R-2000

SUPER ENERGY EFFICIENT HOME PROGRAM

TECHNICAL REPORT

Canada

ENERGY PERFORMANCE OF R-2000 HOMES:
A Comparison of Measured Energy Consumption with the R-2000 Target and Computer Predictions for Homes Built to Current Building Practice

012-MR

Prepared for

The R-2000 Home Program
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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). This report presents the results of monitoring to measure energy consumption in a sample of R-2000 homes. The objectives were to determine whether the homes are performing to R-2000 energy targets and to compare consumption with energy predictions for the homes if they had been constructed in accordance with the 1975 National Building Code and the 1978 Measures for Energy Conservation.

The results indicate that the R-2000 target for space heating was, on average, 4% higher than measured consumption and the target for total annual energy consumption was 2% lower than measured energy consumption. Energy consumed for water heating averaged 13 kWh/day, slightly lower than the target of 14 kWh/day.

Computer predictions for these homes if they had been built to the 1975 Building Code suggest that energy consumption for space heating would have been, on average, 300% higher than measured consumption and total annual energy consumption 125% higher. If the homes had been constructed to the 1978 Measures for Energy Conservation, predicted energy consumption for space heating would have been 125% higher and total annual energy consumption 44% higher.

Energy consumption in individual homes varied because of differences in occupancy, appliance and lighting use and ventilation rates. The seasonal efficiency of Heat Recovery Ventilators (HRVs) and the measured air change rates were generally lower than originally assumed, and only 28% of ventilation systems were balanced according to the R-2000 technical criteria. The target had no provision for energy consumption outside the building envelope, including lighting, automobile block heaters, and lawnmowers. Also, air conditioning, dehumidification and other energy uses during the summer months were not considered. The average number of occupants was found to be three per home and not four as originally assumed.

For many homes these differences had a counteracting effect. For example, lower actual HRV efficiency, which increases energy consumption, would tend to be balanced out by lower average air change rates which reduced space heating demand. Actual energy consumption was generally lower than the target in warmer zones but was slightly higher in colder zones where the efficiency of HRVs was lower and there was possibly higher energy consumption for both interior lighting and exterior energy use because of the longer heating season and shorter days.

The report concludes that R-2000 homes are generally demonstrating energy-saving in close agreement with program goals. However, some of the assumptions used to establish the R-2000 energy target for individual homes need to be adjusted. Guidelines for the installation of whole-house mechanical ventilation equipment will be revised to make it mandatory to measure airflows and to balance HRVs at the time of installation. National training courses for installers, provided through the Heating, Refrigerating and Air Conditioning Institute of Canada (HRAI), will greatly improve quality assurance. A national technical advisory committee will consider any further changes necessary to ensure that the R-2000 Home will continue to represent a high-quality product which meets or exceeds accepted good building practice.

ABRÉGÉ

Le Programme de la maison à haut rendement énergétique R-2000 est une initiative conjointe du gouvernement fédéral et de l'industrie. Parrainé par Énergie, Mines et Ressources Canada (EMR), le programme est administré par l'Association canadienne des constructeurs d'habitations (ACCH). Le présent rapport contient les résultats du programme d'évaluation mis en oeuvre afin de mesurer la consommation d'énergie dans un groupe de maisons R-2000. Le but de ce programme était double : en premier lieu, déterminer si le rendement de ces maisons correspond aux objectifs énergétiques R-2000, et, en second lieu, comparer la consommation énergétique de ces maisons à la consommation prévue pour des maisons qui auraient été construites selon le Code national du bâtiment (édition de 1975) et les Mesures d'économie d'énergie (version de 1978).

Les résultats indiquent que l'objectif R-2000 pour le chauffage des pièces était en moyenne de 4 % supérieur à la consommation d'énergie mesurée; de plus, l'objectif R-2000 pour la consommation annuelle totale d'énergie était en moyenne de 2 % inférieure à la consommation mesurée. Dans ces maisons, le chauffage de l'eau consommait en moyenne 13 kW/jour, ce qui est légèrement inférieur à l'objectif de 14 kW/jour.

D'après les calculs faits sur ordinateur, si ces maisons avaient été construites selon les normes du Code national du bâtiment (1975), leur consommation moyenne pour le chauffage aurait été en moyenne de 300 % supérieure à la consommation mesurée, et leur consommation énergétique annuelle totale aurait été supérieure de 125 %. Si elles avaient été construites selon les Mesures d'économie d'énergie (1978), leur consommation énergétique prévue pour le chauffage des locaux aurait été supérieure de 125 %, et la consommation annuelle totale d'énergie aurait été supérieure de 44 %.

La consommation d'énergie variait d'une maison à l'autre pour plusieurs raisons : mode de vie des occupants, utilisation des appareils ménagers, éclairage, débits des appareils de ventilation. L'efficacité saisonnière moyenne des VRC et les taux mesurés de renouvellement de l'air étaient en moyenne plus faibles que les valeurs supposées au début du programme. En outre, seulement 28 % des systèmes de ventilation étaient équilibrés conformément aux critères techniques R-2000. L'objectif énergétique ne tenait pas compte de la consommation d'énergie à l'extérieur de l'enveloppe du bâtiment, notamment pour l'éclairage, les chauffe-moteur et les tondeuses. De plus, on n'a pas tenu compte des climatiseurs, des déshumidificateurs et des autres utilisations estivales de l'énergie. Le nombre moyen d'occupants s'établissait à trois personnes par maison, et non à quatre personnes comme l'on avait supposé au début.

Dans de nombreuses maisons, ces différences ont eu des effets compensatoires. Par exemple, le rendement moindre des VRC augmente

la consommation d'énergie, mais entraîne des taux de changement d'air plus faibles, ce qui, à son tour, réduit la demande d'énergie pour le chauffage des pièces. La consommation réelle d'énergie était, de façon générale, plus faible que la consommation cible dans les régions où la température est clémente, mais elle était légèrement plus élevée dans les régions plus froides. Cela s'explique par le fait que, dans ces dernières régions, l'efficacité des VRC est moindre et que l'on utilise probablement plus d'énergie pour l'éclairage intérieur et les utilisations extérieures, en raison d'une saison de chauffage plus longue et de journées plus courtes.

Le rapport conclut que la consommation d'énergie des maisons R-2000 correspond, de façon générale, aux objectifs du programme. Toutefois, il faudra modifier certaines des hypothèses retenues dans le calcul de l'objectif énergétique R-2000 pour les maisons particulières. Les lignes directrices pour l'installation du matériel de ventilation mécanique seront révisées, de sorte qu'il sera obligatoire de mesurer les débits d'air (entrée et sortie) des VRC au moment de leur installation. Le contrôle de la qualité sera grandement amélioré par la mise sur pied de cours nationaux de formation, lesquels seront dispensés aux installateurs par l'Institut canadien du chauffage, de la climatisation et de la réfrigération. Un comité technique consultatif national examinera toutes les modifications requises pour faire de la maison R-2000 un produit qui répond ou est supérieur aux normes actuelles de construction.

1.0 INTRODUCTION

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

The R-2000 Home Program actively supports the evolution and commercialization of energy-efficient housing through the development of consensus standards for products and equipment; laboratory testing of products and equipment; training and education programs for the building industry; public awareness; the development of inspection procedures for quality assurance; and an extensive field monitoring program involving all R-2000 demonstration homes.

The objectives of the R-2000 Home Program are:

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

2. To encourage the design, construction and demonstration of a number of R-2000 homes across Canada.

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

4. To document and monitor the construction techniques, problems and energy consumption of houses built under the program to obtain data on the costs, savings and performance of R-2000 homes.

To date, 400 registered R-2000 demonstration homes have been built in Canada. Large-volume construction will only proceed when adequate inspection, testing and quality assurance procedures exist throughout the industry.

This report presents the results of energy monitoring of the initial R-2000 demonstration homes, including analysis to determine whether they are meeting energy performance targets. In addition, a comparison is made between actual measured energy consumption and predicted energy consumption if they had been built to the requirements of the 1975 National Building Code [1] or the 1978 Measures for Energy Conservation [2].

2.0 OVERVIEW OF TECHNICAL REQUIREMENTS FOR R-2000 HOMES

The R-2000 Program technical criteria[3] are essentially performance-oriented. This encourages builders to treat the whole house as a system, incorporating the most appropriate combination of features.

