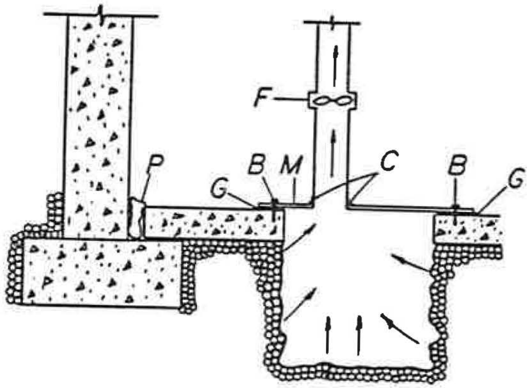

Figure 10 . Sub-slab ventilation using an opening cut through the slab and into the sub-slab gravel. This is simpler than the case of a sump in a sump opening but more than one opening may have to be made to ensure complete sub-slab ventilation without sub-slab drainpipes.

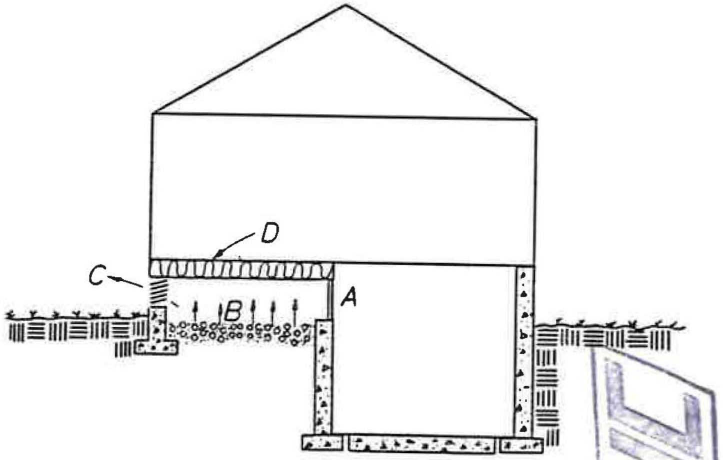

Figure 11 . Illustration of radon isolation and ventilation control technique. A partition (A) is constructed to isolate the crawl space from the basement. The radon (B) from the unpaved crawl space is then ventilated to the outside through an opening (C) constructed in the crawl space wall. To maintain energy efficiency the crawl space (D) is sealed with a vapor barrier and insulated.

PRELIMINARY EVALUATION OF FORMALDEHYDE MITIGATION STUDIES IN UNOCCUPIED RESEARCH HOMES

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The effectiveness of retrofit formaldehyde (CH_2O) mitigation measures for energy efficient homes is being investigated in unoccupied research houses constructed according to East Tennessee building codes. Formaldehyde emissions from carpet-covered, particleboard underlayment throughout these houses have frequently caused indoor CH_2O concentrations to exceed 0.1 ppm comfort guidelines, particularly during warm and humid seasons. The effectiveness of carpet and cushion, vinyl linoleum, and polyethylene vapor barriers over the underlayment have been compared with increased ventilation for reduction of indoor CH_2O concentrations under controlled 23°C and 50% relative humidity (RH) conditions. Approximate 2 to 2.5 fold reductions in CH_2O concentrations were achieved with the linoleum and polyethylene barriers. Simple steady-state models predict that sevenfold increases in air exchange rate would be required for comparable improvements in CH_2O levels. In contrast, common nylon carpet and urethane foam cushion flooring materials were ineffective in reducing CH_2O levels.

Surface emission measurements from a selected floor area were performed with each floor barrier to compare reductions in CH_2O emissions specifically from the underlayment with reductions in indoor CH_2O concentrations, which are complicated by additional CH_2O sources and sinks. Approximate 10 to 30 fold decreases in underlayment emissions were measured with linoleum and polyethylene barriers in comparison to minimal changes with carpet and cushion materials. The comparatively small 2 to 2.5 fold decrease in indoor CH_2O concentrations (with low permeability floor barriers) is presumably caused by the presence of secondary sources and their increased CH_2O emission rates at reduced CH_2O concentrations.

