FORMALDEHYDE EMISSIONS FROM TYPICAL PARTICLEBOARD APPLICATIONS AND ASSESSMENT OF SPECIFIC ABATEMENT MEASURES

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Formaldehyde emissions emanating from particleboard materials made with urea-formaldehyde resin binders have caused much concern to health authorities, regulatory agencies, and affected homeowners. The objectives of this study were to identify and, as far as practically possible, quantify the particleboard-based formaldehyde emission strengths of primary and secondary sources in a Canadian multi-unit residential dwelling. Additional objectives were to select, implement, and evaluate abatement measures to reduce such emissions.

Relative formaldehyde source contributions to the ambient air were determined by a successive provisional elimination of individual sources. Formaldehyde test methods included using Gastec detector tubes, the NIOSH ambient air testing procedure, and Dupont 7-day exposure monitors. In decreasing order of contribution, the sources were identified as particleboard floor underlay, shelving, and built-in furniture.

Abatement measures applied included material removal and substitution, sealing, and chemical and physical treatment of contaminated materials. The initial base level ambient formaldehyde concentration of 0.52 ppm was reduced to 0.05 ppm by the application of abatement measures, representing a reduction of 90%. The results of these experiments are expected to provide the building owners in this and similar cases with practical evaluation and rehabilitation solutions.

Introduction

Formaldehyde emissions emanating from particleboard bonded with urea-formaldehyde (UF) resin binders have caused much concern to health authorities, government regulatory agencies, and affected homeowners. Particleboard tends to emit formaldehyde due to the inherent hydrolytical instability of the UF resin used as a binder in interior grade board. In modern home construction particleboard is used extensively in the built-in furniture and shelving in the kitchen, bathrooms, and closets. In some cases UF-bonded particleboard is also applied in the floor construction. Additional amounts of particleboard are introduced into finished dwellings by furniture.

The identification and evaluation of individual particleboard-based formaldehyde source strengths in existing dwellings is a complex task because of their number, nature, and possible interaction. In addition, non-contaminated materials can become contaminated if they are in contact with a formaldehyde source. These "secondary" sources can then later emit formaldehyde if conditions permit. For this study, a comprehensive, systematic approach was developed to evaluate and reduce formaldehyde sources in a typical Canadian residential housing unit.

Broadly, the various phases of the project were as follows:

- Selection of a Canadian housing unit with contemporary particleboard construction and materials.
- Identification and quantification of formaldehyde sources within a selected apartment.
- Development of physical and chemical treatment methods for confirmed formaldehyde sources.
- Full-scale application of abatement measures to reduce or eliminate formaldehyde emissions in the selected apartment.
- Verification of effectiveness of abatement measures.

Description of the experimental building

A multi-unit senior citizens residence situated in Epiphanie, Québec, was selected for this study. This building was chosen primarily because of extensive ambient air monitoring results that were already available.

The building was constructed in 1979. It has two stories with 15 apartment units. On the ground level there is a concrete floor while upstairs there is particleboard floor underlay over a plywood subfloor. All apartments have a jute-backed carpet in the living room and bedroom. Figure 1 illustrates the cross-section of the construction. Apartment no. 12, on the second floor, was vacated for a one year period to permit this study.

Previously measured formaldehyde levels are presented in Figure 2. In general, formaldehyde levels were much higher on second floor locations (where a particleboard-plywood floor exists), as compared to ground-floor locations (concrete floor).

Investigations at this location had indicated several possible formaldehyde sources, including the floor, the fixed furniture, and the carpet. Subsequent tests revealed that the carpet was not a primary source, but rather had adsorbed formaldehyde from the underlay and was emitting this stored gas.

The following materials were identified as being potential primary or secondary formaldehyde sources in second-floor apartments:

- jute-backed carpet
- particleboard underlay
- plywood subfloor
- particleboard fixed furniture components
- particleboard pantry shelves (the existing paint finish did not seal off emissions)
- movable furniture units

Initial screening tests of these potential sources on the basis of the static concentration equilibrium confirmed that a potential formaldehyde emission effect exists, in varying degrees, from each of these items. The attainment of this equilibrium value followed the general approach established by Skiest (1), but in this case used a container attached to the emitting surface in situ. The values were determined using Gastec formaldehyde detector tubes.

The highest emission potential was measured from the floor components, in particular, from the particleboard underlay. In addition, certain items, such as the carpet, were found to have adsorbed formaldehyde and subsequently to be emitting the gas. These emissions decayed rapidly when the carpet was removed from contact with the particleboard underlay.