The R-2000 energy performance target evolved through detailed negotiations with the CHBA, Canadian Electrical Association, National Research Council of Canada and provincial representatives. The target varied according to house size and climate zone, though the target was fixed for water heating and appliance use, since consumption depends primarily on occupancy and not on house size or climate zone. Initially, no consideration was given to high-efficiency space and water heating equipment, but changes to the R-2000 energy target are planned.

The following formula was used to calculate the energy target for homes built during the demonstration phase of the program:

$$E_{TOTAL} = 10{,}600 + [\,(5 + 45DD/6000) \times M\,]$$

where:
- E_{TOTAL} = annual total energy consumption target in kWh.
- The term in brackets [ ] is the seasonal building envelope heat loss or space heating target in kWh.
- DD is the annual heating degree-days in Celsius degrees for the location of the home.
- M is the equivalent floor area in square metres, based on the interior heated volume (m^3) of the house (including basement), divided by 2.5.
- 10,600 is the non-space heating energy consumption target in kWh, based on 14 kWh/day for domestic hot water and 14 kWh/day for appliances & lighting.

The energy target is determined at the plans examination stage by means of a computer simulation program. This program, known as HOT-2000, is based on the HOTCAN Energy Analysis Program[4] developed by the National Research Council for predicting monthly and annual space-heating requirements in residential buildings.

In addition to the energy targets, other technical requirements were developed for health and safety reasons and relate primarily to indoor air quality and ventilation issues. These requirements include the installation of a controlled mechanical ventilation system; the selection of combustion appliances that prevent accidental backdrafting; and the provision of replacement air for appliances and combustion equipment that exhaust air to the outside.

The technical criteria specify that the air leakage rate through the building envelope must not exceed 1.5 ach at a fan-induced pressure difference of 50 Pa when tested in accordance with the R-2000 test procedure. This procedure is based on the preliminary Canadian General Standards Board (CGSB) draft standard for testing the airtightness of building envelopes[5]. This provision minimizes air leakage to protect the building envelope from moisture damage and permit the efficient operation of a mechanical ventilation system.

The mechanical ventilation system must provide both continuous ventilation for normal occupancy and additional intermittent ventilation to control excessive humidity and contaminants when the need arises. Given Canada's lack of formal standards and experience regarding mechanical ventilation in 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[6]. Following the initial phase of the program, the requirement was established for a minimum continuous ventilation rate of 5 litres per second (L/s) or 10 cubic feet per minute (cfm) to be delivered to each room (including kitchens and bathrooms) based on ASHRAE Standard 62-81, Ventilation for Acceptable Indoor Air Quality[7], and 10 L/s (20 cfm) for basements and utility areas. The criteria also specify that the mechanical ventilation system be balanced - neither creating nor contributing to an overall positive or negative pressure within the building envelope relative to the exterior.

It should be noted that the monitoring results presented in this report are for a sample of the first 300 R-2000 homes built in 1983. These homes were built in accordance with the initial program criteria which have now been refined.

3.0 MONITORING AND ANALYSIS

3.1 Characteristics of R-2000 Homes

The initial R-2000 demontstration homes are characterized by high levels of insulation, control of air leakage by means of improved air barrier sealing techniques, mechanical ventilation systems (often 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. Detailed background information on each home was provided by the builder. This included a set of construction plans, a description of the building envelope characteristics including airtightness test results, information on mechanical systems, data on incremental costs of construction and consumer response and attitudes to R-2000 homes.

Figure 1 indicates the percentage of R-2000 homes built in each region. As would be expected, the larger percentages were built in the provinces of Ontario and Quebec. Figure 2 shows that approximately 60% of these homes were heated with electricity and the remainder primarily with natural gas. Approximately 34% had a woodburning appliance, such as a fireplace or woodstove. The insulation and airtightness characteristics are summarized in Table 1.

FIGURE 1. REGIONAL DISTRIBUTION OF R-2000 HOMES

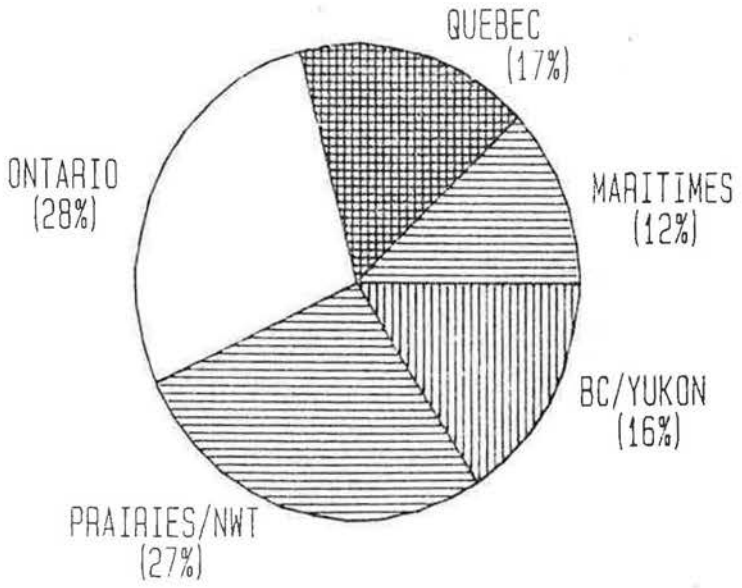


FIGURE 2. SPACE HEATING FUELS AND WOODBURNING APPLIANCES

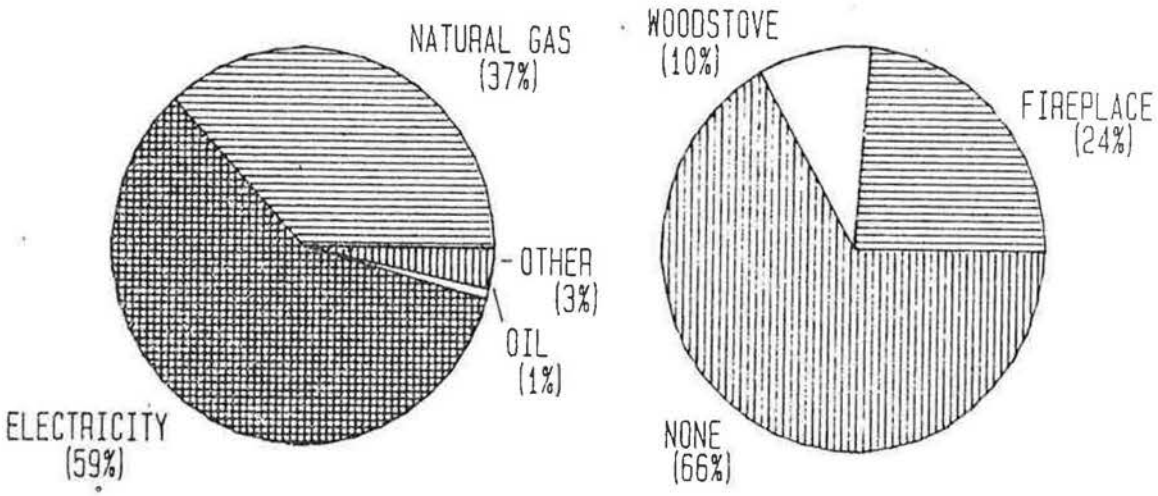


TABLE 1

BUILDING ENVELOPE CHARACTERISTICS OF R-2000 HOMES

	Average	Range
HOUSE VOLUME (m^3)	525	388-662
INSULATION LEVEL (RSI)		
Ceiling	8.2	4.9 - 11.9
Main Walls	5.5	3.5 - 9.6
Basement Walls	3.9	1.3 - 8.8
Basement Floors	1.1	0.0 - 5.0
Windows	0.44	0.21- 0.56
AIRTIGHTNESS		
Air changes at 50 Pa (ach)	0.84	0.13-1.50

3.2 The R-2000 Monitoring Program

The monitoring program has the following overall objectives:

1. To monitor and document the techniques, costs, problems and energy consumption of R-2000 homes in order to evaluate the R-2000 program technical requirements.

2. To obtain information on the ventilation and air quality characteristics of R-2000 homes, and determine whether they comply with program requirements and how performance compares with a sample of conventionally built homes.

3. To determine occupant/user attitudes and the level of satisfaction with the energy-related features of the R-2000 home, including the performance of the various mechanical systems and the level of energy savings and comfort in the home.

To date, the monitoring program has focused on the need for general quality assurance. A number of contaminants have been measured to assess indoor air quality, mechanical ventilation systems have been tested, and energy consumption has been monitored in the initial R-2000 homes. A sample of conventionally built homes constructed by contractors participating in the R-2000 program were also included for comparative purposes.

