AIRTIGHTNESS AND ENERGY EFFICIENCY OF NEW CONVENTIONAL AND R-2000 HOUSING IN CANADA, 1997

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The CANMET Energy Technology Centre (CETC)
Energy Technology Branch, Energy Sector
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PREPARED BY:

Tom Hamlin and John Gusdorf
Buildings Group.
Department of Natural Resources/CANMET
580 Booth Street, Ottawa
Tel.: (613) 947-1959; (613) 947-2044; Fax (613) 996-9416

SCIENTIFIC AUTHORITY:

Tom Hamlin
Buildings Group
The CANMET Energy Technology Centre (CETC)
Energy Technology Branch, Energy Sector
Department of Natural Resources Canada
580 Booth Street, 13th Floor
Ottawa, Ontario
K1A 0E4

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Report on New Conventional Housing

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EXECUTIVE SUMMARY

Natural Resources Canada (NRCan), in cooperation with Canada Mortgage and Housing (CMHC) and the National Research Council of Canada (NRC), has undertaken a national survey of the airtightness and energy efficiency of new housing, including both conventional and R-2000 houses in all southern regions of Canada. The Canadian Home Builders' Association (CHBA) was instrumental in the selection of typical conventional merchant built housing which makes the survey representative. Additional data was received from Hydro-Québec, Centra Gas, Manitoba Hydro and B.C. Hydro.

Canada is a world leader in cold climate housing. The Canadian emphasis on increasing airtightness has led to increased energy efficiency, reduced house moisture damage, and improved comfort. These benefits can be achieved, without causing indoor air quality (IAQ) problems due to inadequate ventilation or depressurization and spillage, by improving ventilation equipment and installing depressurization tolerant combustion appliances.

The database for this study consists of detailed information on 163 new conventional houses and 63 R-2000 houses. The new conventional houses were built in 1990 through 1996 and have an average volume of 652 m^3, and the R-2000 houses were built in 1983 through 1995 and have an average volume of 792 m^3, or 22% larger. The airtightness results from this database are compared with historical trends from a survey of 2,037 houses built from 1793 through 1996.

Airtightness is analyzed in various ways, and shows a general, ongoing trend to more airtight houses with significant but decreasing regional differences, as shown in Figure S1. Although R-2000 houses continue to be significantly tighter and more efficient than new

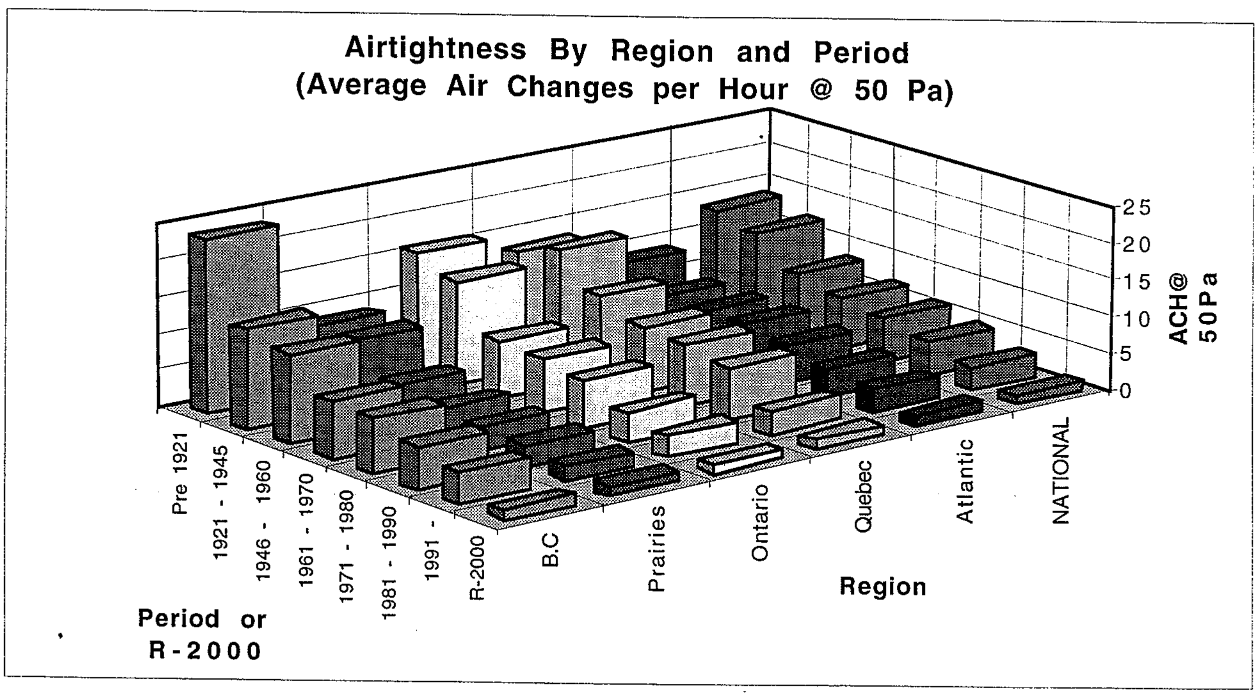

Figure S1. Average Airtightness (Air Changes per Hour @ 50 Pascals) by Region and Period, with R-2000 Houses for Comparison.

conventional houses, the gap is narrowing. Conventional houses built from 1990 to 1996 are thirty-five percent tighter than those built from 1985 to 1989.

Greater airtightness creates a need for mechanical ventilation in order to avoid potential IAQ problems. This study shows that many of the new conventional houses are airtight enough to require mechanical ventilation to minimize IAQ problems, but have no central mechanical ventilation systems. These houses must rely solely on kitchen and bathroom fans which are seldom run continuously. See Table S1. R-2000 houses are all very airtight, but have heat recovery ventilators (HRVs) which are adequately sized to provide sufficient fresh air if run continuously.

Region	Number of Houses	Natural Air Change Rates (ach)			House with Natural ach less than:			
					All Houses		No Mech. Vent.	
		Min	Mean	Max	<0.35	<0.20	<0.35	<0.20
B.C.	12	0.015	0.153	0.390	92%	75%	83%	67%
Prairies	69	0.017	0.156	0.426	97%	68%	22%	13%
Ontario	20	0.063	0.221	0.452	85%	55%	45%	25%
Quebec	30	0.059	0.226	0.605	80%	50%	67%	40%
Atlantic	24	0.060	0.212	0.496	83%	63%	0%	0%
National	155	0.015	0.186	0.605	90%	63%	35%	22%

Table S1. The natural air change rates, and potentials for IAQ problems, of new conventional houses.

Airtight houses are also subject to depressurization which can lead to spillage of combustion products from fuel burning equipment. This occurs when exhaust fans cause the air pressure inside the house to be lower than outside. Then, the combustion gases from furnaces and hot water heaters can be spilled into the house instead of up the flue, causing potentially serious IAQ problems. For houses with spillage susceptible appliances the maximum allowable house depressurization is 5 Pascals (Pa). Up to 40% of spillage-susceptible new conventional houses are subject to depressurization of greater than 5 Pa, as shown in Figure S2. R-2000 houses do not have potential depressurization problems because they always have balanced ventilation, and, if required, have make-up air for any spillage-susceptible devices.

