EXPOSURE TO HIGH CONCENTRATION OF FORMALDEHYDE. A CASE STUDY

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Indoor air quality has become a serious concern for home dwellers since the introduction of energy-efficient building technology. Combined with increased use of synthetic building materials, low ventilation rates can result in build-up of formaldehyde gases.

A series of health problems suffered by an elderly couple soon after they moved into a new 240-m^3 mobile home and initial measurement of an indoor formaldehyde concentration of 0.7 ppm prompted an investigation to determine the source of contamination. The formaldehyde concentrations were persistent, day and night, and remained in the same order of magnitude in all rooms, indicating a widespread source of emission.

The occupants' medical history and physical examination indicated no problems that could account for the current symptoms except formaldehyde exposure. Protection was by evacuation of the premises rather than substitution of the hazardous (building) materials or improvement of the ventilation system. Symptoms characteristic of formaldehyde sensitivity subsided when the subjects moved to an ordinary home.

1.0 INTRODUCTION

Indoor air quality is of increasing concern as the number of energy-efficient air-tight buildings grows. Studies show that the air quality of mobile homes is of even greater concern than that of conventional residential buildings because of some of the building materials used. Many may give off formaldehyde gas (1). This study deals with a multi-disciplinary approach to the problems associated with formaldehyde off-gassing in a mobile home, including industrial hygiene, emission source identification, and health assessment.

Industrial hygiene studies demonstrate that the measured formaldehyde concentrations in mobile homes vary extensively: from 0.1 to 0.5 ppm (mean 0.36 ppm) for two mobile homes in Pittsburgh, PA, up to 1.77 ppm (mean of 0.44 ppm) for 200 mobile homes registering complaints in Washington State, to 3.0 ppm (mean 0.4 ppm) for 431 mobile homes registering complaints in Minnesota, and from 0.023 to 4.2 ppm (mean of 0.88 ppm) for mobile homes registering complaints in Wisconsin (2).

The concentration of formaldehyde inside homes fluctuates diurnally and seasonally as well as with temperature and humidity. Assessments of emission sources for the off-gassing of formaldehyde have shown that pressed wood products can be a major source (3). Modern mobile home construction practices have tended to make use of materials (4) that may be bonded with urea-formaldehyde resin.

Health effects that have been documented seem to correlate with the environmental measurements. Symptoms may include irritation of the eyes and throat, disturbed sleep, unusual thirst on awakening (5), coughing and wheezing, disorientation, diarrhoea, nausea and vomiting (6), dizziness and lethargy, headache, loss of appetite, burning sensation of the skin (7), asthma and sensitization (6). Few of these symptoms have accompanying physical signs, but many have been documented in occupants of mobile homes (8,9).

2.0 INVESTIGATION

2.1 General

The mobile home under investigation (CSA approved and built in Canada in 1983) was occupied from March to May 1984 by an elderly couple, the only occupants since its manufacture. It was located in a mobile home park in a suburban district of Saskatoon, Saskatchewan. The home was 4 m wide and 24 m long (240 m^3 of volume) with a living room, attached kitchen, bathroom, and three bedrooms.

All of the interior walls were covered with particle board panelling with a laminated wood grain or "linen look" finish; the back was unfinished. The ceiling was covered with glossy plastic tiles. Particle board was used for cupboards, shelving and countertops, the undersides unfinished. The subfloor was made of 19-mm particle board and was covered by underlay and wall-to-wall carpeting of medium shag in the living room, short shag in the bedrooms, and linoleum in the kitchen and bathroom. The exterior, floor, and ceiling were insulated with glass fibre insulation. The crawlspace below the trailer was enclosed but well ventilated.

natural (without forced airflow) ventilation was provided by 100-mm diameter duct intakes in the northeast corner of the living room and in the southwest corner of the master bedroom closet 1.8 m above the floor. A range hood in the kitchen provided forced airflow. The bathroom was not equipped with an exhaust fan. The natural gas forced-air furnace was provided with a 125-mm diameter fresh air intake.

2.2 Health Effects

The owners became ill upon moving into their new mobile home, although they had been well until then except for chronic illnesses (decreased hearing, Rheumatoid arthritis, angina, atrial fibrillation, obesity, hypertension and diverticulitis). The wife was in the home all the time. Her early symptoms (first night) were nausea, vomiting, and dizziness. As time went on the symptoms increased to include headache, nausea, vomiting, sleep disturbance, dizziness, shortness of breath, burning eyes, runny nose, and chronic fatique. Headaches were relieved by 292's and ice packs; dizziness was resolved by breathing fresh air.

