. Estimates of time spent indoors at home (other rooms) and doing sports indoors on weekends are significantly correlated to personal exposure concentrations (*Table 3-9*).

These relationships are based on questionnaire responses which are estimates only of time spent undertaking a variety of activities. The participants approximated this information via the questionnaire when they were initially recruited and the estimates may not be an accurate reflection of actual activities on the sampling days.

3.6.1.2 Diary Time Activity Patterns

ANOVA's were performed on diary data (*Table 3.3*) and transformed personal exposure concentrations to identify any significant relationships. These results are presented in *Table 3-10* and Appendix E.4.

Table 3-10 Significance values (<0.05) between diary based time activity patterns and personal exposure formaldehyde concentrations, using ANOVA

Time Activity	Significance (P)		
	Winter	Summer	Combined
Walking	-	-	0.057
Driving	0.073	0.205	0.108
Indoors – Home	0.130	0.042	0.259
Indoors – Other	0.097	0.020	0.003*
Outdoors	0.107	-	0.094

* = significantly impacts on personal exposure formaldehyde concentrations at *P<0.05*

These results indicate that in winter personal exposure concentrations were elevated for 2 participants, which the ANOVA indicated to be significant. While heating may be important there is insufficient power due to the small number to show this. Therefore, this study indicates that there are no factors that significantly contribute to personal exposure concentrations.

In summer, time spent indoors at home and indoors in other locations were significantly related to personal exposure concentrations. When the data is combined, time spent indoors in other locations significantly contributed to personal exposure concentrations (*Table 3-10*).

3.6.2 Regression Analyses

Multiple linear regression was undertaken with a range of input variables incorporated into the regression models (Section 2.8.2). Any categorical variables from the questionnaire which were found to have a significance of P < 0.25, from the ANOVA calculations (above), were included in the model runs to ensure a wide representation of potentially significant variables (*Table 3-11*). Apart from indoor concentrations and hotplate fuel, no other factors were shown

to be a significant contributor to personal exposure concentrations based on the linear regression analysis.

The multiple linear regression model was re-run, removing variables with a low upper bound significance value, negative beta value and confidence intervals with a negative lower bound. This process was repeated several times, each time removing just a small number of variables (see Appendix E.5 for all regression tables). After several model runs, a final model output (*Table 3-12*) was obtained that indicates that indoor concentrations and hotplate fuel used were the only significant characteristics identified in the study that contribute significantly to personal exposure concentrations, despite the ANOVA results shown in *Table 3.9.*

Table 3-11 Initial multiple regression results, including all variables with a significant relationship with personal exposure concentrations of P< 0.25

	Unstandardised Coefficients		Beta Standardised Coefficients	t	Significance	95% Confidence Interval for B	
(Constant)	-.184	2.017		-.091	.928	-4.240	3.871
Indoor concentrations	.718	.094	.764	7.675	.000	.530	.906
Outdoor concentrations	1.135	1.137	.121	.998	.323	-1.152	3.422
Season	-.129	.116	-.116	-1.111	.272	-.363	.104
School	.162	.158	.146	1.027	.309	-.155	.479
Smokers present	-.028	.107	-.024	-.265	.792	-.243	.187
Garage – no internal access	-.044	.151	-.027	-.291	.772	-.348	.260
Carport – free standing	.373	.245	.156	1.526	.133	-.118	.865
Carport – other	-.078	.307	-.023	-.254	.801	-.696	.540
Flooring – bedroom	-.038	.036	-.097	-1.051	.299	-.111	.035
Flooring – living room	-.052	.045	-.117	-1.167	.249	-.142	.038
Hotplate fuel	.211	.101	.188	2.102	.041	.009	.413
Heating – primary	-.079	.054	-.151	-1.470	.148	-.186	.029
Heating – secondary	.030	.042	.072	.707	.483	-.055	.115
Heating use	-.112	.045	-.265	-2.508	.016	-.202	-.022
Cooling – primary	-.054	.050	-.134	-1.065	.292	-.155	.048
Cooling – secondary	.024	.042	.063	.582	.563	-.060	.108
Cooling – tertiary	-.012	.025	-.045	-.493	.624	-.062	.038
Furniture – vinyl	-.119	.116	-.105	-1.027	.309	-.352	.114
Furniture – leather	-.077	.121	-.061	-.636	.528	-.321	.167
Glue use	-.190	.065	-.321	-2.907	.006	-.321	-.059
Deodoriser use	.009	.044	.028	.214	.832	-.079	.098

Table 3-12 Final multiple regression results, indicating significant variables impacting on personal exposure

	Unstandardised Coefficients		Beta Standardised Coefficients	t	Significance	95% Confidence Interval for B	
(Constant)	.207	1.241		.167	.868	-2.274	2.688
Indoor concentrations	.766	.072	.816	10.706	.000	.623	.909
Outdoor concentrations	.306	.787	.033	.389	.698	-1.266	1.879
School	.075	.105	.067	.711	.479	-.135	.285
Smokers	.054	.087	.046	.618	.539	-.120	.228
Hotplate fuel	.211	.083	.188	2.548	.013	.045	.376
Heating use	-.087	.032	-.206	-2.735	.008	-.151	-.024
Glue use	-.122	.047	-.206	-2.611	.011	-.215	-.029

3.7 Models for Estimating Exposure

3.7.1 Indoor Sampling as a Surrogate for Personal Exposure and Time Weighted Model

There are numerous methods used for determining personal exposure concentrations in epidemiological studies, with several common estimation methods available. Several of these estimation methods were compared against the actual measured personal exposure concentrations collected here. The two methods compared were using the indoor concentrations as a surrogate for personal exposure and using a time weighted model equation.

The first method proposes a simple substitution of the stationary indoor concentration for the personal exposure concentration. This method is often used due to the large amount of time people spend in indoor environments, and is particularly relevant to pollutants such as formaldehyde where the main exposure sources are indoors. It is also simpler from a logistics and measurement perspective. The correlation between participants indoor concentrations and their personal exposure concentrations indicates the strength of this relationship.

Spearman correlation coefficients were calculated for indoor domestic and personal exposure concentrations for each area in each season. The correlations were significant at Duncraig, with $r^2 = 0.73$ in winter and 0.67 in summer. The correlations were greater when undertaken on Calista data, with a correlation

coefficient of 0.88 in winter and 0.84 summer. The correlation for all data combined was significant, with a coefficient of $r^2 = 0.78$. These results indicate the strong relationship between indoor and personal exposure concentrations.

The time-weighted model uses a simple calculation (Section 2.8), which combines several stationary measures (domestic indoors, outdoors and school) and time activity data. An exposure concentration is calculated which estimates a participants personal exposure based on time spent in each of the key environments for which a stationary measure is available. The concentration calculated for each individual using the time-weighted model is presented in Appendix E.6. A Spearman correlation of the calculated time weighted model exposure concentrations and the measured personal exposure concentrations was significant at 0.802 (*Table 3-13*).

Table 3-13 Spearman correlation coefficients between personal exposure measures and exposure estimation techniques

	Indoor air surrogate	**Time weighted model**
Personal exposure monitoring	0.778	0.802

The time-weighted model reported a slightly stronger correlation with personal exposure than the indoor air as surrogate method (*Table 3-13*). The correlations also indicate that the time weighted model is more strongly correlated to the indoor air measures than to personal exposure, although the differences are not large. These relationships are shown below in *Figure 3-1* for all participants.

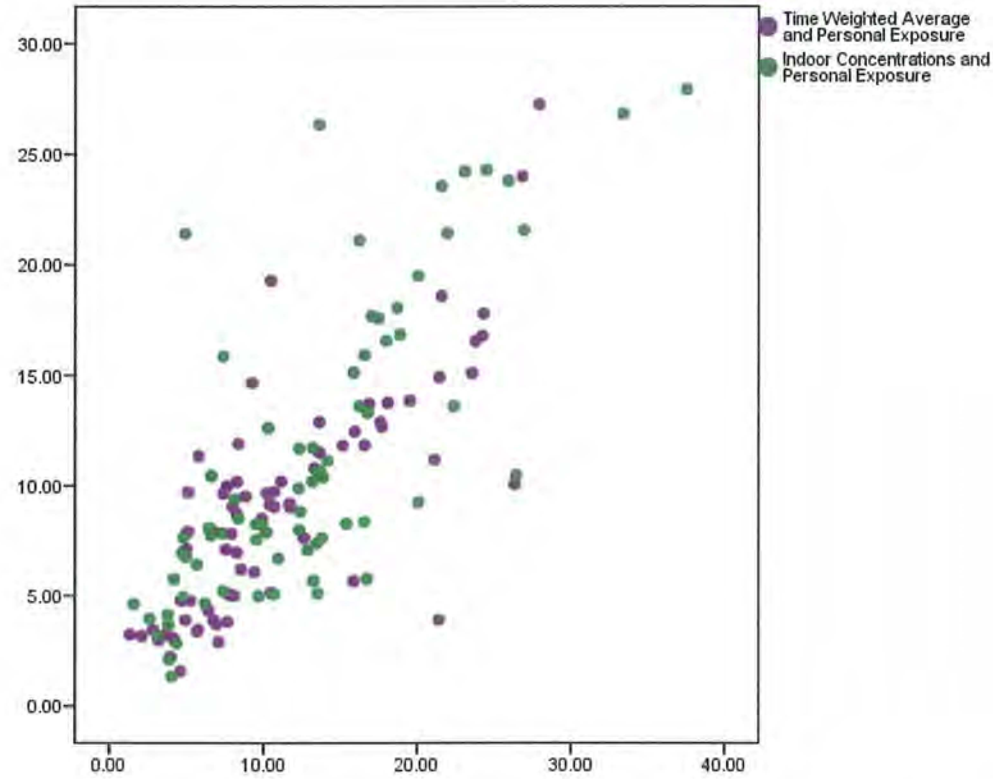

Figure 3-1 Scatter graph of time weighted average and indoor concentrations against personal exposure concentrations (ppb) for all participants

These results indicate that both methods are suitable as estimation methods, due to their significant relationship to the measured personal exposure concentrations. The time-weighted model does not significantly improve the indoor air concentration as a surrogate method. However, the results calculated for the time-weighted model, although significantly correlated to the personal exposure concentrations, tend to underestimate personal exposure. The indoor surrogate method is not consistently higher or lower than the personal exposure method, as can be seen in the results tables in Appendix E.6.

4.0 DISCUSSION

The study found that the concentrations of formaldehyde the participants from Calista and Duncraig, Western Australia, were exposed to were relatively low. Outdoor concentrations were very low, with indoor concentrations significantly higher than outdoor concentrations. Although more elevated than outdoor concentrations, the indoor concentrations tended to be lower than those at which health impacts have been reported in previous investigations (Ritchie & Lehnen 1987; Godish 1990; Dingle & Franklin 2002; Ezratty *et al* 2007; Arts *et al* 2008). Participants spent the majority of their time indoors (> 90%). A significant relationship between measured personal exposure and indoor concentrations of formaldehyde has been identified, largely due to the high proportion of time spent indoors.