Introduction

Formaldehyde (CH_2O) is an important indoor air pollutant that is emitted by a variety of consumer and construction products including pressed-wood products, insulation materials, textiles, and combustion sources (1). The strongest contributors to indoor CH_2O are typically urea-formaldehyde foam insulation and pressed-wood products, such as particleboard underlayment, hardwood plywood paneling, and medium density fiberboard, that are fabricated with urea-formaldehyde resins (2). These products typically have the strongest CH_2O emission rates, the largest product loading [source area (m^2)/compartment volume (m^3)], and are frequently covered with CH_2O-permeable physical barriers.

Control strategies for CH_2O in indoor environments are receiving increased attention, particularly in industrial research efforts to reduce CH_2O emissions from pressed-wood products through improvements in resin and/or board fabrication technologies (3). The effectiveness of retrofit mitigation measures for individual and multiple CH_2O emission sources in indoor environments have recently been surveyed and modeled (2). Product aging for greater than five to ten years and complete removal of all major emission sources were found to be effective but impractical control measures. Increased air exchange rates reduced indoor CH_2O concentrations resulting from all indoor emission sources. However, the modeled increase in CH_2O emission rates from CH_2O resin-containing products at reduced CH_2O concentrations made large improvements in indoor levels energy-costly, particularly during heating and cooling seasons. Tenfold reductions in CH_2O emissions from individual sources have been achieved in laboratory experiments with low permeability barriers such as vinyl linoleum (4). Threefold to tenfold reductions in CH_2O concentrations inside manufactured housing have been experimentally achieved over 0.5 to 1 year periods using ammonia fumigation techniques (2).

Indoor air quality studies, aimed at the control of CH_2O levels in energy efficient homes, have been conducted in three-bedroom, unfurnished research houses constructed in 1981 according to East Tennessee building codes. Interhouse comparison measurements of CH_2O, radon, and air infiltration rates in 1982-4 indicated that the houses were well matched and had CH_2O concentrations in excess of the American Society of Heating and Air Conditioning Engineers (ASHRAE) guideline of 0.1 ppm (5). The impact of variation in indoor temperature and relative humidity (RH) on CH_2O concentrations inside two research houses were measured and modeled in

1984 and compared against the results of prior laboratory studies of particleboard underlayment, the primary emitter in the test houses. The results of the study indicated fourfold variation in CH_2O concentration from 0.07 to 0.27 ppm with potential seasonal conditions of 20°C, 30% RH and 29°C, 80% RH, respectively, consistent with predictions using selected laboratory models (6). The control of indoor CH_2O concentrations below 0.1 ppm by maintaining a cool and dry indoor climate was possible in winter but energy-costly in warmer seasons.

A second study has been performed in a single research house to compare the effectiveness of increased air exchange rates and various retrofit barriers over the particleboard underlayment in reducing indoor CH_2O levels. Measurements of CH_2O concentration were performed as a function of floor barrier and ventilation rate inside the conditioned envelope of the home and inside a 0.2 m^3 chamber that was used as a surface emission monitor over the floor. Thus, the reduction in CH_2O emission rates from the flooring-covered underlayment can be compared against the overall impact on indoor CH_2O concentrations, which is complicated by additional CH_2O emission sources and sinks.

Experimental Design

The CH_2O mitigation measures study was performed using whole house retrofits of the carpet and cushion flooring, which covered particleboard underlayment over about 85% of the accessible floor area (see Figure 1).

