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Paper 16

INDOOR FORMALDEHYGE LEVELS IN ENERGY-EFFICIENT HOMES WITH MECHANICAL VENTILATION SYSTEMS

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SYNOPSIS

Mechanical ventilation systems have been adopted in airtight energy- efficient houses in Canada to provide fresh air, remove moisture and indoor pollutants and provide a comfortable environment for the home-occupants. Homes constructed under the R-2000 Home Program are equipped with mechanical ventilation with heat recovery. Since 1984, the performance of approximately 700 R-2000 Homes has been monitored on an annual basis. This monitoring has included the measurement of indoor levels of formaldehyde and the documentation of ventilation system operation. Levels of formaldehyde in the initial years of the program averaged 0.069 parts per million (ppm). Formaldehyde originates from urea formaldehyde resin which is used in the manufacture of many household furnishings and building products. After revisions to the R-2000 Home ventilation guidelines which then stipulated fresh air distribution in addition to a total fresh air supply capacity (0.5 ach), the average level of formaldehyde has decreased to 0.045 ppm in the most recent years. Since the decrease of formaldehyde levels with increased age of home was not observed, this decrease has been attributed to the revisions to the ventilation guidelines. Details of the ventilation guidelines, the type of ventilation systems used, and the air quality results are presented.

1.0 INTRODUCTION

Mechanical ventilation systems are required for homes built under the R-2000 Super Energy-Efficient Home Program in Canada. The intent of these mechanical ventilation systems is to provide fresh air, remove moisture and indoor pollutants and provide a comfortable environment for the home occupants. The R-2000 Home Program Design and Installation Guidelines for Ventilation Systems[1] outline requirements for a continuous supply of ventilation air to dilute and control contaminants produced within the home and an additional capacity for periods of higher humidity or contaminant source strength. An overview of these guidelines has been previously presented[2].

In 1983 a monitoring program commenced that included air quality and ventilation testing of approximately 300 initial demonstration R-2000 Homes and a sample of conventionally built homes. This monitoring program has been conducted annually since 1983 during the Canadian heating season, mid-November through to mid-April. The program has also been expanded to an additional 400 R-2000 Homes built subsequent to the initial 1983-1984 period. The initial demonstration R-2000 Homes have been monitored each year inorder to determine how they perform with time. The subsequent R-2000 homes have been monitored to determine whether homes constructed by new builders to the program perform the same as the initial demonstration homes. Conventional homes were monitored as controls for comparative purposes.

One of the objectives of the monitoring program is to obtain information on the ventilation and air quality characteristics of R-2000 Homes in order to determine whether they comply with the program criteria and recognized standards or guidelines, and how they compare with a sample of conventionally built homes. Included in this monitoring has been the measurement of the airflow rates of the installed ventilation systems, average airchange rates and indoor air quality.

2.0 VENTILATION SYSTEMS

The mechanical ventilation systems in these energy-efficient homes are balanced systems with heat recovery. These systems are operated continuously inorder to provide ventilation to these airtight homes which must meet a criterion of 1.5 air changes per hour (ach) at a 50 Pa pressure differential. There are two basic ventilation systems; those in houses with forced air heating and those in houses without forced air heating such as baseboard heating.

In the forced air systems (Figure 1), the heat recovery ventilator (HRV) discharges fresh air to a return air register of the forced air system closest to the furnace. The furnace fan is run at low speed continuous to distribute fresh air throughout the house. Dedicated duct work is used to exhaust stale air from bathrooms, kitchen, laundry room, and utility rooms. The stale air exhaust duct discharges through the HRV to the outside.

For baseboard heated houses, the fresh air ductwork from the HRV supplies fresh air to bedrooms, living rooms, dining rooms, basement and rooms without exhausts. Similar to the forced air houses, dedicated duct work is used to exhaust stale air from bathrooms, kitchen, laundry room and utility rooms. Again, stale air discharges through the HRV to the outside.

