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R-2000

SUPER ENERGY EFFICIENT HOME PROGRAM

TECHNICAL REPORT

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VENTILATION AND AIR QUALITY MONITORING IN R-2000 HOMES: MEASUREMENT AND ANALYSIS

002-MR

Prepared for

The R-2000 Home Progam
Energy Conservation Branch
Energy, Mines and Resources Canada

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THE R-2000 HOME PROGRAM TECHNICAL REPORT SERIES

The R-2000 Home Program assists in the ongoing development of the various technologies required to build and operate R-2000 homes. This includes support for standards development and the provision of technical information and resources to the building industry. In addition, R-2000 homes and a control group of conventional homes are being monitored over a two- to five-year period to gather information on construction techniques, the performance of heating and ventilating systems, indoor air quality and energy consumption. The demographic profile and attitudes of R-2000 homeowners are also being surveyed.

This publication is one of a series of reports documenting technical developments and monitoring activities supported by the R-2000 Home Program and the Canadian housing industry. The program's objective is to assist the housing industry to develop the capability to construct and market quality housing that is both energy-efficient and cost-effective,.

For further information on the R-2000 Home Program in general, the series of technical reports, or to obtain additional copies of this document, please contact:

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EXECUTIVE SUMMARY

The R-2000 Super Energy Efficient Home Program is a co-operative industry/government initiative sponsored by Energy, Mines and Resources Canada (EMR) and delivered by the Canadian Home Builders' Association (CHBA). Established in 1980, the program supports building industry development and training of builders to construct energy-efficient houses incorporating high levels of insulation, a well-sealed air barrier and mechanical ventilation systems.

In 1983, EMR embarked on a field monitoring program to obtain data on the performance of R-2000 homes with the objective of evaluating the technical requirements of the program and providing quality assurance for homebuyers. The program included testing of mechanical ventilation systems and measurement of air quality in initial R-2000 super energy-efficient demonstration homes and a sample of control homes that reflected typical building practice.

The purpose of this report is to present the results of field monitoring conducted in R-2000 homes to assess whether the installed mechanical ventilation systems were capable of supplying ventilation air in accordance with R-2000 program requirements, and whether the supply and exhaust airflows of ventilators were balanced in accordance with program requirements. Formaldehyde, radon and nitrogen dioxide levels and average air change rates in R-2000 and control homes were measured and these results are also presented.

Airflow measurements in 259 homes indicated that the ventilation system capacity in most homes exceeded the requirement to provide continuous ventilation at 5 litres per second (L/s) or 10 cubic feet per minute (cfm) per room (including kitchens and bathrooms) based on ASHRAE Standard 62-81, Ventilation for Acceptable Indoor Air Quality, and 10 L/s (20 cfm) for basements and utility areas. The system capacity for both continuous and intermittent ventilation averaged 0.5 air changes per hour (ach), which is the program requirement. Airflows did not vary significantly with house volume, therefore smaller homes generally exceeded this requirement, while some larger homes did not. The monitoring indicated that only 28% of heat recovery ventilators in R-2000 homes had supply and exhaust airflows balanced within 10% of each other, as specified in the program requirements.

The 30-day capillary adsorption tube sampling (CATS) tracer gas procedure was used in 178 homes to determine the average air change rate, which is influenced by natural infiltration, operation of ventilation equipment and occupancy. The average air change rate in 123 R-2000 homes was 0.37 ach. This was similar to the mean air change rate of 0.34 ach measured in 25 conventionally constructed homes. Both R-2000 and control homes with forced-air heating systems generally had air change rates 20-30% higher than those measured in homes with baseboard heating systems.

Formaldehyde levels measured in 248 R-2000 homes in 1984 averaged 0.060 parts per million (ppm). This level was similar to the average of 0.057 ppm measured in 46 conventional control homes. Approximately 8% of all homes had levels above the current Health and Welfare Canada interim guideline of 0.10 ppm. Formaldehyde levels were generally higher in R-2000 and control homes with electric baseboard heating systems. This difference (14% and 23% higher, respectively) was statistically significant. Further testing of 110 R-2000 homes and 16 control homes in the spring of 1985 with another monitor indicated that the mean formaldehyde level measured in conventional control homes was 0.079 ppm, 16% higher than the level measured in R-2000 homes. Only 8% of R-2000 homes exceeded the guideline, while approximately 30% of control homes had elevated levels. Both R-2000 and control homes with electric baseboard heating systems again had slightly higher levels than homes with forced-air heating systems.

The results of radon testing in the spring of 1985 in 148 R-2000 homes showed a geometric mean (GM) of 0.006 radon daughter working levels (WL). The GM of measurements in 33 control homes was slightly higher at 0.007 WL. These levels were well below any of the guidelines under consideration by the Federal/Provincial Advisory Committee on Environmental and Occupational Health. As expected, radon levels varied by region, with measurements in the Maritimes being significantly higher than in other regions but still well below proposed guidelines.

Nitrogen dioxide (NO_2) levels measured to date in both R-2000 and control homes ranged from 0.004 to 0.008 ppm. The levels were similar, and very low when compared with the maximum acceptable level of 0.050 ppm in ambient air established by Environment Canada.

These results indicate that levels of contaminants and CATS average air change rates measured in the initial R-2000 demonstration homes compare favourably with those measured in the sample of conventional homes, and that levels of contaminants were generally within current guidelines. It can be expected that ventilation and air quality in future R-2000 homes will be further improved as a result of program refinements and the experience of the building industry in constructing R-2000 homes.

Considerable effort is now being devoted to the refinement of the technical requirements, the establishment of consensus standards through existing standards organizations such as the Canadian Standards Association, and the development of products, equipment and skills necessary for quality assurance. In addition, mandatory builder training courses and builder technical manuals are being regularly reviewed and updated. A national training course and certification program for installers of ventilation equipment and the availability of improved "second generation" equipment will provide increased quality assurance. A national technical advisory committee has been established to consider any further changes necessary to ensure that the R-2000 Home represents a quality product for the homebuyer.

ABRÉGÉ

Le Programme de la maison à haut rendement énergétique R-2000 est une initiative conjointe de l'industrie et du gouvernement fédéral. Parrainé par Énergie, Mines et Ressources Canada (EMR), le programme est administré par l'Association canadienne des constructeurs d'habitations (ACCH). Depuis sa mise en oeuvre en 1980, le programme contribue au développement de l'industrie de la construction résidentielle, ainsi qu'à la formation des constructeurs afin que ceux-ci puissent construire des maisons à haut rendement énergétique, dont les caractéristiques sont le haut degré d'isolation, la haute étanchéité à l'air et la ventilation mécanique avec récupération de chaleur.

En 1983, EMR a entrepris un programme de surveillance visant à obtenir des données sur le rendement des maisons R-2000, dans le but d'évaluer la qualité de l'air intérieur et de garantir la qualité de ces maisons auprès des acheteurs. Les mesures ont porté sur la qualité de l'air intérieur et sur les systèmes de ventilation des premières maisons R-2000 construites aux fins de démonstration. Dans le but d'établir des comparaisons, on a également réalisé les mêmes mesures dans un groupe de maisons témoins construites selon les normes usuelles de l'industrie.

Ce rapport présente les résultats des essais réalisés dans un certain nombre de maisons R-2000 pour déterminer si les systèmes de ventilation mécanique de ces maisons pouvaient fournir les débits d'airs frais exigés par la norme R-2000. On a également déterminé si les débits d'air (alimentation et évacuation) des ventilateurs récupérateurs de chaleur étaient équilibrés conformément à ces exigences. De plus, on a mesuré le taux de renouvellement de l'air ainsi que les concentrations de formaldéhyde, de radon et de bioxyde d'azote dans les maisons R-2000 et dans les maisons témoins. Ces derniers résultats sont également présentés.

Selon les mesures des débits d'air réalisées dans 259 maisons R-2000, les systèmes de ventilation avaient, dans la plupart des cas, une capacité de ventilation continue égale ou supérieure à 5 litres par seconde (L/s) ou 10 pi^3/min par pièce (y compris la cuisine et les chambres), selon la norme 62-81 de l'ASHRAE, "Ventilation for Acceptable Indoor Air Quality", et de 10 L/s (20 pi^3/min) pour les sous-sols et les pièces utilitaires. La capacité moyenne de ventilation continue et d'appoint, pour l'ensemble des maisons testées, s'établissait à 0,5 renouvellement d'air par heure (RAH), ce qui correspond à l'exigence du programme. On a trouvé que les débits d'air mesurés ne dépendaient pas du volume intérieur des maisons, de sorte que les petites maisons avaient un taux de renouvellement supérieur à l'exigence de 0,5 RAH, alors que certaines maisons de grandes dimensions avaient un taux inférieur. Selon les résultats obtenus, les débits d'alimentation et d'évacuation à faible vitesse étaient équilibrés à 10 % près (comme le stipulent les exigences du programme) dans seulement 28 % des maisons R-2000 testées.

À l'aide d'une technique de surveillance couvrant 30 jours et connue sous le nom d'échantillonnage par tube à adsorption capillaire, lequel contient un gaz traceur inerte, on a mesuré le taux réel de renouvellement d'air dans 178 maisons. Celui-ci est influencé par plusieurs facteurs, dont les infiltrations d'air naturelles, le mode de vie des occupants et la présence d'autres appareils de ventilation. Avec cette méthode, on a enregistré un taux moyen de renouvellement de 0,37 RAH pour 123 maisons R-2000. Ce résultat est du même ordre que le taux moyen de renouvellement de 0,34 RAH mesuré dans les 25 maisons témoins de construction classique. Dans les deux groupes de maison, les taux étaient généralement de 20 à 30 % plus élevés dans les maisons équipées d'un système de chauffage à air pulsé que dans les maisons chauffées par plinthes électriques.

Les concentrations de formaldéhyde mesurées dans 248 maisons R-2000 avaient une valeur moyenne de 0,060 partie par million (ppm). Cette valeur moyenne est du même ordre que la concentration de 0,057 ppm mesurée dans 46 maisons témoins. Dans environ 8 % des maisons, les concentrations de formaldéhyde étaient supérieures à la ligne directrice provisoire de Santé et Bien-être social Canada, laquelle s'établit à 0,10 ppm. On a trouvé que les concentrations de formaldéhyde étaient plus élevées dans les maisons R-2000 et les maisons témoins chauffées par plinthes électriques. Cette différence (14 % et 23 % respectivement) est statistiquement importante. Selon d'autres essais réalisés au printemps de 1985 dans 110 maisons R-2000 et 16 maisons témoins à l'aide d'un autre appareil de mesure, la concentration moyenne de formaldéhyde était de 0,079 ppm dans les maisons témoins, soit 16 % de plus que dans les maisons R-2000. Seulement 8 % des maisons R-2000 avaient des concentrations de formaldéhyde supérieures à la ligne directrice provisoire, alors que ce pourcentage était de 30 % dans le cas des maisons témoins. De nouveau, on a noté que les concentrations de formaldéhyde étaient plus élevées dans les maisons R-2000 et les maisons témoins chauffées par plinthes électriques que dans les maisons équipées d'un système de chauffage à air pulsé.

Au printemps de 1985, on a mesuré les concentrations des produits de filiation du radon. La moyenne géométrique des concentrations mesurées s'établissait à 0,006 unité alpha dans 148 maisons R-2000 et à 0,007 unité alpha dans les 33 maisons témoins. Toutes les concentrations mesurées étaient bien inférieures aux lignes directrices actuellement étudiées par le Comité consultatif fédéral-provincial sur l'hygiène en milieu de travail. Comme on pouvait s'y attendre, les concentrations ont varié d'une région à l'autre. C'est aux Maritimes que l'on a mesuré les concentrations les plus élevées, mais elles étaient toutefois bien en deçà des lignes directrices proposées.

Les concentrations mesurées de bioxyde d'azote (NO_2) étaient très faibles, de l'ordre de 0,004 à 0,008 ppm, tant dans les maisons R-2000 que dans les maisons témoins. De plus, toutes les concentrations mesurées étaient bien en deçà de la limite acceptable établie par Environnement Canada pour l'air ambiant, soit 0,05 ppm.

Selon ces résultats, la qualité de l'air et les taux de ventilation dans les maisons R-2000 se comparent favorablement à ceux des maisons de construction classique. De plus, les concentrations de polluants mesurées dans toutes les maisons étaient en deçà des normes ou lignes directrices actuelles. Il est fort probable que la ventilation et la qualité de l'air augmenteront davantage dans les futures maisons R-2000, à mesure que les correctifs nécessaires seront apportés au programme et que les constructeurs acquerront plus d'expérience avec ce type de maison.