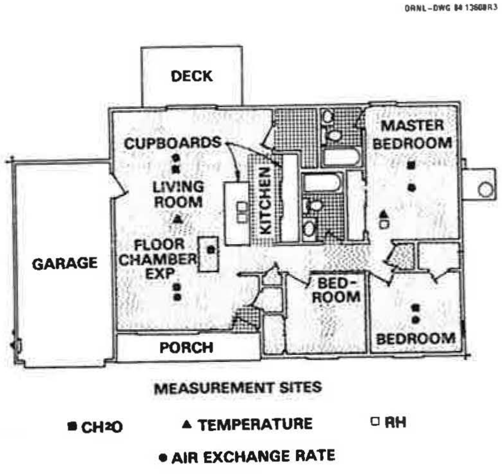

Figure 1: Physical layout and measurment sites inside the research house.

The remaining visible floor area, found primarily in the bathrooms and kitchen, was covered with vinyl linoleum and left unaltered during the mitigation measures study. The order of testing for the different floor-barrier systems was (1) the original nylon carpet and 1.3 cm neoprene sponge rubber cushion, (2) bare underlayment, (3) vinyl linoleum, (4) 6 mil polyethylene sheet, and (5) repeat measurements with the original carpet and replacement cushion. Standard nailstrip construction was used for the installation of carpet following the stapling of the carpet cushion to the underlayment. Linoleum and polyethylene sheet were installed with staples, double sided tape at joints, and a narrow strip of glue under the edges near walls. Such practice provided a continuous seal to the underlayment and easy removal without significant alteration to the surface of the underlayment.

Separate experimental designs were used to evaluate the impact of different flooring barriers on (1) the CH_2O concentrations inside the conditioned envelope of the research house, and (2) the CH_2O emission rates specifically from the particleboard underlayment. In the house experiments, the impact of floor barriers on the CH_2O emission rate from the underlayment were examined indirectly through variations in indoor CH_2O concentrations. The surface emission measurements of the underlayment and barrier combinations examined the impact of specific barriers on the CH_2O emission rate from the underlayment in the absence of secondary sources and CH_2O sinks that are found inside the house.

Both experimental designs involved controlled temperature, RH, air exchange rates, and atmospheric mixing. For the whole house experiment, temperature and RH control were maintained at typically 23 ± 1°C and 50 ± 2% RH with the central HVAC system and several humidifiers/dehumidifiers, respectively. Intercompartment mixing was enhanced using several 0.5 m fans and by keeping interior doors open. The air exchange rate of the home was adjusted to levels of approximately 0.2 h^{-1} (ie., residual level), 0.5 h^{-1} and 1.0 h^{-1} using the HVAC circulation fan, bathroom exhaust fans, and an adjustable fan exhausting into the attic. For the surface emission experiment, the temperature inside the chamber was controlled by the house temperature. The RH and air exchange rates inside the chamber were controlled using a metered air flow that was conditioned with water vapor to approximately 50% RH (7). The air exchange rates through the chamber (ie., 0.6, 1.5 and 3.0 h^{-1}) were chosen to achieve CH_2O concentrations similar to those inside the house with the original carpet and cushion floor barrier. This procedure provided a similar driving force (ie., CH_2O concentration gradient) for CH_2O diffusion from the underlayment into the house and chamber. Mixing of the chamber atmosphere was enhanced with an 8 cm fan and the pumped air supply.

The sequential investigation of the test floor barriers for both the whole house and surface emission experimental designs involved systematic conditioning and measurement of the interior of the home and the floor-chamber micro-environment. After a floor-barrier was installed, the house and chamber were conditioned at approximately 23°C and 50% RH for typically one to two weeks prior to CH_2O measurements. In addition, controlled air exchange rates were established inside the house and chamber for three to six days prior to measurements under each ventilation condition. This dual conditioning protocol was used to establish quasi-steady-state CH_2O concentrations inside the floor chamber and in the conditioned envelope of the home, where the time-dependent CH_2O concentration was complicated by numerous CH_2O sources and sinks. Measurements of the temperature were performed at two floor-level locations at opposite ends of the house (see Figure 1). Measurements of air exchange rate and CH_2O concentrations were performed at opposite ends of the house approximately one meter above the floor. Split sampling lines were used at each end of the house to sample simultaneously from two locations. Relative humidity data were recorded from a single location. However, hygrometers at multiple locations throughout the home indicated typically less than 1 to 2% RH variation. Only CH_2O concentration measurements were performed for the floor chamber.