The field monitoring activities were carried out by trained technicians from EMR regional offices in each province and territory in Canada. A comprehensive monitoring manual was prepared on all aspects of the monitoring program, including administrative procedures, liaison with occupants, questionnaire completion, energy metering, air quality monitoring procedures and ventilation system testing. Laboratory and field support was provided by the Ontario Research Foundation (ORF), regional engineering firms and several laboratories in Canada and the United States.

Since air exchange can account for up to 50% of the heat loss from an R-2000 home, emphasis was placed on measuring the performance of mechanical ventilation systems to determine whether they were operating in accordance with program criteria. Airflows in the supply and exhaust air streams of HRVs were measured using a TSI Model 1650 Air Velocity Meter. Average air change or ventilation rates were measured in a sample of R-2000 homes by means of the capillary adsorption tube sampling (CATS) procedure, developed at Brookhaven National Laboratory[8]. Laboratory testing to determine the efficiency of HRVs was conducted at the Ontario Research Foundation to CSA Standard C439, Methods of Test for Rating the Performance of Heat Recovery Ventilators[9]. These tests were used to predict HRV seasonal efficiencies using a monthly temperature bin model developed for the HOT-2000 program. Information from occupant questionnaires was used to identify differences between actual occupancy and the assumptions made when the energy target was established.

3.3 Energy Consumption Monitoring

The homes were equipped with meters to separately measure energy consumption for space heating and domestic water heating, as well as total consumption. During house visits, EMR regional technicians identified and recorded meter function, multiplier and conversion factors pertaining to the meters, the heating equipment being monitored, and the type of fuel or energy being measured.

EMR regional technicians provided the occupants with meter reading and card completion instructions and asked them to complete meter reading cards each month and mail these to EMR. Occupants were also asked to allow EMR access to utility bills if verification of the meter readings was required.

A detailed comparison of space heating energy consumption with the energy target requires at least one full winter's space heating data. Since energy monitoring in most homes commenced in February 1984, monitoring data for a full heating season were not available until April 1985.

Information was entered in the Energy Data Base, which calculates the energy consumption of each home from actual meter readings. This can then be compared with the energy target or any computer prediction of energy consumption. The Energy Data Base is one of several modules belonging to the Energy Statistics System, which in turn is part of a larger system known as the R-2000 Technical Information System, which stores detailed information for each home on micro-computer.

Based on the type and configuration of installed meters identified by the regional technicians during their initial visit, space heating, water heating and total energy consumption were calculated for each home. Since the energy target is expressed in kWh/day, a conversion factor was used to express the meter readings or measured fuel in kilowatt-hours. The efficiency of the heating equipment was based on the general seasonal efficiency ratings established for use in the HOTCAN energy analysis program (Table 2). The energy target did not take into account the efficiency of the heating equipment.

TABLE 2

SEASONAL EFFICIENCY OF HEATING EQUIPMENT

SPACE HEATING EQUIPMENT	EFFICIENCY %
ELectric:	
Forced-air Furnace	100
Baseboard/Radiant Heaters	100
Gas/Propane:	
Naturally Aspirating Furnace	55
Hydronic/ Boiler	70
Induced Draft-Fan Furnace	75
High Efficiency/Condensing Furnace	85
Pulse Furnace	90
Oil:	
Naturally Aspirating Furnace	55
Hydronic/Boiler	65
Tankless Coil	65
High Efficiency Furnace	75
Condensing Furnace	90
WATER HEATING EQUIPMENT	
Electric Water Heater (tank, heat pump, etc.)	100
Naturally Aspirating Gas Water Heater	55
Power-Vented (Induced Draft Fan) Gas Water Heater	72
Condensing Gas Water Heater	87
Naturally Aspirating Oil Water Heater	50
HEAT RECOVERY VENTILATORS	70

The procedure developed to measure energy consumption in a home and compare it with the energy target can be summarized as follows:

1. Read meters and record dates of readings;

2. Record meter functions and calculate the space heating, water heating and total energy use;

3. Adjust for fuel type and equipment efficiency and express energy consumption in terms of kWh/day;

4. Calculate the percentage difference or the ratio between actual energy consumption and the target or a computer prediction.

The data on space heating, water heating and total energy consumption, and any other pertinent information in the data base, are then transferred to a file for analysis using MICROSTAT Version 4.0 (trademark of Ecosoft Inc.).

3.4 Energy Consumption and Conventional Building Practice

To obtain an indication of energy consumption if the homes had been constructed to conventional levels of energy efficiency, additional HOT-2000 computer simulations were generated using insulation values and thermal characteristics specified in the 1975 National Building Code and the 1978 Measures for Energy Conservation. Table 3 summarizes the assumptions and values used for the computer simulations. Actual energy consumption in homes built to these standards will vary according to occupancy, actual weather conditions, and the characteristics of the home when occupied.

TABLE 3

REFERENCE STANDARDS

1975 National Building Code		CELSIUS DEGREE-DAY ZONE				
		up to 3333	4444	5556	6667	7778
Ceilings	RSI	1.73	2.08	2.38	2.64	2.89
Main Walls	RSI	1.73	2.08	2.38	2.47	2.47
Basement Walls:						
Above Grade	RSI	1.48	1.48	1.48	1.48	1.48
2 ft. Below Grade	RSI	1.48	1.48	1.48	1.48	1.48
2 ft. to Footing	RSI	0.00	0.00	0.00	0.00	0.00
Basement Floor	RSI	0.00	0.00	0.00	0.00	0.00
Doors	RSI	0.40	0.40	0.40	0.40	0.40
Glazing/Windows	RSI	0.15	0.15	0.15	0.35	0.35
Infiltration Rate	ACH	0.45	0.45	0.45	0.45	0.45
Occupancy	kWh/day	3.20	3.20	3.20	3.20	3.20
Appliances/Lighting	kWh/day	16	16	16	16	16
Domestic Hot Water	kWh/day	16	16	16	16	16

1978 Measures For Energy Conservation		up to 3500	5000	6500	8000
Ceilings	RSI	4.7	5.6	6.4	7.1
Main Walls	RSI	2.5	3.0	3.4	3.7
Basement Walls:					
Above Grade	RSI	1.6	1.6	1.6	1.6
Below Grade	RSI	1.6	1.6	1.6	1.6
Basement Floor	RSI	0.0	0.0	0.0	0.0
Doors	RSI	0.7	0.7	0.7	0.7
Glazing/Windows	RSI	0.3	0.3	0.45	0.45
Infiltration Rate	ACH	0.4	0.4	0.4	0.4
Occupancy	kWh/day	3.2	3.2	3.2	3.2
Appliances/Lighting	kWh/day	16	16	16	16
Domestic Hot Water	kWh/day	16	16	16	16

4.0 MONITORING RESULTS

Only general statistical analysis of results is presented in this report, including the arithmetic mean and standard deviation of the ratio of measured energy consumption to the target or predicted consumption for individual homes, and scatter plots.

The differences between actual consumption and the prediction or target may appear to be large, while the absolute difference in kWh/day may be small. This is due to the extremely low energy consumption in some homes. This is most evident in small homes and those in warm weather zones, where small differences in actual consumption can appear to be large when expressed as percentages or ratios.

Student T-Tests with a confidence level of 0.95 were used to determine the statistical significance of the mean and standard deviation of the ratio of measured energy consumption to the target, i.e. when there was a significant difference from the ideal ratio of 1. The difference between measured energy consumption and predictions of energy consumption if the homes had been built to the reference standards is also presented.

4.1.0 Space Heating

Space heating energy consumption was analysed for those homes with meter readings for the 1984/85 heating season, which was defined as September 15, 1984 to April 15, 1985. It was necessary to specify the heating season, since many of the individual space heating meters also recorded energy consumption for other purposes, such as air conditioning and continuous fan operation throughout the year. The R-2000 space heating target was also expressed in terms of kWh/day for the heating season.

The analysis is presented for 126 homes. The data base contained 211 homes for which there were any meter readings, of which 76 homes were excluded because of insufficient meter readings and a further 9 homes because of suspect meter readings or fuel conversion factors. Some homeowners had difficulty reading meters, especially if they were of the "dial" type.

4.1.1 Comparison with Space Heating Target

Actual space heating consumption may differ significantly from the energy target if the assumptions made when the energy target was established do not reflect the characteristics after the home has been constructed and occupied. Ventilation rates and the efficiency of the heating equipment or heat recovery ventilator can be higher or lower than expected. Differences in the number of occupants, lifestyles, amount of time spent in the home, thermostat settings, and patterns of use of appliances and lighting can all have an impact on the space heating requirements. Unusual weather conditions could also lead to differences between actual energy use and the target.