Experimental methods

In order to quantify the formaldehyde emission sources identified by the initial series of tests, a procedure called "successive provisional elimination of sources" was developed. This process involved the systematic removal of suspected formaldehyde sources in the apartment, combined with ambient formaldehyde monitoring. The resulting decrease in formaldehyde concentration in the air was monitored after each elimination. In this manner, the relative contribution effect of each source was quantified under specific conditions.

Apartment Preparation

Many variables affect the level of formaldehyde emissions in a living space. These include temperature, relative humidity, and air exchange rate. The temperature and relative humidity in particular were controlled for this study so as to maintain fairly constant environmental conditions, chosen to simulate relatively typical non-winter conditions. (25°C ± 2°; 50% R.H. ± 5%)

The air exchange rate in the experimental apartment was found to be about 0.6 changes per hour (leakage) as measured by the SF_6 injection and subsequent decay monitoring (Ref. 2). This test was performed once only to show that the building construction had an average tightness. It does not, however, differentiate between air exchange with the outdoors and with adjacent apartments, and thus could not be used for emission rate calculations.

elimination of building-based formaldehyde sources, all movable furniture was removed. The bathroom and bedroom were isolated from the experimental (living room) area by sealing with polyethylene sheets. All water sources (potential formaldehyde sinks) such as humidifier pan, sink, and toilet bowl, were excluded. All electric outlets were sealed, as were the sliding window edges.

Ambient formaldehyde monitoring

Both NIOSH and Dupont dosimeter formaldehyde detection methods were used to measure ambient formaldehyde levels. NIOSH results were used to calculate average concentrations; Dupont dosimeter results were used for comparative purposes only. In general, the Dupont dosimeter results were in fair agreement with averaged NIOSH results for the corresponding period.

The base-level ambient formaldehyde concentration was found to be 0.52 ppm after preparation of the apartment, based on eight NIOSH formaldehyde measurements. This was used as an arbitrary reference level for the quantification of formaldehyde source contributions.

Successive provisional elimination

The sequence of successive provisional eliminations and accentuation (kitchen shelving) of particleboard materials and duration of each evaluation period was as follows:

- floor unit isolated from the living space - 21 days
- permanent kitchen shelving unit contribution evaluated under maximum emission conditions - 14 days
- removable shelving (pantry, linen closet) removed - 19 days
- unfinished kitchen cupboard surfaces sealed - 14 days

Results of formaldehyde source strength quantification

Figure 3 presents the change in ambient formaldehyde concentration with the elimination or accentuation of different sources. Figure 4 presents the estimated relative formaldehyde contributions in the experimental apartment.

Differences in ambient formaldehyde concentrations between the successive elimination phases can only give an approximate expression of the relative contribution capacity from the individual sources. This is due to the natural suppression effects existing between emissions from sources having different emission characteristics such as (a) static equilibrium concentrations, (b) surface area, (c) surface permeabilities, and (d) boundary layer conditions. This means that an elimination sequence other than the one chosen for this study could be expected to produce somewhat different relative contribution estimates.

The largest contribution was found to be from the floor unit (particleboard underlay), representing about 50% of the total contribution. Other sources included other particleboard materials present in the apartment.

A direct relationship between source contributions and their respective surface areas was not found. This is explained by the vast differences in the amount of surface areas exposed to the ambient air, and by the presence of barrier materials such as paint, surface overlays, and the carpet.

... formaldehyde levels in the experimental apartment.

Development and application of specific abatement measures

Abatement measures available included discarding and replacement of materials; physical sealing of the emitting surfaces; temporary removal and ventilation of materials; and chemical treatment of contaminated materials.

In general, discarding a source and replacing it by a non-formaldehyde containing material was considered for accessible and relatively unfinished materials, including the floor underlay, and all removable shelving. This excluded the kitchen countertops, which are covered on their upper surface with an impermeable lamination. Also to be excluded were less accessible areas of underlay under the partition walls and under the impermeable kitchen flooring. The unfinished undersides of the counter tops were sealed with a polyurethane-based varnish and the edges of the remaining underlay were sealed with epoxy. Coverage of the underlay with polyethylene sheet was not considered a satisfactory solution because of the danger of perforation due to abrasion (dirt), and possible sliding of the carpet.

Secondary sources (those having adsorbed formaldehyde from primary particleboard sources, or from the ambient air) did not require permanent removal and replacement. Dissipation of residual formaldehyde by increased ventilation of the carpet, and of the gypsum drywall was found to be adequate. A carpet removed and ventilated for 12 hours showed rapid dissipation with no detectable formaldehyde present after three weeks.

