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OBSERVED FORMALDEHYDE LEVELS IN 20 NEW HOUSES WITH MECHANICAL VENTILATION SYSTEMS

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ABSTRACT

Formaldehyde levels were monitored over a one-year period in 20 new, low-leakage, occupied bungalows of similar size and layout. All contained some form of mechanical ventilation system ranging from bathroom exhaust fans to heat recovery ventilators. Sixteen were built to the R-2000 standard for energy-efficient housing, while four were relatively conventional structures. Formaldehyde levels were observed to be consistently lower in the R-2000 group of houses (which contained the more sophisticated ventilation systems) than in the conventional group of houses. The ASHRAE-recommended exposure guideline for formaldehyde of 0.10 ppm was found to be readily achievable, while the Canadian Federal-Provincial target level of 0.05 ppm could not be reached on a consistent basis using ventilation as the only formaldehyde control measure. Homeowner intervention with the mechanical ventilation systems was found to be a significant problem. It was concluded that mechanical ventilation rates must be established both on the ability of the system to remove pollutants as well as the effect the ventilation rate will have on homeowner intervention. To reduce intervention, ventilation systems must be perceived by homeowners as unobtrusive in terms of energy cost, noise, and comfort. For the houses studied, there was found to be little reduction in mean formaldehyde levels at or above total air change rates exceeding approximately 0.35 ach, which represented an average mechanical ventilation rate of approximately 0.30 ach.

INTRODUCTION

Formaldehyde (HCHO) is a colorless gas found in the indoor and outdoor environments. At elevated levels, such as those sometimes encountered indoors, the gas has a pungent odor. Although formed naturally outdoors, most formaldehyde found in residential environments originates from manufactured goods, materials, and substances used inside the house. Significant sources in new houses may include particleboard, medium-density fiberboard, and hardwood plywood paneling. Consumer products such as draperies, clothing, tapes, and some household chemicals use formaldehyde as constituents of glues or coatings. Cigarette smoke also contains formaldehyde.

Formaldehyde is a suspected carcinogen as well as a sensory irritant, primarily affecting the respiratory and nasal passages and the eyes. Like most indoor pollutants, individuals display varying tolerances although some people, particularly those with chemical sensitivities, are strongly affected by its presence.

For the builder, formaldehyde which originates from construction materials is particularly significant, since the builder can, in theory, exercise some control over the selection and use of those materials. Emission rates from construction materials may vary significantly with time and ambient conditions. They have been demonstrated to increase at elevated temperatures and with increased moisture content of indoor air (Godish and Rouch 1986). Emission rates will generally decrease with time as the chemical is depleted from the exposed surfaces of the material, although this process may extend over several years.

Emission rates from manufactured products may also be affected by the existing formaldehyde concentration in the ambient air, although the evidence is somewhat contradictory. Nelms et al. (1986) investigated emission rates of commercially produced particleboard using a test chamber with varying ventilation rates and material loadings and found that emission rates increased with lower ambient formaldehyde concentrations. However, Godish and Rouch (1987) investigated formaldehyde source interactions in a full-size house and in test chambers but were unable to reproduce chamber results in the full-size structure.

The Canadian formaldehyde exposure guidelines for residential air, as set by the Federal-Provincial Advisory Committee on Environmental and Occupational Health (1987), are 0.05 ppm as a target level and 0.10 ppm as an action level. ASHRAE Standard 62-1981 (ASHRAE 1981) recommends 0.10 ppm for long-term residential exposures.

RESEARCH PROGRAM

Project Houses

The project houses were located in Winnipeg, Canada, and had been constructed in 1985 and 1986 by a single builder. The structures were very similar in size and layout; two floor plans were used with main floor areas, based on interior dimensions, of 60 m^2 and 85 m^2 (646 ft^2 and 915 ft^2), respectively. All had full basements. Sixteen were designed to the R-2000 standard, with the remaining four constructed using relatively conventional practices. The R-2000 standard for residential construction includes requirements for building energy usage, airtightness, heating equipment, and mechanical ventilation systems.

The mechanical ventilation systems used in the houses ranged from intermittent, small-capacity bathroom exhaust fans to heat recovery ventilators (HRV) designed to run continuously and provide outdoor air distribution to all zones of the house. Sixteen of the mechanical systems utilized multi-speed controls which permitted flow rates to be automatically or manually adjusted.