The scatter plot (Figure 3) indicates generally good agreement between measured energy consumption and the space heating target for the 126 homes. The solid line indicates the ideal, i.e. actual energy consumption equal to the target for a given home. The area between the dotted lines indicates where the target is within 30% of actual consumption. Points on the chart represent single homes, while numerals indicate the number of homes where actual consumption and the energy target were the same.

FIGURE 3

SPACE HEATING: CONSUMPTION VERSUS R-2000 TARGET

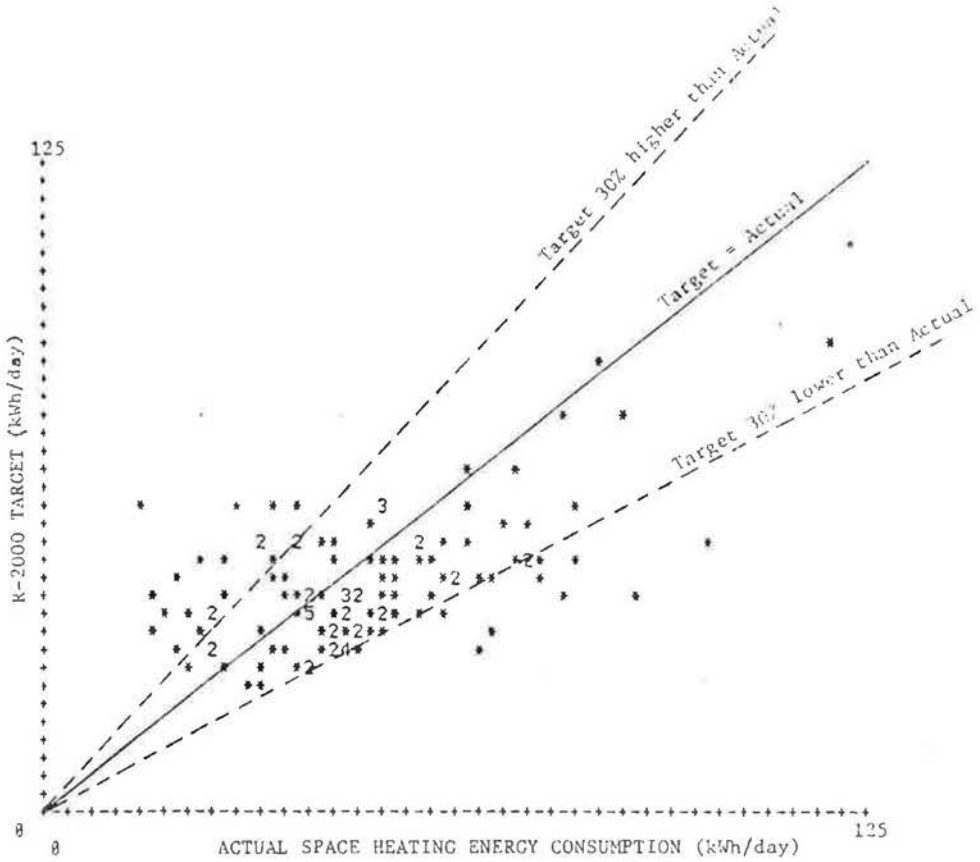


Table 4 shows the difference between actual space heating consumption and the R-2000 target (ratio of target/actual) according to factors that may influence energy consumption. On average, the target was 4% higher than actual measured energy consumption. This was not considered statistically significant.

The target was 4% lower than actual consumption for smaller homes (with a volume less than 500 m^3) but was 12% higher than measured consumption for larger homes (greater than 500 m^3 in volume). Monitoring of air change rates in a sample of homes indicates that part of this difference may be due to lower average air change rates in larger homes. While the average CATS measured air change rate in all R-2000 homes was 0.37 ach[10], the average rate in smaller homes was 0.40 ach and in larger homes the rate was 0.34 ach. Assuming an air change rate of 0.50 ach or the design stage may have led to an overestimate of energy required, particularly in larger homes.

Analysis of the results by type of space heating fuel indicates that the energy target was 6% higher than actual consumption for electrically heated homes but 2% lower than actual consumption for homes heated with other fuels. Although these slight differences are not statistically significant, they could be due to the following factors:

- the actual efficiency of combustion equipment was not known, therefore an average seasonal efficiency was used for the analysis (Table 2);

- the percentage of homes heated with fuels other than electricity was greater in colder climate zones, where the efficiency of HRVs was lower than originally assumed.

The average seasonal efficiency of HRVs, based on laboratory testing at ORF[11], was 57% instead of the 70% originally assumed. The range was 22% to 76%, depending on the HRV and climate zone, when modelled using the R-2000 HRV Seasonal Efficiency Model. This difference would lead to an underestimate of energy consumption for space heating. In addition, only 28% of ventilation systems were balanced within the 10% range, as required by the R-2000 technical criteria. This was determined by comparing the amount of supply air entering the ventilator to the amount of exhaust air leaving it. An imbalanced HRV would tend to recover less energy from ventilation air than had been assumed, causing an underestimate in energy consumed for space heating.

The energy target was 13% higher than actual consumption for homes with more than 4 occupants (average 5), but only 3% higher than actual consumption for homes with 4 or fewer occupants (average 3). Greater use of appliances, lighting and water heating and additional heat contribution from occupants probably reduced the need for space heating in homes with more than four occupants.

The energy target was 15% higher than actual consumption in the climate zone with 4000 Celsius degree-days or less, but consumption was generally higher than the target in colder zones. This was attributed primarily to the lower efficiency of HRVs in colder zones. Homes in locations with more than 6000 Celsius degree-days did not follow this trend because of the large percentage of homes (50%) which had woodstoves and therefore made less use of conventional fuels. It was not possible to monitor wood use in order to calculate energy consumption attributable to wood heating.

TABLE 4

COMPARISON OF SPACE HEATING CONSUMPTION WITH THE R-2000 TARGET
(Heating Season: September 1984 - April 1985)

HOUSE CHARACTERISTICS	No.	RATIO OF TARGET TO CONSUMPTION (Target/Actual) Mean	(Std Dev.)
R-2000 HOMES	124	1.04	(0.58)
HOUSE VOLUME			
<500 m^3	61	0.96	(0.67)
>500 m^3	65	1.12	(0.49)
SPACE HEATING FUEL			
Electricity	95	1.06	(0.62)
Other Fuels	31	0.98	(0.47)
OCCUPANCY			
<= 4 occupants	84	1.03	(0.61)
> 4 occupants	14	1.13	(0.55)
CLIMATE ZONE (Celsius DD)			
0000-3999	18	1.15	(0.54)
4000-4999	61	1.03	(0.49)
5000-5999	36	0.99	(0.79)
>6000	11	1.08	(0.35)
REGION			
Maritimes	21	1.15	(0.48)
Quebec	31	0.83	(0.36)
Ontario	33	1.06	(0.50)
Prairies/NWT	29	1.01	(0.79)
B.C./Yukon	12	1.45	(1.26)

Note: A value of less than 1 indicates that the target was lower than measured consumption.

Differences are evident when the results are analysed by region. The energy target in British Columbia/Yukon was, on average, 45% higher than actual energy consumption, but the results are not statistically significant because of the small sample size and high standard deviation. The lower than expected energy consumption is related to the warmer climate zone and greater use of woodstoves.

The energy target was 17% lower than actual energy consumption for space heating in Quebec. In addition to the impact of lower seasonal efficiencies of HRVs and unbalanced airflows, energy consumption for lighting, appliances and water heating was lower than average during the heating season and the average number of occupants per home was found to 3 instead of 4 as originally assumed. When the energy target was established, the contribution of energy gains from occupancy and appliance use had therefore been overestimated, and the amount of space heating required had been underestimated. The variance was statistically significant in percentage terms, but generally represents only a few kwh/day, since the average volume of homes in Quebec was substantially smaller (400 m^3) than in other provinces (526-586 m^3).

4.1.2 Comparison of Consumption With Conventional Building Practice

Table 5 shows that predicted energy consumption for space heating would have been approximately 300% higher if the homes had been built to the 1975 Building Code, and 109% higher if they had been constructed to the 1978 Measures.