4.1 Study Population

The study participants recruited in this study provide a representative group of 9 to 12 year old children residing in the Perth suburbs of Duncraig and Calista. A number of demographic, behavioural and dwelling characteristics differed between the two areas (Section 3.1). The more elevated age of Calista participants is expected to be due to the slightly different recruitment approaches used (Section 2.4), with Year 6 science students targeted at Calista while all Year 4 to 6 students at Duncraig were approached to participate in the study. Duncraig students who volunteered tended to mostly be in Year 4 with a small number of Year 5 participants. Smoking by parents was more common in Calista, although the difference was not significant, while the occurrence of people smoking indoors was significantly more common in Calista. This is possibly due to the lower socio-economic status of this area, based on weekly household incomes (ABS 2006), although socio-economic characteristics were not targeted as a key factor in the study design.

Differences in dwelling characteristics between the two areas are indicative of suburb specific characteristics. The statistically significant difference in distance

to a four lane road between the two areas occurred as one of the reasons Duncraig was targeted due to the proximity of the suburb to a major freeway. Calista is a slightly newer suburb with newer homes than Duncraig, although 81% of dwellings in Calista in this study were still over 10 years old. While the newer homes in Calista may influence characteristics such as the higher proportion of gas ovens in this area, the homes were not so new that indoor concentrations of formaldehyde were more elevated in this area, as previous studies have indicated can occur (Garrett *et al* 1997; Dingle & Franklin 2002; Raw *et al* 2004).

4.2 Time Activity Impacts

The participants' time activity patterns varied little between the two areas, with the slight differences identified in winter in relation to activities that accounted for a very small proportion of some of the participants' day. The similarity with results presented by Adgate *et al* (2004), for children aged 7 to 13 years in Minnesota in the United States, indicates that these patterns are potentially similar for all children in developed countries. This was observed despite the extremely different climates experienced between Perth, which is temperate, and Minneapolis, which fluctuates between extreme heat and cold each year.

As discussed above, the strong correlation identified between indoor concentrations at home and personal exposure concentrations is largely due to the large proportion of time spent in the indoor environment by children. The participants of this study spent approximately 65% of their time indoors at home, and over 90% of their time in all indoor environments including school (*Table 3-3*). These patterns are very similar to those presented by Adgate *et al* (2004), which found children on average spent 65% of their time indoors at home, 25% of their time at school, and approximately 3% of their time outdoors.

A comparison between the two study areas found that the only significantly different time activity patterns occurred in winter, for proximity to smoking and heating and time spent walking (*Table 3.4*). However, these activities only

occurred for a negligible amount of some of the participant's time, with many participants not spending any time walking or in proximity to heating or near smoking. Therefore the time activity patterns within a key microenvironment (i.e. indoors or outdoors) had limited impact on overall formaldehyde personal exposure.

4.3 Formaldehyde Exposure Sources

A number of household characteristics were found to significantly impact on indoor formaldehyde concentrations (*Table 3.9*). However, despite the strong correlation between indoor and personal exposure, characteristics identified as significantly impacting on indoor concentrations did not always significantly impact on personal exposure concentrations. Presence of a smoker, heating use and disinfectant use significantly impacted on indoor concentrations, but not personal exposure. These factors are potentially explained by the fact that these activities, such as smoking or using disinfectant, are likely to occur when the child is not in proximity to the source. Alternatively, some of these factors may not be significant sources of personal exposure, while others such as tobacco smoke exposure may be less significant for children than has been indicated in studies undertaken on adults (Eisner *et al* 2002).

The targeting of the two areas of Duncraig and Calista aimed to investigate the differences between two sub-populations of children of this age bracket in Perth. The choice of the two areas was driven at the commencement of the study by the presence of distinct outdoor pollution sources in each area, being traffic and woodsmoke pollution in Duncraig and industrial pollution in Calista. There were, however, few differences in the formaldehyde concentrations recorded between the two areas, particularly given that outdoor concentrations were very low and contributed little to indoor concentrations.

As the indoor environment has been identified as the most important source of formaldehyde, the similarities between the dwelling characteristics of the two areas potentially impacted on the studies ability to identify characteristics of

importance to exposure. With factors such as the majority of homes being greater than 20 years old and of brick and tile construction, variability in representation of many dwelling characteristics was limited. A number of studies have indicated the significance of the age of a home and age of building and furniture materials in regard to indoor formaldehyde concentrations in Australian and overseas homes (Brown 2002; Dingle & Franklin 2002; Jurvelin *et al* 2003).

There are a number of limitations in this study for identifying significant sources of formaldehyde within the home. The overall low concentrations reported provide a limited range of concentrations (<4ppb to 37.5ppb), hence limiting the variability of formaldehyde concentrations for comparative analyses. Furthermore, the mild meteorological conditions meant that impacts due to increased off-gassing during warmer weather, ventilation impacts or heating sources would not have been identified (Garrett *et al* 1997; Brown 1999). Finally, the study was not powered to investigate the issue of source characterisation and it was a secondary aim of the study. There have been a number of studies that have evaluated important indoor sources and these have been acknowledged above.

The study design of this investigation focused on Calista and Duncraig to target potential outdoor air sources of formaldehyde (Section 2.3). However, the findings presented here have indicated that the choice of one area representative of a new urban development, with homes less than 5 years, and one area which was older, such as Duncraig, may have aided in providing greater variability of dwelling characteristics between the two areas. This variability in age would potentially provide greater statistical strength to identify factors which significantly impacted on formaldehyde concentrations.

4.4 Factors Affecting Personal Exposure

4.4.1 Relationships between Personal Exposure and Microenvironmental Concentrations

A very strong correlation between the personal exposure concentrations and indoor domestic concentrations was observed, consistent with the findings reported in overseas studies on adults. Regression analyses also supported this finding. This relationship confirms the significance of the indoor domestic environment to formaldehyde exposure for children. The significance of the indoor environment is likely due to the high concentrations found in this microenvironment, from a variety of possible sources, and the large amount of time spent there.

The personal exposure concentrations measured tended to be slightly lower than domestic indoor concentrations across all sampling locations and seasons. The time spent in the indoor domestic environment was approximately 65% for all participants, and other measured microenvironments had lower formaldehyde concentrations. It is therefore expected that the total personal exposure concentration would be lower than the indoor concentrations measured and this finding is consistent with studies undertaken on adults (Jurvelin *et al* 2001; Gustafson *et al* 2005).

4.4.2. Indoor Sources and Personal Exposure

A number of household characteristics and sources were shown to be positively related to personal exposure concentrations (*Table 3-9*). These characteristics included hotplate fuel used, primary cooling and glue use, and are potentially sources which a child will be in proximity to during use. The flooring type in the living room also had a significant relationship with personal exposure. This is unexpected given that flooring type did not significantly impact on indoor concentrations, however, the children may be in closer contact with the floor when playing or if watching television while sitting on the floor.

Multiple linear regression was undertaken to assess which factors where significantly related to personal exposure when considered in combination with other potentially significant characteristics. Of 22 initial variables assessed in the regression, two characteristics were found to be protective factors. These were the questionnaire estimates of heating use and glue use; however, the diary data indicates that during winter sampling there was very little use of heating with only two participants being in proximity to heating at home for short periods of time. Therefore the estimates of heating use by participants were not an accurate reflection of actual heating use occurring during the sampling conducted in this study and measured concentrations of formaldehyde were not impacted by heating sources.

The regression analyses indicated that, when all factors were considered together, the fuel used for the hotplate was the only factor to significantly impact on personal exposure to formaldehyde. The study found that children with gas fuel hotplates (59% of participants), as opposed to electric ones (41%), had an increased exposure to formaldehyde. This finding is supported by other studies which have found that the presence of gas fuelled heating can significantly impact on formaldehyde concentrations (Garrett *et al* 1997) or that gas combustion is a source of formaldehyde (Lowe *et al* 1980). As with the estimates of heating use discussed above, diary data for the sampling periods indicate that children were not in proximity to cooking for significant proportions of time during the sampling period. Yet the hotplate fuel still may have the potential to impact on indoor concentrations and, therefore, personal exposure concentrations.

4.4.3. Personal Exposure, Indoor and Outdoor Concentrations

This study has shown that formaldehyde personal exposure concentrations of children aged 9 to 12 in Perth, Western Australia were relatively low compared with international studies and national and international standards and guidelines. Personal exposure concentrations in this small sample size were also well below domestic concentrations (50ppb) at which health impacts have been previously

been observed (Krzyzanowski *et al* 1990; Franklin *et al* 2000; Rumchev *et al* 2002). The microenvironmental concentrations measured in this study for indoors at home, outdoors and indoors at school were also well below relevant standards and guidelines for all participants.

The study found that Duncraig participants tended to experience lower personal exposure and indoor concentrations compared with Calista participants, although the differences were not significant. Duncraig participants were slightly younger and lived in older homes. The classroom formaldehyde concentrations were significantly lower in Duncraig, while the outdoor measures were very low across both areas. These lower concentrations at Duncraig are likely due to the older age of homes, which is a factor consistently found to impact on indoor formaldehyde concentrations (McPhail 1991; Garrett *et al* 1997; Brown 1999; Franklin & Dingle 2001; Hodgson *et al* 2002; Raw *et al* 2004). It is also an indication that outdoor sources are not a significant source of formaldehyde for personal exposure, as indicated by the proximity to a major road in Duncraig or industrial facilities near Calista, but low overall concentrations outdoors in both areas.

There was little variation detected between the seasonal monitoring periods, with winter samples recording slightly higher concentrations. This is consistent with the findings from the study undertaken on a larger number of Perth homes by Franklin and Dingle (2001), but different to seasonal effects reported by both Rumchev (2002) in Perth and Garrett *et al* (1998) in rural Victoria. There was no statistical difference between the personal exposure, outdoor or school concentrations by season, although the winter indoor measure was significantly higher. The lack of seasonal differences may have been due either to the mild meteorological conditions experienced during both seasons (Section 3.1.3.1) or by the fact that the sample size was small and most homes had relatively low formaldehyde concentrations, ie there may not have been a sufficient range of concentrations to observe seasonal differences.

4.4.3.1 Comparison with Australian and International Data

There are a number of factors that have the potential to impact on the characteristics of Australian microenvironments, making them somewhat different to those found overseas. These include characteristics such as dwelling design, construction materials, sources of heating and cooling, cooking fuel, meteorology and seasonal influences on time activity patterns. For these reasons, it is valuable to obtain Australian specific data when assessing exposures to environmental chemicals. The limited availability of Australian personal exposure data was one of the main reasons for undertaking this study. Overseas data is often all that is available for determining standards and guidelines for Australian conditions. Due to the paucity of Australian data it is prudent to use international data for comparison purposes.

There is limited available data worldwide regarding personal exposure concentrations of formaldehyde for children. Indeed, the Relationship of Indoor, Outdoor and Personal Air (RIOPA) Study in the United States is the only available published data that includes children (Weisel *et al* 2005). Both the RIOPA study and the research conducted on adults have found elevated formaldehyde personal exposure concentrations, compared with those reported here. RIOPA reported mean personal exposure concentrations for children of 16.4ppb and 15.3ppb using passive and active methods, respectively (Weisel *et al* 2005), whereas this study, measuring personal exposures using passive techniques, reported a geometric mean concentration across all participants of 9.6ppb. This highlights the importance of country specific data.

The personal exposure concentrations reported here are also lower than those reported in overseas studies conducted on adults (Jurvelin *et al* 2001; Gustafson *et al* 2005). This finding is consistent with personal exposure studies and ambient air monitoring for other pollutants, with concentrations in Australian studies reported to be lower than overseas (Lee *et al* 2000; Hinwood *et al* 2007; NPI 2007). Jurvelin *et al* (2001) reported average personal exposure concentrations of 21.4ppb for adults living and working in Helsinki; Gustafson *et*

al (2005) reported personal exposure concentrations of 17.9ppb and 18.7ppb in two different areas of Sweden; and Serrano-Trespalacios *et al* (2004) reported a mean concentration of 12.7ppb for adults in Mexico City.