A one to four day measurement period was used for most floor barrier systems at each of three ventilation conditions for the floor chamber (ie., 0.6, 1.5, and 3.0 h^{-1}) and house (ie., approximately 0.2, 0.5, and 1.0 h^{-1}). Near-continuous temperature and RH data were taken in the house using thermocouples and a General Eastern Model 400E electrochemical sensor, respectively. Near-continuous air exchange rate measurements of the house were performed using a Miran Model 1A infrared spectrometer to monitor the time-dependent decline in concentration of injected freon gas (8). Formaldehyde concentration measurements were limited to a 15 minute sampling period per hour in each of the two house locations and the floor chamber. A modified CEA Instrument (9) and a gas switching manifold with teflon-lined valves and teflon tubing were used to sample and measure CH_2O from all three measurement locations. Instruments were generally calibrated at the beginning of measurements for each floor-barrier system.

Results and Discussion

The experimental results for the house and floor-chamber measurements of the CH_2O mitigation study in the research house are reported in Table 1. Average parameter values are listed for each combination of floor barrier and ventilation condition. Temperature, air exchange rate, and CH_2O concentration averages for multiple locations inside the research house are reported. The site to site variation of mean temperature, air exchange rate, and CH_2O concentration were less than 0.7°C, 0.02 h^{-1} and 0.004 ppm, respectively.

To distinguish the impact of the floor barriers on the measured CH_2O concentrations inside the research house from that of the indoor climate and other time-dependent factors, two correction equations are considered. The whole-house CH_2O concentration data are first normalized to standard test conditions of 23°C and 50% RH using a CH_2O concentration model developed in previous studies of the temperature and RH dependence of CH_2O concentrations inside the research houses (6).

$$[CH_2O]_{23°C,50\%RH} = \frac{[CH_2O]_{T,RH}}{e^{-6700\cdot(1/T-1/296)}\cdot(RH/50)^{0.86}} \qquad (1)$$

Table 1. Average results from house and floor-chamber measurements as a function of floor-barrier.

A. Measurements of the Conditioned Envelope

Floor Barrier	Elapsed Time (days)	Temperature (°C)	RH (%)	Air Exchange Rate (h^{-1})	[CH_2O] (ppm)	Corrected* [CH_2O] (ppm)
Carpet, Cushion I	0	24.6 ± 0.4	52.5 ± 0.8	0.20 ± 0.05	0.108 ± 0.005	0.091
	6	23.6 ± 0.4	51.0 ± 1.7	0.50 ± 0.09	0.089 ± 0.013	0.085
	11	23.4 ± 0.2	52.9 ± 1.4	0.94 ± 0.17	0.062 ± 0.007	0.059
Bare Underlayment	32	23.5 ± 0.4	49.6 ± 1.7	0.25 ± 0.05	0.092 ± 0.008	0.099
	38	22.6 ± 0.9	49.0 ± 1.0	0.46 ± 0.07	0.070 ± 0.013	0.082
	46	22.3 ± 1.0	47.6 ± 2.0	0.98 ± 0.11	0.043 ± 0.012	0.053
Vinyl Linoleum	64	22.8 ± 0.5	51.4 ± 0.9	0.24 ± 0.06	0.036 ± 0.004	0.045
	58	23.1 ± 0.7	53.2 ± 0.5	0.48 ± 0.06	0.029 ± 0.006	0.033
	54	23.2 ± 0.6	52.3 ± 0.7	0.87 ± 0.18	0.022 ± 0.003	0.024
6 mil Polyethylene	74	24.1 ± 0.8	50.5 ± 2.1	0.21 ± 0.04	0.044 ± 0.006	0.053
	69	22.9 ± 0.5	51.3 ± 0.9	0.80 ± 0.24	0.024 ± 0.002	0.030
Carpet, Cushion II	84	23.1 ± 0.2	50.5 ± 0.4	0.20 ± 0.04	0.071 ± 0.004	0.097
	90	23.4 ± 0.4	49.9 ± 0.7	0.54 ± 0.05	0.055 ± 0.007	0.072
	96	23.4 ± 0.5	50.3 ± 0.7	1.18 ± 0.34	0.042 ± 0.006	0.055