The energy efficiency of new conventional and R-2000 houses is examined both in terms of space heat energy, and by the newly developed energy rating system of EnerGuide for Houses. There are significant differences in energy efficiency between new conventional and R-2000 houses, and there are some significant regional variations. Based on the datasets, new conventional houses consume an average of 93 giga-Joules per year (GJ/y) for space heating, and this figure varies from 56 in Quebec to 119 in the Prairies. By comparison, R-2000 houses consume 70 GJ/year which is 25% less than new conventional houses, and which varies from 41 in Quebec to 101 in the Prairies. Larger houses consume more energy than smaller ones, and the

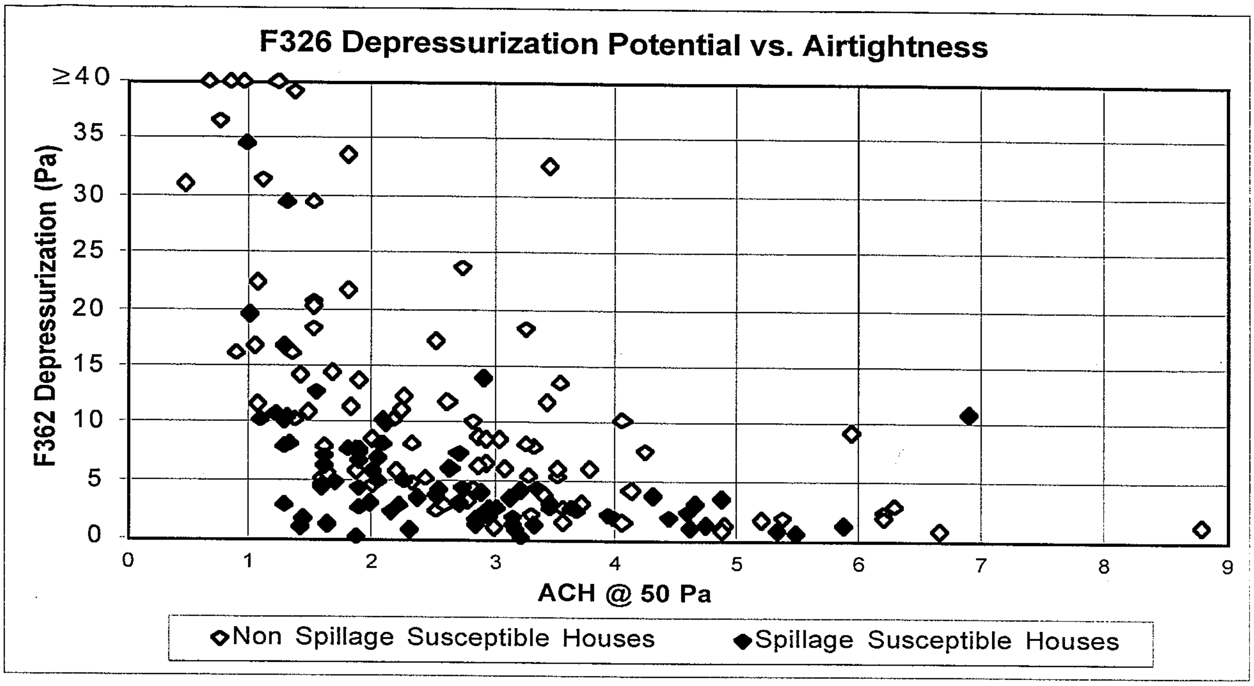

Figure S2. Depressurization Potential vs. Airtightness.

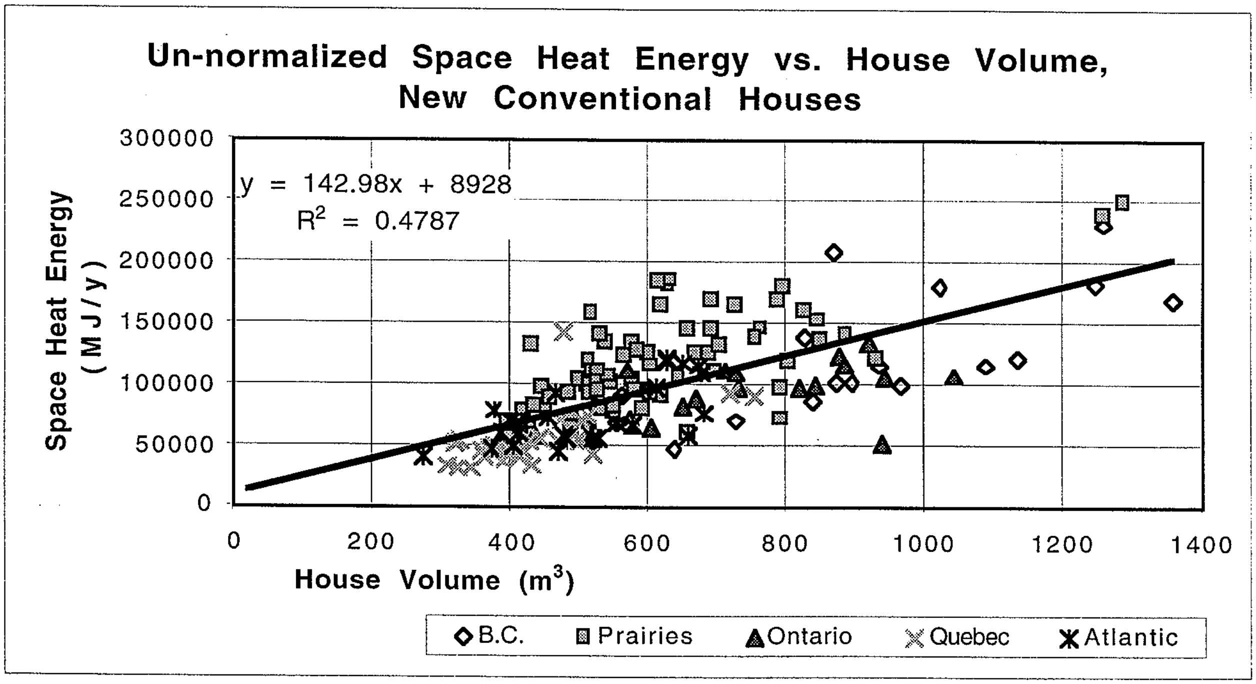

Figure S3: Un-normalized space heat vs. house volume, new conventional houses.

relationship is roughly linear as shown in Figure S3. When normalized by size, and by climate and fuel efficiency, the R-2000 advantage increases to 33%

The EnerGuide for Houses program is a method of rating the energy efficiency of houses normalized by size, climate and fuel efficiency. Because it normalizes energy use by volume it allows large houses which use large amounts of total energy to receive equal ratings with smaller houses which use less total energy. Given the trend toward larger houses with fewer occupants, even significant improvements in the EnerGuide ratings for houses may not result in less energy use for housing. Under the EnerGuide for Houses energy efficiency ratings, new conventional houses average 73 out of 100, and R-2000 houses have an average rating of 79; regional variations are shown in Figure S4.

Figure S5 shows where heat is lost from new conventional and R-2000 houses. The columns show the average amounts of heat lost through the sections of the house envelopes and by natural and mechanical ventilation. It is interesting to note that R-2000 houses lose more heat through windows than conventional houses do, due to their larger size and window area. The largest difference occurs in the basements where new conventional houses lose 38% more heat than R-2000s despite their smaller size. A comparison of the most and least energy efficient new conventional houses shows that the greatest difference between them is in basement heat losses;