Microenvironmental concentrations of formaldehyde reported here are consistent with concentrations reported elsewhere in Australia and internationally (Dingle & Franklin 2002; Garrett *et al* 1997; Jurvelin et al 2001; Gustafson et al 2005). The indoor concentrations reported here (*Table 3.5*) are similar to those reported by Garrett *et al* (1997), who reported a median indoor concentration in Victorian homes of 12.6ppb. Dingle & Franklin (2002) reported indoor formaldehyde concentrations in Western Australian homes which were higher than those reported here, although still relatively low, with higher concentrations in the bedroom than in the lounge room and a geometric mean of 22.8ppb for the whole house. The reason for the higher concentrations is unclear, although there was a higher proportion of newer homes in the Dingle & Franklin (2002) study with 46% of homes less than 10 years old. In this study less than 10% of all houses were less than 10 years old. In that study, age of home was a significant predictor of increased formaldehyde concentrations (Franklin and Dingle 2002). Both the Garrett *et al* (1997) and Dingle & Franklin (2002) studies, which considered exposure of children to formaldehyde via stationary indoor monitoring, found median indoor concentrations of formaldehyde in children's homes in Australia to be relatively low with a small number of homes exceeding the then recommended guideline of 100ppb. A study by Rumchev *et al* (2002) reported similar concentrations to Dingle & Franklin (2002), using similar recruitment and sampling methodologies.

The indoor school measures collected for this study were very low, although they were significantly higher at Calista. The Duncraig indoor school concentrations were below limits of reporting (4ppb) for all samples, while Calista reported an average of 11.6ppb for both seasons. There is some information available for indoor school environments in international studies indicating concentrations in schools can be elevated, but are variable due to factors such as building materials

and ventilation (Wantke *et al* 1996; Lee & Chang 2000; Smedje & Norback 2001). Zhang *et al* (2006) reported formaldehyde concentrations ranging from < 2ppb to 30ppb in 4 schools in the Southern suburbs of Perth. These were all relatively new schools and were not far from Calista. The results for most of the schools are reasonably similar to what was recorded at Calista. Duncraig is a much older school than the Calista and the schools in the Zhang study. Measurements from within workplaces in international studies have indicated that commercial buildings and offices, that are not directly associated with significant occupational exposures, tend to have lower indoor concentrations than in homes (Jurvelin *et al* 2001; Gustafson *et al* 2005).

Outdoor concentrations of formaldehyde reported in this study were also very low and below the analytical detection limit (4ppb) in most cases. Monitoring undertaken by the Department of the Environment and Conservation (DEC) across Perth over the same period reported very low outdoor formaldehyde concentrations, with an average of approximately 1.5ppb, which was consistent with monitoring throughout 2007 (DEC 2007). Median outdoor concentrations reported by Garrett *et al* (1997) in Victoria were 0.6ppb. These low concentrations are likely to be a result of the relatively low urban density and traffic density of Perth at the time of this study. International studies have found elevated outdoor concentrations in high density urbanised areas (Son *et al* 2002; Sexton *et al* 2004; Serrano-Trespalicios *et al* 2004; Weisel *et al* 2005), although, in general, ambient concentrations even in these urban environments are not extremely high.

Due to the very low outdoor concentrations measured in this study, no significant impacts on exposure due to outdoor sources were able to be identified. At the initial study design phase of this investigation, the areas of Duncraig and Calista were targeted due to their potentially significant, yet differing, outdoor air pollution sources. These sources were woodsmoke and traffic impacts at Duncraig, while Calista is in proximity to a major industrial area. The low outdoor formaldehyde concentrations reported indicate that, even in areas with

significant outdoor pollution impacts, formaldehyde concentrations are low and indoor concentrations dominate exposure. While the number of sampling days was limited and maximum outdoor concentrations may not have been reported, these low concentrations are consistent with those reported and ambient air monitoring stations in Perth (DEC 2006).

The indoor and outdoor microenvironmental concentrations reported here tend to be similar, although slightly lower, to those reported in overseas studies. Indoor and outdoor formaldehyde concentrations were reported in several EXPOLIS studies, with Jurvelin *et al* (2001) reporting domestic indoor concentrations of 33.3ppb and outdoor concentrations of 2.6ppb in a Finnish study. Gustafson *et al* (2005) reported mean indoor concentrations of 18.73ppb to 23.61ppb in two areas and mean outdoor values of 3.26ppb in a study in Sweden. A Mexican study by Serrano-Trespalacios *et al* (2004) reported indoor values of 15.96ppb and outdoor concentrations of 4.48ppb. These differences in indoor concentrations are likely due to differences in dwelling construction, particularly ventilation, and materials and the age of materials in the home. Outdoor impacts, although still very low, are likely to be more elevated than those reported in Perth (DEC 2006) due to increased density of urbanisation and differing meteorology.

The concentrations reported here are lower than those at which health impacts have been reported in previous studies (Garrett *et al* 1999; Eisner *et al* 2002; Rumchev *et al* 2002). Garrett *et al* (1999) indicated that among the participants suffering from respiratory symptoms, more frequent symptoms were noted in those children exposed to the more elevated (>40 ppb) domestic formaldehyde levels reported in the study. Rumchev *et al* (2002) found that asthmatic children exposed to higher domestic levels of formaldehyde (>50ppb) were more likely to experience acute asthmatic events, while Franklin *et al* (2000) found increased levels of exhaled nitric oxide in children exposed formaldehyde concentrations of 50ppb or greater in the home.

4.4.4 Appropriate Models for Estimating Exposure

The investigation of techniques for estimating exposure found that indoor domestic measures and time weighted modelling both resulted in estimated exposure concentrations that were significantly correlated with measured personal exposure concentrations. This indicates that both techniques are suitable for use as methods for estimating personal exposure.

The time weighted model used a combination of stationary measures collected indoors at home, outdoors in central neighbourhood locations and indoors at school, in combination with diary data for the corresponding period. A simple equation was applied to this data to calculate exposure, resulting in an estimated personal exposure concentration (Noy *et al* 1990; Jurvelin *et al* 2001).

This calculated concentration tended to underestimate the personal exposure concentration, although the difference was not significant. The time weighted model was found to account for 80% of the variance of personal exposure measures, with the remaining 20% likely to be from a combination of other sources, microenvironments and normal measurement error. It is likely that short duration, but significant, activities could account for a relatively higher proportion of exposure. These activities could include time spent in vehicles or in proximity to elevated sources.

The use of this estimation technique was found to be suitable for the sampling duration of 24 hours applied in this study. Shorter sampling durations can have the benefit of providing more accurate and reliable time activity information as recall bias and error is reduced. This then aids in obtaining stronger correlations between personal exposure and time activity modelling.

The indoor measure as a surrogate was also significantly correlated with the personal exposure concentration reported, although the relationship was not quite as strong as that of the time weighted model. The indoor measure as a surrogate tended to slightly overestimate the exposure concentration of an individual,

although the difference was not significant. These findings are consistent with the studies investigating exposure of adults to formaldehyde which have been conducted overseas (Jurvelin *et al* 2001; Gustafson *et al* 2005).

Both of the time weighted model and the indoor air as surrogate are appropriate methods for estimating exposure to formaldehyde, based on a comparison with the measured personal exposure data presented in this study. The time weighted model provides a slightly more accurate estimate than the indoor measure alone as a surrogate, although the improvement is not significant. This method does require the collection of multiple microenvironmental measures and detailed time activity data. The indoor measure as a surrogate, although less strongly correlated to personal exposure than the time weighted model, is a much simpler method of estimating exposure. This method requires only a single indoor measure per participant and does not require a detailed daily diary.

4.4.5 Seasonal Variation in Personal Exposure

One of the primary aims of this study was to investigate seasonal variations in personal exposure. This has been found to be a significant factor impacting on indoor concentrations of formaldehyde or emissions from formaldehyde containing materials (Godish 1990; Garrett *et al* 1997; Brown 1999; Jurvelin *et al* 2001; Gustafson *et al* 2005) and is hence expected to impact on personal exposure. The ability to identify seasonal variation in personal exposure was limited by the mild meteorological conditions experienced during both winter and summer sampling (Section 3.3).

No seasonal variation in personal exposure concentrations were identified in this study. However, this is considered to be an artefact of the conditions encountered and is not an indication that seasonal variation would not occur during more normal fluctuations in meteorological conditions between seasons.

4.5 Limitations of this Study

This study and some of the findings are subject to certain limitations, due to a number of factors such as sample size, small number of repeat measures and meteorology during sampling. These factors impacted on the ability of the study to statistically identify relationships between personal exposure concentrations and potential sources and other factors. However, the number of samples were sufficient for the primary aims of assessing personal exposure, correlations between personal and indoor measures and seasonal variation.

The mild meteorological conditions encountered during both rounds of sampling may have impacted on this studies ability to identify variability in formaldehyde concentrations based on seasonal impacts. Several studies which have measured formaldehyde have found season to be a significant factor, with indoor concentrations elevated during hot summer months (Garrett *et al* 1997; Jurvelin *et al* 2001; Gustafson *et al* 2005). Although Perth does experience very hot summer weather, the timing of the monitoring was restricted to occur during a school calendar year; therefore the summer monitoring occurred prior to the hottest summer months. Furthermore, the winter monitoring occurred during unseasonable mild weather for the time of year during which the monitoring occurred. While season was not identified as being significant in this study, the mild meteorological conditions encountered may have impacted on the representativeness of the study in regards to season. However, studies conducted in Perth measuring indoor formaldehyde have not been consistent with regard to seasonal impacts. Rumchev *et al* (2002) found that the season did significantly impact on indoor concentrations, while Dingle & Franklin (2002) found no significant relationship, although both studies had similar sample sizes, study populations and sampling methodologies.

The sample size utilised in this study was calculated to aid in determining whether the indoor environment, as opposed to the outdoor environment, was the most significant source for personal exposure. As there was no published personal exposure data for children available at that time, indoor and outdoor

concentrations were utilised. Using the data collected in this study and undertaking a sample size calculation using the indoor and personal exposure concentrations recorded, a sample size of 75 is required. This is much higher than the initial sample size of five calculated in Section 2.8.1. However, this study did recruit 42 participants and through repeat sampling gained 74 paired personal exposure and indoor samples, indicating that the identified relationship between personal exposure and indoor air concentrations is still valid.

As the sample size is increased, so the statistical strength of calculations regarding this relationship will improve. However, although the sample size calculation result was increased to 40 and 74 paired samples were obtained from this population, the resultant sample size did not always provide sufficient variability to statistically support some of the relationships between concentrations reported and characteristics measured. The sample size used in this study is still therefore suitable for the aims of this study, however the ability to identify significant sources of exposure and important time activity patterns was limited.

A number of other factors have the ability to impact on the quality of the data collected. These include common problems such as bias in recruitment, recall bias or errors in diary completion by children, reliability of participants reporting any problems or mistakes or laboratory errors. Every effort has been made through the study design, recruitment, data collection and analytical process to ensure that the possibility of errors occurring are minimised. While these cannot be discounted, they have not been quantified and the study assumes that any such quality issues are minimal and mitigated by the appropriate management of each process as it occurred.