Ten of the houses used high sidewall supply registers to minimize discomfort problems near the supply registers caused by continuous operation of the air distribution system. This technique introduces the heating/ventilation air in a horizontal plume close to the ceiling, permitting mixing and warming of the supply air before it reaches the occupied zone of the room. The 14 houses that used forced air heating systems also employed individual room return air registers to

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TABLE 1

Description of Project Houses

Houses	Year of Completion	Space Heating System	Ventilation System*	Predominant Location of Heating/Ventilation Supply Registers	Energy Performance Standard
#1 to #6	1985	Forced Air Electric Furnace	Heat Recovery Ventilator Connected to Furnance Ductwork	Floor-Mounted	R-2000
#7, #8	1985	Forced Air Electric Furnace	Central Exhaust	Floor-Mounted	Conventional
#9, #10	1985	Forced Air Gas Furnance	Bathroom Exhaust Fan	Floor-Mounted	Conventional
#11, #12	1986	Electric Baseboards & Small Capacity Heat Pump	Exhaust-Only Heat Pump Heat Recovery Ventilator	High Sidewalls	R-2000
#13, #14	1986	Forced Air Electric Furnace	Heat Recovery Ventilator Connected to Furnace Ductwork	High Sidewalls	R-2000
#15, #16	1986	Integrated Forced Air Heating/Ventilation System	Air-to-Air Electric Heat Pump	High Sidewalls	R-2000
#17 to #20	1986	Electric Baseboards	Heat Recovery Ventilator with Dedicated Supply Ductwork	High Sidewalls	R-2000

provide better circulation when interior doors were closed. The effect of these two measures would likely have produced an above-average mean ventilation system efficiency for the houses.

Ventilation rates for the R-2000 houses were established to conform to the R-2000 Home Program Design and Installation Guidelines for Ventilation Systems (Energy, Mines and Resources Canada 1986), which require a minimum continuous mechanical ventilation rate of 0.35 ach (or greater, depending on the number of rooms).

All of the houses, including the conventional structures, were constructed with tight building envelopes to minimize air infiltration. Airtightness levels, determined in accordance with CGSB Standard 149.10-M (CGSB 1986), ranged from 0.44 to 2.20 ach at 50 Pascals when measured in February 1987. Potential sources of formaldehyde used in the construction of the houses included waferboard subfloors and particleboard cabinets.

No other measures, aside from the mechanical ventilation systems, were used to control formaldehyde levels. A more detailed description of the houses is given in Table 1.

MONITORING PROGRAM

Formaldehyde levels, total air change rates, and concentrations of other pollutants were monitored in March 1986, August 1986, October 1986, and February 1987 using passive diffusion dosimeters. Two dosimeters were installed for each test, with one located in the main bedroom and the second in the living/dining area. Exposure periods were approximately one week. Laboratory analysis was performed using a modified chromotropic acid method (Taylor 1981).

Total air change rates were measured simultaneously during three of the four sampling periods using the capillary adsorption tube sampling (CATS) technique (Dietz and Cote 1982). This method has been found to display good agreement with the constant concentration sulphur hexafluoride technique when relatively constant total air change rates are encountered (Piersol and Mayhew 1987). Four calibrated sources that emitted an inert perfluorocarbon tracer gas were situated around the house on exterior walls. Two or four samplers that adsorbed the tracer were installed at central locations on each level of the house. The amount of tracer adsorbed by the samplers was then related to the total air change rate experienced by the house during the monitoring period. Gas chromatographic analysis of the samplers was then performed.

Electrical timers were installed on the mechanical ventilation systems in 18 houses to determine their usage patterns. Additional information on house performance and occupancy was obtained through regular contact with the homeowners.

Average indoor dry-bulb temperatures were measured at a central location in the living/dining areas using thermohygrographs operating continuously during the monitoring periods. Mechanical ventilation system flow rates were measured using eight-point pitot tube flow-measuring stations permanently installed in the ductwork.

RESULTS

Observed formaldehyde and total air change rate data are summarized in Tables 2 and 3. Mean formaldehyde levels were calculated as the average of the two measurements performed in each structure during each test. Formaldehyde data are also presented based on the presence of smokers in the house.

During the routine site visits, several of the ventilation systems were found to have been operated at non-design conditions during the air quality monitoring. Data from these houses were isolated and are presented in Table 4, which gives a breakdown of formaldehyde results for those houses in which the ventilation systems were: a) operated in "nominal" compliance with the ventilation guidelines and b) actually operated in compliance with the guidelines, as verified by examination of the independently measured air change rate data. "Nominal" compliance was defined as instances in which the measured HRV flow rates were, at the time of the site visits, found to equal or exceed the minimum level specified by the R-2000 standard.