Des efforts importants sont actuellement déployés afin d'améliorer les exigences techniques. On cherche également à établir des normes acceptables pour tous les intéressés, par l'entremise des organisations de normalisation telle l'Association canadienne de normalisation. De plus, on poursuit la mise au point des produits, matériel et techniques nécessaires à la construction de maisons de qualité. Les cours de formation obligatoires et les guides techniques sont régulièrement révisés et mis à jour. Un programme national de formation, un programme de certification et la venue sur le marché d'équipement de "deuxième génération" sont d'autres garanties de qualité. Enfin, on a confié à un comité technique consultatif national le mandat de s'assurer que la maison R-2000 soit un produit de haute qualité.

1.0 INTRODUCTION

In 1980, Energy, Mines and Resources Canada in cooperation with the Canadian Home Builders' Association (CHBA) established the R-2000 Home Program for the construction of energy-efficient houses to the R-2000 energy performance target and technical criteria.

The major objectives of the R-2000 Home Program were as follows:

1. To transfer knowledge on the techniques of constructing and marketing R-2000 homes to as many builders as possible across Canada.

2. To provide incentives to encourage the design, construction and demonstration of a number of homes across Canada.

3. To identify and document barriers to the widespread adoption of energy-efficient housing.

4. To document construction techniques, costs and performance of R-2000 homes in order to evaluate the technical requirements of the program.

Since its inception in 1980, the R-2000 Home Program has actively supported the evolution and commercialization of energy-efficient housing through training and education programs for the building industry; the development of energy performance standards; the development of consensus standards for products and equipment; the establishment of improved inspection and compliance procedures; the implementation of field monitoring activities; and support for laboratory testing of products and equipment in order to provide quality assurance for R-2000 homebuyers.

There has been considerable public interest and a desire by an increasing number of builders to construct units. To date, there are approximately 400 registered R-2000 demonstration homes across Canada. Large-volume construction will not proceed until adequate inspection, testing and quality assurance procedures exist throughout the industry.

This report describes the procedures used to monitor air quality and ventilation rates in homes and presents the results of monitoring completed to date.

2.0 OVERVIEW OF TECHNICAL REQUIREMENTS FOR R-2000 HOMES

The R-2000 Home Program technical criteria[1] are essentially performance-oriented. This approach encourages builders to treat the whole house as a system, incorporating the most appropriate combination of features for their particular circumstance. The R-2000 energy consumption target is intended to achieve up to a 70% reduction in energy consumption for space heating based on computer predictions of energy consumption for homes built to the 1975 National Building Code as determined by the HOT-2000 energy analysis program. HOT-2000 is based on the HOTCAN computer program developed by the National Research Council of Canada[2].

The technical criteria specify that air leakage through the building envelope cannot exceed 1.5 air changes per hour (ach) at a fan-induced pressure difference of 50 pascals (Pa) when tested in accordance with a procedure based on the preliminary Canadian General Standards Board (CGSB) draft standard for testing the airtightness of building envelopes[3]. This requirement minimizes uncontrolled air leakage to protect the building envelope from moisture damage and to permit efficient operation of the mechanical ventilation system.

Other technical criteria were established primarily for health and safety reasons, in accordance with the high priority placed on indoor air quality and the control of contaminants. These include a requirement for the installation of a mechanical ventilation system to provide both continuous ventilation for normal occupancy and additional intermittent ventilation to control excessive humidity and contaminants as the need arises. The system must be balanced; neither creating nor contributing to an overall positive pressure that could force indoor air into the wall structure, or to an overall negative pressure within the building envelope relative to the exterior. Provision must be made to provide replacement air for appliances that exhaust air to the exterior, such as combustion equipment and clothes dryers.

Given Canada's lack of formal standards for mechanical ventilation for residential buildings, the Swedish standard of 0.5 ach was adopted as the criterion for the minimum installed mechanical ventilation system capacity for R-2000 homes[4]. Following the initial demonstration phase, a requirement was established for a minimum continuous or average ventilation rate for normal occupancy of 5 L/s (10 cfm) per room (including kitchens and bathrooms) based on ASHRAE Standard 62-81, Ventilation for Acceptable Indoor Air Quality[5] and 10 L/s (20 cfm) for basement and utility areas. Figure 1 illustrates a typical ventilation system installed in a house with a perimeter baseboard heating. Figure 2 illustrates a typical system in a home with forced-air heating.

It should be noted that the monitoring results presented in this report are for the first 300 R-2000 homes. Numerous refinements have since been made to the technical requirements. A national advisory committee has been established to consider any further changes.

FIGURE 1

HRV INSTALLATION IN HOME WITH PERIMETER BASEBOARD HEATING

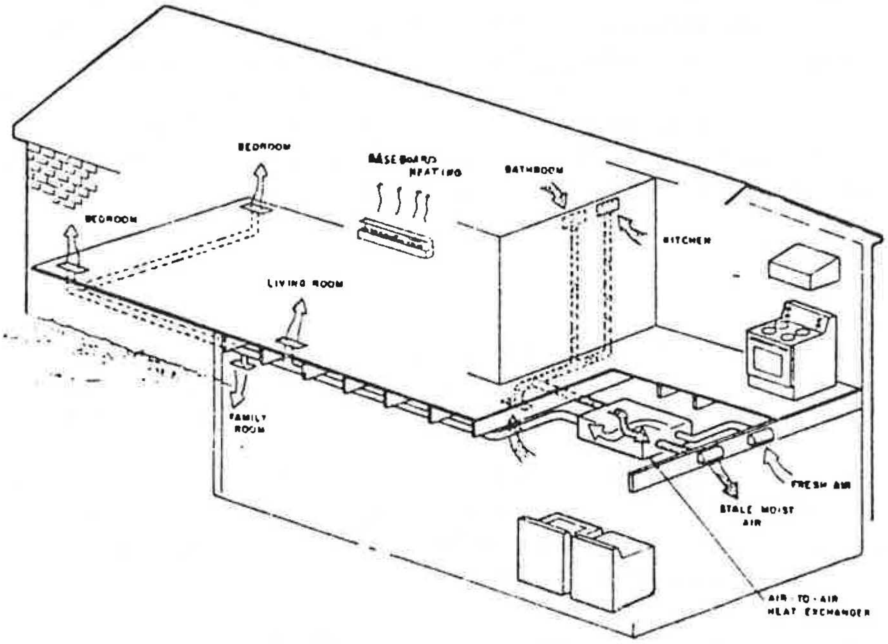
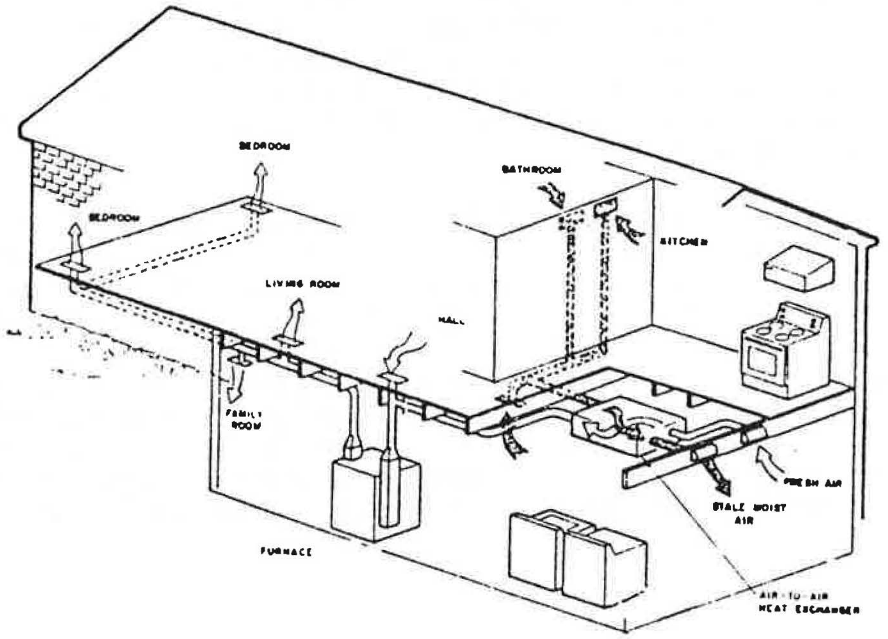


FIGURE 2

HRV INSTALLATION IN HOME WITH A FORCED-AIR HEATING SYSTEM



3.0 THE R-2000 MONITORING PROGRAM

3.1 Background

In 1983, an advisory committee to review and approve funds and procedures for an extensive R-2000 field monitoring program was jointly established by Energy, Mines and Resources Canada and the Buildings Energy Conservation Sector Committee (BECSC), which is composed of representatives from Health and Welfare Canada, National Research Council of Canada, Public Works Canada, Canada Mortgage and Housing Corporation, and Indian and Northern Affairs Canada.

The objectives were as follows:

1. To monitor and document the construction techniques, costs, problems and energy consumption of R-2000 homes for the purpose of evaluating the R-2000 program technical criteria.

2. To survey occupant attitudes and level of satisfaction with the energy-related features of R-2000 homes, including the performance of the various mechanical systems and the level of energy savings and comfort.

3. To obtain data on the ventilation and air quality characteristics of R-2000 homes in order to determine whether they comply with program criteria and recognized standards or guidelines, and how R-2000 homes compare with conventionally built homes.

To date, the monitoring program has concentrated on quality assurance for occupants through indoor air quality monitoring, ventilation system testing and energy metering in all of the initial R-2000 homes. A sample of conventionally built homes recently constructed by contractors participating in the R-2000 program was included for comparison.

The field monitoring was carried out by technicians from EMR regional offices in each province and territory in Canada who were trained to test for formaldehyde, radon and nitrogen dioxide and to measure airflows and ventilation rates in homes. A comprehensive manual was prepared on all aspects of the monitoring program, including administrative procedures, occupant liaison, questionnaire completion, air quality monitoring and ventilation system testing. Laboratory and field support was provided by the Ontario Research Foundation, regional engineering firms and several laboratories in Canada and the United States.

Because of the relatively large number of homes being monitored and their wide distribution across the country, simple, inexpensive equipment for measuring the levels of specific contaminants and air change rates was selected on the basis of laboratory evaluation, ease of use, accuracy, response time and sensitivity, field durability and cost. Some tests were conducted on only a sample of homes. This was due to the distribution of homes, willingness of occupants to participate, and the cost and availability of monitoring equipment.

Detailed background information on each R-2000 home was provided by the builder. This included a set of construction plans, a description of the building envelope characteristics and mechanical systems, a HOT-2000 energy analysis report, airtightness test results, incremental costs of construction, and data on consumer response and attitudes to R-2000 homes in general. Supplementary information concerning construction details, mechanical systems and occupancy was gathered during site visits by regional technicians. Whenever possible, similar information was gathered on a sample of comparable control homes.

This information is stored in the R-2000 Technical Information System, using a data base known as BOSS (Business Oriented Software System, a trademark of the American Planning Corporation, Washington, D.C.) on a microcomputer. The system was linked to a statistical program for analysing all technical information. Student T-Tests were used to assess the significance of results.

3.2 Description of Houses Monitored

R-2000 homes are characterized by high levels of insulation, control of air leakage by means of improved air barrier sealing techniques, mechanical ventilation (usually coupled with heat recovery), improved heating systems and utilization of passive solar energy.

During the pilot and demonstration phase of the R-2000 Home Program approximately 300 homes were built throughout Canada. The largest percentage of R-2000 homes (Figure 3) were built in the provinces of Ontario and Quebec. The regional distribution of 58 conventionally constructed control homes is also shown.

Approximately 60% of the R-2000 homes and 42% of the control homes were heated with electricity and the remainder primarily with natural gas (Figure 4). Approximately 32% of R-2000 homes and 28% of control homes had a woodburning appliance such as a fireplace or wood stove. All R-2000 homes had heat recovery ventilators installed for continuous mechanical ventilation, while only one control home had a mechanical ventilation system. Table 1 summarizes the insulation levels and airtightness characteristics of the R-2000 and control homes.