3.0 FORMALDEHYDE MONITORING PROGRAM

Indoor air quality has been monitored for formaldehyde, radon, and nitrogen dioxide in approximately 700 R-2000 Homes plus approximately 70 conventional homes. The field monitoring activities were carried out by technicians from Energy, Mines and Resources Canada (EMR) regional offices in 10 provinces and two territories in Canada. Individuals from each office were trained in air quality testing for formaldehyde, radon, and nitrogen dioxide and in the measurement of airflows and ventilation rates in homes. A comprehensive monitoring manual was prepared for the field technicians on all aspects of the monitoring program, including administrative procedures, occupant liaison, questionnaire completion, air quality monitoring procedures, and ventilation system testing. Laboratory and field support was provided by regional engineering firms and several laboratories in Canada and the United States.

Formaldehyde was monitored in 1983-84 with passive diffusion badges and then in subsequent years with passive diffusion tubes. Chamber tests indicate that the diffusion tube monitor used from 1985 to 1988 normally will measure approximately 10% to 20% higher than the badge[3]. Formaldehyde levels taken with the badge in 1983-84 have been increased by 15% based on the chamber tests to make them comparable to the results of subsequent years.

The monitors were installed in the homes by EMR regional office technicians and were removed and forwarded by the home owners after seven days to a laboratory for analysis. Formaldehyde levels were measured in a main floor living area such as a family room or living room and in the master bedroom. In all instances, sampling periods were for 7-days.

4.0 FORMALDEHYDE MONITORING RESULTS

Average levels of formaldehyde in both the R-2000 Homes and the conventional homes were below the guideline [4] of 0.10 parts per million (ppm). The mean levels in the R-2000 Homes decreased from 0.069 ppm in 1983-84 to less than 0.05 ppm in 1986-87 and 1987-88. Results are presented in Table 1 and Figure 3. During the monitoring of the initial demonstration homes in the 1983-84 period, measurements were conducted with the mechanical ventilation system operating as installed. Based on other observations made at the time of measurement, this meant that a large portion of the ventilation systems were not operating as required. In 1985, measures were taken to ensure that HRVs were balanced properly and were capable of delivering the required airflow capacity. In 1986, the corrective measures were completed. New revisions to the ventilation guidelines in 1986 also required a minimum continuous flow.

The mean formaldehyde levels in 1983-84 and 1984-85 were 0.069 ppm and 0.068 ppm, respectively. Standard deviations were 0.029 and 0.027 ppm in 1983-84 and 1984-85, indicating a wide range of levels. In 1984-85 values ranged from 0.015 to 0.14 ppm, with approximately 9% of the homes with values greater than the guideline of 0.10 ppm. The frequency histogram in Figure 3 illustrates this range of levels. In 1986-87 and 1987-88 the levels of formaldehyde decreased to 0.045 ppm. The standard deviations also decreased to 0.017 and 0.016 ppm in 1986-87 and 1987-88, respectively. The histograms in Figure 3 for 1986-87 and 1987-88 illustrate the change in the range of formaldehyde levels measured. Less than one percent of the homes measured in these later two years had levels greater than the 0.1 ppm guideline.

During the program 77 new conventional homes without ventilation systems were monitored for formaldehyde as controls, Table 1 and Figure 4. The majority of these measurements were made during the 1983-84 period. For all the conventional homes monitored from 1983-84 to 1986-87, the mean level was 0.069 ppm and the standard deviation was 0.033 ppm. Seventeen percent of these 77 homes had formaldehyde levels of greater than 0.1 ppm. These values are similar to the R-2000 levels in the initial years but greater than the present levels encountered in the R-2000 Homes.

As previously mentioned, the R-2000 Homes have two basic ventilation system designs. Analysis of the air quality data indicates that the measured formaldehyde levels did not differ from one system to the other. When the ventilation systems are operating properly, the levels measured, Table 2, are the same for the two systems. The first readings in the initial demonstration homes, 0.066 ppm for forced air and 0.070 ppm for basebosard, were taken prior to revisions to the ventilation guidelines and are typical of those measured in the 1983-84 and 1984-85 periods. Presently, formaldehyde levels in both the initial homes and the subsequent homes for both baseboard and forced systems are similar.