The upper surface of the plywood subfloor was also found to be contaminated by the particleboard underlay. A chemical treatment of this surface was considered. Previous studies have shown that sodium bisulfite reacts with formaldehyde to form a stable salt (Ref. 3). Laboratory emission test showed that chemical treatment with aqueous sodium bisulfite reduced emissions to insignificant levels within two days, from an initial level of 7500 ug $m^{-2}hr^{-1}$.

The sequence of in-place treatments chosen for the plywood was an initial water flush, followed by a 24 hour ventilation period, followed by an 8% aqueous sodium bisulfite solution (2 coats). SO_2 fumes were released by this treatment and precautionary measures were recommended for full scale application.

In summary, the abatement measures adopted for each formaldehyde source are presented in table I.

Full scale decontamination in the experimental apartment was done in two phases. Initially, the living and kitchen areas were decontaminated (March 7-22, 1984), followed by the bedroom area (Oct. 23-26, 1984). The work proceeded in the following sequence:

- elimination of removable sources
- treatment of unfinished fixed furniture sources
- chemical treatment of subfloor
- replacement of discarded materials
- verification of ambient formaldehyde levels during and after rehabilitation

0.05 ppm immediately after treatment and ventilation, representing a 90% reduction. However, ambient levels stabilized at 0.14-0.16 ppm in the apartment several weeks after complete rehabilitation (Figure 5). This residual level has been largely attributed to infiltration from adjacent apartment and from the corridor. This was confirmed by SF6 tracer gas released in the hallway and adjacent apartment, and captured in the experimental apartment, indicating noticeable infiltration from these areas.

Conclusions

The objectives of the study were to identify and, as far as practically possible, to quantify the formaldehyde emission strengths of the primary particleboard installations and significant secondary sources. Additional objectives were to select, implement and verify measures to reduce emissions.

The abatement measures developed and applied to the experimental apartment resulted in a 90% reduction in the effective ambient formaldehyde concentration. The results of these experiments are expected to provide the building owners in this and similar cases with practical rehabilitation solutions.

The principal conclusions of the study are as follows:

1. The excessive formaldehyde levels in the interior air (frequently above the recommended limit of 0.1 ppm) could be almost entirely attributed to interior installations of particleboard in the building.

2. The procedure of successive elimination of primary and secondary formaldehyde sources provides a practical means for estimating the impact of emissions from individual materials on the interior air quality. By closely monitoring the resultant equilibrium air concentrations, the relative contribution of each source was indicated.

3. The relative formaldehyde source contributions were estimated as follows:

   - particleboard underlay and plywood subfloor - 50%
   - unfinished particleboard surfaces on fixed furniture materials - 20%
   - removable particleboard shelving - 15%
   - other secondary sources (entrance door, finished fixed furniture surfaces) - 15%

4. Abatement measures developed to treat formaldehyde sources included the removal and discarding of a material; the physical sealing of emitting surfaces; the chemical treatment (aqueous sodium bisulfite) of contaminated surfaces; and the dissipation of residual formaldehyde by ventilation.

5. The rehabilitation measures developed were applied on a full-scale level to the experimental apartment. Levels in the apartment decreased to below 0.05 ppm immediately following application of the abatement measures, representing a reduction of ambient formaldehyde concentrations of 90%. Ambient levels of 0.15 ppm in the apartment several weeks after the completion of the rehabilitation were due to infiltration from adjacent apartments.

References

1. E.M. Skiest, "Technical Efforts of the Formaldehyde Institute - An Overview Proceedings: Particleboard Symposium", W.S.U. 14:137-144 (1980).

2. G.T. Tamura and R.G. Evans, "Evaluation of evacuated glass tubes for sampling of SF6/air mixture for air exchange measurement", ASHRAE Journal, p. 40-43 (Oct. 1983).

3. R. Kalnins, "Development of chemical treatment following UFFI removal-laboratory scale", Sodexen contract report for the Division of Building Research, National Research Council, Ottawa, Ont. (1983).