FIGURE 3. REGIONAL DISTRIBUTION OF HOMES MONITORED

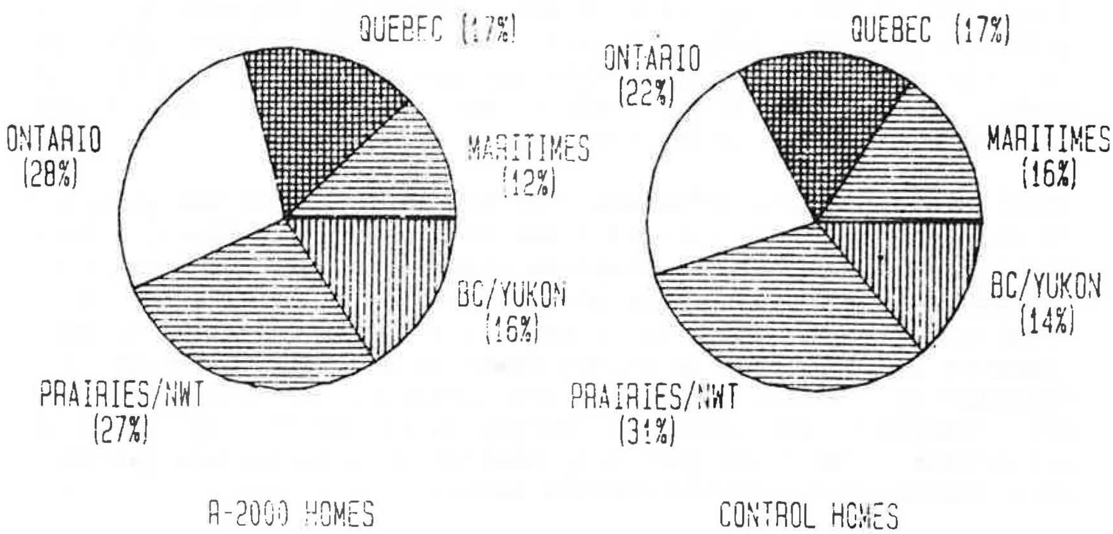


FIGURE 4. SPACE HEATING FUEL

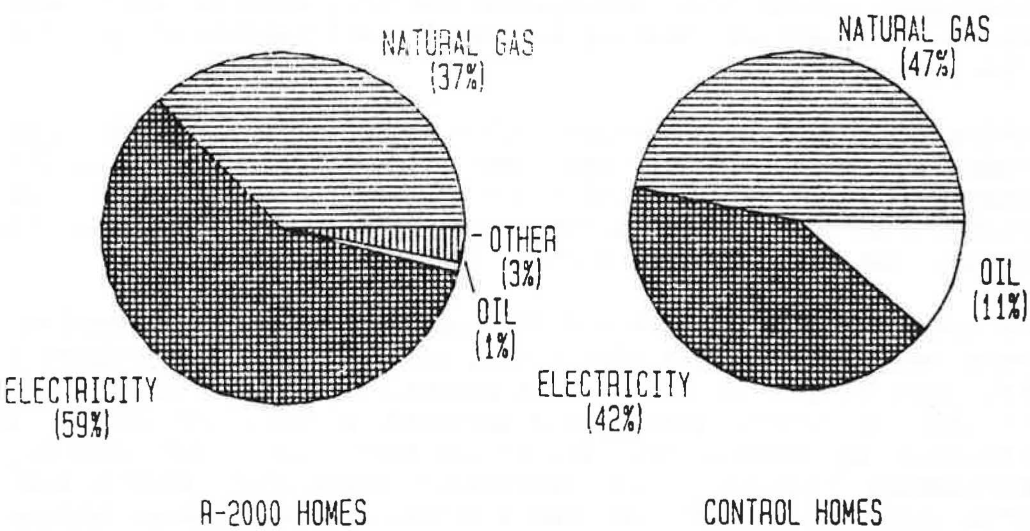


TABLE 1

HOUSE BUILDING ENVELOPE CHARACTERISTICS

	R-2000 HOMES		CONTROL HOMES	
	Average	Range	Average	Range
HOUSE VOLUME (m^3)	525	388-662	462	300-624
INSULATION LEVEL (RSI)				
Ceiling	8.2	4.9 - 11.9	6.1	3.5 - 7.0
Main Walls	5.5	3.5 - 9.6	3.5	2.1 - 5.8
Basement Walls	3.9	1.3 - 8.8	1.9	0.0 - 3.5
Basement Floor	1.1	0.0 - 5.0	0.0	0.0 - 0.0
Windows	0.44	0.21- 0.56	0.34	0.21- 0.49
AIRTIGHTNESS				
Air changes at 50 Pa	0.84	0.13- 1.50	4.58	2.0 - 7.1 (4 homes)

3.3 Ventilation System Capacity Monitoring

3.3.1 Objectives

Mechanical ventilation systems were tested to determine whether they complied with the following:

- a capability to provide continuous ventilation of 5 L/s (10 cfm) per room (including kitchen and bathrooms) based on ASHRAE Standard 62-81, Ventilation for Acceptable Indoor Air Quality and 10 L/s (20 cfm) for basement and utility areas;
- an overall system capacity of 0.5 ach for continuous and intermittent operation; and
- balanced supply and exhaust airflows for heat recovery ventilators.

Technicians were requested to document the quality of ventilation system installations.

3.3.2 Procedures

The required ventilation system capacity for continuous and intermittent ventilation was established at the building plans examination stage by determining the interior heated volume of the house (including basement area) and calculating the required airflow rate which was equivalent to 0.5 ach.

Construction plans supplied by builders were reviewed by technicians to determine the continuous ventilation rate on the basis of 5 L/s per room. Kitchen and bathrooms were included and combined rooms such as living and dining areas were treated as individual rooms for calculation purposes. A requirement of 10 L/s for basement and utility rooms was added, since these areas are not specifically addressed in ASHRAE 62-81.

Airflow tests were performed on both the supply and the exhaust air streams using a TSI Model 1650 Air Velocity Meter. The results represent the average of at least 6 measurements taken across the duct diameter. Static pressure measurements, obtained with a Dwyer 2000-0 Magnahelic Differential Pressure Gauge and Probe, were used to derive airflows on the basis of specific fan curves for each HRV. The fan curves (airflow vs static pressure) were prepared by the Ontario Research Foundation as part of the HRV performance testing to CSA Preliminary Standard C-439, Standard Methods of Test for Rating the Performance of Heat Recovery Ventilators.

3.3.3 Results

The results are presented for the R-2000 homes only, since only one control home had a continuous mechanical ventilation system.

The maximum installed airflows (Table 2) are based on the maximum airflow measured in either the supply air duct to the heat recovery ventilator, which provides outside air to the house, or in the exhaust air duct which removes stale air from the house.

The results show that the mean airflows were similar, regardless of house size, heating distribution system or location. This is not surprising, since in most of the initial R-2000 homes ventilation air was supplied to one or two locations in the home. Natural convection or a forced-air heating system was then relied upon to distribute the air throughout the house.

TABLE 2

MAXIMUM AIRFLOWS MEASURED IN R-2000 HOME VENTILATION SYSTEMS

HOUSE CHARACTERISTICS	MEASURED SYSTEM AIRFLOWS (L/s)			
	No.	Mean	Std Dev.	Median
ALL R-2000 HOMES	259	69.3	19.6	69.8
HOUSE VOLUME				
$<500\ m^3$	124	69.4	20.3	67.2
$>500\ m^3$	135	69.2	19.1	72.2
SPACE HEATING DISTRIBUTION				
Electric Baseboard	94	68.8	21.3	67.2
Forced-Air	165	69.6	18.7	70.8
REGION				
Maritimes	34	64.0	23.0	67.5
Quebec	45	65.1	22.1	63.7
Ontario	71	70.4	18.2	71.7
Prairies/NWT	66	71.6	16.6	70.5
British Columbia/Yukon	43	72.7	20.1	75.0

Table 3 and Figure 5 express the measured maximum airflows shown in Table 2 in terms of air change rates (ach). The mean measured installed ventilation system capacity in R-2000 homes was 0.5 ach. Given that the measured airflows did not vary significantly with house category, the results indicate that smaller homes (less than 500 m^3 in volume) had a mean ventilation system capacity equivalent to 0.61 ach, while in larger homes (greater than 500 m^3), the system capacity was equivalent to 0.41 ach. The difference is statistically significant and and reflects the lack of HRVs able to meet the requirement for an installed capacity of 0.5 ach in some large homes. The variation in results by region and by space heating distribution system reflect differences in average house volume.

These measurements do not include any contribution from natural air leakage or infiltration through the building envelope, which is estimated to be 0.05 ach for the average R-2000 home.

TABLE 3

INSTALLED VENTILATION SYSTEM CAPACITY

HOUSE CHARACTERISTICS	MEASURED SYSTEM CAPACITY (ach)			
	No.	Mean	Std Dev.	Median
R-2000 HOMES	259	0.50	0.21	0.47
HOUSE VOLUME				
$<500\ m^3$	124	0.61	0.23	0.58
$>500\ m^3$	135	0.41	0.14	0.41
SPACE HEATING DISTRIBUTION				
Electric Baseboard	94	0.56	0.21	0.54
Forced-Air	165	0.47	0.21	0.45
REGION				
Maritimes	34	0.44	0.17	0.42
Quebec	45	0.55	0.18	0.52
Ontario	71	0.47	0.20	0.42
Prairies/NWT	66	0.52	0.25	0.47
British Columbia/Yukon	43	0.55	0.22	0.56

Table 4 shows the minimum continuous ventilation requirements, expressed in both L/s and equivalent air changes per hour, for the interior heated house volume. The mean required continuous ventilation rate was 49.2 L/s which is equivalent to 0.35 ach. The rate for smaller homes was 43.6 L/s or 0.38 ach, and 55 L/s or 0.32 ach for larger homes.

TABLE 4

CONTINUOUS VENTILATION REQUIREMENTS BASED ON ASHRAE 62-81

HOUSE CHARACTERISTICS	No.	Ventilation Rate L/s	ach
ALL R-2000 HOMES	258	49.2	0.35
HOUSE VOLUME			
$<500\ m^3$	124	43.6	0.38
$>500\ m^3$	134	55.0	0.32
SPACE HEATING DISTRIBUTION			
Electric Baseboard	94	45.1	0.37
Forced-Air	164	51.6	0.34
REGION			
Maritimes	33	49.7	0.33
Quebec	42	41.3	0.35
Ontario	68	53.5	0.35
Prairies/NWT	72	49.4	0.35
British Columbia/Yukon	43	49.1	0.38

NOTE: Includes kitchen and bathrooms and a rate of 10 L/s for basement and utility areas since these were not specified in ASHRAE 62-81

Table 5 and Figure 5 show that the measured system capacity was, on average, 45% greater than that necessary to meet the requirement for continuous ventilation; 27% greater in large homes and 64% greater in small homes.