Limitations in the analytical approach impacted on the limit of reporting, due to slightly elevated background concentrations of formaldehyde in some of the laboratory blank QA/QC samples. Therefore several samples, including the majority of the outdoor samples, could not be accurately quantified for

concentrations below 4ppb. Despite this, the strong correlations of the HPLC calibration curves indicate that the results above limits of reporting are within narrow margins of reporting error. Field blanks and duplicates were all within acceptable bounds (Section 2.6.1).

5.0 CONCLUSIONS

The results of this investigation have provided an important measure of actual formaldehyde personal exposure concentrations for children in Perth, Western Australia. Concentrations reported were low and tended to be lower than concentrations reported in investigations conducted elsewhere in Australia and overseas. The results indicated a strong correlation between measured personal exposure concentrations and domestic indoor concentrations.

This study has confirmed the importance of the indoor domestic environment to personal exposure concentrations of formaldehyde for children in Perth, Western Australia. The importance of this environment is due to a combination of both the high proportion of time spent indoors at home by children, and because of the high concentrations found in this microenvironment. These findings are consistent with those reported in Australian and international studies which have assessed exposure to formaldehyde.

An analysis of alternative exposure assessment methodologies was conducted, including the use of a stationary indoor air sample as a surrogate and time weighted modelling. This comparison has indicated that, due to the high proportion of time spent indoors and the elevated concentrations of formaldehyde found in this environment, these alternative methods of assessment are both suitable for evaluating exposure of children to formaldehyde, with time weighted modelling providing a more accurate alternative.

The activity patterns of the children in this study are very similar to both adults and children in developed countries overseas, with over 90% of their time spent in indoor environments at home and school. This pattern emphasises the importance of the indoor environment in environmental chemical exposure studies.

The concentrations reported are very low and well below concentrations at which health impacts have been identified. However, further studies will be required to

confirm if health impacts are being experienced by children at these low concentrations, due to the lack of studies on measured environmental concentrations and health effect impacts.

Further investigations with a larger sample size, which provide a greater range of temporal data would also be recommended. This would be of value given the limitations of the study, such as the lack of seasonal variability detected and the limitations on confirming the relationship between measured formaldehyde concentrations and dwelling characteristics.

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APPENDIX A

ETHICS AND OTHER APPROVALS

Victoria LAZENBY

From: Research Ethics
Sent: Monday, 29 August 2005 4:43 PM
To: Victoria LAZENBY
Cc: Andrea HINWOOD; Karen LECKIE; Christianne WHITE
Subject: 05-123 LAZENBY

Dear Victoria

05-123 LAZENBY
Investigation into factors influencing personal exposure to formaldehyde in children.

Student Number: 2022215

The ECU Human Research Ethics Committee (HREC) has reviewed your response to their concerns and has granted ethics approval for your research project.

The approval period is from 29 August 2005 to 28 February 2007.

The Graduate School has been informed and they will issue formal notification of approval. Please note that the submission and approval of your research proposal is a separate process to obtaining ethics approval and that no recruitment of participants and/or data collection can commence until formal notification of both ethics approval and approval of your research proposal has been received.

The *National Statement* indicates that the HREC is required to retain on file a copy of each approved research project. Please forward one signed paper copy of your finalised application, including all attachments, to the ethics office (if this has not already been done).

Please note the following conditions of approval:
The HREC has a requirement that all approved projects are subject to monitoring conditions. This includes completion of an annual report (for projects longer than one year) and completion of a final report at the completion of the project. An outline of the monitoring conditions and an ethics report form are attached for your information. You will also be notified when a report is due.

Please feel free to contact me if you require any further information.

Regards
Kim

Kim Gifkins
Research Ethics Officer
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Fax: (08) 6304 2661
Email: research.ethics@ecu.edu.au

Department of Education and Training
Government of Western Australia

Your ref:

Our ref: DO05/252793

Enquiries:

Ms Victoria Lazenby
Centre for Ecosystem Management
School of Natural Sciences
Edith Cowan University
100 Joondalup Drive
JOONDALUP WA 6027

Dear Ms Lazenby

Thank you for your letter dated 25 November 2005 requesting approval from the Department of Education and Training to conduct a study of children's exposure to the chemical formaldehyde.

Approval is granted to approach school principals to inform them of the study and invite their school to participate. The decision then rests with the principal.

Please keep me informed of any preliminary findings of the study and forward a copy of the final report when it is completed.

Yours sincerely

DAVID AXWORTHY
A/EXECUTIVE DIRECTOR
CURRICULUM STANDARDS

Department of Health
Criminal Record Screening
Clearance Card

Name	VICTORIA LAZENBY
Card Number	00151991-1
Date Cleared	20051202
Certifying Officer	PHIL RIGG

151 Royal Street, East Perth, Western Australia 6004

APPENDIX B

INFORMATION PACK FOR PARTICIPANTS

Edith Cowan University
School of Natural Sciences
Centre for Ecosystem Management
100 Joondalup Drive, Joondalup
Western Australia 6027
Telephone: (08) 6304 5766
Facsimile: (08) 6304 5509
Email: v.lazenby@ecu.edu.au

CONSENT FORM

To be completed by the parent/guardian for each child participating in the 'Children's Formaldehyde Exposure' study.

I, ____ (full name)

Of ____ (address)

____

____

Voluntarily consent for my child ______________________________ (child's name) to take part in the 'Children's Formaldehyde Exposure' study.

I have read the information sheet provided and I am confidant that the aims and procedures of the study have been fully explained to my satisfaction.

I also understand that I can withdraw from the study at any time.

Signed ____ Date ____________

Witnessed by ____

Witnesses signature ______________________________ Date ____________

ECU EDITH COWAN UNIVERSITY

Edith Cowan University
School of Natural Sciences
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100 Joondalup Drive, Joondalup
Western Australia 6027
Telephone: (08) 6304 5766
Facsimile: (08) 6304 5509
Email: v.lazenby@ecu.edu.au

CONTACT DETAILS

To be completed if you are interested in your child participating in the 'Children's Formaldehyde Exposure' study. This information will be kept confidential at all times.

Name (child) ________________________________

Name (parent) ________________________________

Address ________________________________

____

____

Phone (home) ________________________________

Phone (mobile) ________________________________

Phone (work) ________________________________

Email ________________________________

A study investigating the factors which influence personal exposure to formaldehyde in children

Background Information

What is formaldehyde?

Formaldehyde (HCHO) is a colourless, strong smelling organic molecule that is classified as an 'air toxic'. Air toxics are substances that are present in air in small amounts, but are toxic at high concentrations. Formaldehyde is produced from a variety of sources, resulting in its presence in both indoor and outdoor air. The primary use of formaldehyde is for the production of resins, which are used as glues in the production of particleboard, fibreboard and plywood, as well as a wide range of other applications. It is also a by-product of fuel and wood combustion.

Health impacts of formaldehyde

Formaldehyde has a number of health impacts, particularly on the respiratory system. Exposure to inhaled formaldehyde may irritate the nose, eyes and throat, and this irritation can then aggravate asthma and other respiratory illnesses. There is some evidence that formaldehyde is also associated with cancer production in people exposed to high concentrations over extended periods. Research has shown that the health effects of air pollution are particularly significant among certain groups, including children, therefore making them a particularly vulnerable group. There is currently no Australian Standard for formaldehyde, although an interim concentration of 0.1parts per million (ppm) has been recommended by the National Health and Medical Research Council.

What Participation Involves

This study will be measuring how much formaldehyde children are exposed to on different days and in different seasons. This will require the involvement, cooperation and consent of both the child and their parent. Once a parent has agreed to allow their child to take part in the study, the parent and child will be given an interview administered questionnaire at their own home to collect a range of information. This will include information on the child's age, gender, school and main methods of transport, as well as information on their home, including age of home, building materials, type of cooking appliances and heating and cooling systems.

The child will then be asked to wear a small plastic sampler clipped to their clothing (and beside the bed while sleeping) for one 24 hour period, on a weekday, in the week following the interview. On this day, the parent will be asked to place one small sampler outside their home and one sampler inside the main living area for the same 24 hour period.

During each 24 hour period a daily diary will need to be completed by the child with the parents help. This will involve providing information on where the child was during each part of the day, what modes of transport were used and time spent in proximity to gas appliances and cigarette smokers.

As the child will be recruited through their school, there will be multiple children in the same classroom wearing the formaldehyde samplers. Therefore another sampler will be placed inside the classroom for an 8 hour weekday period.

This monitoring will take place in winter (June 2006), and again in summer (December 2006). Parents will be contacted one month prior to the summer monitoring period to remind them of the study and to ensure they are still available and interested in participating.

All samples and diaries will be collected from the school at the completion of the monitoring. Once the samples are analysed, the participants will be sent information on the overall results of the study. All information collected will be kept confidential and will only be accessible to the researchers.

If you have any queries at any time, please contact Victoria Lazenby on (08) 6304 5766 or 0402 837327, or via email on v.lazenby@ecu.edu.au. Or contact Dr Andrea Hinwood on (08) 6304 5372 or via email on a.hinwood@ecu.edu.au.

Should you have any complaint concerning the manner in which this research is conducted, please do not hesitate to contact the Human Research Ethics Committee at:

Human Research Ethics Committee
Edith Cowan University
100 Joondalup Drive
Joondalup WA 6027
Telephone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

Edith Cowan University
School of Natural Sciences
Centre for Ecosystem Management
100 Joondalup Drive, Joondalup
Western Australia 6027
Telephone: (08) 6304 5766
Facsimile: (08) 6304 5509
Email: v.lazenby@ecu.edu.au

Dear Parent,

I am conducting a study to identify whether children across Perth are being exposed to the chemical formaldehyde. To complete the study, I am looking for volunteers aged between 7 and 12 years old who attend (*will insert school name here*).

Attached to this letter is an information sheet providing some background information on formaldehyde and its health effects. The information sheet also outlines what will be required of you and your child if you agree to participate in this study. Participation is entirely voluntary and, if you do agree to participate, you may withdraw from the study at any time.

If you are interested in your child participating in the study, please complete the attached contact details form and return to your child's teacher. I will then call you directly to arrange an appointment. If you require any further information, please do not hesitate to contact me at the above phone number or email address.

I look forward to hearing from you soon.

Regards

Victoria Lazenby

School of Natural Sciences

Edith Cowan University
School of Natural Sciences
Centre for Ecosystem Management
100 Joondalup Drive, Joondalup
Western Australia 6027
Telephone: (08) 6304 5766
Facsimile: (08) 6304 5509
Email: v.lazenby@ecu.edu.au

Dear Parent,

I am conducting a study to identify whether children across Perth are being exposed to the chemical formaldehyde. To complete the study, I am asking students in years 6 and 7 who attend Calista Primary School to participate. Calista Primary School has agreed to run the study as a class science project, however I do require your consent so that your child can participate.

Attached to this letter is an information sheet providing some background information on formaldehyde and its health effects. The information sheet also outlines what will be required of you and your child during the study. Participation is entirely voluntary and, if you do agree to participate, you may withdraw from the study at any time.

If you are happy for your child to participate in the study, please complete the attached contact details form and return to your child's teacher. I will then call you directly to further discuss the project with you. If you require any further information, please do not hesitate to contact me at the above phone number or email address.

I look forward to hearing from you soon.