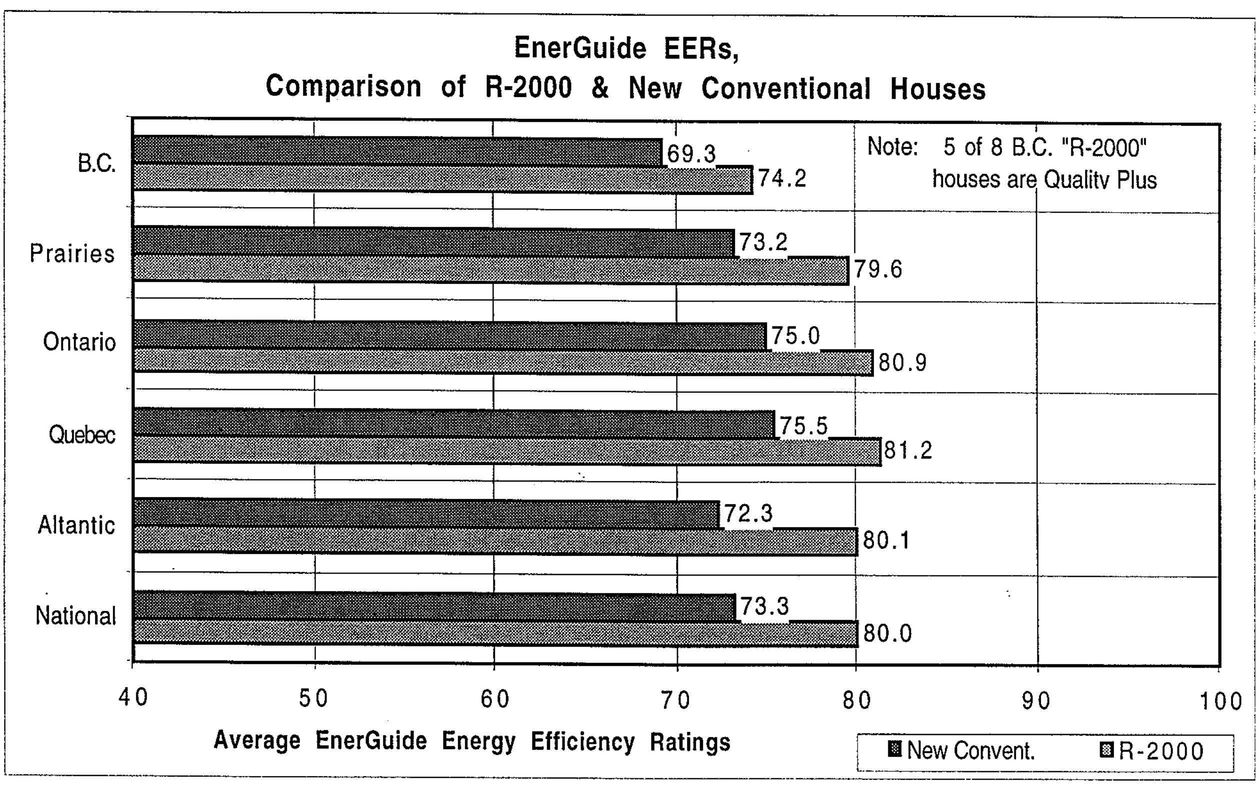

Figure S4. Average EnerGuide for Houses Ratings of New Conventional & R-2000 Houses.

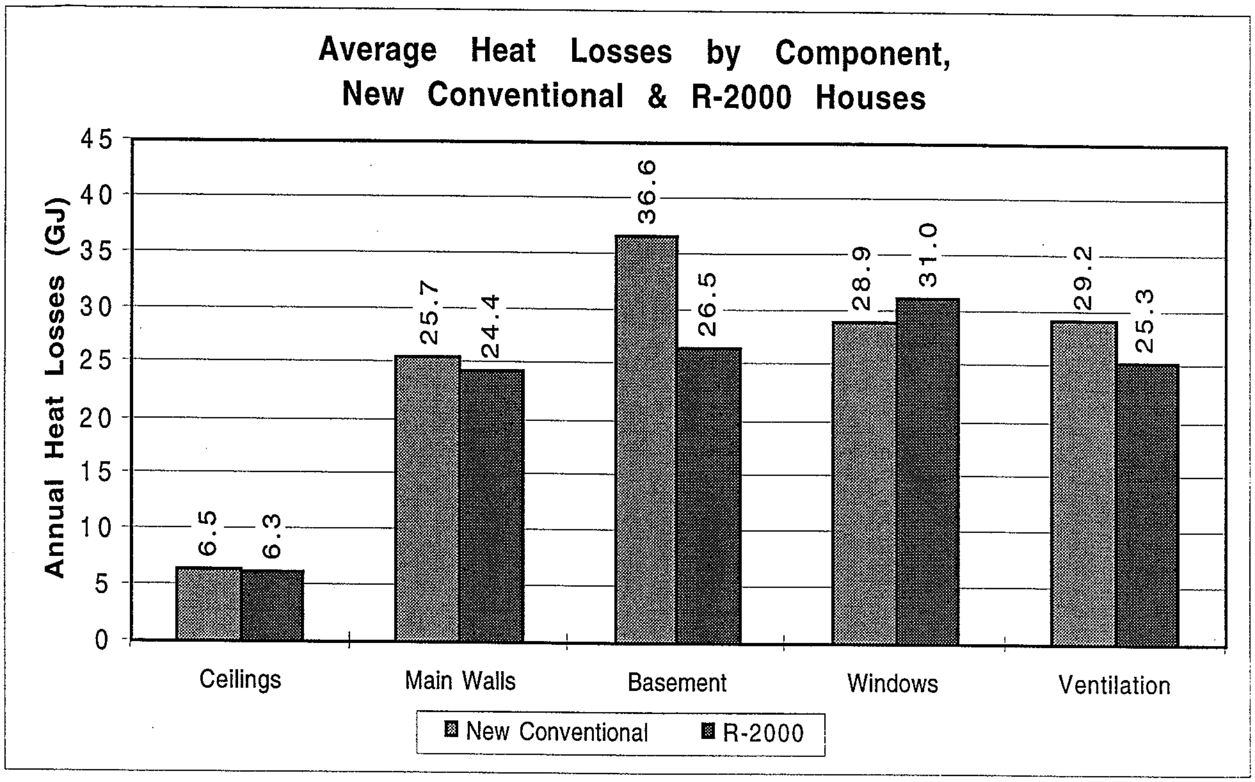

Figure S5. Average heat losses by component, new conventional and R-2000 houses.

the least efficient 10% of new conventional houses lose over 40% of their heat through their basements while the most efficient lose about 27% through their basements. These results indicate that greater attention should be given to basement insulation.

Canadian houses continue to become more airtight and energy efficient. R-2000 houses are still significantly tighter and more efficient than new conventional houses, but the gap is narrowing. Increased airtightness does create potential IAQ problems, but these can be dealt with by ventilation and combustion equipment installed according to the existing codes.

Étanchéité et efficacité énergétique des habitations neuves au Canada en 1997 (maisons classiques et Maisons R-2000)

RÉSUMÉ

Ressources naturelles Canada, en collaboration avec la Société canadienne d'hypothèques et de logement et le Conseil national de recherches du Canada, a entrepris une étude nationale sur l'étanchéité et l'efficacité énergétique des nouvelles habitations, c'est-à-dire les maisons classiques et les Maisons R-2000, construites dans toutes les régions du sud du Canada. L'Association canadienne des constructeurs d'habitations a contribué d'une façon particulière à la sélection des habitations classiques construites par des entrepreneurs réguliers, un élément qui a rendu l'étude représentative du marché actuel. Les sociétés Hydro-Québec, Centra Gas, Manitoba Hydro et B. C. Hydro ont, pour leur part, fourni d'autres données utiles.

Le Canada compte parmi les chefs de file mondiaux de la production d'habitations destinées aux climats froids. La tendance générale qui se manifeste au pays visant à accroître l'étanchéité des maisons a permis d'augmenter l'efficacité énergétique, de diminuer les dommages causés par l'humidité et d'élever le niveau de confort. Il est possible de recueillir tous ces bénéfices sans pour autant provoquer des problèmes au chapitre de la qualité de l'air intérieur (QAI), problèmes découlant d'une ventilation inadéquate, d'une dépressurisation ou d'un rejet accidentel, et cela en apportant des améliorations à l'équipement de ventilation et en installant des appareils de combustion insensibles à la dépressurisation.

La base de données mise sur pied en vue de cette étude contient des renseignements détaillés concernant 163 maisons classiques neuves et 63 Maisons R-2000. Les maisons classiques neuves, qui ont été construites à partir de 1990 jusqu'à 1996, présentent un volume moyen de 652 m^3, tandis que les Maisons R-2000, qui ont été construites à partir de 1983 jusqu'à