TABLE I. ABATEMENT MEASURES APPLIED TO FORMALDEHYDE SOURCES IN THE EXPERIMENTAL APARTMENT

PRIMARY SOURCES	
- Floor underlay	- remove, discard and replace under carpet; seal remaining edges
- Removeable shelving	- remove, discard and replace
- Fixed furniture	- sealing of unfinished faces and edges
SECONDARY SOURCES	
- Carpet	- dissipation by ventilation (8 hr)
- Plywood subfloor	- chemical treatment (sodium bisulfite)
- Gypsum drywall	- natural dissipation
- Fire retardant paper (floor)	- remove, discard and replace

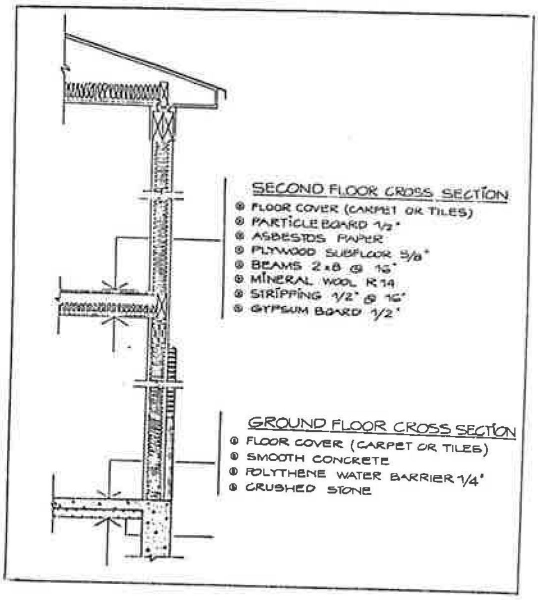

Figure 1. **Floor construction of selected apartment building**

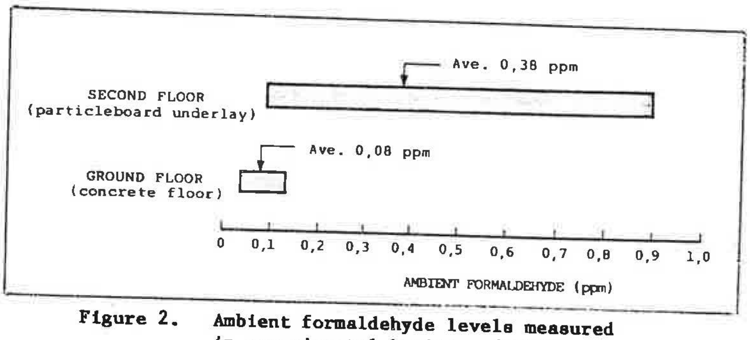

Figure 2. **Ambient formaldehyde levels measured in experimental building (NIOSH and Dupont exposure monitor results; Jan.1982-Aug.1983).**

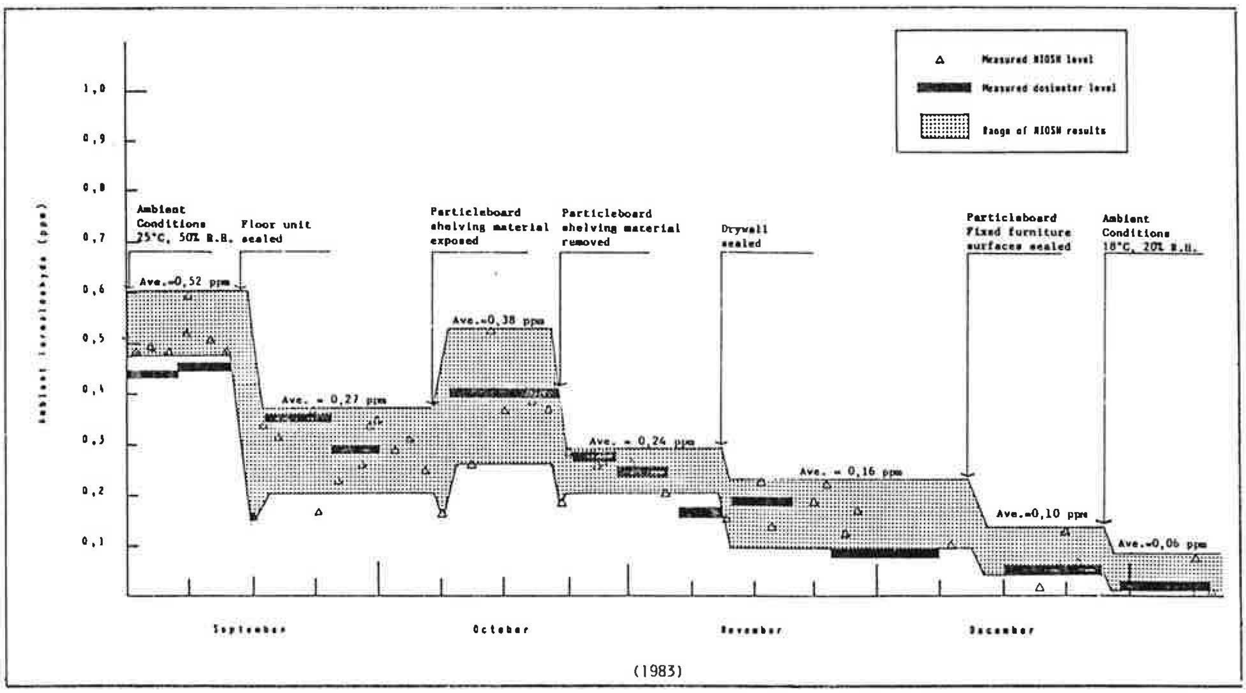

Figure 3. **Ambient formaldehyde concentrations in experimental apartment during successive elimination of sources (Average;NIOSH values)**