Regards

Victoria Lazenby

School of Natural Sciences

ECU EDITH COWAN UNIVERSITY

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Email: v.lazenby@ecu.edu.au

Dear Mr James Mumme,

As part of my M.Sc. degree I am conducting a study to identify whether children across Perth are being exposed to the chemical formaldehyde. To complete the study, I am looking for volunteers aged between 7 and 12 years old who attend primary school in the Calista/Duncraig *(delete as appropriate)* area. Recruitment will involve me visiting the classroom of years 4 to 7 to inform the students of the project, request the student's involvement and provide them with written information to take home to their parents.

Attached to this letter is the information sheet I will be providing to the children and their parents providing some background information on formaldehyde and its health effects. The information sheet also outlines what will be required of any children who agree to participate in this study. I have also included the contact details form and consent form I will require the participants to complete.

I have also attached an approval form for you to sign to ensure the project is conducted with the full knowledge and consent of the school. If you feel that the project has been fully explained to you and you are interested in allowing me to conduct this research through your school, please sign the attached approval form.

If you have any further queries which arise through the duration of the study, I can be contacted through the above contact details, or my supervisor, Dr Andrea Hinwood, can be contacted on 6304 5372 or via email on a.hinwood@ecu.edu.au.

Regards

Victoria Lazenby

School of Natural Sciences

APPENDIX C

QUESTIONNAIRE

ECU EDITH COWAN UNIVERSITY

Formaldehyde Exposure Study

Questionnaire

ID: ☐☐☐☐☐

Name of Child: ______________________________

Address: ______________________________

____

____

Phone: Home: ______________________________

Person completing questionnaire: ____________________

Relationship: ____________________

Phone: Work: ____________________

Mobile: ____________________

Date questionnaire completed: ____/____/______

All information will be kept confidential, with questionnaire data only identified through the use of an identification number.

Household and Personal Information

Office Use Only

1. **Date of Birth:** ___/___/_____ **Age:** ________ years — 1. ☐☐

2. **Gender:** Male ☐1 Female ☐2 — 2. ☐

3. **School Attended:** ______________________________ — 3. ☐

4. **Do any smokers live in the house?** Yes ☐1 No ☐2 — 4. ☐

5. **If anyone smokes, where do they smoke?** Indoors ☐1 Outdoors ☐2 Both ☐3 — 5. ☐

Dwelling Information

6. **How old is your home?**

< 1 year	☐1	6. ☐
1-3 years	☐2	
4-10 years	☐3	
10-20 years	☐4	
> 20 years	☐5	

7. **Does your home have any of the following?**

	Yes	No	
7.1 Carport (semi-enclosed) attached to dwelling with internal access	☐1	☐2	7.1 ☐
7.2 Garage (fully-enclosed) attached to the dwelling with internal access	☐1	☐2	7.2 ☐
7.3 Carport (semi-enclosed) attached to dwelling without internal access	☐1	☐2	7.3 ☐
7.4 Garage (fully-enclosed) attached to the dwelling without internal access	☐1	☐2	7.4 ☐
7.5 Free standing carport (semi-enclosed)	☐1	☐2	7.5 ☐
7.6 Free standing garage (fully enclosed)	☐1	☐2	7.6 ☐
7.8 Other (specify) ____________________			7.7 ☐

8. **What is the main building material of the outer walls?**

Brick	☐1	8. ☐
Timber	☐2	
Fibro	☐3	
Asbestos	☐4	
Stone	☐5	
Other ______________	6	

ID: ☐☐☐☐☐

9. What is the main type of floor covering in each of the following rooms?

	Carpet	Tiles	Floorboards	Vinyl	Other (specify)	Office Use Only
9.1 Child's bedroom	❑1	❑2	❑3	❑4	❑ ____5	9.1. ☐
9.2 Kitchen	❑1	❑2	❑3	❑4	❑ ____5	9.2. ☐
9.3 Living room	❑1	❑2	❑3	❑4	❑ ____5	9.3. ☐
9.4 Meals	❑1	❑2	❑3	❑4	❑ ____5	9.4. ☐

10. What is the main material used for internal walls in each of these rooms?

	Brick	Concrete	Plaster	Panels	Fibro	Other (specify)	
10.1 Child's bedroom	❑1	❑2	❑3	❑4	❑5	❑ ____6	10.1. ☐
10.2 Kitchen	❑1	❑2	❑3	❑4	❑5	❑ ____6	10.2. ☐
10.3 Living room	❑1	❑2	❑3	❑4	❑5	❑ ____6	10.3. ☐
10.4 Meals	❑1	❑2	❑3	❑4	❑5	❑ ____6	10.4. ☐

11. Have you undertaken renovations in the last 12 months?

Yes ❑1 No ❑2 Don't Know ❑3 11. ☐

12. What type of fuel do you use to operate your hot-plate?

Gas	Electric	Wood	Other (specify)	
❑1	❑2	❑3	❑ ____4	12. ☐

13. What type of fuel do you use to operate your oven?

Gas	Electric	Wood	Other (specify)	
❑1	❑2	❑3	❑ ____4	13. ☐

14. What is the primary type of heating in your house?

Gas	Electric	Wood	Reverse-cycle	Other (specify)	
❑1	❑2	❑3	❑4	❑ ____5	14. ☐

15. What is the secondary (if any) type of heating in your house?

Gas	Electric	Wood	Reverse-cycle	Other (specify)	
❑1	❑2	❑3	❑4	❑ ____5	15. ☐

16. How often do you use your heating in winter?

Less than 5 times	❑1	16. ☐
Less than once a week in winter	❑2	
Once to 4 times a week in winter	❑3	
More than 4 times a week in winter	❑4	
Every day	❑5	

ID: ☐☐☐☐☐

17. What is the primary source of cooling in your house?

Office Use Only

17. ☐

Air-conditioning	☐1
Ceiling fans	☐2
Portable fans	☐3
Evaporative air conditioner	☐4
Opening windows	☐5
No cooling	☐6
Other (specify)	☐ ______7

18. What is the secondary (if any) source of cooling in your house?

18. ☐

Air-conditioning	☐1
Ceiling fans	☐2
Portable fans	☐3
Evaporative air conditioner	☐4
Opening windows	☐5
Other (specify)	☐ ______6

19. What is the third (if any) source of cooling in your house?

19. ☐

Air-conditioning	☐1
Ceiling fans	☐2
Portable fans	☐3
Evaporative air conditioner	☐4
Opening windows	☐5
Other (specify)	☐ ______6

20. How often do you use your cooling system in summer?

20. ☐

Less than 5 times	☐1
Less than once a week in summer	☐2
Once to 4 times a week in summer	☐3
More than 4 times a week in summer	☐4
Every day	☐5

21. Does your home have furnishings made of any of these materials?

		Yes	No	
21.1	Wood	☐1	☐2	21.1 ☐
21.2	Particle board	☐1	☐2	21.2 ☐
21.3	Vinyl	☐1	☐2	21.3 ☐
21.4	Leather	☐1	☐2	21.4 ☐
21.5	Cotton	☐1	☐2	21.5 ☐
21.6	Plastic	☐1	☐2	21.6 ☐
21.7	Other ______	☐1	☐2	21.7 ☐

ID: ☐☐☐☐☐

22. How often are the following products used in the home?

	Daily	Weekly	Monthly	A few times a year	Never	Office Use Only
22.1 Paint	❑1	❑2	❑3	❑4	❑5	22.1 □
22.2 Glue/adhesives	❑1	❑2	❑3	❑4	❑5	22.2 □
22.3 Shoe polish	❑1	❑2	❑3	❑4	❑5	22.3 □
22.4 Floor varnish/wax	❑1	❑2	❑3	❑4	❑5	22.4 □
22.5 Deodorisers	❑1	❑2	❑3	❑4	❑5	22.5 □
22.6 Disinfectant	❑1	❑2	❑3	❑4	❑5	22.6 □
22.7 Carpet cleaner	❑1	❑2	❑3	❑4	❑5	22.7 □

Transport Information

23. What is the main form of transport used to travel to the following places?

	Car	Bus	Walk/cycle	Train	
23.1 School	❑1	❑2	❑3	❑4	23.1 □
23.2 Sports/Organised activities	❑1	❑2	❑3	❑4	23.2 □
23.3 Shops	❑1	❑2	❑3	❑4	23.3 □
23.4 Friends/Families homes	❑1	❑2	❑3	❑4	23.4 □
23.5 Other ______________	❑1	❑2	❑3	❑4	23.5 □

24. How long (to the nearest ¼ hour) is spent in the following modes of transport on a normal weekday? (Insert 0 if not used).

24.1	Car/Motor vehicle	________	24.1 □□
24.2	Bus	________	24.2 □□
24.3	Walking/Cycling	________	24.3 □□
24.4	Train	________	24.4 □□
24.5	Other __________	________	24.5 □□

25. How long (to the nearest ¼ hour) is spent in the following modes of transport on a normal weekend (average Saturday and Sunday)? (Insert 0 if not used).

25.1	Car/Motor vehicle	________	25.1 □□
25.2	Bus	________	25.2 □□
25.3	Walking/Cycling	________	25.3 □□
25.4	Train	________	25.4 □□
25.5	Other __________	________	25.5 □□

26. Distance to nearest four lane road?

< 50 metres	❑1	26. □
50 – 200 metres	❑2	
200 – 500 metres	❑3	
> 500 metres	❑4	

ID: □□□□□

Activity Pattern Information

Office Use Only

27. On an average weekday how much time is spent (to the nearest ¼ hour) in the following locations or doing the following activities? (Insert 0 if not applicable)

27.1 In bedroom	________	27.1 ☐☐
27.2 In living room	________	27.2 ☐☐
27.3 In kitchen	________	27.3 ☐☐
27.4 Inside at home (other rooms)	________	27.4 ☐☐
27.5 Outside at home	________	27.5 ☐☐
27.6 At school	________	27.6 ☐☐
27.7 At sports/activities indoors	________	27.7 ☐☐
27.8 At sports/activities outdoors	________	27.8 ☐☐
27.9 Other (specify) ____________	________	27.9 ☐☐

28. On an average weekend day how much time is spent (to the nearest ¼ hour) in the following locations or doing the following activities? (Insert 0 if not applicable)

28.1 In bedroom	________	28.1 ☐☐
28.2 In living room	________	28.2 ☐☐
28.3 In kitchen	________	28.3 ☐☐
28.4 Inside at home (other rooms)	________	28.4 ☐☐
28.5 Outside at home	________	28.5 ☐☐
28.6 At shops	________	28.6 ☐☐
28.7 At sports/activities indoors	________	28.7 ☐☐
28.8 At sports/activities outdoors	________	28.8 ☐☐
28.9 Other (specify) ____________	________	28.9 ☐☐

ID: ☐☐☐☐☐

APPENDIX D

DAILY ACTIVITY DIARY

Daily Activity Diary **Sampler Opened:** ______________ **Sampler Closed:** ________________ **ID:** ☐☐☐☐

Mark appropriate box with a cross for each 15 min period during the day and note major activities in left hand column

Date: ________			**Location**									**Activities**		
Time		**Briefly describe your main activities**	I am travelling by …				I am currently at …					I am near…		
			foot/ bike	car/ vehicle	bus	train	Home		School	Other		Cooking	Heating	Someone smoking
							Indoors	Outdoors	Indoors	Indoors	Outdoors			
7	00													
	15													
	30													
	45													
8	00													
	15													
	30													
	45													
9	00													
	15													
	30													
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	30													
	45													
12	00													
	15													
	30													
	45													
1	00													
	15													
	30													
	45													
2	00													
	15													