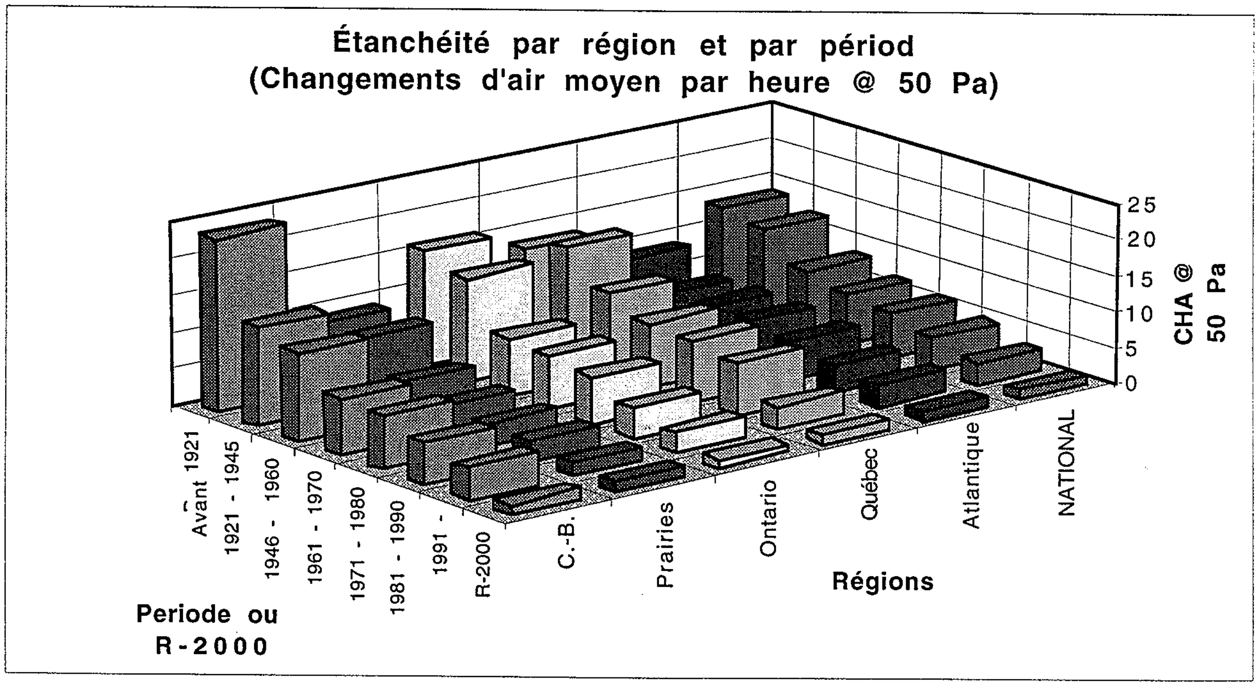

Figure R1. Étanchéité moyenne (changements d'air par heure @ 50 pascals) par région et par période, en plus de celle des Maisons R-2000 à titre de comparaison.

1995, disposent d'un volume moyen de 792 m^3, soit 22 % plus grand. Les données relatives à l'étanchéité qui se trouvent dans la base sont comparées aux tendances constatées dans le cas d'une étude portant sur 2 037 maisons érigées entre 1793 et 1996.

Tel que montré à la figure R1, on a analysé l'étanchéité de diverses façons et découvert une constante générale à accroître l'efficacité des maisons qui se manifeste avec des différences régionales importantes, bien que décroissantes. Malgré le fait que les Maisons R-2000 continuent à présenter une étanchéité et une efficacité énergétique plus grandes que les maisons classiques neuves, l'écart tend à diminuer. Ainsi, l'étanchéité des maisons classiques construites entre 1990 et 1996 est 35 % plus élevée que celle des maisons construites entre 1985 et 1989.

Régions	Nombre de maisons	Taux de changements d'air naturels (cha)			Maisons avec cha naturels inférieurs à:			
					Toutes les maisons		Sans vent. méc.	
		Min.	Moyens	Max	<0,35	<0,20	<0,35	<0,20
C.-B.	12	0,015	0,153	0,390	92%	75%	83%	67%
Prairies	69	0,017	0,156	0,426	97%	68%	22%	13%
Ontario	20	0,063	0,221	0,452	85%	55%	45%	25%
Québec	30	0,059	0,226	0,605	80%	50%	67%	40%
Atlantique	24	0,060	0,212	0,496	83%	63%	0%	0%
National	155	0,015	0,186	0,605	90%	63%	35%	22%

Tableau R1. Taux de changements d'air naturels, et possibilités de problèmes de QAI, des maisons classiques neuves.

Une plus grande étanchéité entraîne la nécessité de se doter d'une ventilation mécanique afin d'éviter les problèmes possibles reliés à la QAI. Cette étude a permis de constater que les maisons classiques neuves étaient suffisamment étanches pour nécessiter la présence d'une telle ventilation afin d'atténuer les problèmes de QAI, mais la plupart n'étaient pas dotées d'un système central de ventilation mécanique. Ces maisons devaient compter uniquement sur les ventilateurs de cuisine et de salle de bains, des mécanismes qui fonctionnaient rarement sans interruptions. À ce propos, veuillez vous référer au tableau R1. Les Maisons R-2000 font toutes preuve de grande étanchéité, disposant, cependant, de ventilateurs de récupération de la chaleur (VRC) qui sont conçus pour fournir suffisamment d'air frais lorsqu'ils fonctionnent sans interruptions.

Les maisons étanches sont également sujettes à la dépressurisation qui peut entraîner des rejets accidentels de produits de combustion provenant de l'équipement de brûlage des combustibles. Ce phénomène se produit lorsque les ventilateurs d'évacuation du bâtiment provoquent une baisse de la pression de l'air intérieur par rapport à l'air extérieur. C'est alors que les gaz de combustion provenant de la chaudière et du chauffe-eau peuvent être rejetés dans le bâtiment au lieu de monter par le carneau, ce qui peut causer de sérieux problèmes de QAI. Dans le cas des maisons dotées d'appareils susceptibles de provoquer des rejets, la dépressurisation maximale permise est de 5 pascals (Pa). Tel que montré à la figure R2, jusqu'à 40 % des maisons classiques neuves susceptibles de rejets sont sujettes à une dépressurisation plus grande de 5 Pa.

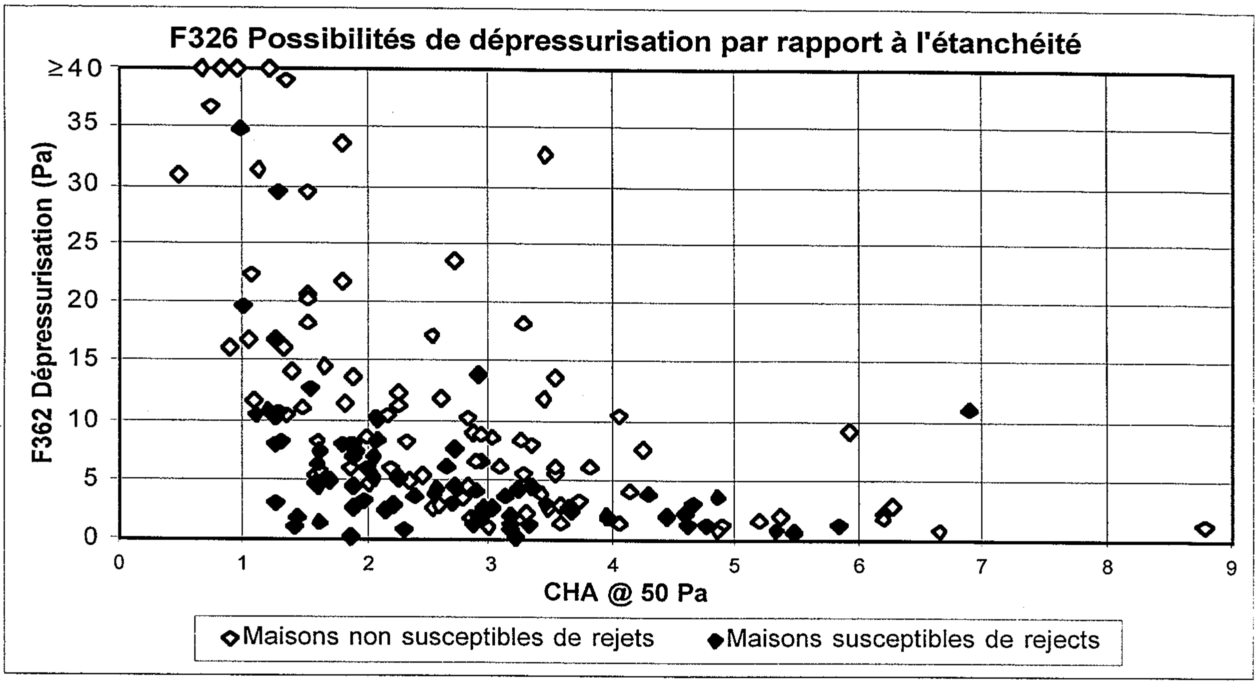

Figure R2. Possibilités de dépressurisation par rapport à l'étanchéité.