The husband developed running eyes and nose. On waking he experienced headache, blurred vision, dizziness, and fatigue. His sleep was frequently interrupted. He spent his days driving a taxicab and before going to work he would have to walk outside for half an hour to "clear his head."

Both were non-smokers and non-drinkers; they had not experienced any infections or exacerabations of chronic illness that could account for their current problems. The physical examination was normal except for those signs related to chronic ailments.

2.3 Formaldehyde Sampling Procedure

Air sampling (stationary area, NIOSH standard No. P & CAM 125 proposed by Physical and Chemical Analysis Branch of the National Institute for Occupational Health and Safety) consisted of a train of two midget impingers filled with 20 mL of absorbing solution (distilled deionized water) and aspirated at 1 L/min for 60 min (10). The collection efficiency of this method is expected to be 95%. The sampler inlet was kept 0.3 m above the floor so as to collect a representative zone of ambient air containing formaldehyde.

The analytical method (10) used the chromotropic acid-sulfuric acid method. Formaldehyde collected in the absorbing solution reacts with the chromotropic acid-sulfuric acid to form a purple mono-cationic chromogen. Absorbtance of the coloured solution is read in a spectrophotometer at 580-nm wavelength. The measuring range of this method is 0.1 to 2.0 ppm, with a precision of ±5%.

2.4 Formaldehyde Emission Sources

High, uniform HCOH concentrations indicated an evenly distributed source rather than a point source. Preliminary observations of furnishings and occupant-related activities did not indicate potential formaldehyde sources, and an investigation of the trailer construction materials was initiated. Since interior-grade particle boards (usually bonded with urea-formaldehyde resin) have been shown to be potentially high formaldehyde sources (11), tests were conducted to determine the relative emissive strengths of the building materials used in the home. Measurement of formaldehyde off-gassing from building materials involves placing material samples in an environmental chamber with controlled conditions of temperature, humidity, and air flow. While fundamentally accurate, this

method cannot be used for in-situ testing of materials. Matthews (5) has proposed a portable surface emission monitor for measuring formaldehyde release from building materials, but this system is not commercially available.

Testing for the relative HCOH emission strenths of the various particle board surfaces in the trailer involved covering a surface with a 2 L rectangular polyethylene box and allowing 24 h to elapse until the HCOH reached an equilibrium concentration. The concentration was then measured. Although this is not a standardized test, it is useful for ranking the relative strengths of surface emission sources; concentration values thus obtained are not directly related to indoor air pollutant levels. This test was carried out on carpets, the front and back of wall panelling, and kitchen cabinets. Measurements of the HCOH concentration were also taken in wall cavities, closets, and kitchen cupboards. The results are given in Table 1.

2.5 Formaldehyde Levels

The test values (emission sources) listed in Table 1 were used as indication of potential sources of HCOH. The large surface area and high equilibrium concentration of particle board wall panelling suggest that it is the major HCOH source in the mobile home. By contrast, the particle board subfloor/carpet system had equilibrium values lower than the indoor air levels. The HCOH levels in the kitchen cupboards and closets were not significantly above the indoor levels, and were considered to be secondary sources. The higher HCOH concentration in the cupboard over the refrigerator resulted from elevated temperature caused by heat liberated from the condenser coils of the refrigerator.

Initial point sampling by the public health inspectors (Saskatoon Community Health Unit) indicated a formaldehyde level of 0.8 ppm. In the industrial hygiene survey, the concentration was determined in two impingers separately to obtain the slippage. The mass of formaldehyde collected in the two impingers was corrected by the sampling efficiency of 0.95 to obtain a true mean concentration of formaldehyde during the sampling period (1 h each in late afternoon before cooking and in the evening). The slippage values of the impingers were: 13.5% for the living room sample, and 18.6% for the bedroom sample.

The daytime concentration of formaldehyde in the living room was 0.67 ppm; the night time value in the bedroom was 0.68 ppm. Both values far exceed the federal regulatory limit of 0.1 ppm. A previous study (12) showed that among 16 cases with UFFI insulation and health complaints only one case reached a maximum of 0.85 ppm, or a mean of 0.455 ppm. The values obtained inside the mobile home, therefore, are comparable to those for homes with UFFI insulation. The formaldehyde concentration was as high during the day as at night, and was uniform throughout the rooms tested.