B. Floor Surface Emission Measurements

Floor Barrier	Air Exchange Rate (h^{-1})	[CH_2O] (ppm)	CH_2O Emission Rate (mg/m^2h)
Carpet and Cushion I	0.60 ± 0.03	0.127 ± 0.008	0.060 ± 0.005
	1.50 ± 0.08	0.078 ± 0.006	0.093 ± 0.009
	3.00 ± 0.15	0.060 ± 0.004	0.143 ± 0.012
Bare Underlayment	0.60 ± 0.03	0.124 ± 0.018	0.059 ± 0.009
	1.50 ± 0.08	0.083 ± 0.012	0.098 ± 0.015
	3.00 ± 0.15	---	---
Vinyl Linoleum	0.60 ± 0.03	0.014 ± 0.002	0.006 ± 0.001
	1.50 ± 0.08	0.008 ± 0.002	0.010 ± 0.003
	3.00 ± 0.15	0.003 ± 0.003	0.008 ± 0.007
6 Mil Polyethylene	0.60 ± 0.45	0.025 ± 0.002	0.012 ± 0.001
	1.50 ± 0.08	0.007 ± 0.003	0.009 ± 0.003
	3.00 ± 0.15	0.002 ± 0.001	0.005 ± 0.003
Carpet and Cushion II	0.60 ± 0.03	0.120 ± 0.005	0.057 ± 0.004
	1.50 ± 0.08	0.092 ± 0.006	0.109 ± 0.009
	3.00 ± 0.15	0.059 ± 0.008	0.139 ± 0.020

*See text for description of temperature, RH and time dependent corrections applied.

To estimate the impact of time-dependent factors, such as product aging or outdoor environmental effects, on the CH_2O concentrations inside the research house during the course of the permeation barriers study, repeat measurements with a carpet and cushion barrier were performed at the end of the study. The results from the floor-chamber experiments show no systematic increase or decrease in measured CH_2O concentrations between the beginning and end of the study. This indicates there was little change in the CH_2O emission strength of the underlayment due to product aging. In contrast, the results for the house experiments show consistent 30-40% decreases in CH_2O concentrations between the initial and final measurements with the carpet/cushion barrier at air exchange rates of approximately 0.2, 0.5, and 1.0 h^{-1}. The cause for this decline in CH_2O levels is uncertain but may be related to decreasing outdoor temperatures during the progression of the study from 09/84 to 12/84. The cooling of the crawl space may have caused the bottom side of the underlayment to be exposed to progressively lower temperatures, particularly near the perimeter of the home. Such lower temperature exposures could reduce the average CH_2O emission strength of the underlayment and, therefore, indoor CH_2O concentrations while relatively constant CH_2O levels could be measured in the floor chamber experiment near the center of the home where temperature sensors were located and best temperature control was achieved. As a result, the CH_2O concentration data for the whole house experiments were normalized to those values determined at the beginning of the study assuming a linear decline in CH_2O concentration as a function of elapsed time between the initial and final measurements with the carpet/cushion barrier (see Appendix). The time-dependent correction factors for the results of the bare underlayment and linoleum and polyethylene barriers are typically less than 1.25.