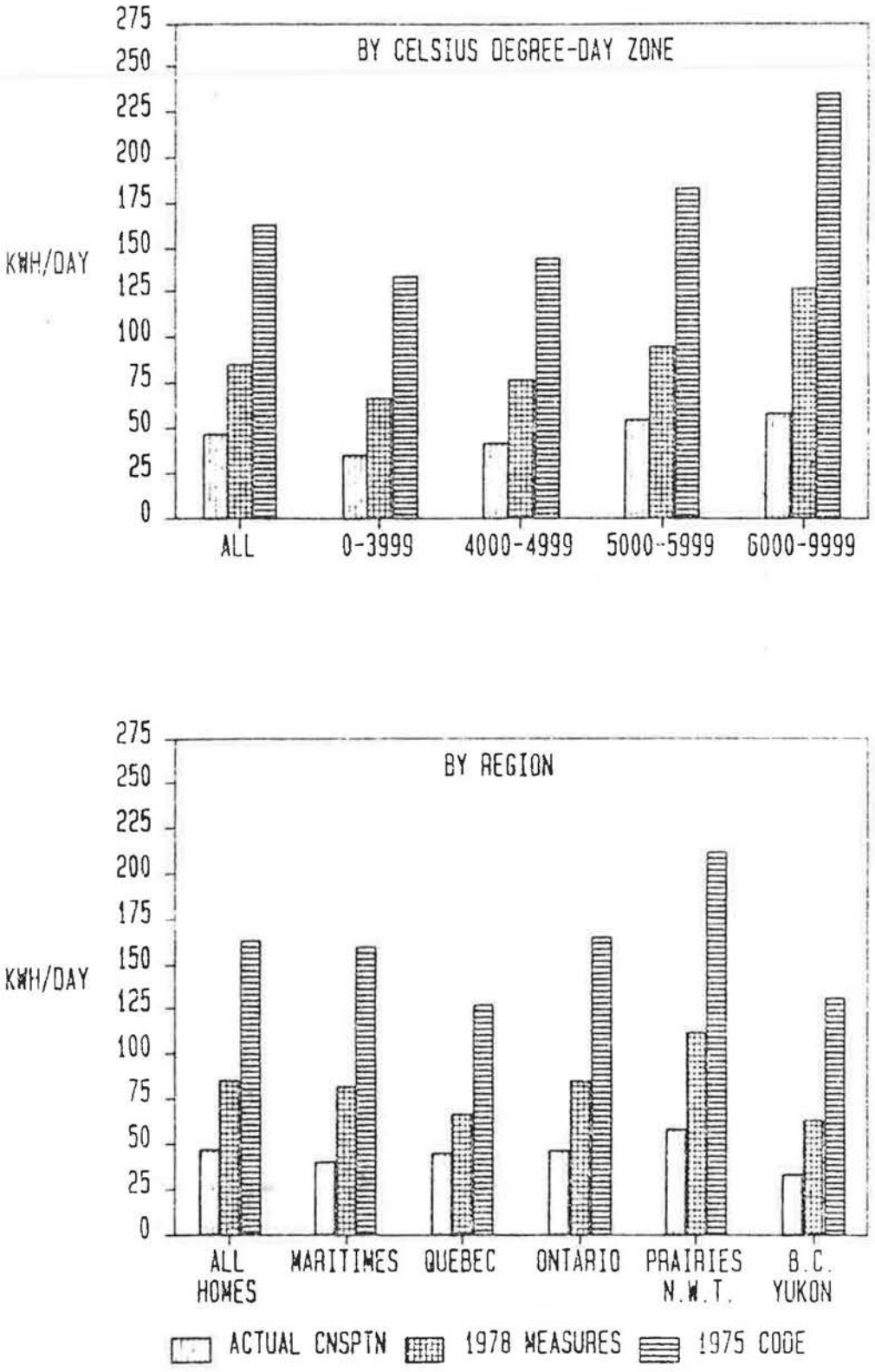
Figure 4 presents the average actual energy consumption and predicted energy consumption if the homes had been built to the reference standards. The results are expressed in kWh/day for the heating season and presented by climate zone and region. Average energy consumption was 46 kWh/day and, as expected, increased in colder zones.

TABLE 5

COMPARISON OF SPACE HEATING CONSUMPTION WITH THE 1975 NATIONAL BUILDING CODE AND 1978 MEASURES FOR ENERGY CONSERVATION
(Heating Season: September 15, 1984 - April 15, 1985)

HOUSE CHARACTERISTICS	PERCENT. DIFFERENCE FROM ACTUAL CONSUMPTION		
		1975 BLDG CODE (Code-Act.)/Act.	1978 MEASURES (Meas.-Act.)/Act.
	No.	Mean %	Mean %
R-2000 HOMES	126	303	109
HOUSE VOLUME			
<500 m3	56	258	83
>500 m3	65	348	134
SPACE HEATING FUEL			
Electricity	95	300	105
Other Fuels	31	311	118
OCCUPANCY			
<= 4 occupants	84	296	102
> 4 occupants	14	340	133
CLIMATE ZONE (Celsius DD)			
0000-3999	18	336	112
4000-4999	61	301	111
5000-5999	36	287	101
>6000	11	301	115
REGION			
Maritimes	21	358	130
Quebec	31	217	76
Ontario	33	312	117
Prairies/NWT	29	302	114
B.C./Yukon	12	397	138

FIGURE 4. ENERGY CONSUMPTION FOR SPACE HEATING (September to April)



4.2. Total Annual Energy Consumption

The total annual energy consumption analysis, which includes all energy use for lights, appliances and water heating as well as space heating, was for the period from May 1984 to April 1985. The results presented are for 120 homes. There were 210 homes in the data base for which there were meter readings, of which 81 were excluded due to insufficient meter readings and a further 9 due to suspect meter readings.

4.2.1 Comparison with R-2000 Target

The scatter plot (Figure 5) of total annual energy consumption in kWh/day versus the total energy target in kWh/day shows generally good agreement. The solid line represents the ideal, i.e. actual energy consumption equal to the target for a given home. The area between the dotted lines indicates where the target is within 30% of measured energy consumption.

FIGURE 5

TOTAL ANNUAL CONSUMPTION VERSUS R-2000 TARGET

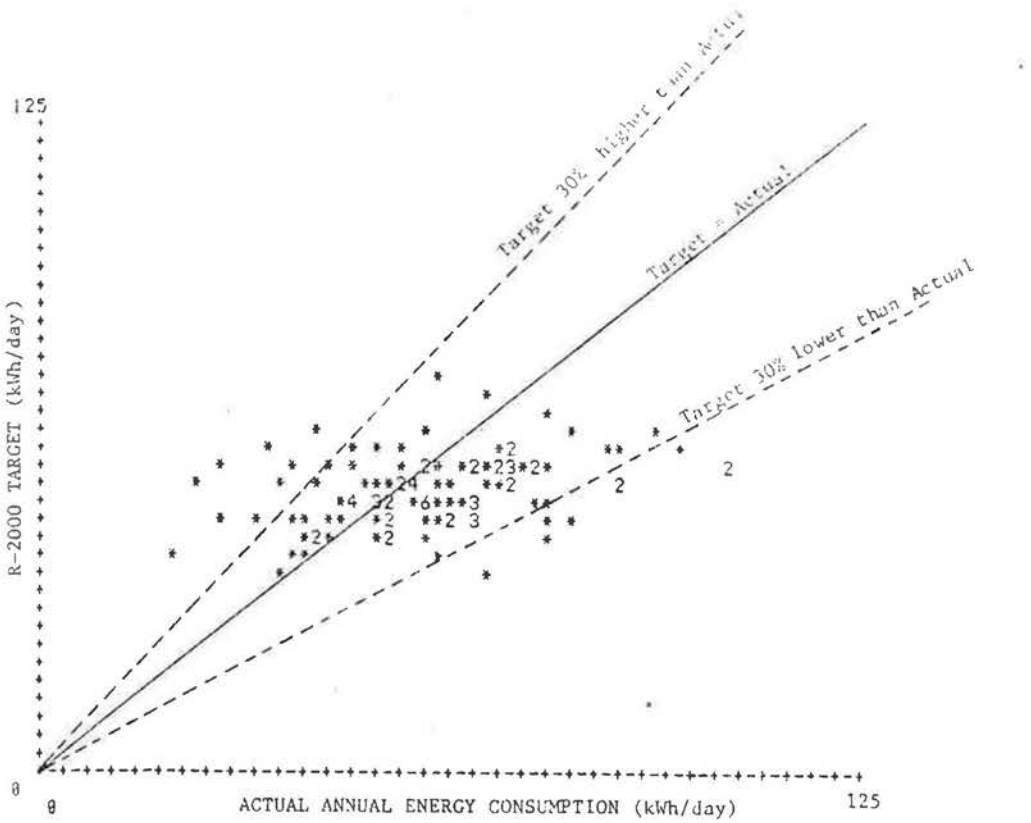


Table 6 presents the mean of the ratio or difference between actual annual energy consumption and the R-2000 target according to various factors. On average, the annual target was 2% lower than actual energy consumption. Although not statistically significant, the higher energy consumption is believed to be related to the lack of provision for energy usage outside the building envelope, e.g. for exterior lighting, automobile block heaters and lawnmowers, as well as air conditioning, de-humidification and other energy uses during the summer. These were not considered when the R-2000 target was established.