Initially, a new product containing urea formaldehyde resin will emit somewhat higher levels of formaldehyde gas. The emission rate will decrease to a lower level over time. Comparisons were made between older and newer R-2000 Homes to determine whether the lower indoor levels of the later years were a result of such a time-related decrease, or whether this decrease was related to more effective ventilation. Figure 5 presents histograms for formaldehyde conducted in 1986-87 in two groups of homes built a few years apart. Ninety homes were three to four years old and 66 homes were one to two years old. There is not a significant difference between the mean formaldehyde levels measured in those homes which were three to four years old, 0.044 ppm, and those which were one to two years old, 0.046 ppm. This trend differs from decreases found by others[5,6]. It is believed that the low levels of formaldehyde measured in these homes are approaching the lower limit attainable in the new generation of energy-efficient housing. Levels of less than 0.02 ppm are rarely experienced[7,8,9] in even older houses. At levels below 0.05 ppm the introduction of sources such as new furniture which contains urea formaldehyde resin materials can have a measurable impact on the indoor formaldehyde levels.

Inorder to further investigate which factors influence formaldehyde levels in these energy-efficient homes with mechanical ventilation systems a study was conducted on a smaller set of homes. Formaldehyde sources and factors such as tobacco smoking, building materials and furnishings containing urea-formaldehyde resin, indoor temperature and humidity and the adequacy of ventilation were studied in a sample of 35 R-2000 Homes. These 35 homes had formaldehyde levels ranging from 0.023 ppm to 0.088 ppm. It was determined that indoor temperatures greater than 21°C, indoor humidity greater than 50% RH, new furnishings and/or recent renovations, tobacco smoking, and HRVs that operate at less than 80% of the flow required by the R-2000 technical airflow requirements could, in combination, raise formaldehyde levels above a base level of 0.04 ppm. These findings are summarized in Table 3 and in the following.

For homes with mechanical ventilation systems which were properly installed, operated and maintained then:

(i) formaldehyde levels were less than 0.05 ppm when there no major sources and low to moderate indoor temperature and humidity, or when there is one major source or high indoor temperature and humidity; and

(ii) formaldehyde levels were greater than 0.05 ppm when there were two or more major sources and high indoor temperature and humidity.

For homes with mechanical ventilation systems which were improperly installed, operated and poorly maintained then:

(i) formaldehyde levels were less than 0.05 ppm when there were no major sources and low to moderate indoor temperature and humidity; and

(ii) formaldehyde levels were greater than 0.05 ppm when there were one or more major sources or high indoor temperature and humidity.

As previously mentioned, measurements were taken in a main floor living area and the master bedroom. The monitoring data was analyzed to determine if a variation existed between levels in the living area and the bedroom. On average, levels of formaldehyde were the same in the two areas monitored even when the ventilation systems were not operating as required. These similar levels may be because the formaldehyde sources are evenly distributed throughout the homes. Formaldehyde is also a gas and as such should mix well and disperse throughout the homes by diffusion and ventilation transfer. A summary of monitoring results are presented in Table 4. Data for livingrooms and bedrooms for the last readings in the initial demonstration R-2000 Homes are presented in Figure 8 to illustrate the relationship between the levels in the different rooms.

In addition to evaluating the formaldehyde levels in smokers and no-smokers homes in the set of 35 homes, national data was also analyzed. Nationally the levels for these two groups were the same. For 74 smokers homes the mean formaldehyde level was 0.047 ppm and for 214 non-smokers homes the mean level was 0.046 ppm.

5.0 CONCLUSIONS

The results of this monitoring program indicate that energy-efficient housing with mechanical ventilation systems have indoor formaldehyde levels comparable to, or lower than, conventional housing. The ventilation systems, if properly installed and operated should maintain formaldehyde levels well below 0.1 ppm in houses with low to moderate sources of formaldehyde. Pollutant source strength, not ventilation, is the predominant parameter in determing indoor pollutant levels. If a home has new urea formaldehyde containing furnishings, high indoor temperature and humidity and an HRV not providing adequate airflow these factors may, in combination, result in formaldehyde levels approaching or exceeding guideline comfort levels.