The CH_2O concentration data for the house experiments that are corrected for variation in indoor temperature, RH, and other time dependent factors are listed in Table 1 and illustrated in Figure 2. Little variation is observed between the bare underlayment and underlayment covered with nylon carpet and neoprene sponge rubber cushion at air exchange rates of approximately 0.2, 0.5, and 1.0 h^{-1}. In contrast, approximate 2 to 2.5 fold reductions in CH_2O concentrations are indicated with both the vinyl linoleum and 6 mil polyethytlene sheet barriers over an approximate 0.2 to 1.0 h^{-1} range of air exchange rate. These findings are generically confirmed in the results of the floor-chamber experiments. Minimal differences in measured CH_2O emission rates are observed between the bare underlayment and carpet/cushion covered underlayment. In contrast, 10 to 20 fold and 5 to 30 fold reductions in CH_2O emission rates are observed with vinyl linoleum and 6 mil polyethylene sheet.

The large reductions in CH_2O emission rates from the linoleum- and polyethylene-covered underlayment measured in the floor-chamber experiments in comparison to the moderate decreases in indoor CH_2O concentrations is evidence for (1) the existence of CH_2O emitters other than the underlayment inside the home, and (2) enhanced CH_2O emissions from these secondary emitters under reduced CH_2O concentrations. The potential contribution of CH_2O due to convective transport via infiltration from the underside of the underlayment is unknown. A survey of potential secondary CH_2O emitters was performed by selective removal of product samples for laboratory

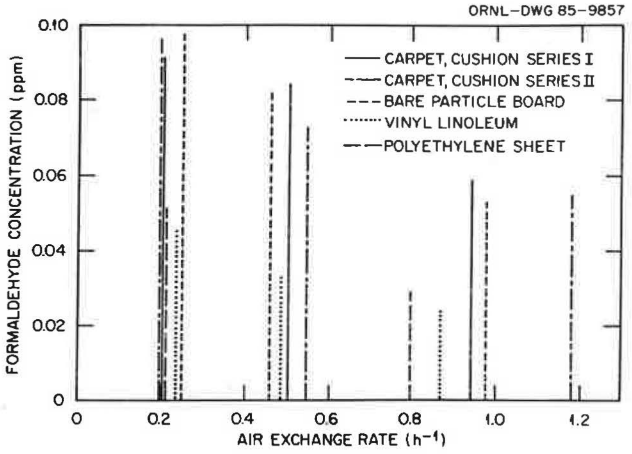

Figure 2: Average indoor formaldehyde concentrations as a function of floor barrier and air exchange rate. Data corrected to 23 C, 50% RH and an elapsed time of zero for the barriers study.

conditioning and measurement using a Formaldehyde Surface Emission Monitor (10). Only the particleboard and hardwood paneling products incorporated in counter tops and cabinet shelves had CH_2O emission rates (ie., 0.04-0.11 mg/m^2h) comparable to those of the underlayment. The carpet, carpet cushion, and most of the decorative exterior of the cabinets were insignificant emitters (ie., typically <0.01 mg/m^2h). The remaining CH_2O resin containing products are fibrous glass insulation and softwood plywood subflooring. These products are fabricated with phenol formaldehyde resins and are anticipated to be minimal contributors to indoor CH_2O concentrations (2). An additional source of CH_2O during the permeation barriers study, was the uncovered areas of underlayment near walls where the floor barriers could not be effectively applied. The combined area of particleboard near walls, in cabinet shelves and under counter tops is estimated to be about 11 m^2, approximately 15% of the area of the carpet/cushion covered underlayment. Although the contribution of these secondary emitters is anticipated to be small in the presence of the carpet/cushion covered underlayment, their contribution is enhanced at the reduced concentrations resulting from the linoleum or polyethylene barriers over the underlayment. At reduced CH_2O concentrations, the driving force for CH_2O transport from the particleboard to the surrounding atmosphere is enhanced. The negative CH_2O concentration dependence of the CH_2O emission rate (ER) from pressed-wood products has been modelled according to principles of molecular diffusion (11),

