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Formaldehyde in Occupied and Unoccupied Caravans in Australia

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Key Words
Formaldehyde · Caravans · Exposure levels

Abstract
A study of 132 unoccupied and 60 occupied caravans was conducted to determine levels of formaldehyde and factors which may affect these levels. Repeat monitoring was carried out 6 months later in 50 of the occupied caravans. A questionnaire was also used to assess potential factors associated with the recorded levels. Mean formaldehyde levels of 100 ppb in unoccupied caravans and 29 ppb in occupied caravans were recorded. A negative correlation was found between formaldehyde levels and the age of caravans. There were significant seasonal differences in formaldehyde levels measured, with higher levels recorded in winter.

Introduction

Over the last 20 years, there has been a gradual deterioration of indoor air quality in homes. This is partly due to changes in housing design, aimed at conserving energy by reducing ventilation, and by changes in the building materials used in the structure and furnishings of homes [1]. Studies have found that people spend 80% or more of their time at home [2], and therefore it is important to gain an understanding of the concentrations of pollutants in the air of homes.

Formaldehyde is a strong respiratory irritant [3] and at high concentration is considered a potential carcinogen [4]. Potential symptoms of formaldehyde exposure include dyspnoea, bronchospasm and increased sputum production [5]. Adverse health effects have been reported in healthy children at concentrations as low as 50 ppb [5].

Formaldehyde levels in homes are the result of the interaction of many factors, some of which increase the levels and others which suppress or even reduce the levels of formaldehyde [6]. Temperature, relative humidity [7, 8] and ageing of materials [6] have been identified as major factors affecting formaldehyde concentrations. Major sources of formaldehyde in homes have been identified as pressed or glued wood products (also known as reconstituted wood-based panels), such as particle board and medium density fibreboard [9,10] and urea formaldehyde foam insulation (UFFI) [7,11].

Previous studies characterising formaldehyde levels in homes have often focused on homes where residents have complained of indoor air quality problems, particularly in

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Table 1. Formaldehyde concentrations in occupied and unoccupied caravans

Caravan type	Mean age, years (age range)	Mean concentration ppb (arithmetic)	Range, ppb	Number
Occupied	14.4 (3–45)	29 (35)	10–855	60
Unoccupied	6.9 (1–27)	100 (154)	8–175	132

the case of homes and mobile caravans treated with UFFI or containing pressed or glued wood products [6]. While these studies provide us with information about a select group of homes, it does not provide a clear picture of typical levels or exposures. The characterisation of typical exposures in homes is necessary prior to estimating population exposures for risk analysis and identifying unsuspected and less obvious sources of exposure [6].

Australian Bureau of Statistics figures show that for the December quarter of 1990 there were some 2,687 caravan parks operating in Australia, comprising approximately 273,962 sites of which 48,337 (17.64%) were occupied by long-term residents [12]. In Western Australia alone there are an estimated 27,000 sites, 21% of which are occupied by permanent residents [12]. In the Perth metropolitan region permanent residents occupy 55% of total sites, a figure which is on the increase [13].

In this study the levels of formaldehyde were investigated in 132 unoccupied and 60 occupied caravans of varying ages around the Perth metropolitan area.

Materials and Methods

Concentrations of formaldehyde were determined in 132 unoccupied and 60 occupied caravans in summer. Occupied caravans were selected at random from within four major caravan parks in the Perth metropolitan area. Unoccupied caravans were selected at random from within the same four major caravan parks in addition to two caravan sale yards. Formaldehyde concentrations were determined 6 months later during winter, in 50 of the occupied caravans, to investigate associations between formaldehyde concentrations and the effects of seasonal and temporal factors. A questionnaire on caravan characteristics and residents' activities during monitoring was conducted in the occupied caravans.