The annual target was 7% lower than actual consumption for smaller homes. This is statistically significant and is related to higher than anticipated energy consumption for space heating (Table 4). The annual target was 3% higher than actual consumption for larger homes.

The target for all electrically heated homes was 1% lower than actual consumption, and was 5% lower for homes heated with gas and other fuels. Although not statistically significant, the slightly higher consumption in homes heated with gas and other fuels could be due to the higher percentage of homes in colder climate zones, where energy consumption was slightly above the target.

The annual target for homes with 4 or fewer occupants was only 1% lower than actual consumption, but 7% lower for homes with more than 4 occupants. This slightly higher consumption in homes with more than four occupants is attributed to an increase in energy use for appliances, lighting and water heating.

Analysis by climate zone indicates that the target was higher than actual consumption in warmer zones but lower in colder zones. The target was 10% lower than actual consumption in the 5000 to 6000 degree-day zone and 12% lower for 6000 degree-days and higher. This is considered significant and is due not only to higher energy consumption for space heating but to a longer heating season and shorter days. This probably led to increased energy consumption for both interior lighting and exterior uses, such as lighting and car block heaters. These factors were not taken into account when the energy target was established.

Analysis by region indicates that the target was slightly lower than measured actual consumption in all regions except British Columbia/Yukon, where it was 23% higher than actual consumption. This was attributed to a warmer climate and shorter heating season for the majority of homes. The energy target was 14% lower than measured energy consumption in Quebec, primarily due to the impact of higher than expected consumption for space heating. Quebec was the only region where the variance was considered significant.

TABLE 6

COMPARISON OF TOTAL ANNUAL ENERGY
CONSUMPTION WITH THE R-2000 TARGET
(May 1984 - April 1985)

HOUSE CHARACTERISTICS	RATIO OF TARGET/ACTUAL CONSUMPTION		
	No.	Mean	(Std Dev.)
R-2000 HOMES	120	0.98	(0.34)
HOUSE VOLUME			
<500 m^3	57	0.93	(0.27)
>500 m^3	63	1.03	(0.38)
SPACE HEATING FUEL			
Electricity	86	0.99	(0.33)
Gas and Other Fuels	34	0.95	(0.35)
OCCUPANCY			
<= 4 occupants	95	0.99	(0.34)
> 4 occupants	14	0.93	(0.44)
CLIMATE ZONE (Celsius DD)			
0000-3999	25	1.09	(0.45)
4000-4999	50	1.01	(0.32)
5000-5999	35	0.90	(0.28)
>6000	10	0.88	(0.20)
REGION			
Maritimes	19	0.95	(0.17)
Quebec	21	0.86	(0.16)
Ontario	27	0.92	(0.22)
Prairies/NWT	29	0.94	(0.26)
B.C./Yukon	24	1.22	(0.57)

Note: A value of less than 1 indicates that the target was lower than actual consumption.

4.2.2 Comparison with Current Building Practice

Table 7 shows that if the R-2000 homes had been built to the 1975 Building Code, energy consumption would have been 125% higher, and if the homes had been built to the 1978 Measures, consumption would have been 44% higher. Predicted annual savings varied and were not as great in smaller homes, including those in Quebec. Energy usage for appliances, lighting and water heating is a larger portion of annual energy consumption in smaller homes, since it varies according to occupancy and climate zone and is not directly related to house size.

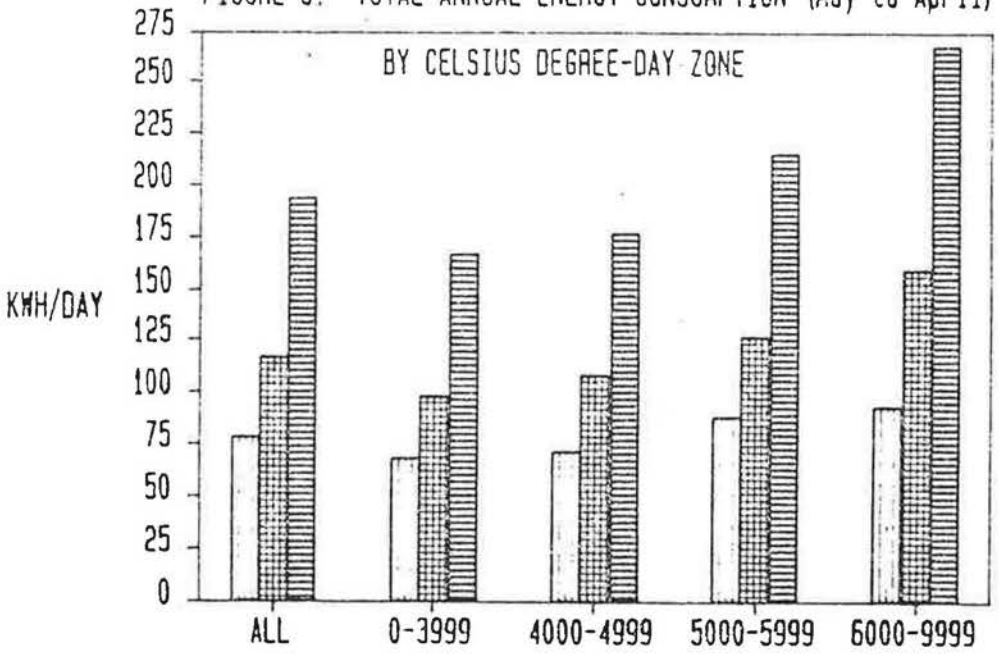
TABLE 7

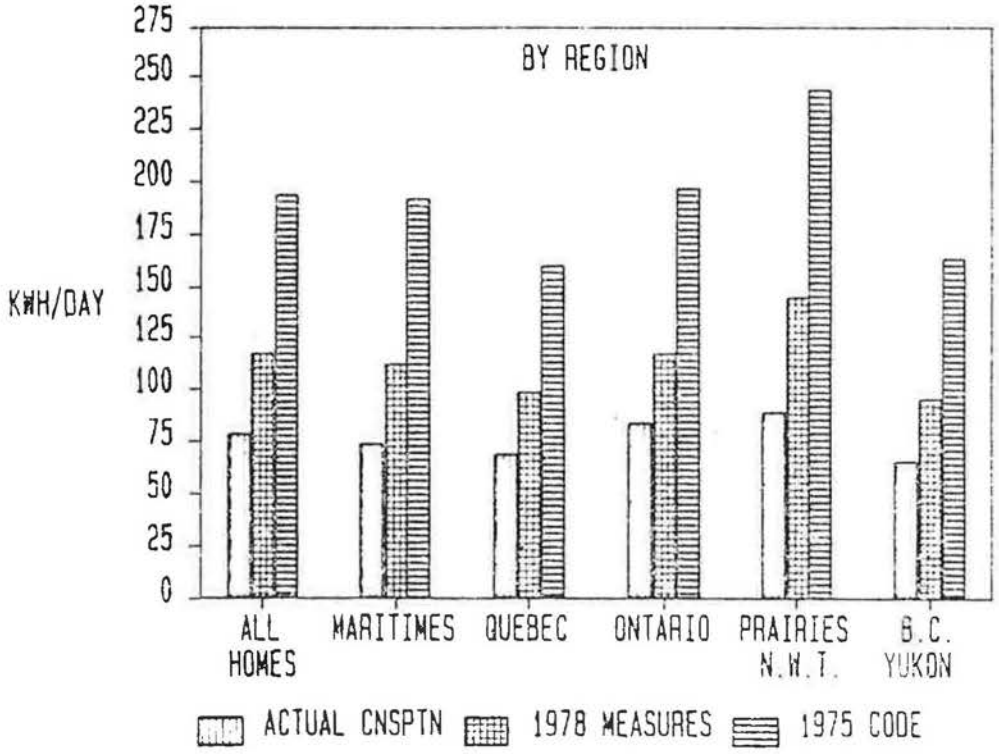
COMPARISON OF TOTAL ANNUAL ENERGY CONSUMPTION WITH THE 1975 NATIONAL BUILDING CODE AND 1978 MEASURES FOR ENERGY CONSERVATION
(May 1984 - April 1985)