Time		**Briefly describe your main activities**	foot/ bike	car/ vehicle	bus	train	Home		School	Other		Cooking	Heating	Someone smoking
							Indoors	Outdoors	Indoors	Indoors	Outdoors			
2	30													
	45													
3	00													
	15													
	30													
	45													
4	00													
	15													
	30													
	45													
5	00													
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8	00													
	15													
	30													
	45													
9	00													
	15													
	30													
	45													
10	00													
	15													
	30													
	45													

APPENDIX E

ADDITIONAL RESULTS

APPENDIX E

RESULTS TABLES AND FIGURES

E.1 Questionnaire Responses

Table E-1 Characteristics of Participants Identified in Questionnaire

Characteristic	Response	Duncraig (n = 20) (%)	Calista (n = 21) (%)
Age	9 years	70	0
	10 years	20	10
	11 years	10	48
	12 years	0	42
Gender	Male	40	38
	Female	60	62
Smoker in house	Yes	25	48
	No	75	52
Location of smoking	Indoors	0	0
	Outdoors	100	76
	Both	0	24
Age of Home	1-3 years	0	5
	4-10 years	0	14
	10-20 years	5	33
	>20 years	95	48
House Car Bay (Type: Access)	Carport: Internal	5	14
	Garage: Internal	0	0
	Carport: No Internal	65	48
	Garage: No Internal	25	14
	Carport: Freestanding	0	5
	Garage: Freestanding	0	5
	Other	5	14
External walls	Brick	100	100
Floor coverings: Bedroom	Carpet	75	80
	Tiles	0	0
	Floorboards	5	10
	Vinyl	10	0
	Other	10	10
Floor coverings: Kitchen	Carpet	0	0
	Tiles	30	38
	Floorboards	5	19
	Vinyl	25	43
	Other	40	0
Floor coverings: Living Room	Carpet	60	61
	Tiles	25	10
	Floorboards	5	19
	Vinyl	5	0
	Other	5	10

Characteristic	Response	Duncraig (n = 20) (%)	Calista (n = 21) (%)
Floor Coverings: Meals	Carpet	20	19
	Tiles	25	29
	Floorboards	5	19
	Vinyl	20	28
	Other	30	5
Internal Walls: Bedroom	Plaster	100	95
	Fibro	0	5
Internal Walls: Kitchen	Plaster	90	90
	Brick	10	5
	Fibro	0	5
Internal Walls: Living Room	Plaster	100	95
	Fibro	0	5
Internal Walls: Meals	Plaster	85	90
	Brick	15	5
	Fibro	0	5
Renovations within last year	Yes	50	29
	No	50	71
Hotplate fuel	Gas	50	67
	Electric	50	33
Oven fuel	Gas	0	33
	Electric	100	67
Heating fuel: Primary	None	5	0
	Gas	60	71
	Electric	0	14
	Wood	5	10
	Reverse cycle	30	5
Heating fuel: Secondary	None	60	52
	Gas	15	14
	Electric	10	14
	Wood	10	10
	Reverse Cycle	5	10
Heating Use in Winter	None	5	10
	< Once week	5	5
	1-4 a week	40	10
	> 4 a week	15	19
	Every day	35	56
Cooling Type: Primary	Reverse cycle	35	24
	Ceiling fans	5	24
	Portable fans	10	5
	Evaporative	45	37
	Open Windows	5	10
Cooling Type: Secondary	None	30	0
	Reverse cycle	5	10
	Ceiling fans	25	24
	Portable fans	40	33

Characteristic	Response	Duncraig (n = 20) (%)	Calista (n = 21) (%)
	Evaporative	0	5
	Open Windows	0	28
Cooling Type: Tertiary	None	70	33
	Reverse cycle	0	5
	Ceiling fans	0	5
	Portable fans	15	10
	Evaporative	5	14
	Open Windows	10	33
Cooling Use in Summer	< Once week	10	0
	1-4 a week	20	19
	> 4 a week	35	38
	Every day	35	43
Furnishing/ Fittings Materials	Wood	100	100
	Particle Board	100	100
	Vinyl	30	57
	Leather	30	19
	Cotton	100	100
	Plastic	30	57
	Other	30	0
Paint Usage	Weekly	15	0
	Monthly	40	5
	A few times a year	40	81
	Never	5	14
Glue Usage	Weekly	65	14
	Monthly	15	33
	A few times a year	20	38
	Never	0	15
Shoe polish Usage	Daily	0	5
	Weekly	5	0
	Monthly	5	5
	A few times a year	30	42
	Never	60	48
Floor varnish usage	Weekly	0	14
	Monthly	0	5
	A few times a year	10	10
	Never	90	71
Deodoriser usage	Daily	25	43
	Weekly	15	28
	Monthly	5	10
	A few times a year	10	10
	Never	45	9
Disinfectant usage	Daily	5	19
	Weekly	55	76
	Monthly	10	0
	A few times a year	10	0

Characteristic	Response	Duncraig (n = 20) (%)	Calista (n = 21) (%)
	Never	20	5
Carpet Cleaner usage	Weekly	0	0
	Monthly	5	14
	A few times a year	30	48
	Never	65	38
Transport: school	Car	55	71
	Bus	0	0
	Walk/cycle	45	29
Transport: Sports/ activities	Car	95	100
	Bus	0	0
	Walk/cycle	0	0
Transport: Shops	Car	85	100
	Bus	0	0
	Walk/cycle	10	0
Transport: Friends/ family homes	Car	80	95
	Bus	0	0
	Walk/cycle	20	5
Transport: Other	Car	15	100
	Bus	0	0
	Walk/cycle	35	0
Distance to 4 lane road	<50m	5	5
	50-200m	60	19
	201-500m	15	14
	>500m	20	62

E.2 Distribution Graphs

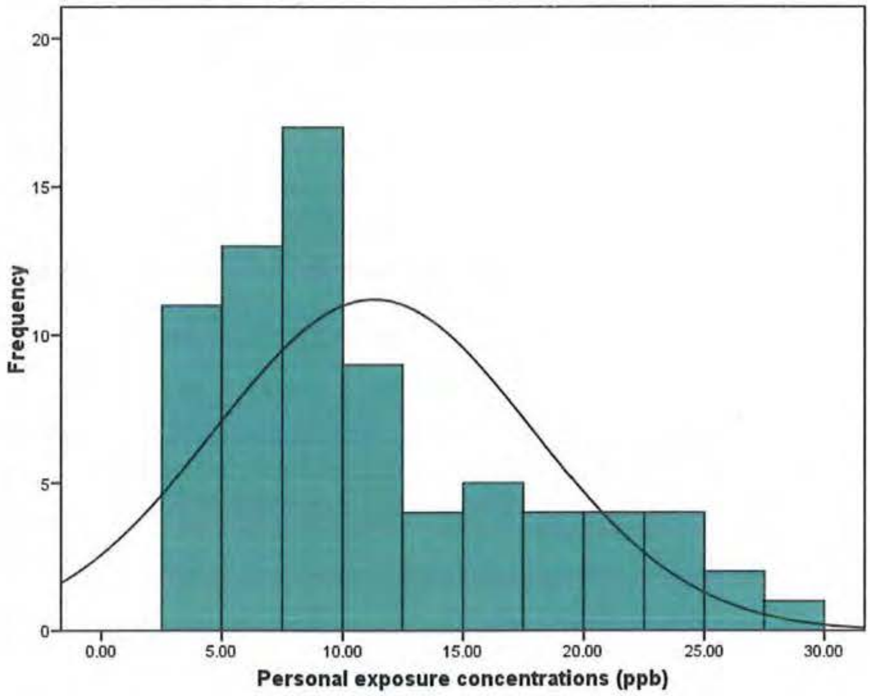

Figure E.1 Frequency distribution of personal exposure formaldehyde monitoring concentrations (ppb)

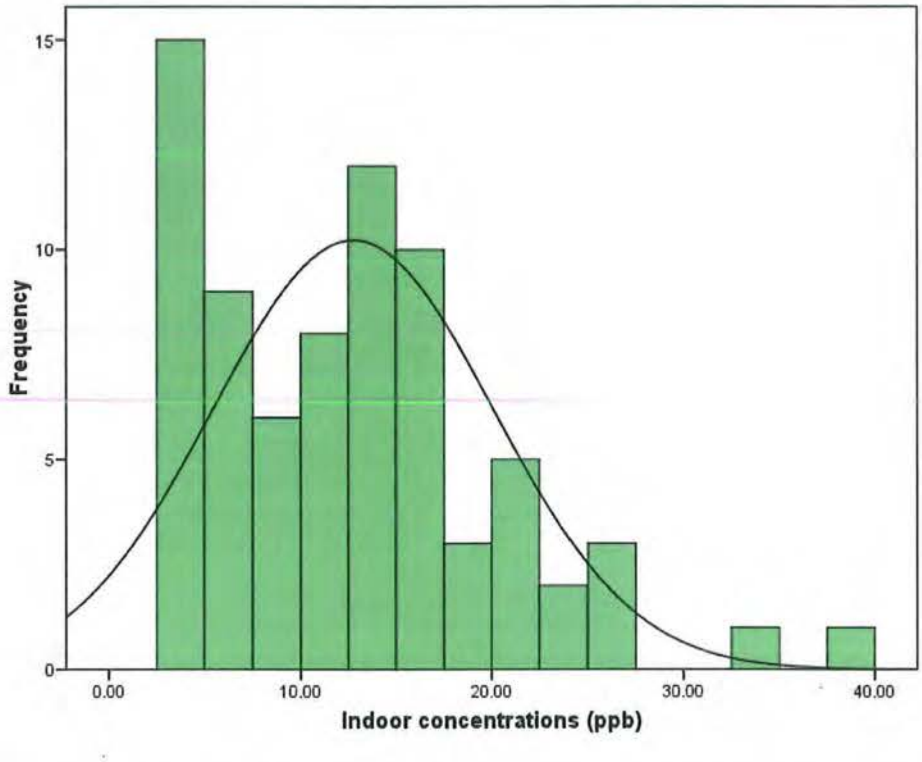

Figure E.2 Frequency distribution of indoor formaldehyde monitoring concentrations (ppb)