TABLE 5

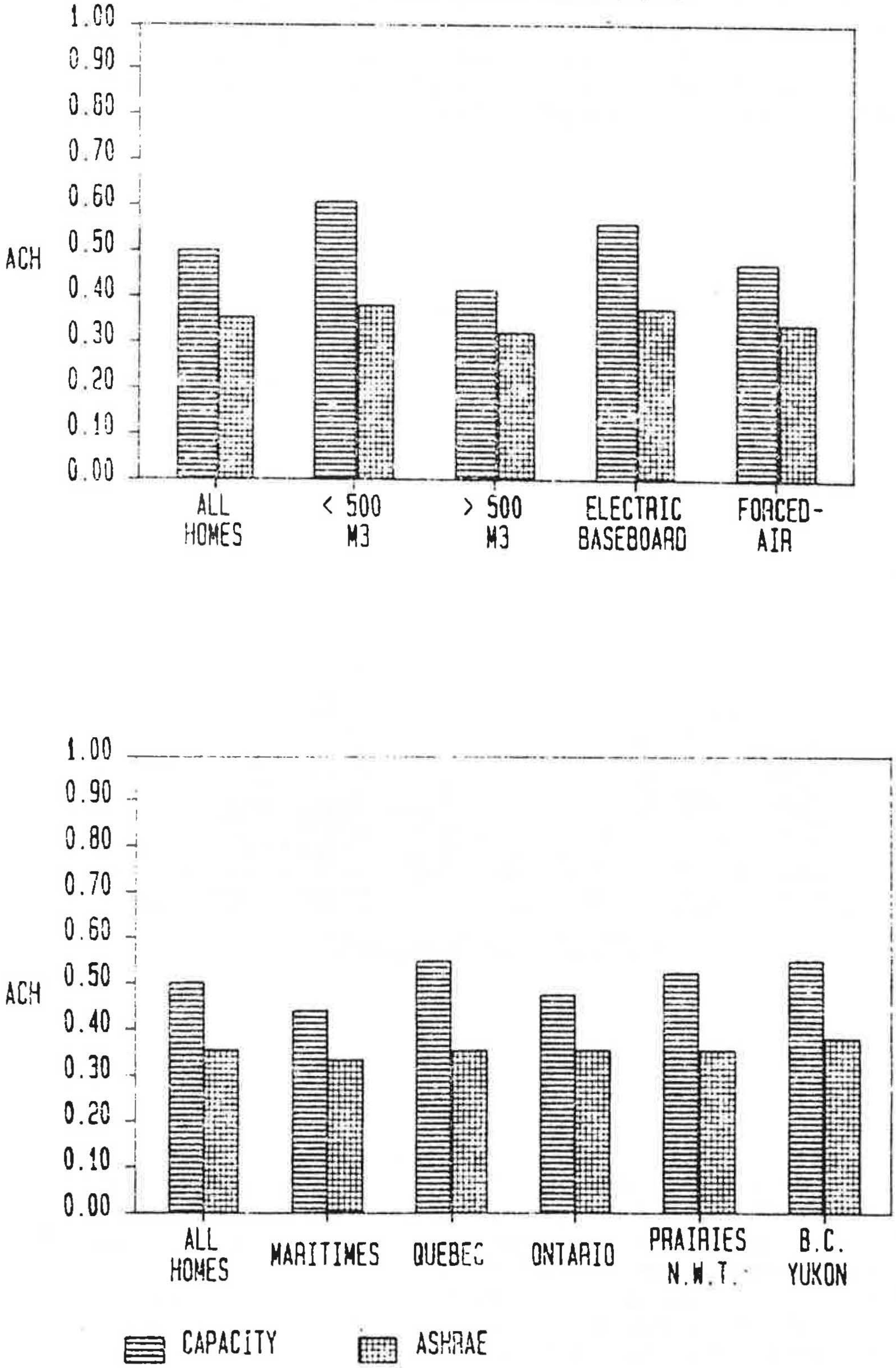
COMPARISON OF MEASURED AIRFLOWS WITH REQUIREMENTS FOR CONTINUOUS VENTILATION

	No.	PERCENT. DIFFERENCE* Mean %	Std Dev. %	Median %
ALL R-2000 HOMES	253	44	51	40
HOUSE VOLUME				
$<500\ m^3$	123	62	53	56
$>500\ m^3$	127	27	43	24

* [(measured airflow - req'd airflow)/req'd airflow] x 100

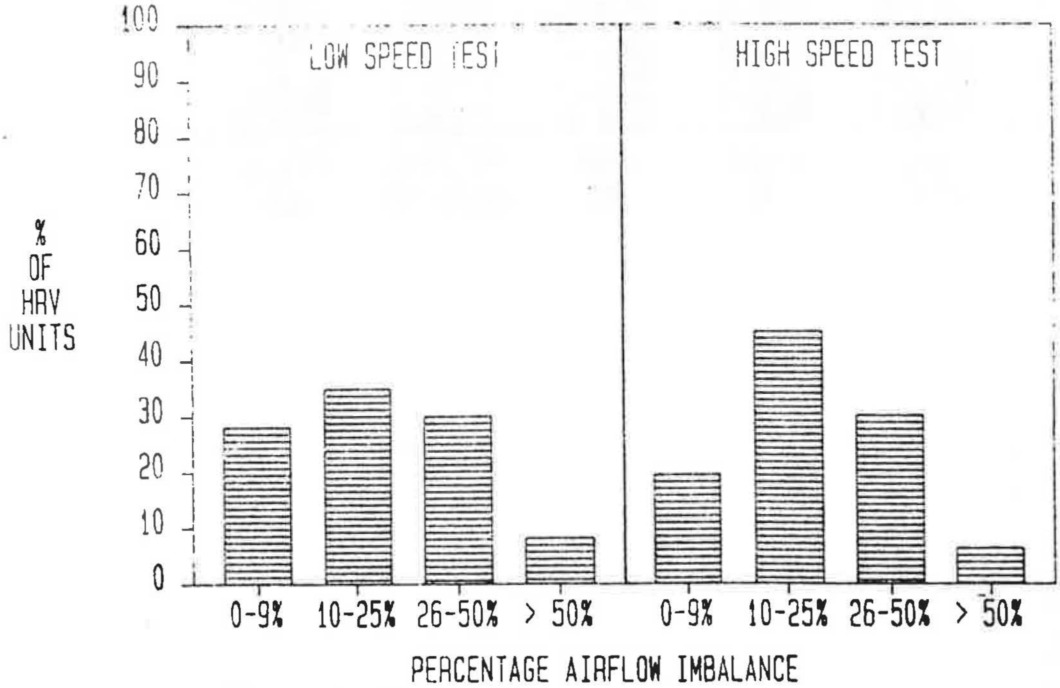
FIGURE 5

FIGURE 5. COMPARISON OF VENTILATION SYSTEM CAPACITY WITH ASHRAE REQUIREMENTS



In order to determine whether HRVs were balanced in accordance with program requirements, the percentage difference between the measured supply airflow entering the ventilator and the measured exhaust airflow leaving the ventilator during low speed and high speed operation was calculated. Figure 6 shows that at low speed operation only 28% of ventilation systems were balanced within the 10% range specified by the R-2000 technical criteria, and at high speed only 19% were balanced within 10%.

FIGURE 6. FREQUENCY DISTRIBUTION OF HRV AIRFLOW IMBALANCE



It was apparent that the majority of installers did not carry out field balancing of the systems. Less than 15% of the installations contained balancing dampers. This is not surprising, since most installers did not have access to balancing equipment and were not aware that unbalanced airflows can affect HRV heat recovery efficiency and increase the amount of energy consumed for space heating.

Field reports indicate that good airflows depend more upon the quality of the installation than on the rated airflow capacity of a particular HRV. The monitoring visits revealed that poor duct design, excessive use of flexible ducting, and the use of ducts measuring 125 mm or less in diameter led to a significant reduction in airflow in some units. Most of these problems can be attributed to the lack of trained and experienced installers.

Steps are being taken to ensure that all HRV units are balanced and meet minimum airflow requirements. Balancing of mechanical ventilation systems would normally involve installing a simple damper in the duct with the highest airflow in order to reduce the airflow. However, this may lower the system capacity to below that required by the R-2000 program. Balancing an existing system may therefore necessitate changes to ventilation equipment and ductwork in some homes in order to maintain the required minimum ventilation capacity. The R-2000 monitoring program will continue to test R-2000 homes to verify that the ventilation requirements are being met.

3.4 Air Change Rate Monitoring

3.4.1 Objectives

While the program specifies the ventilation system capacity and continuous ventilation rate in R-2000 homes, these requirements may not reflect the actual average air change rate. Factors such as how air is supplied and circulated throughout the house, control settings, occupant activities, operation of other air-exhaust equipment (range hood, bathroom fans, clothes dryer, etc.) and natural air infiltration have an impact on the average air change rate in a home.

The objective of air change rate monitoring was to measure the average ventilation rates in R-2000 homes and in a sample of conventionally built homes which relied solely on natural air leakage or infiltration for ventilation.

3.4.2 Procedures

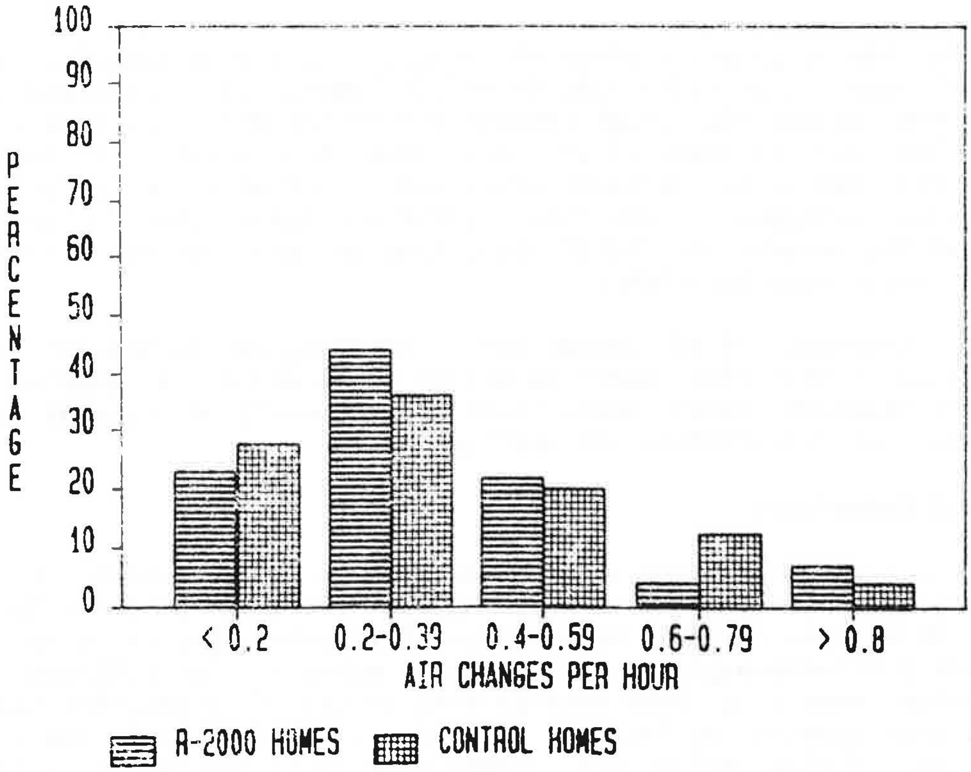
The average air change rate for each house was determined by the capillary adsorption tube sampling (CATS) procedure[6] developed at Brookhaven National Laboratory. Calibrated sources emit an inert perfluorocarbon tracer (PFT) gas which is then collected by passive samplers. Four sources were installed on exterior walls and four samplers on interior partition walls for the 30-day test period, during which the houses were operated under normal conditions. Temperature, house volume, and relative humidity were recorded. The samplers were then sent to the Brookhaven National Laboratory, New York for gas chromatographic analysis.

This technique is relatively new and has not been extensively validated. It was selected as the only inexpensive method of measuring air change rates in a large sample of homes in all regions of the country. The R-2000 program is comparing air change rates measured in a small sample of test homes by means of the CATS procedure with those obtained using a continuous tracer gas technique.

3.4.3 Results

The following analysis is based on measurements completed in 123 R-2000 homes and 25 control homes in the spring of 1984. The frequency distribution (Figure 7) indicates similar measurements for both R-2000 and control homes, with approximately 73% of results lying within the range 0.2 to 0.8 ach.

FIGURE 7. FREQUENCY DISTRIBUTION OF CATS MEASUREMENTS, 1984



The results were analyzed by arithmetic mean, standard deviation and medians. No attempt was made to screen out measurements that may have been unreasonable, i.e. greater than 1 ach or less than 0.1 ach. Due to the long delay (12 months) in completing the analysis at the Brookhaven National Laboratory and the high cost of repeat testing, it was not possible to check suspect measurements. As a result, the standard deviations are high and there may be some skewness of the data, but the distribution and trends shown by the data are consistent and allow general conclusions to be drawn. However, none of the trends were considered to be statistically significant due to the high standard deviation.

The analysis presented in Table 6 indicates that the average CATS air change rate was 0.37 ach in R-2000 homes, 10% higher than in control homes (0.34 ach). Factors such as house size, location and type of space heating distribution system were also examined (Table 6 and Figure 8).

Smaller R-2000 homes exhibited an average air change rate of 0.40 ach, slightly higher than larger homes (0.34 ach). This is probably a reflection of the capability of the HRVs to provide a higher air change rate in smaller homes. Similarly, the average air change rate in smaller control homes was 0.41 ach, somewhat higher than in larger homes (0.28 ach).

The mean CATS rate in R-2000 homes with electric baseboard heating was 0.32 ach, while homes with forced-air heating systems had a CATS rate of 0.39 ach. Control homes with a forced-air heating system also had a higher rate (0.38 ach) than those with electric baseboard heating systems(0.28 ach). Although these results are not statistically significant, they do indicate that good air circulation within the building envelope may be a factor in overall ventilation effectiveness. The lower rates in R-2000 homes in the Maritimes and Quebec reflect this trend, since these regions had a high percentage of electric baseboard heated homes (60% and 100% respectively), compared with Ontario (14%), the Prairies (17%) and British Columbia (36%).