A second daytime measurement was performed with the house pre-conditioned by operating the furnace fan continuously for the previous 24 h. The living room HCOH concentration was 0.41 ppm at a ventilation rate of 0.35 air changes per hour (ACH). The ventilation rate was determined by N_2O tracer gas decay test.

During the health assessment, the couple both displayed symptoms similar to those of other formaldehyde-exposed individuals. There was no other evidence, from history and physical examination, to explain their symptom complexes for any ailment other than the determined environmental exposure.

3.0 DISCUSSION

The occupants' exposure to airborne formaldehyde can be controlled, in principle, by substitution of materials, isolation, and ventilation. As the building materials were identified as the major source of formaldehyde emission, they might be removed and materials substituted that emit significantly less or no formaldehyde. The major HCOH source is the wall panelling, however, and substitution would involve rebuilding the entire interior of the trailer.

The second option is impractical also. The occupants might be protected from inhaling the formaldehyde by sealing the emission sources, but at the present time there is no reliable technique for doing this.

The third option is to increase the ventilation rate to reduce the airborne concentration of formaldehyde. For a constant pollutant supply rate to a space (assuming the removal rate is due to dilution alone and there is no transient storage/release effect), the indoor concentration can be modelled (13) by:

$$C = C_o + \frac{\dot{N}}{\dot{V}}$$

where C = indoor air HCOH concentration
C_o = outdoor air HCOH concentration (assumed to be negligible)
$\dot{N}$ = pollutant supply rate in the space
$\dot{V}$ = ventilation rate.

If this model is applied to the initial conditions of 0.41 ppm at 0.35 ach, then a ventilation rate of ≈1.5 ach (360 m^3/h) would be required to reduce the HCOH concentration to 0.1 ppm (14). This solution would impose a large heating/cooling energy penalty on the occupants and would require substantial modifications to the heating and ventilating system.

Literature addressing the problem (15) suggests that formaldehyde release from building materials has a half life of between 30 and 60 months; for a constant ventilation rate, it would therefore take a minimum of 30 months for the indoor HCOH level to drop to one half the present level. Increasing the temperature and/or humidity could reduce the half life, but times in the order of years could still be required to deplete the HCOH sources. In this situation, simply waiting for the problem to disappear does not seem to be advisable.

4.0 CONCLUSION

1. The formaldehyde levels in the mobile home were consistently high (>0.6 ppm) and uniformly distributed.
2. The major identified emission source was the particle board panelling used throughout the trailer.
3. The occupants experienced symptoms that could be attributed to formaldehyde exposure.
4. Conventional methods of controlling the pollutant in the trailer would involve extensive modifications and are therefore unsatisfactory.

The subjects have since moved into an ordinary home with low indoor formaldehyde levels and the symptoms characteristic of formaldehyde sensitivity have subsided.

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TABLE 1. Material Test Results
(Inside air temperature 23°C, relative humidity 35%)

Location	HCOH Conc (ppm)
Box A, top of living room carpet	0.45
Box B, U/S of kitchen cupboard shelf (unfinished)	0.75
Box C, back of wall panel above furnace	0.85
Box D, inside surface of wall panel with 300 mm x 5 mm crack	2.0
Box E, inside surface of wall panel	1.7
Box F, top of bedroom carpet	0.35
Inside of kitchen cupboards over refrigerator	1.15
Inside of water heater closet	0.65
Inside of interior wall cavity (bedroom)	3.25
Inside of exterior wall cavity	0.5

HEALTH STATUS OF RESIDENTS IN HOMES INSULATED WITH UREA FORMALDEHYDE FOAM

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The purpose of this study was to compare the health status of the occupants of 450 UFFI homes with that of 225 control homes. Each house was monitored for both formaldehyde and carbon dioxide, while the occupants were assessed using a health questionnaire and tests of pulmonary function, nasal airway resistance, sense of smell, nasal inflammatory cell and epithelial cytology, as well as contact sensitivity to formaldehyde and urea formaldehyde resin. The formaldehyde levels of the UFFI houses were found to be fractionally higher than those of the controls, while the carbon dioxide levels were similar across all groups. The UFFI house occupants showed an excess of numerous symptoms relative to the controls, and a small increase in the degree of squamous metaplasia of their nasal lining cells. Also, level of formaldehyde exposure showed a direct relationship with a number of symptoms present in excess among the UFFI house occupants. These results represent a preliminary phase in the analysis of these data, and tentatively indicate that living in a UFFI house is associated with subjective and to a lesser extent objective indicators of adverse health effects.