ACNOWLEDGEMENTS

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REFERENCES

1. R-2000 Home Program Design and Installation Guidelines for Ventilation Systems, R-2000 Home Program, Energy, Mines and Resources Canada, November 1986.

2. Riley, M.A., An Overview of the R-2000 Home Program Design and Installation Guidelines for Ventilation Systems, Paper 13, Ventilation Technology - Research and Application, 8th AIVC Conf., Uberlingen, Federal Republic of Germany, Sept. 1987.

3. AQRI, Air Quality Research International, Performance of PF-1 and Dupont Passive Formaldehyde Monitors in AQRI Test Atmosphere Chamber, prepared for the UFFI Center, Corporate and Consumer Affairs, Canada.

4. Health and Welfare Canada, Exposure Guidelines for Residential Indoor Air Quality, A Report of the Federal-Provincial Advisory Committee on Environment and Occupational Health, April 1987.

5. Reiland, P., M. McKinstry and P. Thor, Preliminary Formaldehyde Testing Results for the Residential Standards Demonstration Program, Office of Conservation, Bonneville Power Administration, U.S. Dept. of Energy, Aug. 1985.

6. Figley, D.A., and J.T. Makohon, Measured Formaldehyde Levels and Ventilation Rates in Mobile Homes, Preprint 88-74.2, APCA 81st Annual Meeting, Dallas TX, June 1988.

7. Grimsrud, D.T., B.H. Turk, I. Harrison, R.J. Prill, A Comparison of Indoor Air Quality in Pacific Northwest Existing and New Energy Efficient Homes, presented at the 79th Annual Meeting APCA, Minneapolis MN, June 1987.

8. Sexton, K., L.A. Lui and M.X. Petreas, Formaldehyde Concentrations Inside Private Residences: A Mail Out Approach to Indoor Air Quality Monitoring, Journal of the APCA, Vol. 36(6), June 1986, p698-704.

9. Scheuneman, E. and G. Wilson, Air Quality Results for Tightened Houses, presented at ASHRAE IAQ '86, Atlanta 1986.

TABLE 1
INDOOR FORMALDEHYDE LEVELS (PPM)

Homes	Period	Number of Homes	Mean	Standard Deviation	Median
R-2000 Homes	'83-84	248	0.069	0.029	0.061
	'84-85	110	0.068	0.027	0.064
	'85-86*	70	0.050	0.020	0.048
	'86-87	254	0.045	0.017	0.041
	'87-88	345	0.045	0.016	0.043
Conventional Homes	'83-84	63	0.070	0.037	0.066
	'84-85	16	0.079	0.037	0.067
	'85-86*	4	0.071	0.024	--
	'86-87	5	0.057	0.025	--

Note: * Monitoring of formaldehyde in 1985-86 was conducted only in the Province of Ontario.

TABLE 2
VENTILATION SYSTEM FORMALDEHYDE LEVELS (PPM)

R-2000 Homes	Ventilation/Heating Systems					
	Forced Air			Baseboard		
	# of Homes	Mean	Standard Deviation	# of Homes	Mean	Standard Deviation
Initial Demo Homes						
First Reading	52	0.066	0.025	101	0.070	0.035
Last Reading	49	0.047	0.015	82	0.045	0.018
Subsequent Homes						
First Reading	27	0.041	0.012	73	0.049	0.023
Last Reading*	6	--	--	18	0.045	0.018

Note: * Insufficient data to determine level for forced air systems, last reading for subsequent homes.

TABLE 3
FACTORS INFLUENCING INDOOR FORMALDEHYDE LEVELS

Factor	Distribution of Homes According to Formaldehyde Concentration <0.05 ppm	>0.05 ppm
Ventilation Systems		
• Airflow >80% of technical requirement	57%	44%
• Continuous system operation	100%	67%
• Airflow >80% of technical requirement and continuous operation	57%	22%
• Maintenance performed	64%	0%
Formaldehyde Sources		
• Smokers	7%	46%
• Indoor temperature >21°C	14%	69%
• Indoor humidity >50%	21%	85%
• New furnishings and/or renovations	7%	31%

TABLE 4
LIVINGROOM AND BEDROOM FORMALDEHYDE LEVELS (PPM)