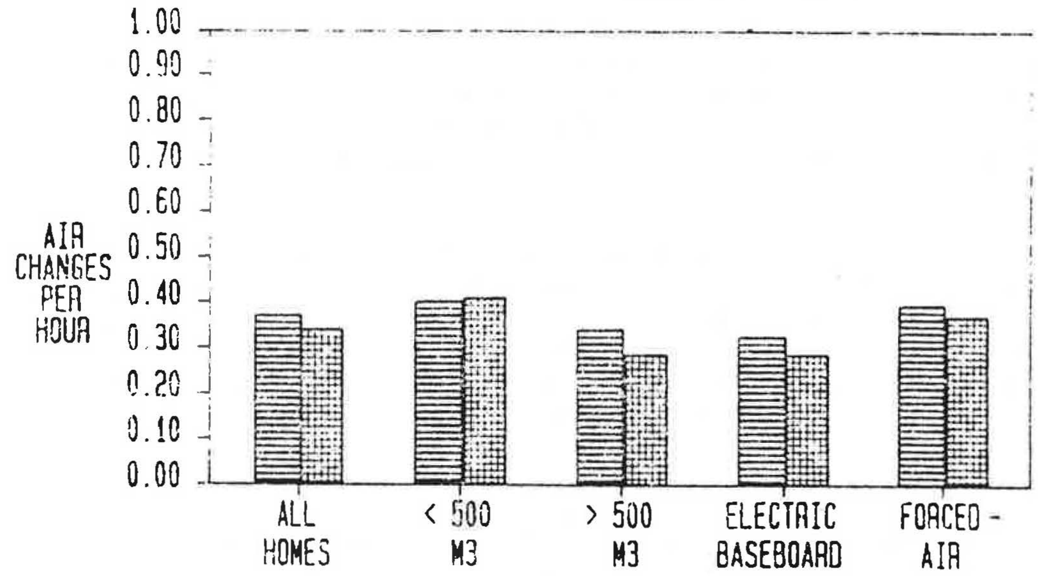
TABLE 6

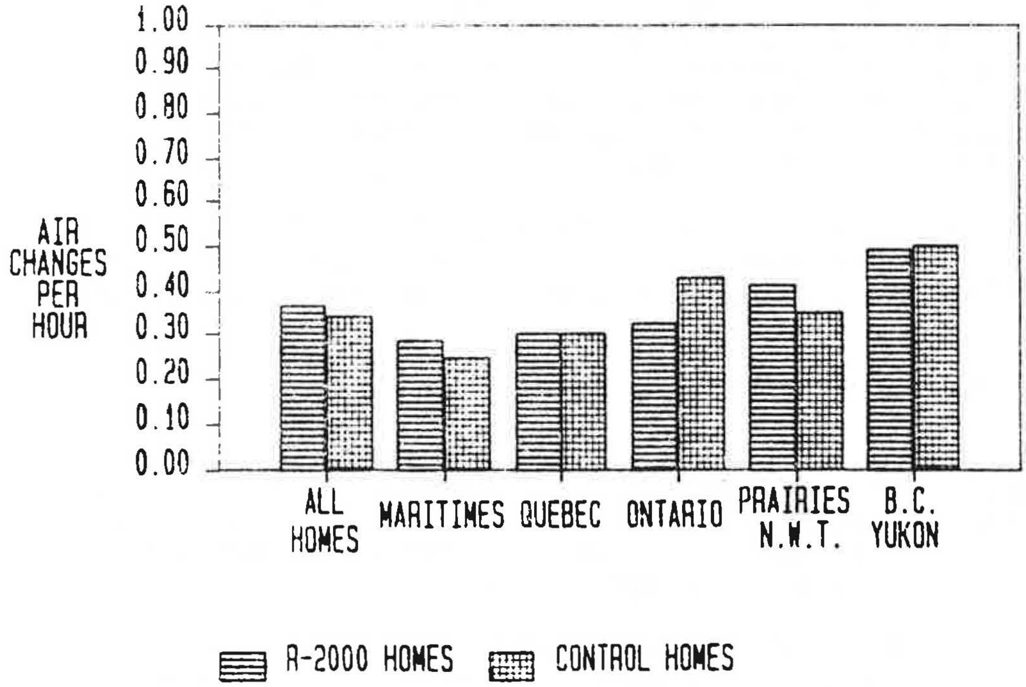
AIR CHANGE RATES (CATS)

HOUSE CHARACTERISTICS	CATS* AIR CHANGE RATE (ach)			
	No.	Mean	Std Dev.	Median
R-2000 HOMES				
All R-2000 Homes	123	0.37	0.34	0.28
House Volume				
$<500\ m^3$	54	0.40	0.39	0.29
$>500\ m^3$	69	0.34	0.29	0.27
Space Heating Distribution				
Electric Baseboard	40	0.32	0.24	0.27
Forced-air	76	0.39	0.46	0.28
Region				
Maritimes	16	0.30	0.15	0.26
Quebec	17	0.30	0.29	0.27
Ontario	35	0.33	0.15	0.28
Prairies/NWT	34	0.41	0.43	0.26
British Columbia/Yukon	21	0.49	0.47	0.43
CONTROL HOMES				
All Control Homes	25	0.34	0.22	0.28
House Volume				
$<500\ m^3$	14	0.41	0.22	0.38
$>500\ m^3$	10	0.28	0.21	0.27
Space Heating Distribution				
Electric Baseboard	7	0.28	0.22	0.20
Forced-Air	18	0.37	0.22	0.38
Region				
Maritimes	5	0.26	0.06	0.28
Quebec	4	0.30	0.29	0.18
Ontario	3	0.43	0.16	0.34
Prairies/NWT	11	0.35	0.27	0.26
British Columbia/Yukon	2	0.50	0.02	0.50

* "Capillary adsorption tube sampling" tracer gas method [6].

FIGURE 8. AVERAGE AIR CHANGE RATES (CATS)





3.5 Formaldehyde Monitoring

3.5.1 Objectives

Formaldehyde is a chemical substance belonging to a group of organic compounds known as aldehydes. Formaldehyde gas can be released into the air as a result of 'offgassing' or 'outgassing' from household products and building materials. The amount of formaldehyde in the indoor air is small and measurements are normally given in parts per million (ppm).

Resins incorporating formaldehyde are used in the manufacture of building materials, such as particleboard, panelling and plywood, as well as furnishings, paint and common household products like adhesive tape and glue. Normally a new product will emit somewhat higher levels of formaldehyde gas initially and then the emission rate will decrease to a lower level over time.

Draperies, carpets, clothing and other consumer goods may also contain formaldehyde, either as a glue component or as a coating on the fibres to reduce wrinkling. After new fabrics are washed, however, formaldehyde levels are greatly reduced. Formaldehyde is also released as a product of some types of combustion, including cigarette smoking.

Individuals show varying tolerance to formaldehyde gas. While many people experience no negative effects, even at high levels, others are sensitive to somewhat lower concentrations. At high levels of exposure, formaldehyde can cause eye, nose and throat irritation or respiratory problems. The likelihood depends on the concentration of formaldehyde in the air and the sensitivity of individuals, their general health, smoking habits and the degree of previous exposure to the gas.

The objectives in monitoring formaldehyde levels were to determine the concentration and distribution of formaldehyde gas in R-2000 and control homes, to assess whether these levels were within the current guideline.

3.5.2 Monitoring Procedures

EMR regional office technicians installed Dupont Pro-Tek badges, purchased from Dupont de Nemours of Wilmington, Delaware, in a living and sleeping area in 248 R-2000 homes and 46 conventional control homes. The badges were installed during the late winter and early spring (February to April) of 1984.

Three badges were installed in each home. One was located in a bedroom and one in a central location; the third was not exposed in order to serve as a laboratory control. Temperature and humidity measurements were taken to determine the environmental conditions at the start of exposure. The badges were left in the home for seven days and then sent to I.E.C. Beak Laboratories, Mississauga for laboratory analysis.

In the late spring of 1985 (March through May), repeat monitoring was conducted on a large sample of homes using a second type of monitoring device, the AQRI PF-1 formaldehyde monitor developed at Air Quality Research Incorporated in Berkeley, California. These monitors were installed in the living and sleeping areas of 110 R-2000 and 76 control homes. The AQRI monitors were also removed after seven days and sent to the Ontario Research Foundation laboratories for analysis. The PF-1 monitor was selected for the 1985 tests because of its availability, lower cost, ease of installation and transportation, and ease of analysis.

3.5.3 Results

The frequency distribution of measurements taken in bedrooms in 1984 (Figure 9) shows that results were similar for both R-2000 homes and control homes. Only 8% of R-2000 homes and 9% of control homes exceeded the Health and Welfare Canada interim guideline of 0.1 ppm. The measurements obtained in 1985 with the AQRI monitor show that 30% of control homes exceeded the interim guideline, while only 8% of R-2000 homes exceeded the guideline. The increase in the percentage of control homes with elevated formaldehyde levels in 1985 may reflect lower air change rates and higher humidity levels. The 1985 measurements were taken later in the spring when natural infiltration rates may have been lower in control homes. Control homes did not incorporate mechnical ventilation systems.

Table 7 and Figure 10 present further analysis of the measurements taken in the bedrooms of both R-2000 and control homes in the spring of 1984. Levels in bedroom and living areas were similar, therefore the living room measurements are not shown. Factors such as house size, location and space heating distribution system were examined.

Both the R-2000 and control homes had similar average formaldehyde levels; 0.060 ppm and 0.057 ppm respectively. These are well below the Health and Welfare Canada interim guideline. The slightly higher level in the sample of R-2000 homes could be due to the higher percentage with electric baseboard heating systems (38%) compared with the control homes (30%); homes with electric baseboard heating were generally found to have slightly higher formaldehyde levels. Control and R-2000 homes with electric baseboard heating systems exhibited a mean formaldehyde concentration of 0.062 to 0.065 ppm, 15-20% higher than homes with forced-air heating systems. For the R-2000 homes this was statistically significant. Formaldehyde levels were slightly higher in R-2000 homes in the Maritimes and Quebec, where electric baseboard heating predominates. House volume seems to have little effect on observed formaldehyde levels.