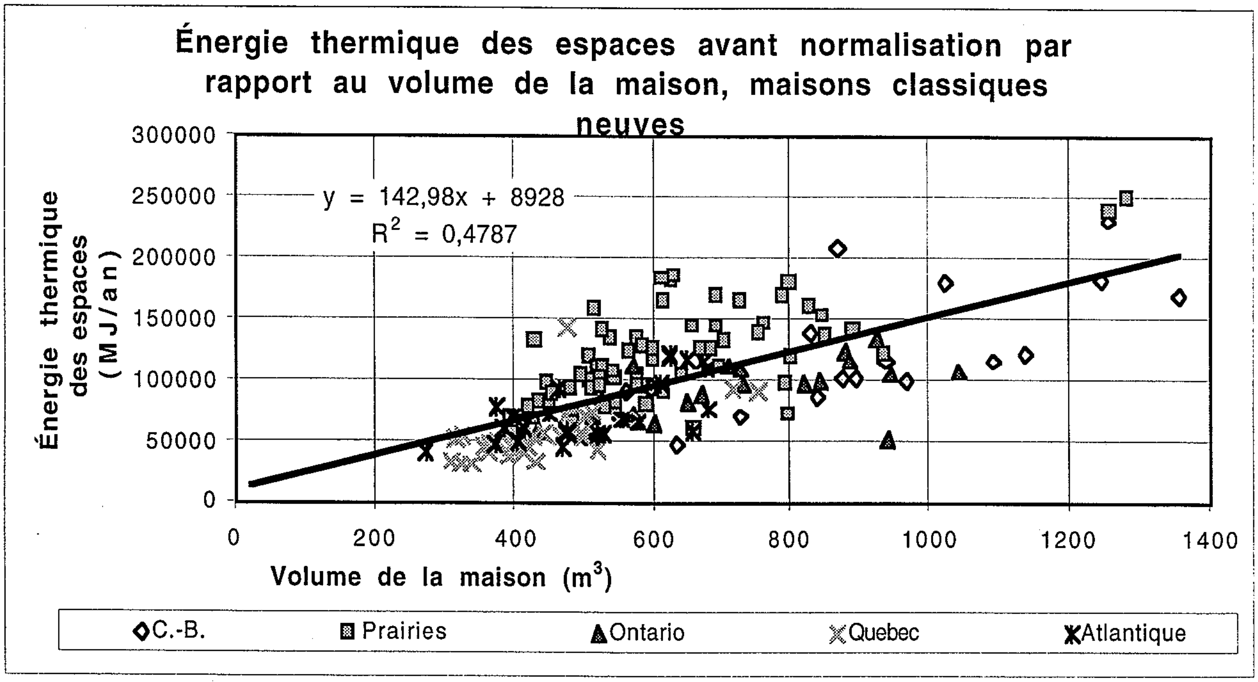

Figure R3. Énergie thermique des espaces avant normalisation par rapport au volume de la maison, maisons classiques neuves.

Les Maisons R-2000 ne présentent aucun problème éventuel de dépressurisation en raison de leur ventilation équilibrée continuelle, en plus de la possibilité de recourir, le cas échéant, à de l'air d'appoint pour parer à tout problème de rejet provenant d'un appareil quelconque.

L'efficacité énergétique des maisons classiques neuves et des Maisons R-2000 fait l'objet d'un examen en s'appuyant sur l'énergie thermique des espaces et sur le tout récent Système de cotation ÉnerGuide pour les maisons. À ce chapitre, on a constaté des écarts significatifs entre les maisons classiques neuves et les Maisons R-2000, ainsi que des variations substantielles entre les diverses régions. En se basant sur l'ensemble des données obtenues, on s'aperçoit que les maisons classiques neuves consomment une moyenne de 93 gigajoules par année (GJ/an) pour le chauffage des espaces, un résultat qui varie de 56 au Québec à 119 dans les Prairies. En comparaison, les Maisons R-2000 consomment 70 GJ/an, un bilan, de 25 % moindre que dans le cas des maisons classiques neuves, qui varie de 41 au Québec à 101 dans les Prairies. Comme le montre la figure R3, les grandes maisons amènent une consommation énergétique plus importante que les petites, alors que la relation se rapportant à cet état de fait constitue, grosso modo, une courbe linéaire. Après normalisation en fonction de la taille, du climat et de l'efficacité du combustible utilisé, l'avantage que procurent les Maisons R-2000 monte de 33 %.

Le Système de cotation ÉnerGuide pour les maisons constitue une méthode de cotation de l'efficacité énergétique se rapportant à une maison donnée, le tout normalisé en fonction de la taille, du climat et de l'efficacité du combustible utilisé. Parce qu'il permet de normaliser la consommation énergétique par volume, ce système accorde aux grandes maisons, qui utilisent d'importantes quantités totales d'énergie, une cotation équivalente aux petites maisons qui utilisent des quantités totales d'énergie moindres. Compte tenu de la tendance actuelle vers la possession de grandes maisons avec peu d'occupants, même des améliorations substantielles aux cotations

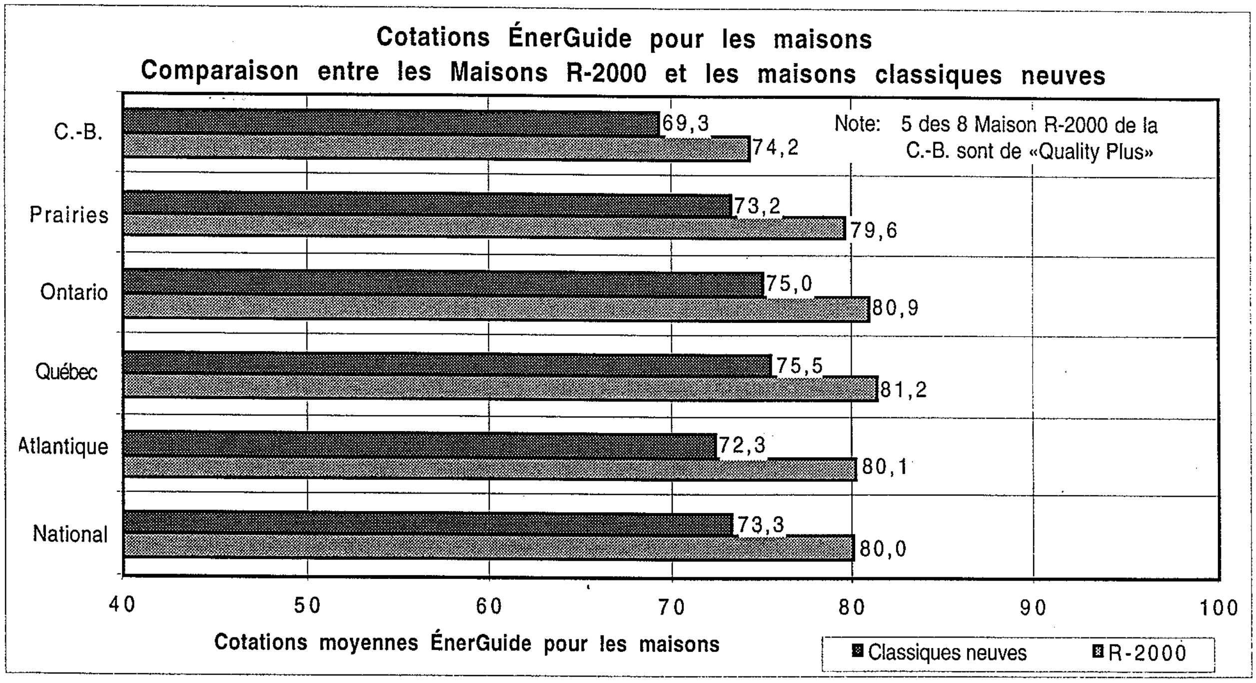

Figure R4. Cotations moyennes ÉnerGuide pour les maisons classiques neuves et les Maisons R-2000.