R-2000 Homes	Number of Homes	Livingroom	Bedroom
Initial Demo Homes			
First Reading	256	0.066	0.068
Last Reading	218	0.046	0.046
Subsequent Homes			
First Reading	405	0.047	0.047
Last Reading	77	0.046	0.048

FIGURE 1
VENTILATION SYSTEMS WITH FORCED AIR
HEATING

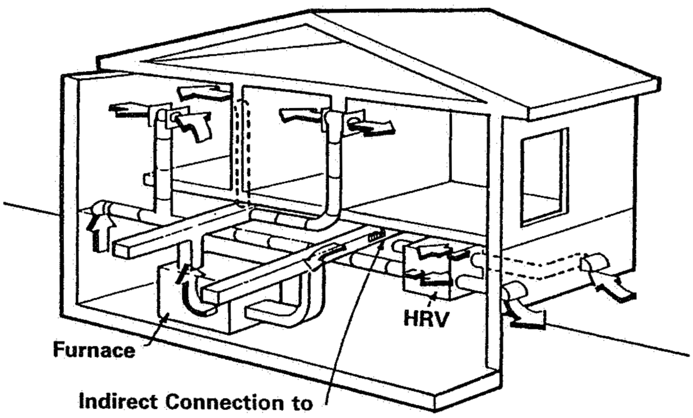
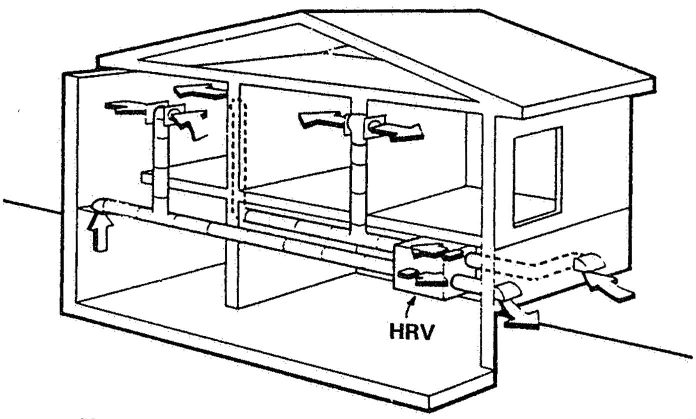


FIGURE 2
VENTILATION SYSTEMS FOR BASEBOARD
HEATING



Note: Every room should be connected to the HRV
(exhaust or fresh air)