FIGURE 9. FREQUENCY DISTRIBUTION OF FORMALDEHYDE MEASUREMENTS

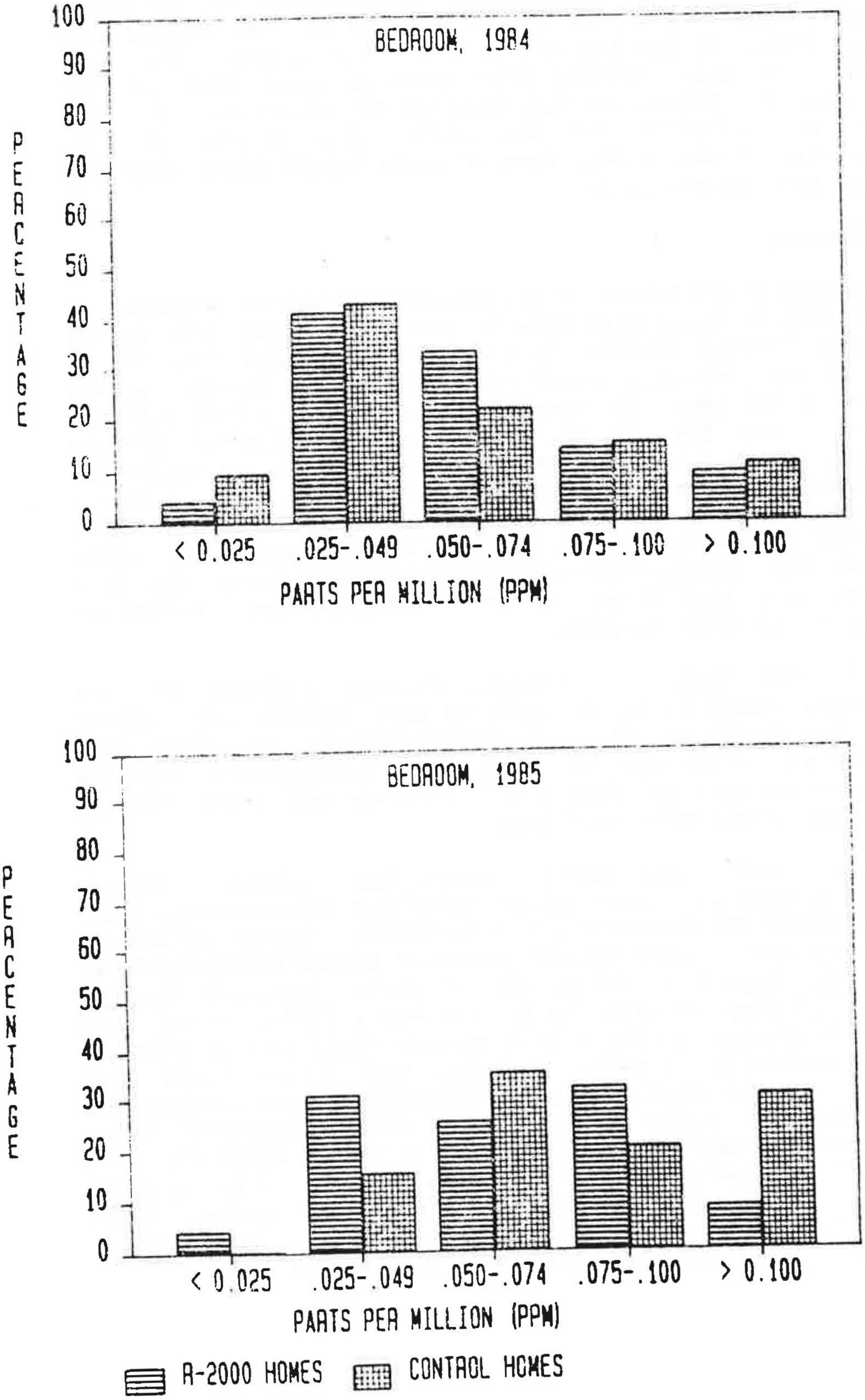
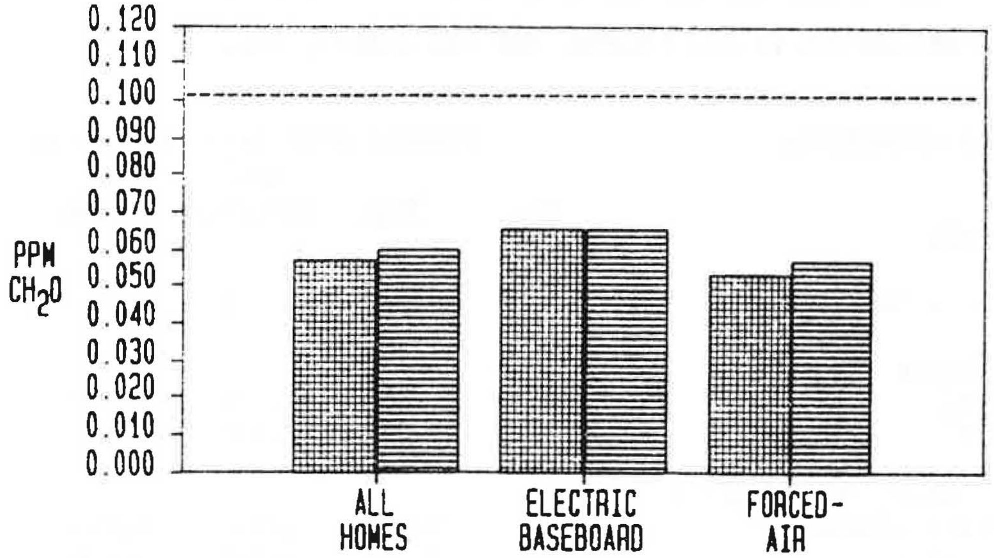


TABLE 7

FORMALDEHYDE LEVELS (DUPONT PRO-TEK BADGE), 1984

HOUSE CHARACTERISTICS	FORMALDEHYDE LEVEL (BEDROOM) (ppm)			
	No.	Mean	Std Dev.	Median
R-2000 HOMES				
All R-2000 Homes	248	0.060	0.029	0.053
House Volume				
<500 m^3	126	0.060	0.027	0.053
>500 m^3	122	0.060	0.031	0.055
Space Heating Distribution				
Electric Baseboard	95	0.065	0.032	0.059
Forced-Air	148	0.057	0.027	0.058
Region				
Maritimes	33	0.069	0.034	0.072
Quebec	46	0.066	0.029	0.061
Ontario	52	0.054	0.026	0.048
Prairies/NWT	71	0.061	0.029	0.057
British Columbia/Yukon	46	0.051	0.024	0.043
CONTROL HOMES				
All Control Homes	46	0.057	0.030	0.047
Space Heating Distribution				
Electric Baseboard	14	0.065	0.033	0.057
Forced-Air	32	0.053	0.029	0.040
Region				
Maritimes	7	0.052	0.018	0.047
Quebec	7	0.075	0.041	0.057
Ontario	10	0.050	0.027	0.047
Prairies/NWT	16	0.054	0.029	0.041
British Columbia/Yukon	6	0.062	0.036	0.059

FIGURE 10. FORMALDEHYDE LEVELS (PRO-TEK BADGE), 1984



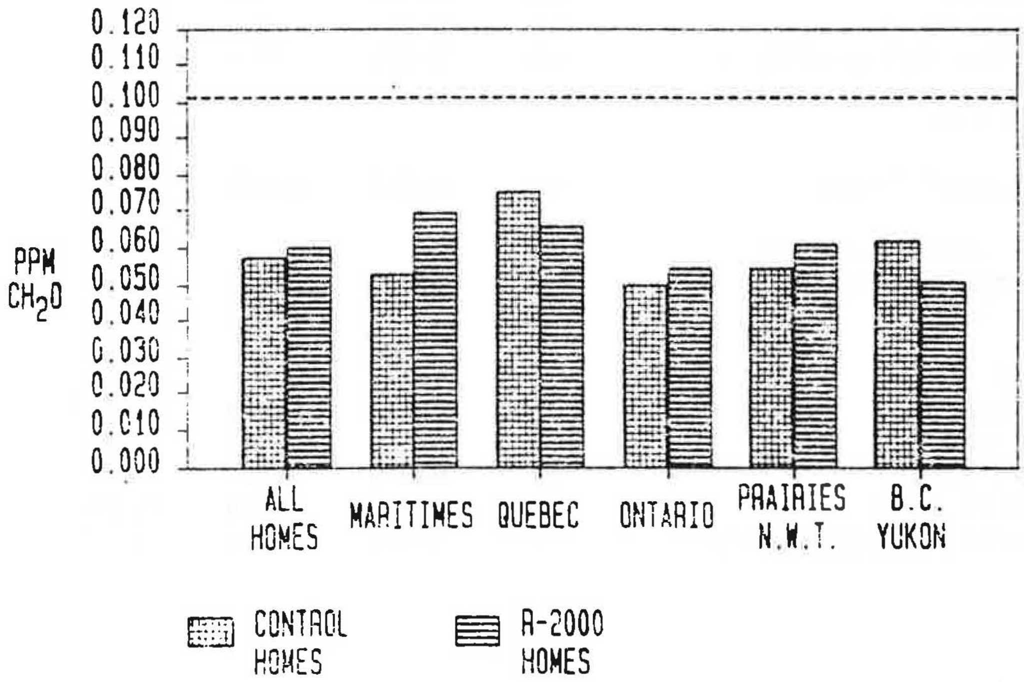


Table 8 and Figure 11 present the results of repeat testing completed in the spring of 1985 with the AQRI PF-1 monitor. Since a different monitoring device was used, the results cannot be directly compared with those obtained in 1984. Chamber tests indicate that the PF-1 monitor will normally measure 10% to 20% higher than the Dupont badge[7].

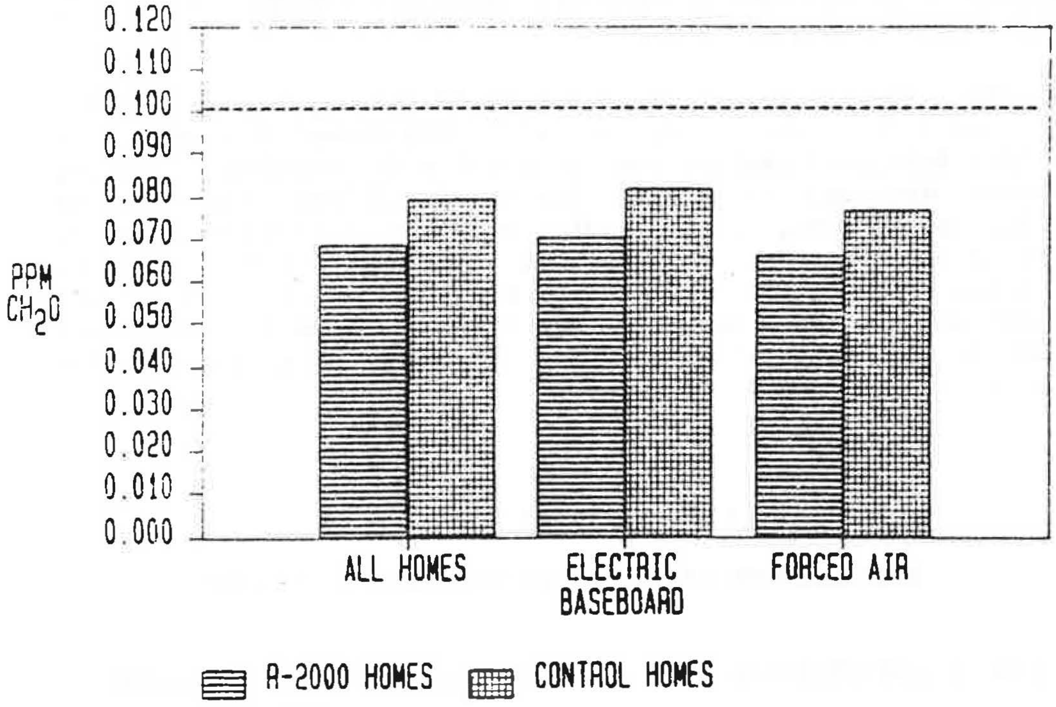
The 1985 results show mean levels to be 16% higher in control homes than in R-2000 homes, and 6% to 10% higher in homes with electric baseboard heating than in homes with forced-air heating systems. Although not statistically significant due to the smaller sample size, these results show a similar trend to those obtained in 1984. The 1985 results also indicate that there is no rapid reduction in formaldehyde levels in homes as they age. Conventional wisdom had been that there would be a significant reduction in levels during the first years following construction of a home.

TABLE 8

FORMALDEHYDE LEVELS (AQRI PF-1 MONITOR), 1985

HOUSE CHARACTERISTICS	FORMALDEHYDE LEVEL (BEDROOM) (ppm)			
	No.	Mean	Std Dev.	Median
R-2000 HOMES				
All R-2000 Homes	110	0.068	0.027	0.064
Space Heating Distribution				
Electric Baseboard	46	0.070	0.027	0.069
Forced-Air	64	0.066	0.028	0.061
CONTROL HOMES				
All Control Homes	16	0.079	0.037	0.067
Space Heating Distribution				
Electric Baseboard	10	0.081	0.032	0.079
Forced-Air	6	0.076	0.048	0.056

FIGURE 11. FORMALDEHYDE LEVELS (AQRI PF-1 MONITOR), 1985



Although the level of formaldehyde in individual homes depends on a number of factors, including source concentration, humidity and temperature and the age of the home, in this large sample of homes formaldehyde levels were found to be generally higher in homes with electric baseboard heating and without an air circulation system. Further analysis of 17 R-2000 homes which exceeded the Health and Welfare Canada guideline shows that 70% had electric baseboard heating systems and 47% had ventilation air supplied to the basement, where natural air movement was relied upon to distribute the air through the house. However, other influencing factors may have been inappropriate control settings, intermittent operation and occupant behaviour, since none of these homes exhibited a CATS air change rate in excess of the calculated minimum continuous ventilation requirement (equivalent to 0.32 ach for these homes), although the mean capacity of the ventilation systems was 0.46 ach.

Formaldehyde monitoring of all R-2000 and control homes will continue during the 1985/86 monitoring period to determine whether levels decrease over time. The small number of homes with high formaldehyde levels are being visited and retested to determine ways of reducing these levels. Given that the majority of R-2000 homes with high formaldehyde levels had sufficient measured system capacity, the issues of system controls and occupant behaviour will be examined and assessed. The R-2000 program criteria have already been revised to require that ventilation air be distributed continuously to each room of the house (including kitchen and bathrooms) at a minimum rate of 5 L/s per room and 10 L/s (20 cfm) for basement and utility areas.

3.6 Radon Monitoring

3.6.1 Objectives

Radon is a colourless, odourless gas that is normally present in air at low concentrations. It is formed during the natural decay of radioactive elements which are present in the ground in all areas of Canada. Since the amount of radon is related to the particular characteristics of the surrounding subsoil, rock and groundwater, levels vary widely from region to region. Radon gas itself quickly breaks down by radioctive decay into radon daughters which also have a very short half-life of less than 27 minutes.