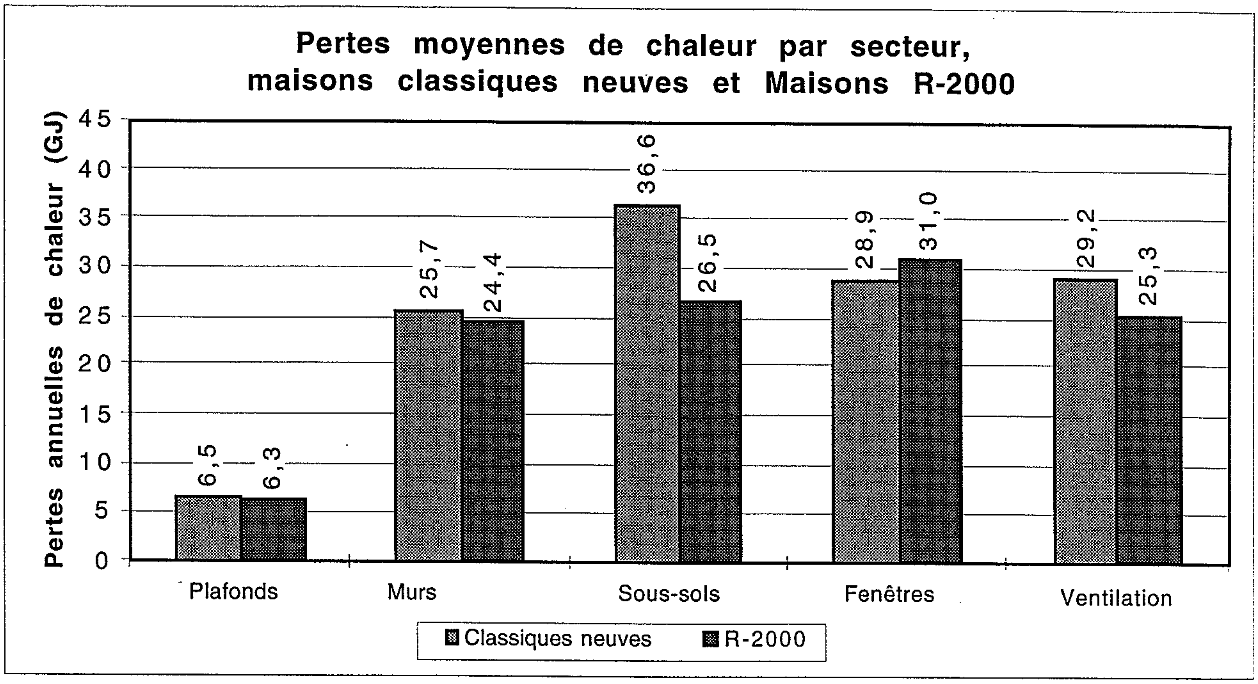

Figure R5. Pertes moyennes de chaleur par secteur, maisons classiques neuves et Maisons R-2000.

d'ÉnerGuide pourraient ne pas signifier une consommation énergétique atténuée pour l'habitation. En ayant recours au Système de cotation ÉnerGuide pour les maisons, les maisons classiques neuves obtiennent des résultats moyens de 73, alors que les Maisons R-2000 affichent une moyenne de 79. La figure R4 donne un tableau des variations par région.

La figure R5 indique les secteurs de pertes de chaleur dans les maisons classiques neuves et dans les Maisons R-2000. Les diverses colonnes que contient la figure montrent la quantité moyenne de chaleur perdue par les différents secteurs de l'enveloppe de la maison et en conséquence de l'utilisation de ventilation naturelle et mécanique. Il est intéressant de noter que les Maisons R-2000 perdent une quantité supérieure de chaleur par les fenêtres que les maisons classiques en raison de leurs dimensions plus vastes et des zones vitrées plus nombreuses. La plus grande différence s'est manifestée au niveau du sous-sol, alors que les maisons classiques neuves y ont perdu 38 % plus de chaleur que les Maisons R-2000 en dépit de leur taille inférieure. La comparaison faite entre la maison classique neuve à rendement énergétique maximum et celle du même genre à rendement énergétique minimum démontre clairement que la plus grande différence entre elles se situe au niveau des pertes de chaleur par le sous-sol : les 10 % de maisons les moins efficaces parmi cette catégorie ont laissé échapper plus de 40 % de leur chaleur par le sous-sol, tandis que les plus efficaces en laissaient passer environ 27 % par le même endroit. Ces résultats donnent à penser qu'il faut s'occuper en priorité de l'isolation des sous-sols.

Les maisons, au Canada, continuent à accroître leur étanchéité et leur efficacité énergétique. Les Maisons R-2000 sont toujours plus étanches et favorisent davantage l'efficacité énergétique que les maisons classiques neuves, mais l'écart se rétrécit sans cesse. L'étanchéité accrue des maisons suscite la possibilité de problèmes liés à la QAI, toutefois, on peut remédier à cette situation à l'aide de systèmes de ventilation et d'équipements de combustion installés selon les codes en vigueur.

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1. Introduction.

Natural Resources Canada (NRCan), in cooperation with Canada Mortgage and Housing (CMHC) and the National Research Council of Canada (NRC), has undertaken a national survey of the airtightness and energy efficiency of new housing, including both conventional and R-2000 houses in all southern regions of Canada. The Canadian Home Builders' Association (CHBA) was instrumental in the selection of typical conventional merchant built housing which makes the survey representative. Additional data was received from Hydro-Québec, Centra Gas, Manitoba Hydro and B.C. Hydro.

The data for this study was gathered by detailed field audits on individual houses carried out by contractors in the various regions of Canada. The data was presented in the form of HOT2000 or AUDIT2000 files, and supplementary paper files. The HOT2000 house simulation program, and its more detailed version AUDIT2000, predict the energy use for space heat, domestic hot water (DHW), and other uses in a house. Their house files can be used by BATCH HOT2000 to produce detailed spreadsheet data on large numbers of houses, and such data are the basis of this report.

Where sufficient meter reading were available, reconciliation was performed. This consists in comparing predicted energy use with actual meter readings, and in reducing differences by varying a set of house and occupant parameters. It provides a check on the general accuracy of predictions of energy use which can be applied to subsequent sections. Airtightness is analyzed in various ways, and shows a general, ongoing trend to more airtight houses with significant but decreasing regional differences. Energy efficiency is examined both in terms of normalized space heat energy, and by the newly developed energy rating system of EnerGuide for Houses, and shows regional variations. The potential for depressurization by exhaust fans, which can result in spillage of combustion gases into houses, is examined and found to be significant.

Increasing airtightness is an integral part of the ongoing increase in energy efficiency and comfort of new housing. Increased airtightness also minimizes moisture damage to buildings. However, in poorly designed buildings, airtightness can increase the potential for lower indoor air quality. Almost all new houses have low natural air change rates, especially during spring and fall when windows are closed. Ventilation can be provided by quiet fans with automatic controls, or by heat recovery ventilators. Ventilation capacities are given in the CSA F-326 standard, in building codes, and in balancing and room-by-room distribution criteria.

2. The Database.

This report is based on the analysis of detailed descriptions of two-hundred and twenty-six new conventional and R-2000 houses in Canada, and on airtightness data for 2,037 houses of all ages. The detailed data was gathered by contractors for Natural Resources Canada and is in the form of HOT2000 files. It is compared with utility meter readings from the houses to produce correction factors, and then analyzed to produce energy efficiency ratings for each house. The airtightness data is analyzed to show long term trends for comparison with the newer houses, and the airtightness new houses is analyzed in more detail. Statistics on the number of existing houses by age and region are used to weight national averages.

2.1 The New House Dataset.

This is the primary database for this report. The other two are used for comparisons with new conventional houses. It consists of data on 163 conventional houses constructed in 1990 through 1996, and is based on recent HOT2000 or AUDIT2000 files. The distributions by regions for all three datasets are shown in Table 1. Figure 1 and Tables 2 through 4 show some of the characteristics of the new conventional houses in this dataset. The national averages are weighted according to the number of existing houses (Section 2.4, below); the highest values in each category are shown in bold type, and the lowest values are in italic.