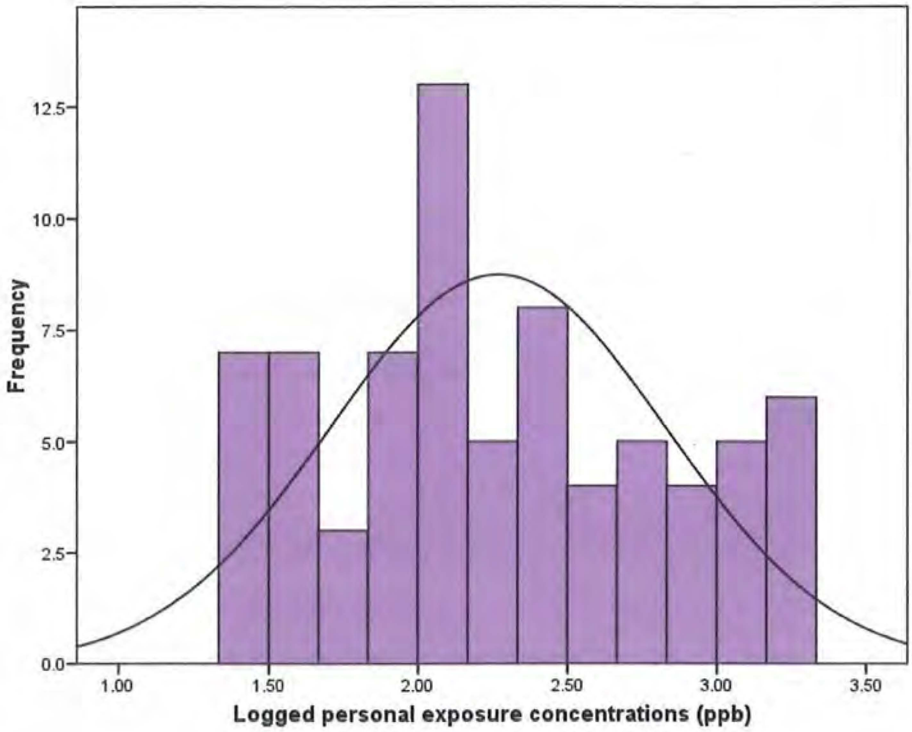

Figure E.3 Frequency distribution of logged personal exposure formaldehyde monitoring concentrations (ppb)

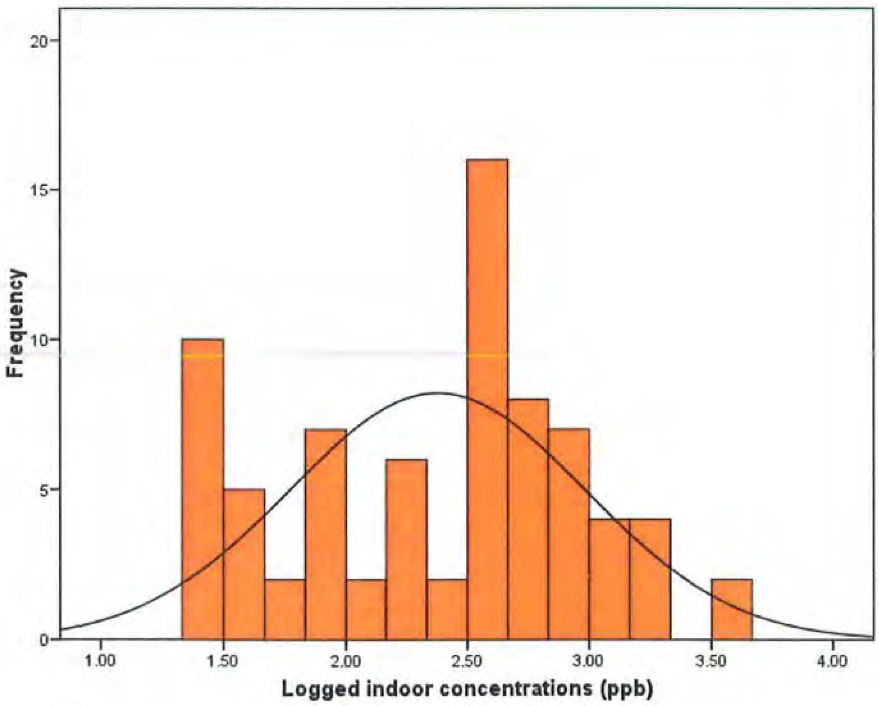

Figure E.4 Frequency distribution of logged indoor formaldehyde monitoring concentrations (ppb)

E.3 Scatter Graphs of Formaldehyde Monitoring Results

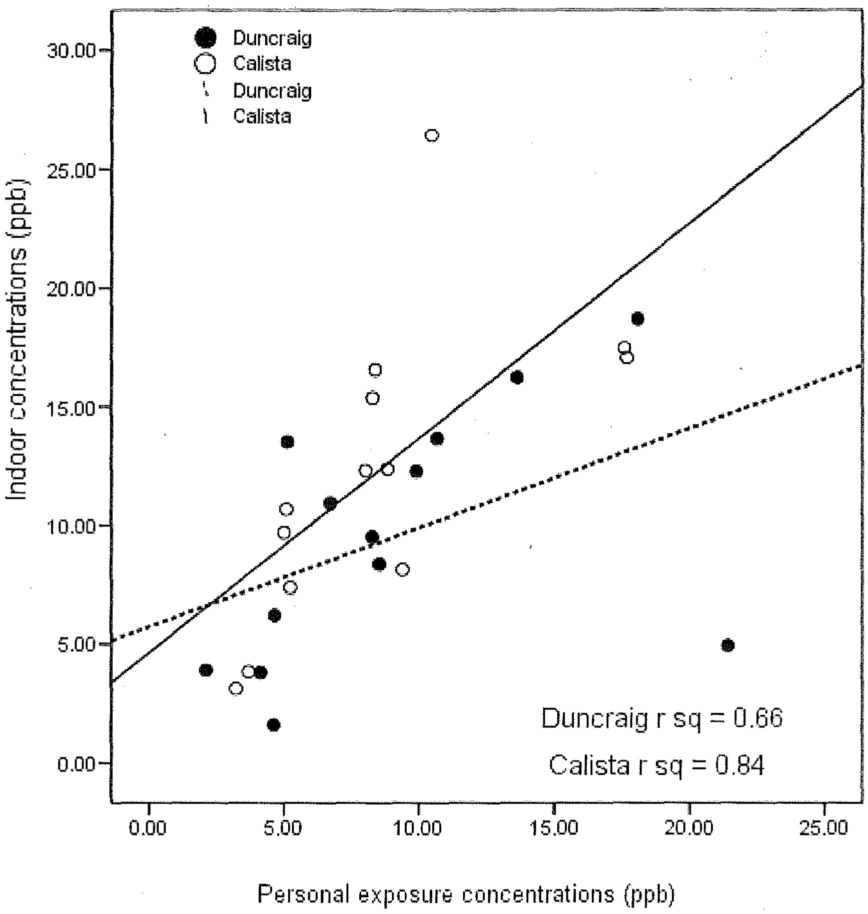

Figure E.5 Personal exposure versus indoor concentrations in summer

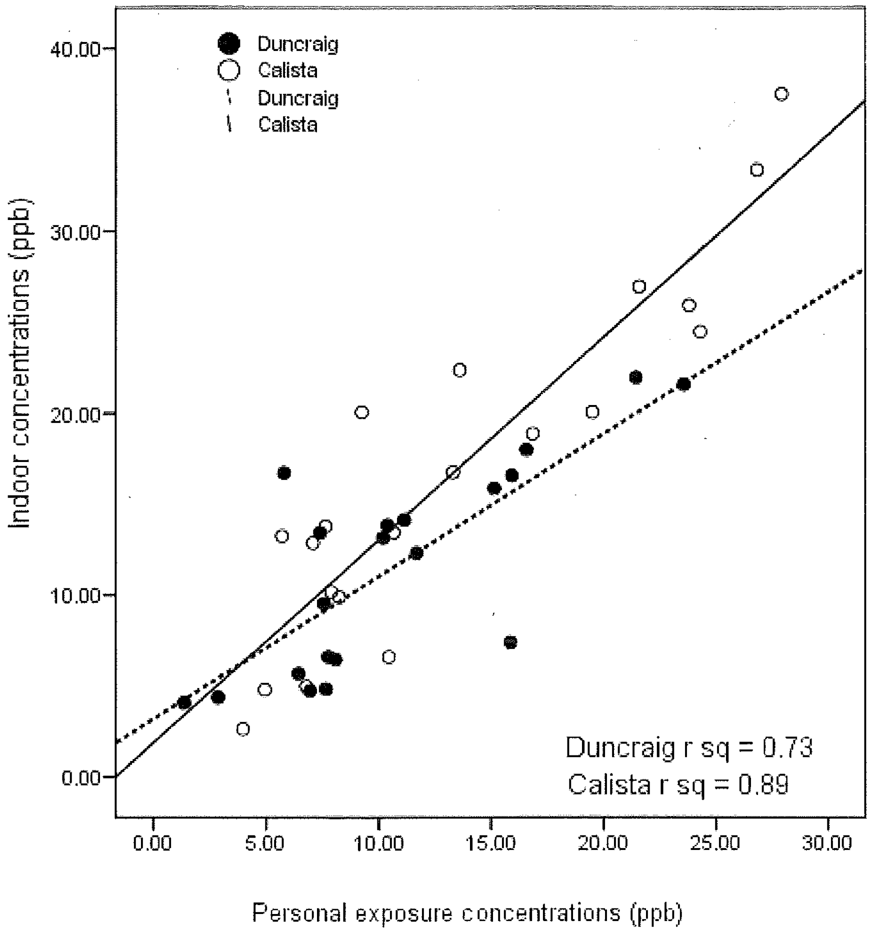

Figure E.6 Personal exposure versus indoor concentrations in winter

E.4 ANOVA Results

Table E-2 ANOVA results between Questionnaire Characteristics and Personal Exposure and Indoor Concentrations

Factor	Personal Exposure	Indoor
School	0.830	0.094
Smoking	0.141	0.056
Garage no internal access	0.915	0.074
Carport freestanding	0.147	0.334
Carport other	0.219	0.033
Flooring bedroom	0.068	0.077
Flooring living room	0.009	0.227
Hotplate fuel	0.076	0.721
Heating primary	0.156	0.145
Heating secondary	0.076	0.167
Heating use	0.122	0.067
Cooling primary	0.083	0.428
Cooling secondary	0.590	0.168
Cooling - third	0.205	0.025
Furniture - vinyl	0.035	0.041
Furniture - leather	0.170	0.258
Glue use	0.042	0.944
Deodoriser use	0.001	0.122
Disinfectant use	0.246	0.025
Transport to school	0.065	-
Transport to sports/activities	0.219	-
Transport to shops	0.125	-
Transport to friends	0.037	-
Car weekdays (wd)	0.001	-
Walking wd	0.065	-
Car weekends (we)	0.043	-
Walking we	0.083	-
Distance to 4 lane road	0.283	0.130
Living room wd	0.053	-
Kitchen wd	0.034	-
Inside home wd	0.002	-
Outside home wd	0.043	-
School wd	0.160	-
Other time wd	0.101	-
Kitchen we	0.012	-
Inside home we	0.001	-
Outside home we	0.021	-
Shops we	0.053	-
Sport Indoor we	0.000	-
Other time we	0.142	-