Radon gas can enter buildings from the soils on which they are constructed by way of foundation cracks and other openings. Radon can also be introduced in the water supply, particularly from a well. Small quantities can be released from building materials, such as stone, brick, concrete and plaster. Since radon normally enters buildings from the the surrounding soil, the concentration of the gas is usually highest in the basement.

Levels inside a home can vary significantly according to the concentration in the surrounding soil, how well the foundation is sealed, the barometric pressure and the relative air pressures inside and outside the house. In addition, air movement within the building, the direction and strength of the wind, and even the time of year can all affect radon levels.

The objectives of radon monitoring were to measure the levels in R-2000 and control homes and determine whether they were below the current guideline.

3.6.2 Procedures

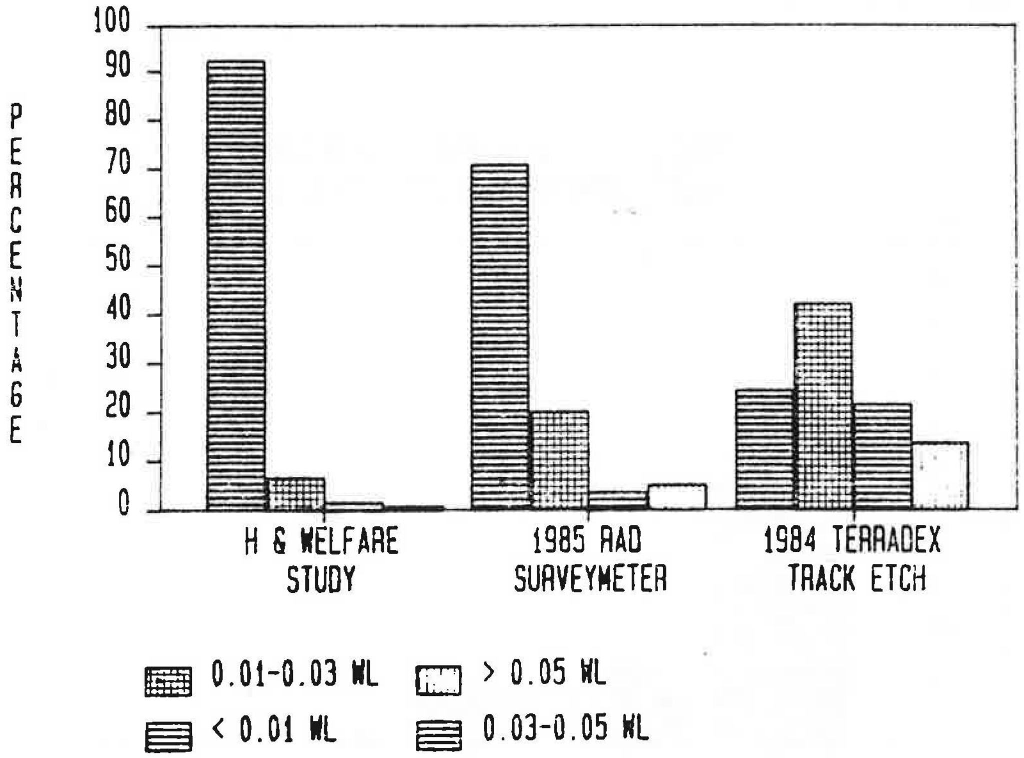
During the initial phase of monitoring in 1984, the Track Etch cup, manufactured by the Terradex Corporation (Walnut Creek, California), was used to measure radon gas in basements over a thirty-day period. Testing was performed concurrently with CATS air change rate monitoring. The Track Etch radon cup detects the presence of alpha particles by means of etchings on a sensitive filament within a cup. A special filter allows only radon 222 to enter the cup to strike the filament and excludes other radioactive and sub-atomic particles. EMR regional office technicians installed the cups in the basement, where the highest levels were expected.

The Terradex cup was selected because of its low cost, wide use, and acceptance by building researchers throughout North America for general field studies, even though the procedure does not require data on house characteristics, volume, airflow near the etching surface, humidity, dust particulates, etc., but uses only the exposure period and empirically derived relationships to determine radon and radon daughter levels.

During the initial monitoring program it became apparent that there were unexplained inconsistencies and variations in the results. Duplicate testing in six homes also produced large variations in some measurements, and analysis of 10 field blanks by the laboratory indicated some exposure to radon gas when the readings should have been near zero. Furthermore, the Terradex procedure uses a standard equilibrium factor of 0.5 to derive radon daughter working levels (WL) from radon gas concentrations measured in picocuries/litre (pCi/L), but this does not allow for variability of factors such as particulate level, ventilation rate, air movement, age of the radon gas, and plateout or deposition of radon daughters on surfaces. Concern was raised as to whether certain features of R-2000 homes, such as insulated floor slabs or the discharge of ventilation air and the resulting air circulation in the basement, may alter the equilibrium factor. Also, thirty days' exposure is considered to be the minimum recommended period for monitoring and this may have been a contributing factor. The frequency distribution of results obtained with the Terradex cups (Figure 12) in 1984 was substantially different from that of measurements obtained in a Health and Welfare Canada survey of 10,000 homes across Canada[8]. Therefore, the results were considered to be questionable and have not been included in this report. Terradex believes that the minimum exposure time (1 month) and handling problems may have contributed to the inconclusive results. It was suggested that 3 to 5 detectors be deployed to establish radon concentrations, but the cost of retesting rendered this recommendation impractical.

The RAD surveymeter, an inexpensive active monitoring device that measures actual radon daughter levels, was selected for use in the spring of 1985. This device, manufactured by R.A.D. Service and Instruments Ltd. (Scarborough, Ontario), consists of an air pump and a detecting surface to measure actual working levels of radon daughters. The detection sensitivity is controlled by the pump airflow rate and exposure time. Duplicate test results and three controlled tests conducted at the Elliot Lake Radiation Laboratory and the Environmental Measurements Laboratory, New York indicate good agreement (within 10-15%) with actual levels in the chambers. Figure 12 shows that the distribution of the 1985 RAD results agrees well with the national survey performed by Health and Welfare Canada. A detailed report on the validation of the RAD surveymeter is in preparation.

FIGURE 12. COMPARISON OF FREQUENCY DISTRIBUTION OF RADON DAUGHTER WORKING LEVELS

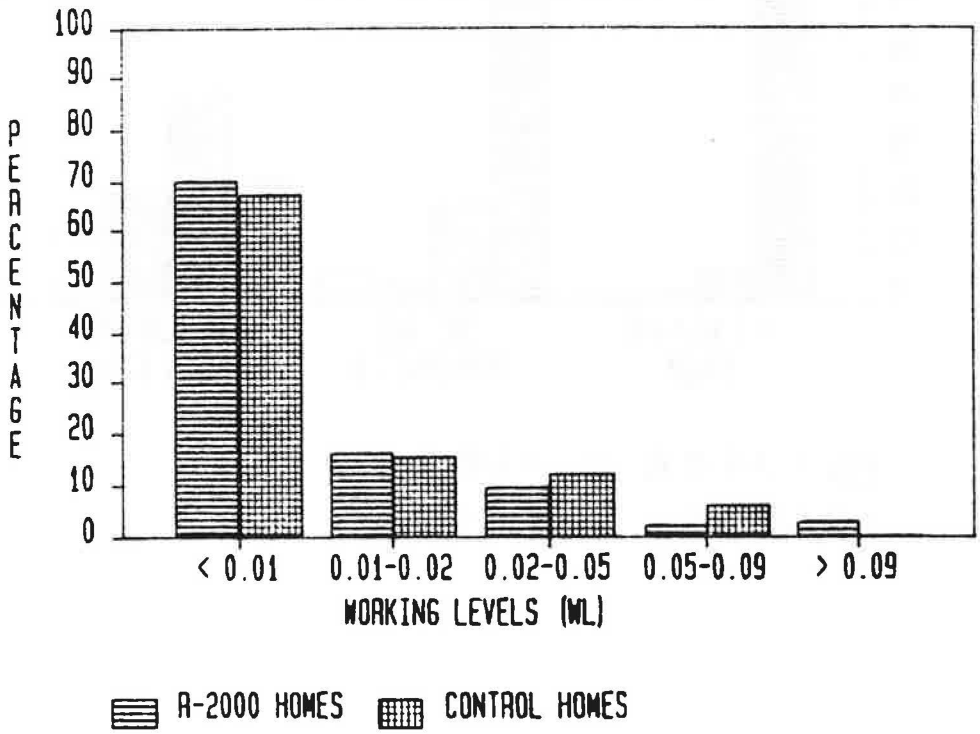


3.6.3 Results

Due to the log normal distribution (Figure 13), the 1985 radon results (Table 9) are presented in terms of the geometric mean (GM) and not the arithmetic mean. The GM is the antilog of the sum of the logarithms of the measurements divided by the number of measurements. To determine the log distribution around the GM, the GM is multiplied by the geometric standard deviation. Because of the log normal distribution, a large geometric standard deviation is expected. The geometric mean is generally used for analyzing a large number of radon measurements which follow a log normal distribution, including the Health and Welfare Canada survey.

Table 9 shows that the GM of radon working levels measured in the spring of 1985 was 0.006 WL in 148 R-2000 homes and 0.007 WL in 33 control homes. These levels are similar, and are well below proposed guidelines being considered by the Sub-Committee on Radiation Surveillance, which is in the process of determining a satisfactory level for homes on behalf of the Federal/Provincial Advisory Committee on Environmental and Occupational Health. The the current interim guideline is 0.1 WL and proposed levels range from 0.02 to 0.1 WL.

FIGURE 13. FREQUENCY DISTRIBUTION OF RADON DAUGHTER WORKING LEVELS, 1985



The breakdown of radon levels by region (Table 9 and Figure 14) shows a GM of 0.012 WL for R-2000 homes and 0.011 WL for control homes in the Maritimes. These levels were 57-100% higher than the GM for all homes, and are thought to be caused by the underlying geological strata, which are composed of granites and other formations with higher uranium content. Although the difference is statistically significant, these levels are still well below any of the guidelines being considered by Health and Welfare Canada. Radon levels in the Prairies were not significantly higher than in other locations, though the soils are more permeable and are generally thought to support the diffusion of radon to the surface or into basements. Cost constraints prohibited a detailed geological study of the soils surrounding each home. Results are not available for British Columbia because of delays in completing the 1985 field monitoring activities.

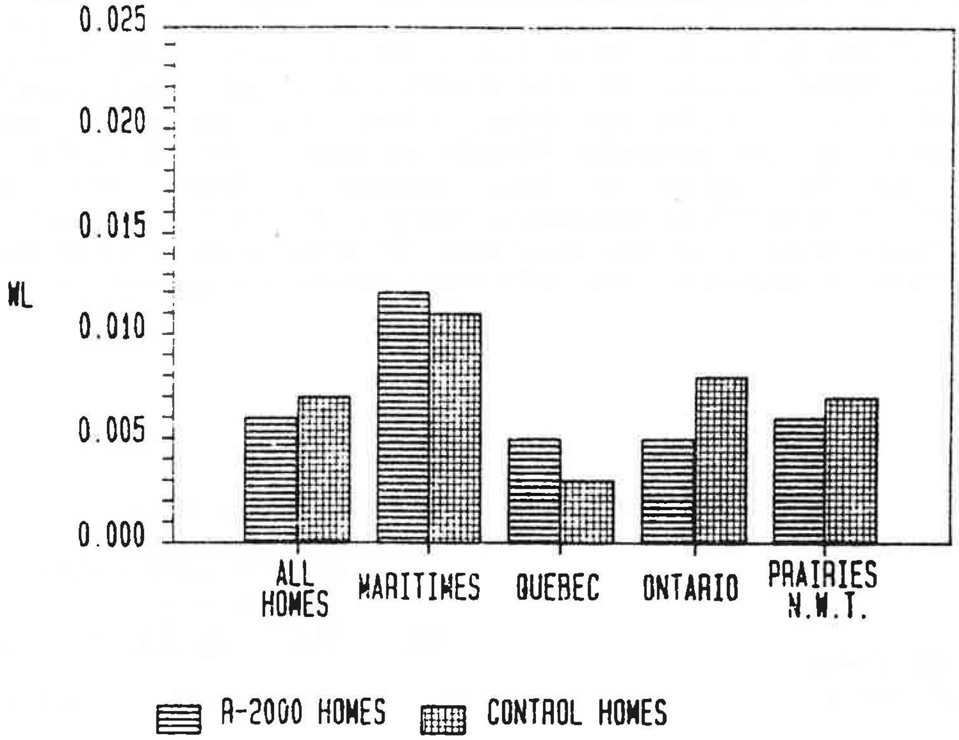
TABLE 9

GEOMETRIC MEAN OF RADON LEVELS BY REGION, 1985

		WORKING LEVELS (WL) Geometric		
	No.	Mean	Std Dev.*	Median
R-2000 HOMES				
All Homes	148	0.006	3.29	0.006
Region				
Maritimes	24	0.012	4.24	0.011
Quebec	30	0.005	4.16	0.004
Ontario	47	0.005	2.48	0.005
Prairies/NWT	47	0.006	2.75	0.006
British Columbia/Yukon	0	0.000	0.00	0.000
CONTROL HOMES				
All Homes	33	0.007	3.24	0.007
Region				
Maritimes	5	0.011	2.05	0.009
Quebec	7	0.003	2.99	0.003
Ontario	8	0.008	3.03	0.008
Prairies/NWT	12	0.007	3.86	0.008
British Columbia/Yukon	1	0.010	0.00	0.010

* Geometric standard deviation is multipied by the mean to determine the deviation around the mean.