Figure 1 shows the average insulations values of various house components, including windows. The highest values of ceiling insulations are found in the Prairies, and the lowest are in Ontario. Quebec has the highest values of main (non-basement or crawl space) walls, and B.C. has the lowest. For basement walls above ground, the highest average insulation values are found in Ontario, while the lowest values are in Atlantic Canada. For basement walls below grade the highest values are found in the Prairies with Quebec only slightly lower, and the lowest are in Atlantic Canada. The highest average thermal resistance of windows in the main wall (excluding windows in basements and crawl spaces) are found in the Prairies, and the lowest are in Ontario. In all cases, B.C. is below the national average for insulation values. This is partly due to the milder climate of the west coast, but as Section 5 (Energy Efficiency) will show, the efficiency of B.C. houses is low when climate is taken into account. Table 2 shows that British Columbia has the largest houses by a significant margin, while the smallest are in Quebec and Atlantic Canada.

Table 3 shows the percentages of new conventional houses with electric space heat, and the percentage which have electric heat combined with forced air circulation. The latter is very small except in the Prairies where accounts for almost one-third of the houses. Table 4 shows the general types of ventilation systems. Atlantic Canada has the highest percentage of houses with heat recovery ventilators (HRVs), and no houses without any central ventilation system. Quebec has the highest percentage of houses with no central system, and the lowest percentage with HRVs. More detailed tables of new conventional house characteristics are found in Appendix I.

2.2 The R-2000 House Dataset.

This set consists of 63 R-2000 houses, and is based on recent HOT2000 or AUDIT2000 files. These houses were completed between 1983 and 1995, and qualified as R-2000 houses under a variety of R-2000 Technical Guidelines. In particular, the eight R-2000 houses in British Columbia were enrolled as follows: five qualified under the prescriptive standard of the Quality Plus program, two qualified under the Technical Guidelines using HOT2000 5.06, and 1 under HOT2000 6.02. As will be seen in Section 5, the performance of this selection of B.C. R-2000 houses is significantly different from those in the remainder of the country. Two of the sixteen R-2000 houses in the Prairies were built to an R-2000 prescriptive standard; however, the performances of these two houses are close to the means for all of Canada and for the Prairies, so they are not distinguished in Section 5.

Figure 2 and Tables 5 & 6 show some of the characteristics of the R-2000 houses. As above, national averages are weighted, and maximum and minimum values are shown in bold and italic types. Figure 2 shows average insulation values of various components including windows. The best insulated ceilings are found in the Prairies while Quebec has the lowest values. Quebec has the highest values for main wall insulation, and B.C. has the lowest. Quebec also has the most insulated basement walls above ground, while Ontario's are the least insulated. This is also true of basement walls below ground. The windows with the highest thermal resistances are found the Prairies, and those with the lowest are found in B.C.. Table 5 shows that on average the largest R-2000 houses are found in Ontario and the smallest are in Quebec, while both the largest and smallest individual houses are on the Prairies. On average, R-2000 houses are 22% larger than new conventional houses; in B.C. they are 3% larger, and on the Prairies they are 38% larger. Table 6 shows the percentage of houses with electric space heat, and with electric space heat with forced air circulation. There are no electrically heated R-2000 houses on the Prairies, but they predominate in Quebec and Atlantic Canada. One-sixth of the houses in Ontario, and just over a third of those in Ontario have electric-forced air systems. All the R-2000 house in the dataset have HRVs, so there is no table on ventilation systems. More detailed tables of R-2000 house characteristics are shown in Appendix I.

2.3 The Airtightness Dataset.

This set includes all of the houses in the above two datasets plus data on airtightness for an additional 1,811 houses assembled by Scanada Consultants.[1] It includes houses built from 1793 through 1996. The total number of houses is 2,037. This data is analyzed in Section 4.

2.4 Numbers of Existing Houses in Canada.

The numbers of existing single-detached houses by region and time period were used to weight the regional results in order to produce national results which are more representative. Data for periods up to 1990 were taken from Home Energy Retrofit in Canada,[2] and data for the period 1991 - 1995 is from *Canadian Housing Statistics*,[3] and is linearly extrapolated to estimate numbers for 1996. NRCan's statistics on the number of R-2000 houses by region are also included, as shown in Table 7.

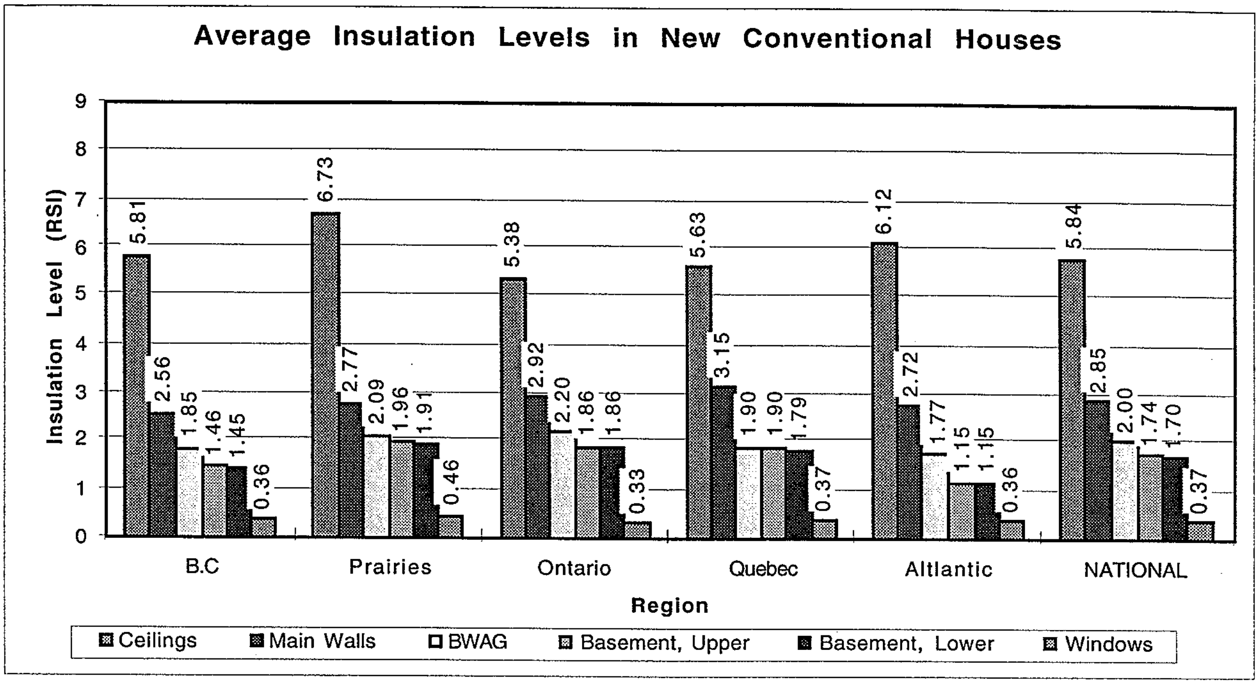

Figure 1. Average insulation values in new conventional houses in the dataset.