FIGURE 3
FORMALDEHYDE LEVELS IN R-2000 HOMES

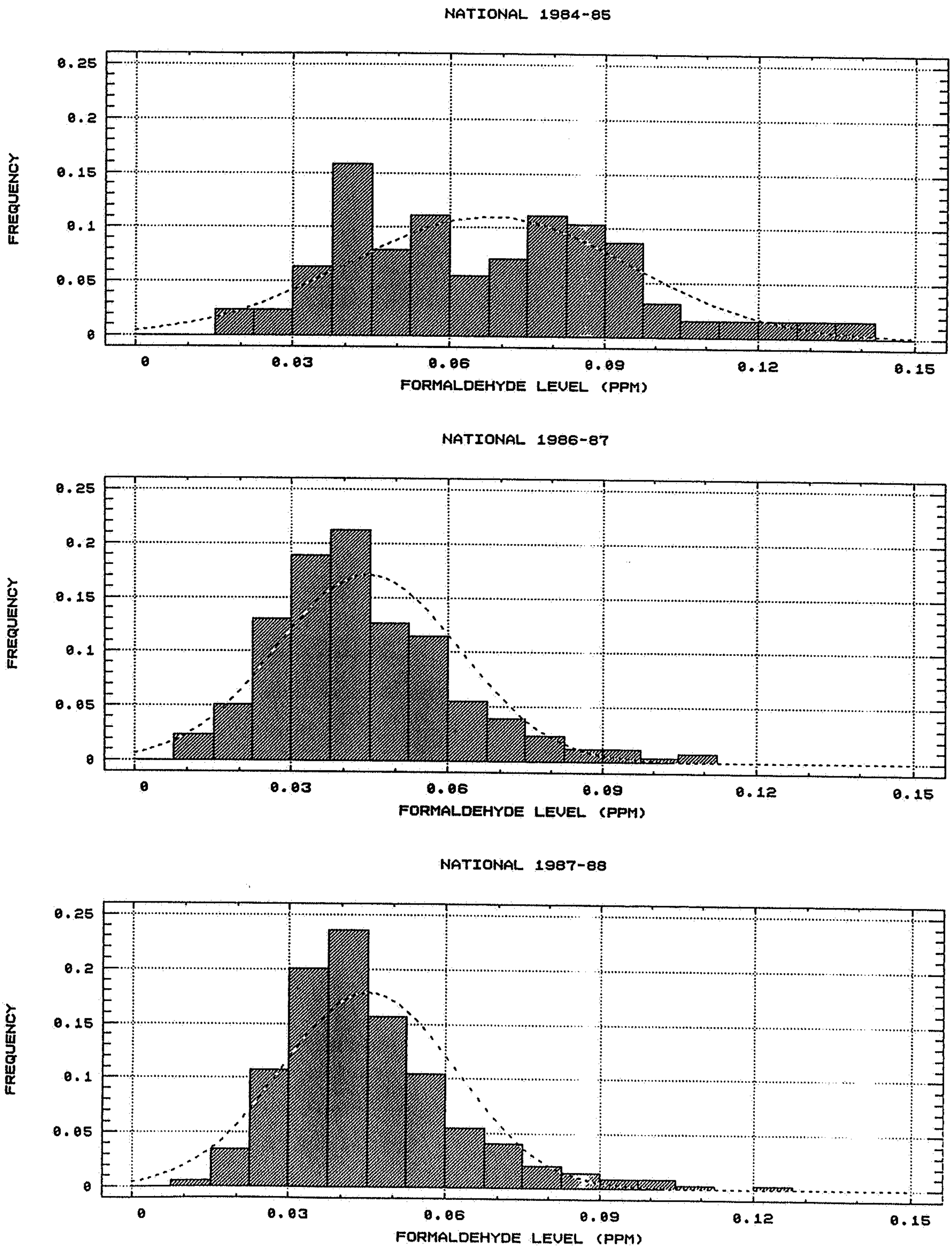


FIGURE 4
FORMALDEHYDE LEVELS IN CONVENTIONAL HOMES

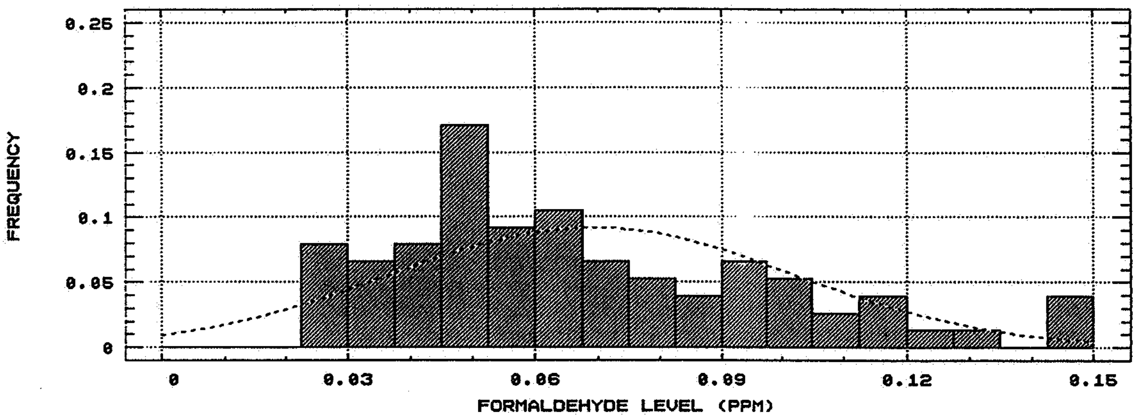
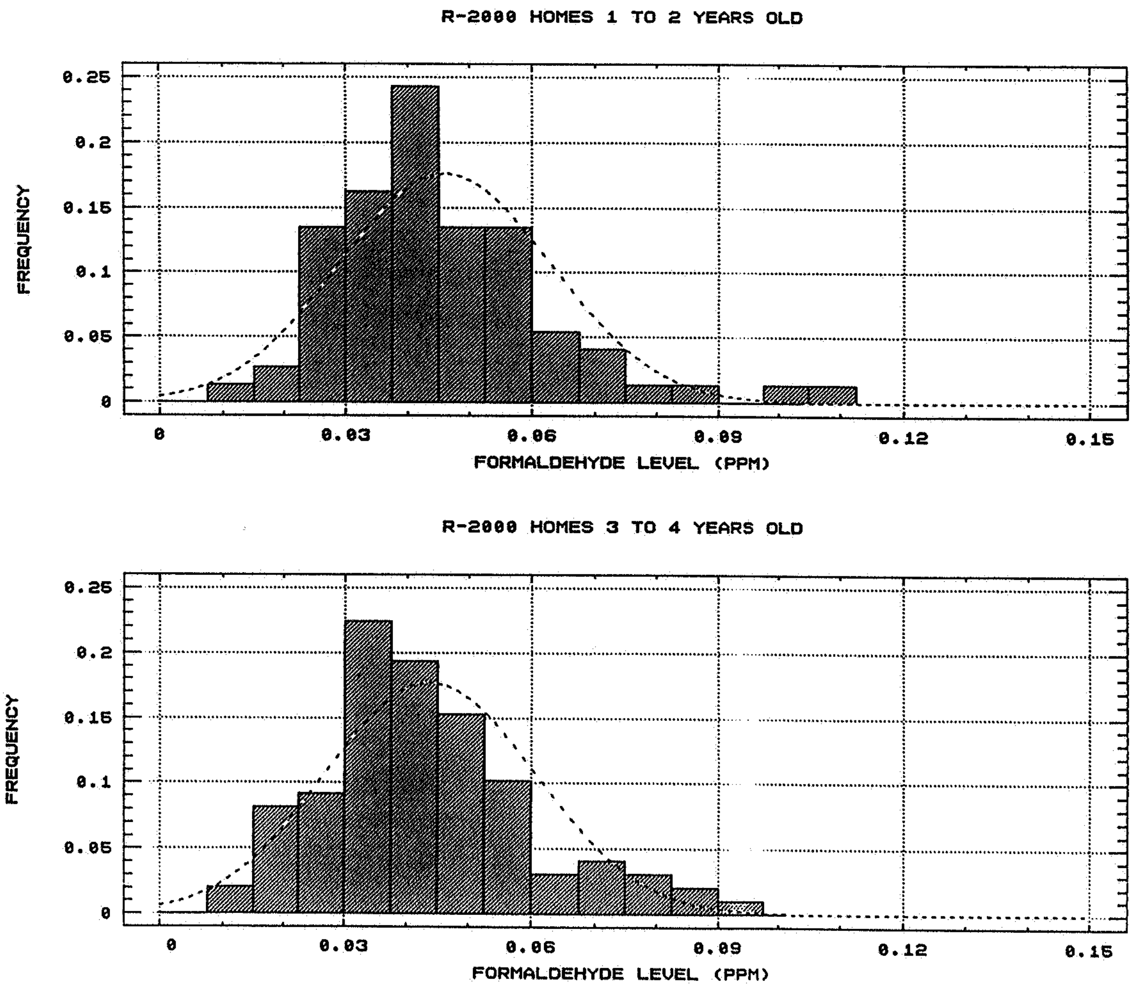


FIGURE 5
FORMALDEHYDE LEVELS IN HOMES OF DIFFFERENT AGES



Discussion

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C-A. Roulet (Ecole Polytechnique Federale de Lausanne, Switzerland) Do you have any information on the air change rate of the R-2000 buildings before and after the application of the Ventilation Rules?

M. Riley (Energy, Mines and Resources, Ottawa, Canada) We did undertake PFT air change rate sampling and issued a report on average air change rates in early R-2000 homes. One can assume that the air change rate in new homes was similar to the mechanical ventilation
rate specified (0.3 to 0.4 per hour).