E5 Regression Models

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95% Confidence Interval for B Lower Bound	95% Confidence Interval for B Upper Bound
1	(Constant)	-.289	2.029		-.142	.887	-4.371	3.793
	ln_Ind_LOR	.725	.094	.772	7.685	.000	.535	.914
	ln_Outdoor	1.093	1.143	.116	.956	.344	-1.207	3.393
	Season	-.120	.117	-.108	-1.023	.312	-.356	.116
	School	.178	.160	.161	1.117	.270	-.143	.500
	Smokers	-.028	.107	-.024	-.265	.792	-.244	.187
	Grg_noin	-.041	.152	-.025	-.269	.789	-.347	.265
	Crpt_fre	.377	.246	.158	1.537	.131	-.116	.871
	Car_Othr	-.038	.313	-.011	-.120	.905	-.667	.592
	Floor_bd	-.038	.036	-.098	-1.057	.296	-.112	.035
	Floor_lv	-.056	.045	-.126	-1.243	.220	-.147	.035
	Hotplate	.199	.102	.177	1.944	.058	-.007	.404
	Heatprim	-.074	.054	-.142	-1.367	.178	-.183	.035
	Heat_sec	.024	.043	.058	.563	.576	-.063	.111
	Heat_use	-.115	.045	-.270	-2.544	.014	-.205	-.024
	Coolprim	-.039	.054	-.098	-.728	.470	-.147	.069
	Cool_sec	.028	.042	.073	.663	.510	-.057	.113
	Cool_thr	-.010	.025	-.039	-.418	.678	-.061	.040
	Furn_vin	-.100	.119	-.089	-.848	.401	-.339	.138
	Furn_lea	-.081	.122	-.064	-.669	.507	-.326	.164
	Glue	-.210	.070	-.355	-2.986	.004	-.351	-.068
	Deoder	-.015	.054	-.045	-.281	.780	-.124	.093
	Disinfec	.044	.056	.098	.789	.434	-.068	.156

a. Dependent Variable: ln_PE_LOR

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95% Confidence Interval for B Lower Bound	95% Confidence Interval for B Upper Bound
1	(Constant)	-.333	1.698		-.196	.845	-3.744	3.078
	ln_Ind_LOR	.737	.086	.785	8.535	.000	.563	.910
	ln_Outdoor	1.026	1.102	.109	.931	.356	-1.187	3.240
	Season	-.115	.114	-.103	-1.010	.317	-.343	.114
	School	.152	.141	.137	1.078	.286	-.131	.435
	Smokers	-.020	.102	-.017	-.194	.847	-.225	.186
	Crpt_fre	.365	.224	.152	1.629	.110	-.085	.814
	Floor_bd	-.038	.035	-.097	-1.083	.284	-.109	.033
	Floor_lv	-.060	.040	-.135	-1.504	.139	-.140	.020
	Hotplate	.192	.094	.171	2.038	.047	.003	.381
	Heatprim	-.073	.046	-.141	-1.600	.116	-.166	.019
	Heat_sec	.024	.041	.058	.591	.557	-.058	.106
	Heat_use	-.121	.040	-.286	-3.048	.004	-.201	-.041
	Coolprim	-.030	.045	-.076	-.679	.500	-.120	.060
	Cool_sec	.029	.038	.075	.760	.451	-.047	.105
	Furn_vin	-.084	.111	-.074	-.754	.455	-.306	.139
	Furn_lea	-.094	.115	-.074	-.819	.417	-.325	.137
	Glue	-.207	.061	-.351	-3.421	.001	-.329	-.086
	Deoder	-.024	.051	-.069	-.468	.642	-.125	.078
	Disinfec	.049	.053	.109	.919	.362	-.058	.155

a. Dependent Variable: ln_PE_LOR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.463	1.600		.289	.774	-2.745	3.671
	ln_Ind_LOR	.747	.079	.796	9.440	.000	.589	.906
	ln_Outdoor	1.089	1.095	.116	.994	.324	-1.106	3.284
	Season	-.127	.111	-.114	-1.146	.257	-.350	.095
	School	.071	.122	.064	.578	.566	-.174	.316
	Floor_bd	-.030	.032	-.075	-.911	.366	-.094	.035
	Floor_lv	-.042	.037	-.094	-1.121	.267	-.117	.033
	Hotplate	.169	.083	.151	2.028	.047	.002	.337
	Heatprim	-.100	.042	-.192	-2.369	.021	-.184	-.015
	Heat_sec	.005	.035	.012	.140	.889	-.065	.075
	Heat_use	-.120	.037	-.284	-3.278	.002	-.194	-.047
	Coolprim	-.066	.036	-.165	-1.817	.075	-.138	.007
	Cool_sec	.002	.033	.005	.056	.956	-.065	.068
	Furn_vin	-.112	.087	-.099	-1.282	.205	-.286	.063
	Furn_lea	-.076	.102	-.060	-.741	.462	-.281	.129
	Glue	-.148	.051	-.250	-2.904	.005	-.250	-.046

a. Dependent Variable: ln_PE_LOR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-.373	1.653		-.225	.823	-3.686	2.941
	ln_Ind_LOR	.769	.084	.819	9.133	.000	.600	.937
	ln_Outdoor	1.274	1.141	.135	1.116	.269	-1.013	3.560
	Season	-.117	.116	-.105	-1.012	.316	-.350	.115
	School	.084	.127	.076	.663	.510	-.171	.340
	Floor_bd	-.038	.035	-.098	-1.108	.273	-.108	.031
	Floor_lv	-.035	.039	-.079	-.918	.362	-.113	.042
	Hotplate	.184	.089	.164	2.058	.044	.005	.362
	Heat_use	-.111	.038	-.262	-2.955	.005	-.186	-.036
	Coolprim	-.040	.032	-.099	-1.244	.219	-.103	.024
	Cool_sec	.016	.035	.041	.450	.655	-.054	.086
	Furn_vin	-.110	.089	-.097	-1.227	.225	-.289	.070
	Furn_lea	-.053	.102	-.042	-.526	.601	-.257	.150
	Glue	-.124	.051	-.211	-2.429	.018	-.227	-.022
	Smokers	.039	.100	.033	.387	.700	-.161	.239

a. Dependent Variable: ln_PE_LOR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.251	1.215		.207	.837	-2.180	2.682
	ln_Ind_LOR	.758	.077	.807	9.856	.000	.604	.911
	ln_Outdoor	.896	.891	.095	1.005	.319	-.888	2.679
	Season	-.092	.102	-.082	-.899	.372	-.295	.112
	Floor_bd	-.043	.031	-.110	-1.394	.169	-.105	.019
	Floor_lv	-.026	.036	-.058	-.719	.475	-.098	.046
	Hotplate	.154	.080	.137	1.923	.059	-.006	.314
	Heat_use	-.104	.035	-.245	-2.996	.004	-.174	-.035
	Coolprim	-.045	.030	-.112	-1.478	.145	-.105	.016
	Furn_vin	-.120	.086	-.106	-1.394	.169	-.291	.052
	Glue	-.099	.043	-.168	-2.295	.025	-.186	-.013

a. Dependent Variable: ln_PE_LOR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.775	1.022		.759	.451	-1.268	2.818
	ln_Ind_LOR	.749	.072	.798	10.362	.000	.605	.894
	ln_Outdoor	.399	.677	.042	.589	.558	-.956	1.753
	Floor_bd	-.044	.030	-.111	-1.427	.159	-.104	.017
	Hotplate	.169	.078	.151	2.157	.035	.012	.326
	Heat_use	-.099	.032	-.234	-3.112	.003	-.163	-.035
	Coolprim	-.048	.029	-.121	-1.676	.099	-.106	.009
	Furn_vin	-.116	.083	-.103	-1.402	.166	-.282	.049
	Glue	-.105	.042	-.178	-2.503	.015	-.189	-.021

a. Dependent Variable: ln_PE_LOR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	1.304	.323		4.035	.000	.659	1.950
	ln_Ind_LOR	.736	.071	.782	10.388	.000	.595	.878
	Floor_bd	-.034	.030	-.085	-1.152	.254	-.094	.025
	Hotplate	.184	.077	.162	2.395	.019	.031	.337
	Heat_use	-.090	.032	-.209	-2.871	.006	-.153	-.028
	Coolprim	-.053	.028	-.130	-1.849	.069	-.109	.004
	Furn_vin	-.095	.081	-.084	-1.181	.242	-.256	.066
	Glue	-.116	.041	-.193	-2.826	.006	-.197	-.034

a. Dependent Variable: ln_PE_LOR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	1.181	.386		3.059	.003	.410	1.952
	ln_Ind_LOR	.743	.072	.790	10.287	.000	.599	.888
	Floor_bd	-.030	.031	-.074	-.961	.340	-.092	.032
	Hotplate	.192	.078	.169	2.451	.017	.036	.349
	Heat_use	-.088	.032	-.205	-2.779	.007	-.152	-.025
	Coolprim	-.051	.029	-.127	-1.787	.079	-.108	.006
	Furn_vin	-.103	.082	-.091	-1.255	.214	-.267	.061
	Glue	-.115	.041	-.191	-2.793	.007	-.197	-.033
	Smokers	.052	.087	.044	.593	.555	-.122	.226

a. Dependent Variable: ln_PE_LOR

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	1.212	.314		3.860	.000	.585	1.838
	ln_Ind_LOR	.717	.069	.762	10.385	.000	.579	.855
	Hotplate	.188	.077	.166	2.447	.017	.035	.342
	Heat_use	-.080	.030	-.185	-2.647	.010	-.141	-.020
	Coolprim	-.059	.028	-.146	-2.101	.040	-.115	-.003
	Furn_vin	-.075	.079	-.067	-.954	.343	-.233	.082
	Glue	-.109	.041	-.181	-2.681	.009	-.190	-.028

a. Dependent Variable: ln_PE_LOR

E6 Time Weighted Model Results

Table E-3 Time Weighted Model Results, compared against measured Personal Exposure and indoor Concentrations

Concentrations (ppb)		
Personal Exposure	Indoor	Time Weighted Calculation
10.4	13.85	9.16
6.94	4.73	3.70
15.14	15.86	11.82
7.56	9.53	7.11
5.78	16.72	11.34
15.87	7.38	5.68
6.42	5.68	4.35
21.44	21.95	14.92
16.57	17.98	11.84
7.39	13.42	9.64
7.65	4.83	3.83
8.08	6.46	5.01
7.75	6.59	5.06
15.93	16.56	12.46
11.69	12.31	9.18
2.86	4.37	3.45
1.35	4.06	3.25
11.14	14.13	10.19
23.57	21.57	15.10
10.19	13.16	9.66
10.67	13.66	9.05
NA	6.53	4.96
4.65	6.21	4.78
9.88	12.28	8.51
21.41	4.91	3.91
2.12	3.9	3.18
21.12	16.22	11.18
8.25	9.52	6.97
4.62	1.6	1.59
4.14	3.8	3.09
26.34	13.61	10.06
18.07	18.68	13.76
5.11	13.51	9.69
6.7	10.94	7.94
8.52	8.37	6.21
13.62	16.22	11.50
12.62	10.29	7.63
19.51	20.05	13.85
6.77	4.97	3.90
13.31	16.76	10.80
8.24	9.88	8.74
13.61	22.38	12.89
4.94	4.79	3.91
24.3	24.48	17.80
16.85	18.87	13.70
26.83	33.39	24.01
10.67	13.44	9.72
21.58	26.94	18.60

Concentrations (ppb)		
Personal Exposure	**Indoor**	**Time Weighted Calculation**
9.25	20.06	14.67
7.08	12.86	2.91
5.69	13.24	3.39
3.97	2.63	2.23
27.93	37.53	27.25
7.63	13.78	9.99
23.8	25.92	16.55
7.88	10.17	7.82
10.45	6.6	5.14
11.73	13.2	9.04
9.39	8.13	6.09
NA	3.1	2.65
7.85	7.28	5.08
3.21	3.11	2.99
5.22	7.38	4.78
3.69	3.84	3.28
17.6	17.46	12.89
24.23	23.08	16.80
8.36	16.56	11.90
4.99	9.68	7.14
10.47	26.43	19.29
5.09	10.67	7.91
17.7	17.04	12.68
8.0	12.31	9.06
8.27	15.37	10.18
8.82	12.38	9.52
5.76	4.2	3.47