Passive reusable formaldehyde monitors adapted from the standard three-section 37-mm aerosol cassette (Millipore Corp.) were utilised in the monitoring of formaldehyde levels. A set of paired monitors was located in the kitchen/dining room area and placed 1–2 m above the floor and suspended or supported on a non-compound wood, glass or metallic surface, so as to allow free flow of air from all directions and to avoid close proximity to possible sources of formaldehyde. Monitors were exposed for 3–5 days, with exposure times recorded.

In occupied caravans measurements were carried out under normal living conditions. Once the monitoring period had elapsed, all monitors were sealed, then placed in an airtight plastic bag and sealed. Monitors were collected within 3 days of completion of the sampling and returned directly to the laboratory.

The procedures and the preparation of DNPH coated filters used were based on the work by Levin et al. [14,15] and Dingle [16]. Uptake rate was calculated at 60 ml of formaldehyde per minute and was not influenced by sampling time [16]. Sensitivity of the technique was 1 ppb in a 24-hour sample and 3 ppb in an 8-hour sample [15]. Analysis was conducted by high performance liquid chromatography (HPLC) using 0.5-μm reverse phase-18 column (Merck liChroCART 125-4) with a mobile phase of 70% methanol (BDH HPLC grade) in water. Hydrazone was detected with a Spectra-physics 2050 variable detector at 365 nm. Retention time at a flow rate of 1 ml/min was 2.9 min.

Quality assurance procedures included preparation of calibration curves during each analysis, standardisation of reagent stock solutions, replicate analysis, evaluation of laboratory blanks and field controls [16].

Results

A significant correlation was found between the two parallel formaldehyde measurements conducted in the caravans ($r^2 = 0.96$). The correlation was found between the duplicate formaldehyde concentrations recorded in the 60 occupied ($r^2 = 0.96$) and 132 unoccupied caravans ($r^2 = 0.97$). Using a two-tailed t test there was no significant difference between the duplicate samplers ($p = 0.0002$), indicating that the measurements using paired monitors were highly reproducible.

Table 1 illustrates that the age of the unoccupied caravans ranged from 1 to 27 years with a mean of 6.9 years. The age of the occupied caravans ranged from 3 to 45 years with a mean 14.4 years. Eighty percent of the unoccupied caravans were less than 1,100 m^3 in size. Seventy-one percent of the caravans had only 1 room, 22% had 2 rooms, 6% had 3 rooms and 1 caravan (0.8%) had 5 rooms. Of the occupied caravans, 53% were less than 1,100 m^3 in size. Forty percent of the occupied caravans had only 1 room, 36% had 2 rooms, 13% had 3 rooms, 1 caravan (1.8%) had 4 rooms, 7% had 5 rooms and 1 caravan (1.8%) had 6 rooms.

Table 2. The differences in mean formaldehyde concentrations from samples taken 4–7 months apart

	Mean concentration[1], ppb		Mean difference in concentrations between assessments[2], ppb	Probability (p)
	summer	winter		
Occupied caravans	29.3 (35.3)	36.4 (41.5)	6.2	0.0002

[1] At two assessments; geometric mean and arithmetic mean (in parentheses).
[2] Two-tailed t test.

Formaldehyde concentrations in the unoccupied caravans ranged from a minimum of 10 ppb to a maximum of 855 ppb, with a geometric mean concentration of 100 ppb (AM = 154 ppb, SD = 139). Fifty-one percent of caravans exceeded the Australian [15] recommended guideline of 100 ppb. With the exception of 1 caravan all levels were below 460 ppb. One unoccupied caravan recorded a mean formaldehyde concentration of 855 ppb.