D. Harrje (Princeton University, USA) What about the question of maintenance which, according to your results, varied significantly between groups of homes?

M. Riley (Energy, Mines and Resources, Ottawa, Canada) We are very interested in the issue of maintenance versus the performance of the ventilation system, but have not had the time to examine this in detail. Although we have looked at the mould and fungi growth in poorly maintained systems.

W. Fisk (Lawrence Berkeley Laboratory, USA) Have you studied the seasonal variations in formaldehyde concentrations in these houses? If so, what are the results?

M. Riley (Energy, Mines and Resources, Ottawa, Canada) We have done some limited studies of seasonal variations. Generally the results indicate higher levels during periods of high outside humidity and temperature, such as those found in the summer.

P. Hartmann (EMPA Duebendorf, Switzerland) You show a decrease in formaldehyde concentration in new R-2000 homes. Is it proven that there is no significant change in the production or manufacture of particle boards during recent times?

M. Riley (Energy, Mines and Resources, Ottawa, Canada) We have no evidence of any change in the particle boards being used in R-2000 homes. In addition, when ventilation systems are not being operated correctly, levels return to those found in earlier studies.

R. Grot (National Bureau of Standards (USA) (a) The age data which you presented agrees with laboratory data on pressed wood products which we have collected. There is very little decay after an initial rapid decay (3 months) caused by the release of free formaldehyde. (b) Formaldehyde is stored and released by many building materials, such as gypsum (just like moisture), therefore a building does not rapidly respond to formaldehyde transients, nor does the formaldehyde concentration change rapidly after changes in ventilation rate - this explains why transient operation of ventilation cannot effectively control formaldehyde levels.

M. Riley (Energy, Mines and Resources, Ottawa, Canada) (a) Your work confirms our results. We had assumed that there would be a steady decline in levels, based on research conducted by others. (b) This is correct. We were using 7 day passive samplers which dampen the effect of short-term fluctuations in formaldehyde levels due to emissions such as smoking.

P. Hartmann (EMPA Duebendorf, Switzerland) You described overall formaldehyde levels in R-2000 buildings. Can you indicate a typical split between the sources of formaldehyde: background, particle board, furniture, smokers etc.?

M. Riley (Energy, Mines and Resources, Ottawa, Canada) I don't have a detailed split, but recent work at our Flair homes project would seem to indicate that the building itself is the major source, followed by furnishings.

W. De Gids (TNO Division of Technology for Society, Holland) What measures did you take to reduce formaldehyde levels in the R-2000 homes in which concentrations exceeded 0.1 ppm?

M. Riley (Energy, Mines and Resources, Ottawa, Canada) Initially we adjusted the ventilation systems to address most problems. Recent problems are mostly due to high source emissions, such as new painting or carpeting. These have normally been reduced by rapid reduction in emission rates in the subsequent months.

W. Raatschen (Dornier Systems GmbH, W. Germany) (a) What facility do occupants have to control their ventilation system? Is it purely on/off control? (b) Can they control individual rooms? (c) What basic ventilation rate can you recommend (i.e. with no occupants present) to dilute non-human related contaminants, such as formaldehyde?

M. Riley (Energy, Mines and Resources, Ottawa, Canada) (a) The "continuous" mode is usually set by the installer, but can be varied by changing fan speed via a speed controller or by adjusting dampers. In addition most systems have a high speed (boost) mode of operation. (b) Some systems offer good control over individual room ventilation rates by adjustment of grille outlets. In most cases however control is limited because of poor design. (c) Generally a level of 0.3 to 0.4 air changes/hour keep concentrations at a satisfactory level. This applies specifically to Canadian climate and house construction.

O. Nielsen (Ministry of Housing and Building, Denmark) Typically, what is the outdoor concentration of formaldehyde found in Canadian cities?

M. Riley (Energy, Mines and Resources, Ottawa, Canada) We have not measured outdoor concentrations coincident with our indoor measurements. This was not practicable for the time of year (late winter) when measurements were being made. It is my understanding that levels are typically very low (<0.02 ppm). It should be noted that most new houses are in suburban areas, not in high density downtown areas.