HOUSE CHARACTERISTICS	PERCENT. DIFFERENCE FROM ACTUAL CONSUMPTION		
		1975 Code (Code-Act.)/Act.	1978 Measures (Meas.-Act.)/Act.
	No.	Mean (%)	Mean (%)
R-2000 HOMES	120	125	44
HOUSE VOLUME			
<500 m^3	57	97	29
>500 m^3	63	150	58
SPACE HEATING FUEL			
Electricity	86	121	42
Gas and Other Fuels	34	134	49
OCCUPANCY			
<= 4 occupants	95	126	45
> 4 occupants	14	120	41
CLIMATE ZONE (Celsius DD)			
0000-3999	25	133	48
4000-4999	50	128	49
5000-5999	35	112	35
>6000	10	127	43
REGION			
Maritimes	19	121	41
Quebec	21	83	22
Ontario	27	117	40
Prairies/NWT	29	129	47
B.C./Yukon	24	165	67

Figure 6 presents the average measured total annual energy consumption and predicted energy consumption if the homes had been built to the 1975 National Building Code and the 1978 Measures, all expressed in kWh/day for different climate zones and regions. The average annual energy consumption for all homes was 58 kWh/day.

FIGURE 6. TOTAL ANNUAL ENERGY CONSUMPTION (May to April)





4.3 Domestic Water Heating

This analysis was performed to compare energy consumption for water heating with the R-2000 target of 14 kWh/day. The analysis was based on 184 homes with at least 90 meter-reading days. There were 233 homes with readings, of which 10 were eliminated due to insufficient readings and a further 39 due to suspect readings.

The frequency distribution chart (Figure 7) indicates that energy consumption was 10-18 kWh/day in 57% of homes, less than 10 kWh/day in 25% of homes and greater than 18 kWh/day in 18%.

FIGURE 7. FREQUENCY DISTRIBUTION OF DHW ENERGY CONSUMPTION

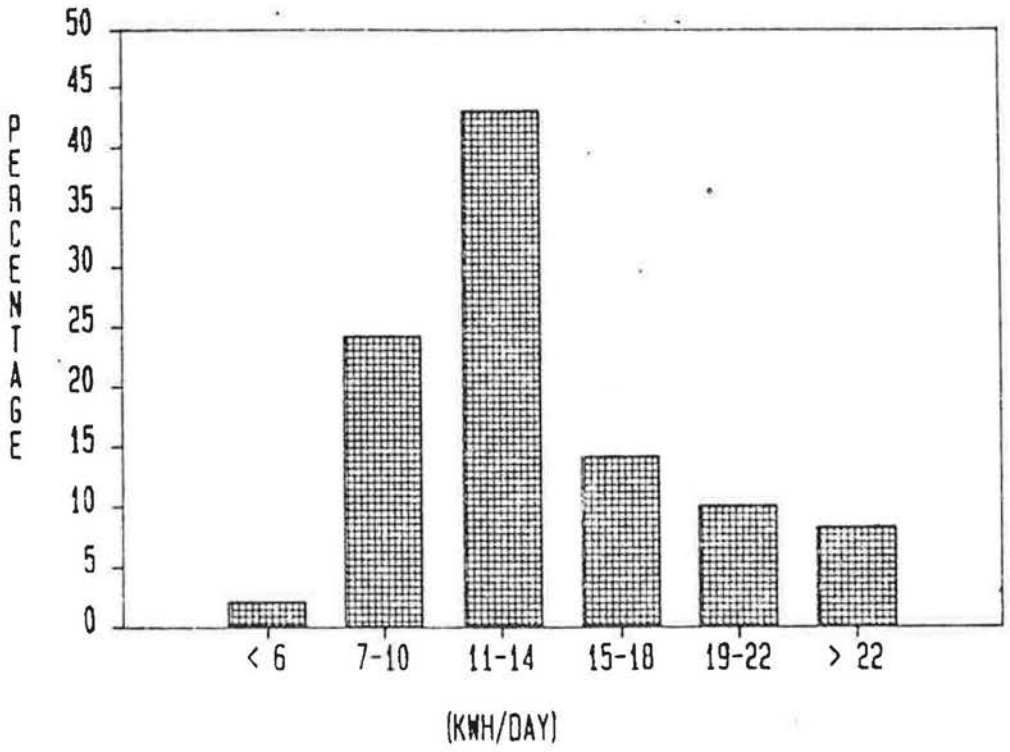


Table 8 and Figure 8 show that average energy consumption for water heating was 13 kWh/day, slightly lower than the target of 14 kWh/day. There was no difference in energy consumption on the basis of house size. However, as would be expected, homes with more than 4 occupants recorded higher energy consumption (16 kWh/day) than homes with 4 or fewer occupants (12 kWh/day). It should be noted that only 10% of homes had more than 4 occupants.

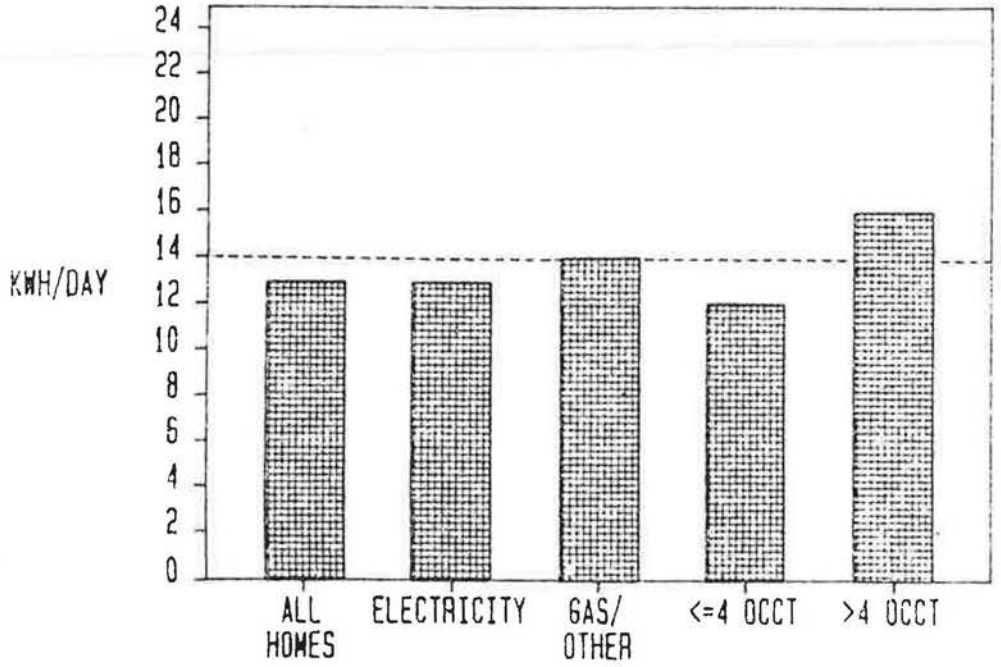
Table 8 also shows that consumption in homes with gas-fired water heating averaged 14 kWh/day, slightly higher than in homes with electric water heaters. This could reflect differences between actual seasonal efficiency of combustion equipment and assumed efficiency (Table 2), or the higher percentage of homes heated with gas and other fuels that were located in colder climate zones where energy consumption is slightly higher. This slight increase in energy consumption in colder zones may be attributed to the need for additional energy to warm the colder water supplied to homes in these areas. Analysis by region showed that British Columbia/Yukon, where the majority of homes are in warmer zones, exhibited lower than average energy consumption, while in the Prairies/NWT consumption was somewhat higher.