TABLE 2

Formaldehyde Levels

	Number of Houses	Mean (ppm)	Standard Deviation (ppm)	Median (ppm)	Measurements >0.05 ppm Number	%	Measurements >0.10 ppm Number	%
R-2000 Houses								
March 1986	6	0.061	0.016	0.060	4	67%	0	0%
August 1986	16	0.058	0.023	0.057	10	63%	1	6%
October 1986	16	0.080	0.028	0.072	16	100%	2	13%
February 1987	16	0.057	0.021	0.057	9	56%	1	6%
Cumulative	54	0.064	0.025	0.061	39	72%	4	7%
Conventional Houses								
March 1986	4	0.078	0.029	0.077	3	75%	1	25%
August 1986	4	0.067	0.014	0.065	4	100%	0	0%
October 1986	3	0.090	0.021	0.086	3	100%	1	33%
February 1987	4	0.067	0.019	0.060	4	100%	0	0%
Cumulative	15	0.074	0.021	0.066	14	93%	2	13%
R-2000 Houses								
Forced Air Heating Systems	36	0.063	0.027	0.058	25	69%	3	8%
Baseboard Heating Systems	18	0.067	0.020	0.064	14	78%	1	6%
R-2000 & Conventional								
Smokers	32	0.065	0.016	0.063	28	88%	2	6%
Non-Smokers	37	0.068	0.029	0.063	25	68%	4	11%

TABLE 3

Total Air Change Rates

	Number of Houses	Mean (ach)	Standard Deviation (ach)	Median (ach)	Measurements >0.40 ach Number	%	Measurements >0.50 ach Number	%
R-2000 Houses								
March 1986	6	0.28	0.18	0.26	5	83%	1	17%
October 1986	16	0.30	0.16	0.29	11	69%	2	13%
February 1987	15	0.43	0.13	0.45	4	27%	4	27%
Cumulative	37	0.35	0.16	0.36	20	54%	7	19%
Conventional Houses								
March 1986	4	0.16	0.05	0.14	4	100%	0	0%
October 1986	4	0.15	0.05	0.17	4	100%	0	0%
February 1987	4	0.20	0.07	0.18	4	100%	0	0%
Cumulative	12	0.17	0.05	0.17	12	100%	0	0%

DISCUSSION

Observed mean formaldehyde levels for the two groups of houses (R-2000 and conventional) were generally consistent during the March 1986, August 1986, and February 1987 monitoring periods, while elevated levels were encountered in October 1986. For each monitoring period, the mean formaldehyde level in the R-2000 group of houses was lower than the mean level for the group of conventional structures.

The majority of measured levels were between 0.05 ppm and 0.10 ppm, values representing the Canadian target level and the ASHRAE guideline, respectively. The mean formaldehyde level in the R-2000 houses was 0.064 ppm, with 72% of the measurements exceeding 0.05 ppm and 7% greater than 0.10 ppm. As noted above, this includes results from houses that were not operated in compliance with the R-2000 standard. In the conventional structures, the mean formaldehyde level was 0.074 ppm, with 93% and 13% exceeding 0.05 ppm and 0.10 ppm, respectively.

From a standards perspective, the goal of 0.10 ppm was

TABLE 4

Effect of "Nominal" & Actual Compliance with R-2000 Ventilation guidelines Upon Formaldehyde Levels

1		2	
OCTOBER 1986	#1, #3, #4, #5, #13, #14, #20	OCTOBER 1986	#5, #14, #20
FEBRUARY 1987	#1, #2, #3, #4, #5, #13, #14, #19, #20	FEBRUARY 1987	#1, #2, #3, #5, #14, #19, #20
FORMALDEHYDE:			
n	16		10
Mean	0.070 ppm		0.055 ppm
Standard Deviation	0.031 ppm		0.014 ppm
Median	0.064 ppm		0.058 ppm

1. Houses operated in compliance with the R-2000 ventilation guidelines, as determined by a single measurement of the HRV flow rate.
2. House *actually* operated in compliance with the R-2000 ventilation guidelines.