$$ER\ (mg/m^2h) = -A(m/h)\cdot[CH_2O]\ (mg/m^3) + B\ (mg/m^2h) \qquad (2)$$

where A and B are constants. As a result of this diffusion effect, the impact of large reductions in CH_2O emission rate from a single source (through source removal or the use of effective permeation barriers) is lessened in the presence of other CH_2O emitters. A detailed treatment of the research houses using Equation 2 could not be performed. The requisite CH_2O emission rate data as a function of CH_2O concentration for emitters other than the underlayment was unavailable to determine the A and B constants.

The results of the permeation barriers study provide the necessary data to compare the effectiveness of various permeation barriers versus increased air exchange rates for reduction of CH_2O concentrations in the research houses. The requisite air exchange rate to achieve fixed reductions in CH_2O can be estimated using the following single compartment model (11,12),

$$[CH_2O]^{-1}(m^3/mg)=[1.8\underline{+}0.1(m^2h/mg)\cdot N(h^{-1})/0.29\underline{+}0.02(m^{-1})]+7.5\underline{+}0.2(m^2/mg) \qquad (3)$$

where N is the air exchange rate (h^{-1}) and 0.29 is the loading (m^2/m^3) of carpet/cushion covered underlayment, which is assumed to be the only CH_2O emitter. The model coefficients were determined by fitting the corrected CH_2O concentration data from carpet/cushion measurement Series I and II to the model. Substituting into Equation 3 for air exchange rates N_1 and N_2 under initial and final conditions, respectively,

$$[CH_2O]_1^{-1} = [(1.8\cdot N_1/0.29) + 7.5] \qquad (4)$$

$$[CH_2O]_2^{-1} = [(1.8\cdot N_2/0.29] + 7.5] \qquad (5)$$

Combining expressions, the N_2 required to achieve an X-fold reduction in the CH_2O concentration measured at N_1 is then,

$$N_2 = N_1\cdot X + 1.22\cdot X - 1.22 \qquad (6)$$

The $N_1\cdot X$ term of Equation 5 represents simple ventilation theory that would predict a reduction in CH_2O concentration proportionate to the increase in air exchange rate. The second and third terms of Equation 5 result from the negative CH_2O concentration dependence of the CH_2O emission rate from pressed-wood products that has been modeled according to principles of molecular diffusion (see Equation 2). As the CH_2O concentration decreases with increased air exchange rates, the CH_2O emission rates from the solid CH_2O emission sources increase, reducing the impact of the enhanced ventilation. It is instructive to note that the second and third terms of Equation 6 are dependent on X (the reduction factor in CH_2O concentration) and/or CH_2O emission constants, but independent of N_1. This is illustrated in Table 2 for X values of 2 and 4 with both low and high values of N_1, the initial air exchange rate. For large values of N_1, N_2 is approximately equal to $N_1 \cdot X$. This indicates that the decrease in CH_2O concentration with increased ventilation is insensitive to the CH_2O concentration dependence of the CH_2O emission rate from the pressed-wood products at the low CH_2O levels that are achieved with high air exchange rates. In contrast, at N_1 values consistent with those frequently found in the research house (eg., 0.2 h^{-1}), the X dependent and constant terms of Equation 6 predominate. As a result, 8 and 24 fold increases in air exchange rate are required for twofold and fourfold reductions in CH_2O concentrations, respectively, with N_1 equal to 0.2 h^{-1}.

The small reductions in CH_2O concentrations measured inside the Karns house with large increases in ventilation are exemplified in Figure 2. Approximate 1.2 and 1.6 fold reductions in CH_2O concentration were obtained for 2.5 and 5 fold increases in air exchange rate (from about 0.2 to 0.5, and 1.0 h^{-1}). In contrast, the polyethlene sheet and vinyl linoleum barriers achieved approximate 1.8 and 2.1 fold reductions in CH_2O concentrations at an air exchange rate of about 0.2 h^{-1}. According to Equation 6, approximate six and eight fold increases in air exchange rate would be required for comparable improvements in CH_2O concentrations.