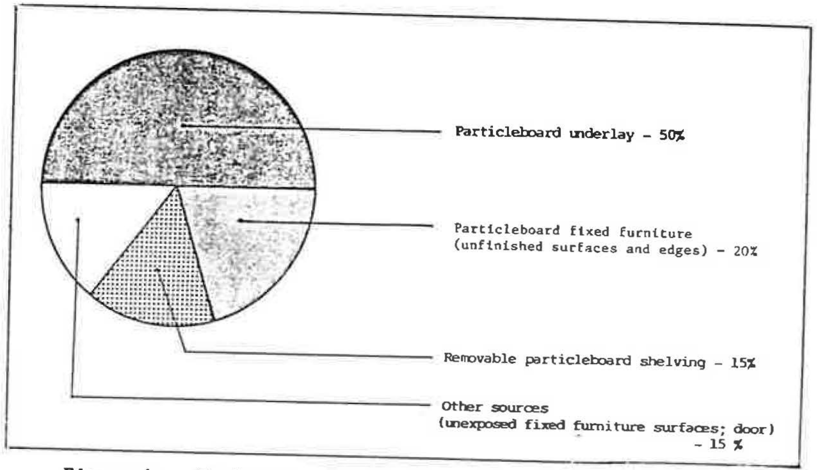

Figure 4. Estimated contributions of formaldehyde sources in the experimental apartment.

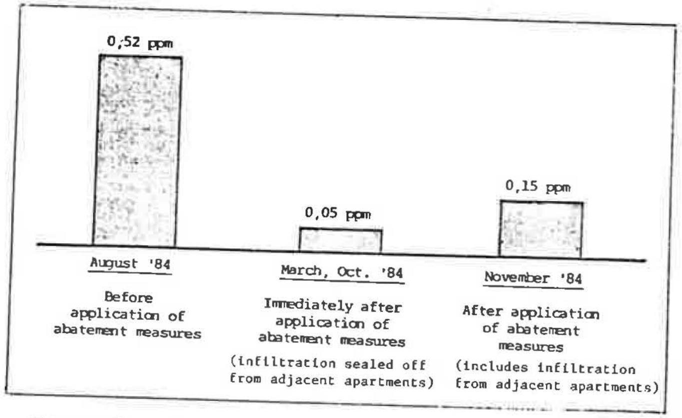

Figure 5. **Ambient formaldehyde in experimental apartment before and after application of abatement measures.**

AVOIDANCE OF CHIMNEY BACKDRAFTING IN HOUSES: IDENTIFYING THE CRITICAL CONDITIONS

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Partial or total failure of furnace venting due to spillage or backdrafting has recently been identified as a possible source of pollution in modern housing. The phenomena of chimney backdrafting, and the performance of furnaces and flues under conditions that lead to backdrafting, were investigated in an analytical and modelling study of the problem. The study was undertaken to develop a better understanding of the phenomena of spillage and backdrafting, and to suggest means of avoiding these potential sources of indoor pollution.

The work consisted of: a review of existing literature; interviews with scientific authorities in Canada; the conceptualization of heat and mass flows of the furnace, fluepipe, and chimney systems operating within a house of modern construction; the development of a modelling framework; the parameterization and implementation of that framework on a microcomputer; test simulations, preliminary model validation and a sensitivity analysis.

The project has produced a useful simulation tool for the study of spillage from, and backdrafting of flues. As well, the sensitivity analysis produced a number of noteworthy results: the house itself was found to act as a competing chimney - the extent of which depends on the size and vertical location of the envelope's leakage sites. Fan and fireplace exhaust flows were shown to easily depressurize houses with current levels of envelope airtightness, thus discouraging proper chimney flow. The furnace was modelled as a short chimney. It was shown to assist the main chimney in establishing proper flow of flue gas, depending on the configuration of the dilution device joining the two. However, spillage of combustion products into the living space occurs during the period that the furnace is assisting the chimney.

The model is being evaluated by performing simulations of the performance of furnaces and chimneys that have been monitored in the field.