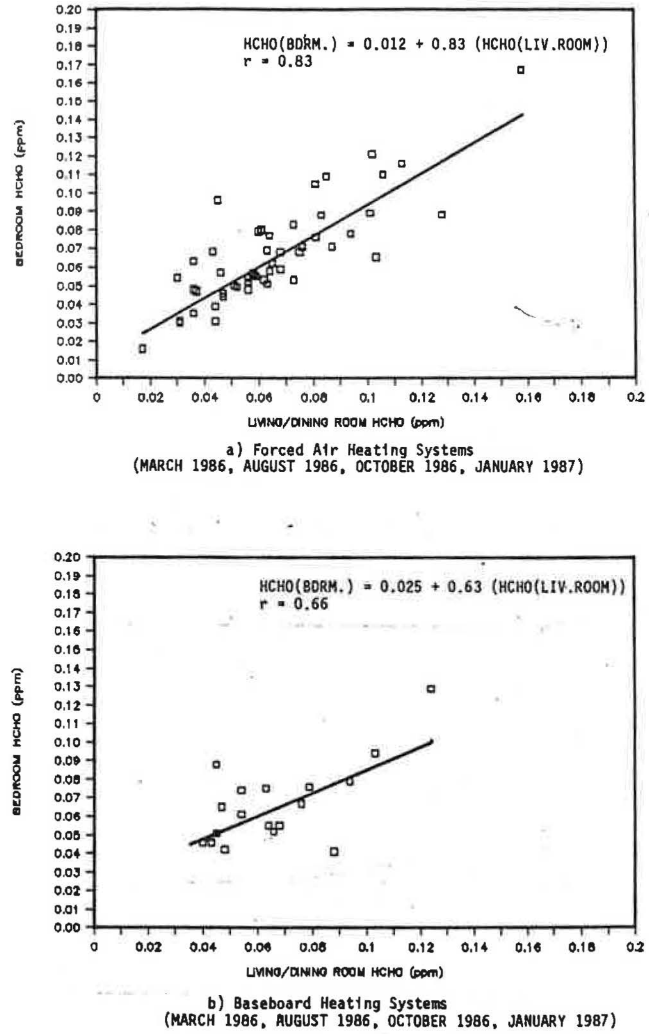

Figure 1 Measured bedroom formaldehyde levels vs. living/dining room formaldehyde levels (March/86, August/86, October/86, January/87)

found to be readily achievable given the use of a quality mechanical ventilation system. However, to achieve 0.05 ppm on a consistent basis would have required additional measures such as source control.

Homeowner intervention with the ventilation system was found to be an important factor affecting formaldehyde levels. Houses operated in "nominal" compliance with the R-2000 standard had measured HRV flow rates sufficient to provide a minimum mechanical ventilation rate of 0.35 ach. However, in approximately one-third of these cases, the independently measured total air change rate was found to be substantially lower than the values indicated by the HRV flow measurements. Investigation revealed that homeowners had adjusted the HRV speed control or disconnected the power supply to the unit. Those houses independently verified to have been operated at the design ventilation rate demonstrated lower formaldehyde levels and reduced standard deviations. The mean value of 0.055 ppm and standard deviation of 0.014 ppm were similar to those reported by Piersol and Mijailovic (1987) for a broader population of R-2000 houses.

The issue of homeowner intervention is significant from the perspective of ventilation standards. The homeowners in the project houses received instructions on the purpose and use of the ventilation systems, including the need for continuous system operation. However, discussions with them indicated that many were reducing ventilation rates to cut energy costs, control noise, or reduce drafts. If any of these factors were perceived by the homeowners to be excessive, the flow rate was generally reduced. This raises the concern that ventilation systems with "high" design flow rates could inadvertently result in degraded air quality by increasing the frequency of homeowner intervention. (The "design" flow rate is defined here as the continuously operating ventilation rate.) Conversely, systems with lower design flow rates might experience less intervention and, subsequently, better air quality would be achieved.

Mean formaldehyde levels were found to be similar in houses that contained a smoker as compared to those that did not. This was a surprising observation since tobacco smoke is recognized as a formaldehyde source. The observed behavior may be due in part to the slightly higher total air change rates experienced by the houses containing smokers (0.32 ach vs. 0.29 ach).

Figure 1 plots measured bedroom formaldehyde levels vs. living/dining room levels for houses with forced air and

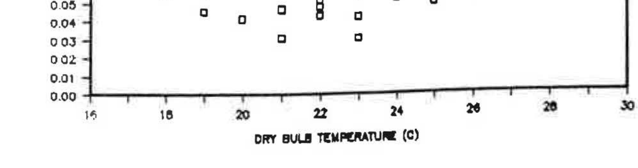

Figure 2 Formaldehyde vs. dry bulb temperature (March/86, October/86, January/87)

baseboard heating systems, respectively. Both R-2000 and conventional houses were included in the sample group. The degree of scatter about the regression line illustrates the effectiveness of the ventilation systems at achieving a well-mixed space in the houses. As evidenced by the plots and their respective correlation coefficients (0.83 and 0.66), the forced air systems provided superior mixing compared to the dedicated ventilation systems used in houses with baseboard heating.