Table 2. Modeled increase in air exchange rate [N (h^{-1})] from N_1 to N_2 required to achieve X fold reductions in CH_2O concentrations from $[CH_2O]_1$ to $[CH_2O]_2$.

X	N_1	N_2	N_2/N_1
	A. Low Air Exchange Rate Simulation		
1	---	---	1
2	0.2	1.6	8.1
2	0.5	2.2	4.4
2	1.0	3.2	3.2
4	0.2	4.5	22.3
4	0.5	5.7	11.3
4	1.0	7.7	7.7
	B. High Air Exchange Rate Simulation		
2	2.0	5.2	2.6
2	5.0	11.2	2.2
4	2.0	10.4	5.8
4	5.0	23.7	4.7

Conclusions

The effectiveness of (1) nylon carpet and neoprene sponge rubber cushion, (2) vinyl linoleum, and (3) 6 mil polyethylene sheet as CH_2O permeation barriers over particleboard underlayment has been studied using whole-house retrofits of floor coverings in an unoccupied research house. Although the carpet/cushion barrier had a minimal impact on the CH_2O emissions from the underlayment, the polyethylene and vinyl linoleum barriers reduced CH_2O emission rates measured specifically from the underlayment by 5 to 30 and 10 to 20 fold, respectively. However, the vinyl linoleum and polyethylene barriers resulted in only 2 to 2.5 fold reductions in indoor CH_2O concentrations. The comparatively small decrease in indoor levels is ascribed to secondary CH_2O emission sources inside the house whose emission rates are enhanced at the reduced CH_2O concentrations.

Approximate 1.6 fold reductions in CH_2O concentrations were achieved with a fivefold increase in air exchange rate from about 0.2 to 1.0 h^{-1}. Simple steady-state models incorporating single compartment, single emitter assumptions for the research house predict that sixfold and eightfold increases in air exchange rate would be needed for 2 to 2.5 fold reductions in CH_2O levels comparable to those achieved with the polyethylene and linoleum barriers.

Acknowledgements

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Appendix: Normalization factors for time-dependent decline in temperature, RH corrected CH_2O concentration data for the Karns house

The CH_2O concentration inside a single compartment with a single CH_2O emission source, uniform mixing, constant temperature and RH at time zero (ie., $[CH_2O]_I$), and time final (ie., $[CH_2O]_F$), representing carpet/cushion measurement Series I and II, respectively, may be modeled as (11,12)

$$[CH_2O]^{-1}\ (mg/m^3) = A_I\ (m^2h/mg)\cdot N/L\ (m/h) + B_I\ (m^3/mg), \qquad (A1)$$

and

$$[CH_2O]^{-1}_{F_{N/L}}\ (mg/m^3) = A_F\ (m^2h/mg)\cdot N/L\ (m/h) + B_F\ (m^3/mg). \qquad (A2)$$

Assuming a linear decrease in CH_2O concentrations with elapsed time, the modeled CH_2O concentration at time Z (ie., $[CH_2O]_Z$) is

$$[CH_2O]_{Z_{N/L}} = [CH_2O]_{I_{N/L}} - (\text{Time Z/Total Time})\cdot([CH_2O]_{I_{N/L}} - [CH_2O]_{F_{N/L}}) \qquad (A3)$$

To normalize temperature and RH corrected CH_2O concentration data for all barrier conditions (ie., $[CH_2O]_B$) to the carpet/cushion Series I measurements, the final expression is

$$[CH_2O]_{B_{Norm}} = ([CH_2O]_{I_{N/L}} / [CH_2O]_{Z_{N/L}})\cdot[CH_2O]_B \qquad (A4)$$