FIGURE 14. RADON LEVELS BY REGION, 1985



3.7 Nitrogen Dioxide Monitoring

3.7.1 Objectives

Nitrogen dioxide (NO_2) is a gas formed as a product of combustion. It is colourless and has no odour unless present in high concentrations. Potential sources of NO_2 in the home include tobacco smoke and fuel-burning appliances, such as gas or wood stoves, fireplaces and space heaters, if these are not properly vented to the outside, are defective, or are not properly maintained and operated. Nitrogen dioxide may also enter the home from outside sources such as automobile exhaust, fuel burning and industrial processes.

Depending on its concentration and the sensitivity of the individual, NO_2 in the air is known to cause irritation of the skin and eyes. At high levels (above 50 ppm) prolonged exposure could possibly contribute to lung damage. However, knowledge of the health effects is limited because of the difficulty of isolating the effects of NO_2 from those of other pollutants in the air.

The objective of this monitoring activity was to determine the effect of combustion appliances and smoking on the levels and distribution of nitrogen dioxide.

3.7.2 Procedures

The device used to measure NO_2 was a passive monitor developed by Air Quality Research Incorporated of Berkeley, California. This monitor, containing a screen for absorbing nitrogen dioxide, was exposed in the home for a seven-day period and then sent to the Ontario Research Foundation for analysis. Measurements were taken in the spring of 1985 in those homes containing an operable combustion appliance (fireplace, wood stove, gas, kerosene or propane space heater, gas range, gas furnace or water heater) and in homes occupied by smokers.

Two monitors were installed in most homes with combustion appliances, one near the appliance and one in a bedroom without a combustion appliance. In homes where occupants smoked, a monitor was installed in the living room. Monitors were suspended from the ceiling in a location free from drafts.

3.7.3 Results

Nitrogen dioxide levels measured to date in both R-2000 homes and control homes have generally been low. Although a formal guideline for NO_2 in the indoor environment has not yet been established in Canada, the levels measured (0.004 to 0.008 ppm) were significantly below the maximum acceptable level of 0.05 ppm in ambient air established by Environment Canada.

The frequency distribution charts (Figure 15) show that levels in the living rooms and basements of R-2000 and control homes were generally below 0.010 ppm and none exceeded 0.020 ppm.

FIGURE 15. FREQUENCY DISTRIBUTION OF NITROGEN DIOXIDE LEVELS, 1985

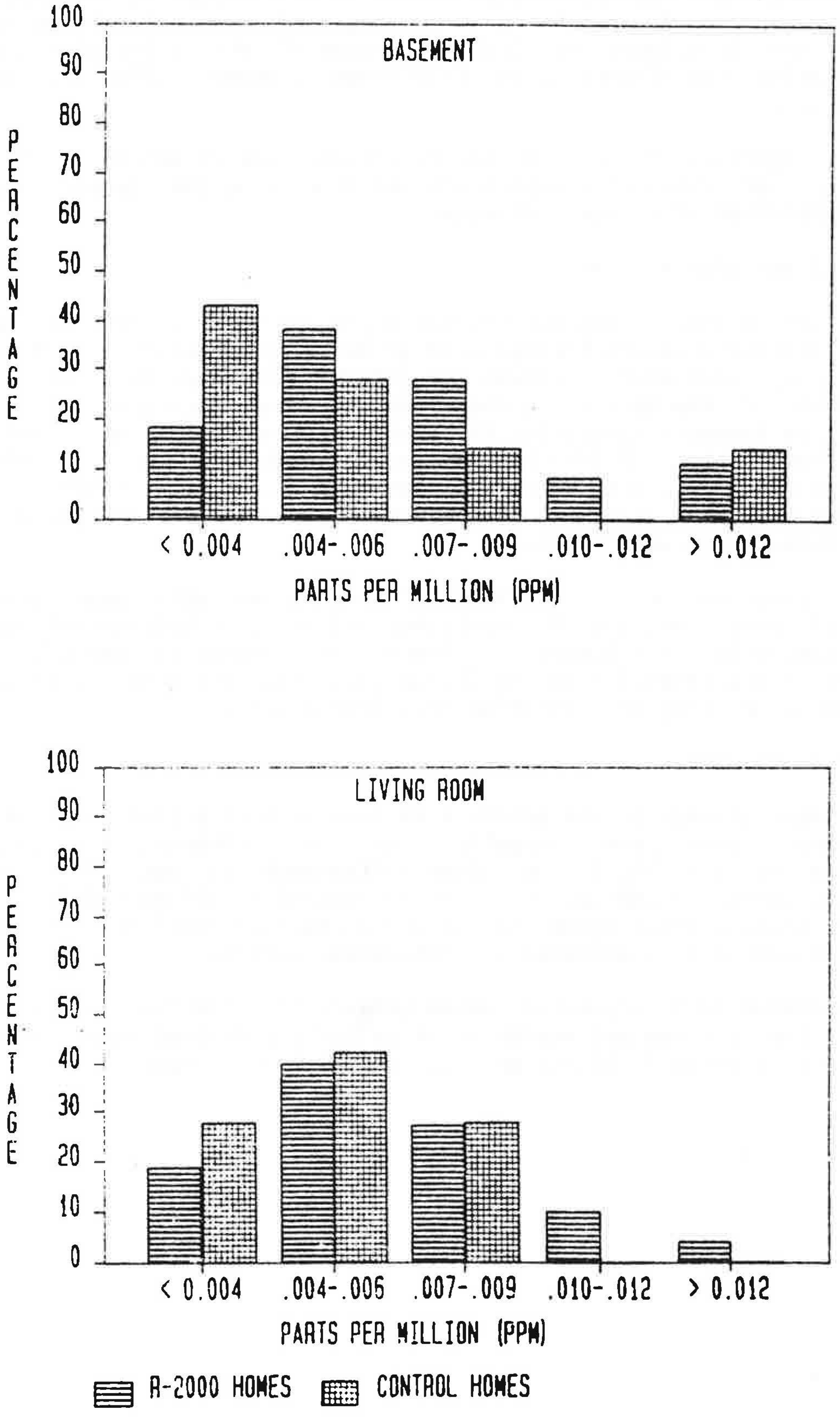


Table 10 shows that NO_2 levels in the basements of R-2000 and control homes were similar. Homes with fuel-fired equipment had slightly higher levels than electrically heated homes. The differences are not statistically significant and interpretation of the results must be limited in view of the low levels measured and the small sample of control homes.

TABLE 10

NITROGEN DIOXIDE LEVELS - BASEMENT, 1985

HOUSE CHARACTERISTICS	NITROGEN DIOXIDE LEVEL (ppm)			
	No.	Mean	Std Dev.	Median
R-2000 HOMES				
All R-2000 Homes	40	0.006	0.004	0.006
Space Heating Fuel				
Electricity	12	0.006	0.004	0.005
Other Fuels	28	0.007	0.004	0.006
CONTROL HOMES				
All Control Homes	7	0.006	0.005	0.004
Space Heating Fuel				
Electricity	3	0.005	0.003	0.006
Other Fuels	4	0.006	0.006	0.004

Table 11 shows that NO_2 levels in the living rooms of R-2000 homes with occupants who smoked were slightly higher, but this was not statistically significant. In homes with fireplaces and woodstoves the levels were no higher than in homes without woodburning appliances. This could be attributed to the season when testing was carried out (spring), when these appliances may have been operated infrequently, and to the fact that the R-2000 technical criteria require woodburning appliances to have well-sealed doors and an outside air supply for combustion.

Homes in the Maritimes appear to have NO_2 levels lower than those in other regions. Results are not available for British Columbia because of a delay in completing the 1985 field monitoring activities.

TABLE 11

R-2000 HOMES: NITROGEN DIOXIDE LEVELS IN LIVING ROOMS, 1985

HOUSE CHARACTERISTICS		NITROGEN DIOXIDE LEVEL (ppm)		
	No.	Mean	Std Dev.	Median
ALL R-2000 HOMES	74	0.006	0.003	0.005
WOODBURNING APPLIANCES				
Fireplace	24	0.006	0.003	0.006
Woodstove	6	0.006	0.002	0.006
No woodburning appliance	44	0.006	0.003	0.005
SMOKING				
Smokers	16	0.007	0.003	0.007
Non-Smokers	58	0.006	0.003	0.005
REGION				
Maritimes	16	0.003	0.002	0.003
Quebec	17	0.007	0.003	0.007
Ontario	24	0.006	0.002	0.005
Prairies/NWT	17	0.007	0.003	0.006
British Columbia/Yukon	0	0.000	0.000	0.000

4.0 CONCLUSIONS

The results of current monitoring activities indicate that air quality and ventilation rates in the first R-2000 homes are comparable with those in conventional homes. Air change rates and levels of formaldehyde, radon and nitrogen dioxide were similar.

In general, higher formaldehyde levels and lower CATS air change rates were measured in homes with electric baseboard heating systems. This indicates that further monitoring is necessary to determine the need for mechanical ventilation and air circulation systems in all newly constructed homes. These systems are now a requirement in all R-2000 homes.

The relatively low working levels of radon daughters measured in both R-2000 and conventional homes indicate that radon may not be a serious problem except in certain locations in some regions, such as the Maritimes. The R-2000 program has now commenced work on identifying and mapping radon risk areas in order to advise builders in these areas of a potential problem in advance of construction. Inconsistent results obtained during the initial phase of the program indicate a need for further validation of inexpensive monitors commonly used to measure radon gas over extended periods of time.

Ventilation systems in most R-2000 homes exceeded the requirement of being capable of providing continuous ventilation at a rate of 5 L/s per room (including kithen and bathrooms) and 10 L/s for basement and utility areas. Systems in some larger homes were not able to meet the program requirement for providing 0.5 ach capacity for both continuous and intermittent ventilation. It is now recognized that this requirement may be excessive for large homes, and revised ventilation requirements will be determined primarily by the number of rooms in the home and by a ventilation rate for each room based on ASHRAE Standard 62-81. Specifications are also being developed for acceptable strategies for controlling the ventilation system. These changes, coupled with the availability of improved "second generation" ventilation equipment, should resolve most of the problems relating to the installed capacity of ventilation systems in large homes.

Many ventilation systems were installed without supply and exhaust airflows balanced in accordance with program criteria. The R-2000 program has now developed guidelines for installing ventilation equipment which make it mandatory to measure airflows and to balance the unit at the time of installation. National training courses and an installer certification program provided through the Heating, Refrigerating and Air Conditioning Institute of Canada[9] will greatly improve the level of compliance with program criteria and improve quality assurance. Also under consideration is a requirement for airflow measuring sensors to be permanently installed in the ventilation system.

There is a need to better inform occupants about the correct way of operating their ventilation systems. Futhermore, the systems must be designed to ensure that occupants will operate them as intended. A guide to operating and maintaining ventilation equipment is being prepared as the first step in addressing these issues.

Support has been provided to the Canadian Standards Association (CSA) for the development of preliminary standards for testing and rating the performance of HRVs[10] and the development of national guidelines for installing ventilation systems[11]. The R-2000 program has also sponsored testing of HRV equipment in accordance with CSA Preliminary Standard C-439 by the Ontario Research Foundation[12].

It can be expected that ventilation and air quality in future R-2000 homes will be further improved as a result of program refinements and greater experience on the part of the building industry in constructing R-2000 homes. Program refinements include revisions to technical requirements, revised training courses, improved certification and inspection procedures, and revisions of national standards to address any concerns or issues raised during this monitoring phase. The program will continue to monitor ventilation and air quality in R-2000 homes.

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