Figure 2 plots mean formaldehyde levels vs. the average dry-bulb temperature recorded during the monitoring period. The correlation was observed to be weak over the range of temperatures encountered. The correlation coefficient, 0.23, suggests that temperature, by itself, was a weak indicator of formaldehyde concentration. Godish and Rouch (1986) were able to demonstrate a strong dependence between formaldehyde levels and temperature in an unoccupied mobile home, with other variables held constant, using indoor temperatures ranging from 20°C to 30°C.

Total air change rates in the R-2000 houses were generally low during the March 1986 and October 1986 periods because of homeowner intervention with the ventilation system or mechanical problems (typically motor burnouts or control malfunctions). During February 1987, after homeowners had been requested not to adjust the HRVs and any necessary repairs had been completed, mean levels increased to 0.43 ach. The average natural air infiltration rates for R-2000 houses is assumed to be 0.05 ach. Using this value, the estimated mean mechanical ventilation rate would have been 0.38 ach. This includes air change provided due to both continuous and peak operation of the ventilation system.

Mean formaldehyde levels are plotted against total air change rates in Figure 3. As shown, formaldehyde demonstrated a moderate dependence upon air change rates with a correlation coefficient of 0.65. Beyond approximately 0.35 ach, little reduction in measured formaldehyde levels was observed. Assuming a natural infiltration rate of 0.05 ach, the mechanical ventilation component of this figure would have been approximately 0.30 ach. Also, this value represents the combined air change rate due to operation of the system at all speeds so that the minimum required continuous rate would be less than 0.30 ach. However, it must be remembered that the project houses likely operated with above-average ventilation efficiencies as a result of the individual room returns used in 14 houses and the high sidewall supply registers in 10 of the structures. Also, they do not represent a random sample of house sizes and types. For comparison purposes, the design mechanical ventilation rate for houses using the 85 m^2 floor plan, calculated in conformance with the R-2000 standard, was determined to be 0.36 ach. The design mechanical ventilation rate capability calculated in conformance with the current draft of CSA F326.1, "Residential Mechanical Ventilation Requirements," (1988) was calculated to be 0.40 ach. This figure represents the design rate of the system, which does not necessarily have to be maintained at all times.

CONCLUSIONS

Detailed monitoring of 20 new, low-leakage, occupied houses equipped with mechanical ventilation systems found that a design goal for formaldehyde of 0.10 ppm was readily achievable, while a level of 0.05 ppm could not be reached on a consistent basis using mechanical ventilation as the only formaldehyde control measure. For each monitoring period, the mean formaldehyde level in the R-2000 group of houses was lower than the mean level for the group of conventional structures.

The results of the study indicate that the design mechanical ventilation rate must be established on the basis of both the ability of the system to remove pollutants as well as the effect the ventilation rate will have on homeowner intervention with the system. Homeowners tended to reduce the ventilation rate if they perceived the system as expensive to operate, noisy, or responsible for discomfort problems. Intervention appears to increase at higher design ventilation rates and may result in large reductions in the ventilation rate with a corresponding degradation of air quality.

For the houses studied, only nominal reductions were observed in mean formaldehyde levels at total air change rates, which exceeded approximately 0.35 ach. Assuming an average natural infiltration rate of 0.05 ach, the mechanical ventilation component of this figure would have been approximately 0.30 ach (comprising the net effect of both continuous and high-speed operation).

ACKNOWLEDGMENTS

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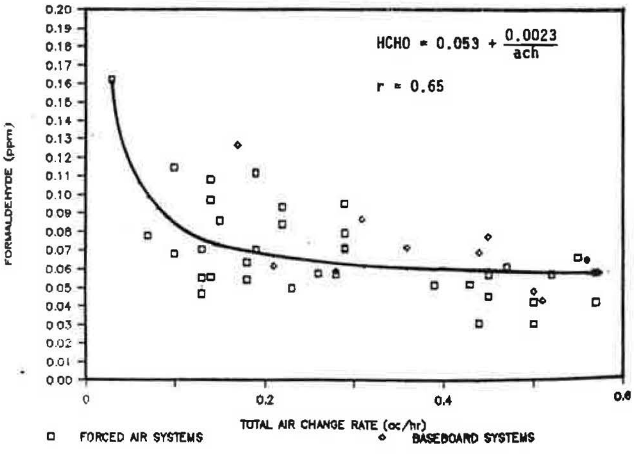

Figure 3 *Formaldehyde vs. total air change rate (March/86, October/86, January/87)*

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