TABLE 8

ENERGY CONSUMPTION FOR WATER HEATING

HOUSE CHARACTERISTICS	MEASURED CONSUMPTION	
	Cases	Mean (Std Dev.) kWh/day
ALL R-2000 HOMES	184	13 (5)
HOUSE VOLUME		
<500 cu.m.	97	13 (5)
>500 cu.m.	87	13 (5)
OCCUPANCY		
<= 4 occupants	119	12 (4)
> 4 occupants	17	16 (5)
SPACE HEATING FUEL		
Electricity	146	13 (5)
Gas and Other Fuels	38	14 (5)
CLIMATE ZONE (Celsius D.D.)		
0-3999	28	12 (4)
4000-4999	82	13 (5)
5000-5999	57	13 (5)
>6000	17	14 (4)
REGION		
Maritimes	29	13 (5)
Quebec	38	12 (5)
Ontario	49	13 (4)
Prairies/NWT	44	14 (6)
British Columbia/Yukon	24	11 (3)

FIGURE 8. ENERGY CONSUMPTION FOR DOMESTIC WATER HEATING



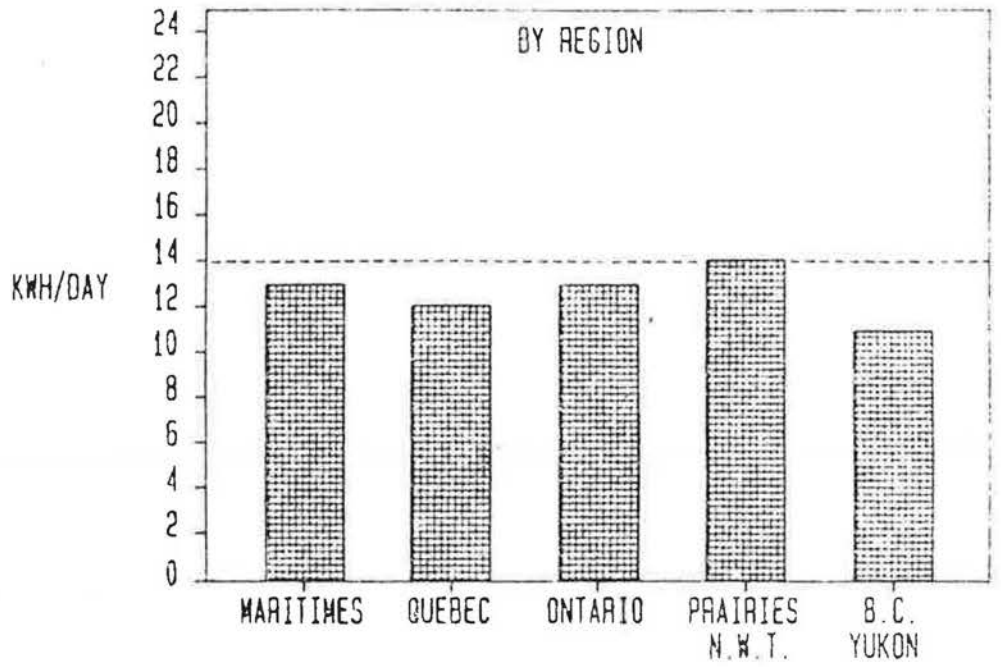
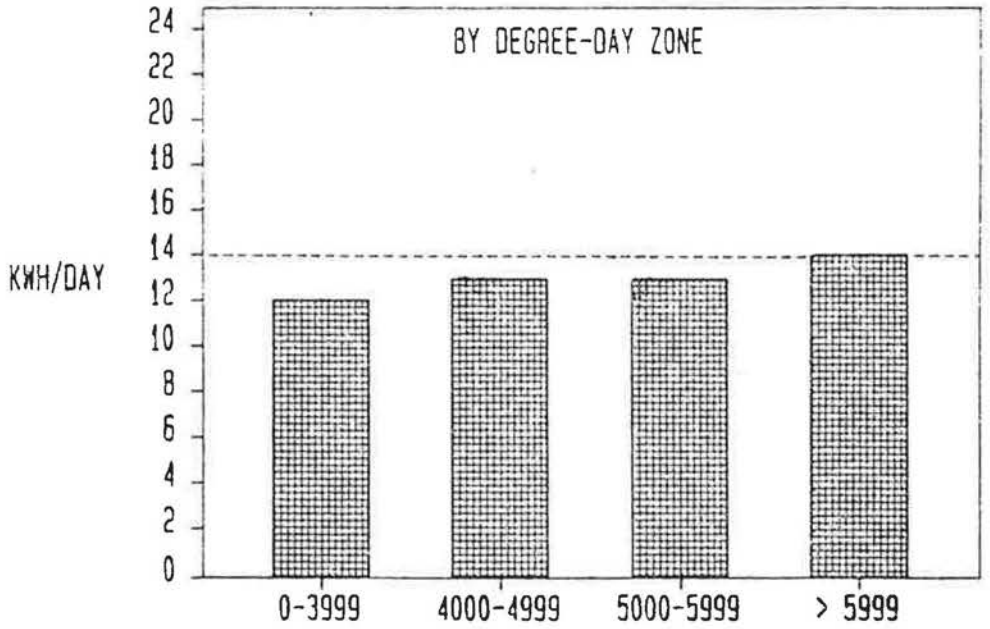


FIGURE 8 CONT'D. ENERGY CONSUMPTION FOR DOMESTIC WATER HEATING



5.0 CONCLUSIONS

These results indicate that R-2000 demonstration homes are performing, on average, closely to program energy targets. The space heating target was 4% higher than actual energy consumption, and the total annual energy target was 2% lower than actual energy consumption. The average energy consumption for water heating was 13 kWh/day, 7% lower than the target of 14 kWh/day.

Computer predictions indicated that energy consumption for space heating would have been, on average, 300% higher than measured consumption if the homes had been built to the 1975 Building Code and 109% higher if they had been constructed to the 1978 Measures for Energy Conservation. Total annual energy consumption would have been 125% higher than measured consumption if the homes had been built to the 1975 Building Code and 44% higher if they had been constructed to the 1978 Measures.

Measured energy consumption was generally lower than the target in warmer zones but higher in colder zones. This was attributed to the lower efficiency of HRVs in colder zones, and to an increase in energy used for interior lighting and for exterior uses such as lighting and car block heaters as a result of the longer heating season and shorter days.

There was some variability in the results based on occupancy, climate zone, house size, and type of heating and ventilating equipment installed in the homes. Smaller homes generally exhibited higher energy consumption for space heating. This may be due to slightly higher ventilation rates measured in smaller homes and the impact of lower HRV efficiencies and unbalanced ventilation airflows.

There were a number of variances from the assumptions used to establish the energy target. For example, no provision was made for energy consumption outside the building envelope for lighting or block heaters, or for energy use during the summer for air-conditioning and de-humidification. As a result, total annual energy consumption was slightly higher than the target. Some variances had a balancing effect. For example, lower actual HRV efficiency, which would increase energy consumption, would tend to be balanced by lower average air change rates which would reduce the space heating demand. This would not always apply, however, especially in smaller homes in colder zones, where the average air change rate may be high and the HRV efficiency very low. In some cases, energy consumption was so low that any error in assumptions appeared to be significant in percentage terms, but may have represented only a few kWh/day.

As a result of monitoring activities, the following changes are planned to the assumptions used in establishing the energy targets:

1. The efficiency ratings for all heat recovery ventilators (air-to-air heat exchangers) will be based on testing at 0 and -25 degrees C, performed in accordance with CSA Standard C439, Standard Methods of Test for Rating the Performance of Heat Recovery Ventilators, issued as a preliminary standard in April 1985.

2. An average ventilation or air change rate will be based on a mechanical ventilation rate of 0.35 ach plus an additional 0.05 ach from natural infiltration, instead of 0.50 ach.

3. The assumed heat gains from occupants will be reduced to 2 kWh/day from 3.2 kWh/day, since monitoring showed the average number of occupants to be 3 and not 4.

4. An additional 2 kWh/day for energy use outside the building envelope for yard lighting, car block heaters, lawnmowers, etc. will be assumed.

5. The efficiency of combustion equipment for space and water heating will be based on the Seasonal Gas Utilization Efficiency (SGUE) rating or a 'nominal seasonal efficiency' derived from the steady-state efficiency of the particular heating equipment.

The R-2000 program has also prepared revised guidelines for the installation of whole-house mechanical ventilation equipment which make it mandatory to measure airflows and to balance units at the time of installation. National training courses for installers, being provided through the Heating, Refrigerating and Air Conditioning Institute of Canada (HRAI), will greatly improve compliance with program requirements for continuous ventilation and balanced airflows for air-to-air HRVs.

A national technical advisory committee with representation from public and private sector groups and associations has been established to consider any further changes to the program criteria which may be necessary to ensure that the R-2000 home continues to represent a high quality product that will meet or exceed accepted good building practice.

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