Table 2 illustrates that during summer, concentrations in the occupied caravans ranged from a minimum of 8 ppb to a maximum of 175 ppb, with a geometric mean concentration of 29 ppb (AM = 35 ppb, SD = 26). Only 2 occupied caravans exceeded the recommended formaldehyde guideline of 100 ppb while 51 caravans (85%) had levels below 50 ppb. In winter, the geometric mean concentration of formaldehyde was 36 ppb (AM = 42 ppb, SD = 24) with a minimum of 12 ppb and a maximum of 153 ppb. Using a paired two tail t test, a significant difference (p = 0.0002) was identified between the first measurements taken in summer and the measurements taken 6 months later during winter (mean x – y = 6.2 ppb) with higher levels of formaldehyde in winter. A negative correlation was found between the age of the caravans and formaldehyde concentrations although the correlation was not as strong for the occupied caravans (r^2 = –0.16) compared to the unoccupied caravans (r^2 = –0.36). No correlation was found with temperature, humidity or the volume of either the occupied or unoccupied caravans.

During summer, the windows, doors and vents of occupied caravans were opened for a mean time of 11.64, 8.85 and 12.89 h, respectively (SD = 6.1) with a range of 4–24 h. During winter, windows, doors and vents were open significantly less compared to summer. Windows, doors and vents were opened for a mean time of 4.33, 3.29 and 7.58 h, respectively. The number of people in the occupied caravans ranged from 1 to 6 with a mean of 2.2 persons in each caravan.

Discussion

Table 1 shows that formaldehyde levels recorded in caravans in this study are consistent with other studies reported by Hanrahan et al. [18], Sexton et al. [19], and Spengler and Sexton [20]. Studies in the United States have reported levels of formaldehyde in mobile homes ranging from less than 10 to 2,840 ppb, with the majority of mobile homes under 400 ppb [18] while a similar study of formaldehyde in caravans in the US yielded concentrations ranging from 30 to 2,400 ppb [20]. Formaldehyde concentrations are particularly high in portable buildings due to the higher load factor and because they are more airtight than conventional homes [21]. The load factor of a typical mobile home is approximately 1.4 $m^2 \cdot m^{-3}$ compared to a typical load factor in conventional homes ranging from 0.3 to 1.1 $m^2 \cdot m^{-3}$ [22].

Results in table 2 show a seasonal dependence in formaldehyde levels with levels being higher in winter compared to summer (p = 0.0001, paired t test). This may be explained by the reduction in ventilation (closed windows, doors and vents) in the winter period, allowing formaldehyde concentrations to build up. In a study of 24 caravans and portable buildings in Australia, McPhail et al. [23] found average levels of formaldehyde in opened (ventilated) new caravans of 256 $\mu g \cdot m^{-3}$ (214 ppb), and greater than 850 $\mu g \cdot m^{-3}$ (705 ppb) when closed (restricted ventilations).

Wolkoff et al. [24] reported significant changes in formaldehyde levels as a result of habitation in houses, with marked reductions in levels in summer, as a result of occupants being in the home. Concentrations of formaldehyde in occupied caravans (mean 35 ppb) were significantly lower than unoccupied caravans (mean 154 ppb) even when adjusted for age (mean 64 ppb). This difference may be a result of increased ventilation due to occupant activities. In the occupied caravans windows, doors and vents were open for a mean time of 11.64, 8.85 and

12.89 h, respectively. In the unoccupied caravans the doors were open for only brief periods during each day and the windows and vents were kept closed during the monitoring period.

A negative correlation was found between formaldehyde concentrations and the age of unoccupied ($r^2 = -0.36$) and occupied caravans ($r^2 = -0.16$). This negative correlation is consistent with other studies, which have shown the lowest levels to occur in older homes [25–27]. This is likely to be a result of a reduction in the rate of formaldehyde release from sources, such as pressed woods, with age [28] and the higher ventilation rates in older conventional homes [23].

The difference in correlations found between the ages of the unoccupied caravans ($r^2 = -0.36$) compared to ages of the occupied caravans ($r^2 = -0.16$) and formaldehyde concentrations may be explained by the influence of the occupants on the formaldehyde concentrations in occupied caravans. The increased activity and ventilation in occupied caravans is likely to introduce more factors influencing the formaldehyde concentrations by comparison to unoccupied caravans.

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