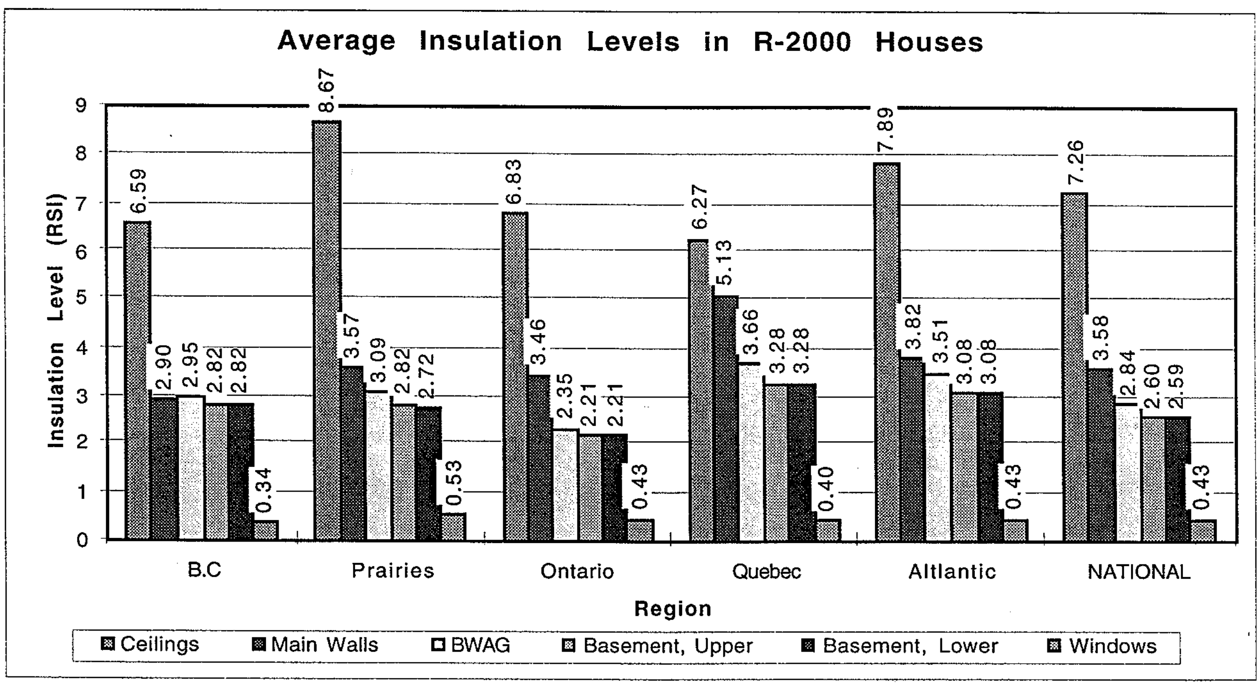

Figure 2. Average insulation levels of R-2000 houses in the dataset.

Datasets	Region					National
	B.C	Prairies	Ontario	Quebec	Atlantic	
New Conventional Houses	20	69	20	30	24	163
R-2000 Houses	8	16	12	14	13	63
Airtightness, additional houses	165	454	384	665	143	1,811

Table 1. Number of houses in the three datasets.

Region	Number of Houses	Volume (m3)				
		Minimum	10th %ile	Mean	90th %ile	Maximum
B.C	20	**504.3**	**517.4**	**840.4**	**1246.2**	**1358.0**
Prairies	69	396.0	443.4	621.7	808.5	1286.5
Ontario	20	407.6	503.7	721.6	940.9	1042.9
Quebec	30	308.7	*324.6*	*447.0*	*555.9*	753.6
Atlantic	24	*271.6*	378.5	514.1	669.0	*679.8*
NATIONAL	163	271.6	396.7	651.6	883.2	1358.0

Table 2. Volumes of new conventional houses.

Region	Number of Houses	Percentages of houses with	
		Electric Heat	Electric Heat with Forced Air
B.C	20	5.0%	0.0%
Prairies	69	34.8%	29.0%
Ontario	20	0.0%	0.0%
Quebec	30	100.0%	3.3%
Atlantic	24	95.8%	4.2%
NATIONAL	163	37.2%	6.4%

Table 3. New conventional houses with electric heat, and electric heat with forced air.

Region	Number of Houses	Percentages with			
			Central Fans		
		HRVs	Balanced	Exhaust only	No system
B.C	20	25.0%	0.0%	0.0%	75.0%
Prairies	69	17.4%	34.8%	18.8%	21.7%
Ontario	20	55.0%	0.0%	0.0%	45.0%
Quebec	30	6.7%	6.7%	0.0%	86.7%
Atlantic	24	83.3%	16.7%	0.0%	0.0%
NATIONAL	163	34.2%	9.3%	3.5%	51.7%

Table 4. Mechanical ventilation of new conventional houses.
Note: 5 Prairie houses (7.2%) have Supply Only Fans.

Region	Number of Houses	Volume (m3)				
		Minimum	10th %ile	Mean	90th %ile	Maximum
B.C	8	550.3	583.7	867.4	1187.2	1188.7
Prairies	16	*350.8*	552.5	859.1	**1221.1**	**1509.2**
Ontario	12	**650.0**	**682.7**	**904.2**	1149.8	1364.7
Quebec	14	376.0	*387.8*	*488.8*	*638.9*	*677.3*
Atlantic	13	420.3	500.1	593.7	691.6	719.5
NATIONAL	63	350.8	425.8	792.2	1123.8	1509.2

Table 5. Volumes of R-2000 houses.

Region	Number of Houses	Percentages of houses with	
		Electric Heat	Electric Heat with Forced Air
B.C	8	12.5%	0.0%
Prairies	16	0.0%	0.0%
Ontario	12	16.7%	16.7%
Quebec	14	85.7%	35.7%
Atlantic	13	92.3%	7.7%
NATIONAL	63	39.7%	11.9%

Table 6. R-2000 houses with electric heat, and electric heat with forced air.

PERIOD	REGION					NATIONAL
	B.C.	Prairies	Ontario	Quebec	Atlantic	
Pre-1920	30,145	110,948	293,520	127,881	104,486	666,980
1920-45	107,100	168,504	244,171	92,711	71,687	684,173
1946-60	186,710	294,130	523,527	235,390	116,284	1,356,041
1961-70	133,505	186,788	291,760	185,087	77,904	875,044
1971-80	211,649	275,851	318,531	227,748	123,055	1,156,834
1981-90	158,924	180,763	364,300	188,034	87,499	979,520
1991-	103,223	90,360	149,492	103,226	44,562	490,864
TOTAL	931,256	1,307,344	2,185,301	1,160,077	625,477	6,209,456
R-2000	595	608	3797	227	2226	7453

Table 7. Numbers of single detached Canadian houses, by region and period.

3. Reconciliation.

Reconciliation consists of comparing AUDIT2000 predictions of monthly energy use by a house with its actual meter readings, and in reducing the difference between predicted and actual values by varying a set of house parameters, or reconciliation factors, within predefined limits.[4] The difference is defined by comparing the monthly values of predicted and metered energy in terms of average difference and root-mean-squared (RMS) errors. Reconciliation was performed on the eighteen new houses and twenty-seven R-2000 houses for which there were sufficient numbers of meter readings. Both new conventional and R-2000 houses from Alberta, Ontario, New Brunswick and Nova Scotia were reconciled.

Reconciliation was attempted for all houses for which the average error was more than five percent. (One house with an average error of 5.1% was not further reconciled). For each house, reconciliation is performed in three steps. First, if both space heat and domestic hot water (DHW) are non-electric, then AUDIT2000's baseload energy is set to the average from the house's electrical meter. Baseload energy is the energy used in the house for all purposes other than space heat and DHW. If the house uses electricity for either space heat or DHW, then this step is skipped. Second, if necessary, the DHW consumption is adjusted to give a good fit during the non-heating season. Third, the set of reconciliation factors shown in Table 8 are varied within their predefined limits. Four of the nine factors can only increase predicted energy use, and so are only applicable to houses for which predicted energy use is less than the metered amounts. For example, the efficiencies of HRVs and space heating equipment may be less than their rated values due to improper installation or maintenance, but are unlikely to be greater. All houses are initially reported as having no solar shading, so any shading will decrease solar gains. As will, almost all houses are reported as being in soil of normal conductivity, and AUDIT2000's other soil options have higher conductivities.

Factor	Abbreviation	Limits	Effect on Predicted Energy Use
Indoor Temperature (excluding basement)	Tin	± 2.5 °C	Both
Basement Temperature	Tbsmt	± 2.5 °C	Both
Heat Recovery Ventilator (HRV) Efficiency	HRV	- 33%	Increase only
Insulation Values	RSI	± 10%	Both
Airtightness	ACH	± 0.1 ACH	Both
Solar Shading	Shade	+ 30%	Increase only
Soil Conductivity	Soil	+ one level	Increase only
Space Heater Efficiency	Furn Eff	- 15%	Increase only
Mechanical Ventilation Rate	Mvent	±33%	Both

Table 8. Reconciliation factors, their limits and effects.

In step three of reconciliation, all applicable factors are varied by a percentage of their limits, e.g., all are varied by 50% of the limits shown in Table 8. Various percentages are tried, until the average difference between the predicted and metered monthly energy use is 5% or less. If varying the applicable factors by 100% cannot reduce the average error to within 5%, then the house is considered to be unreconcilable. The results are summarized in Table 9. Results are shown separately for new conventional and R-2000 houses. The houses monitored by one of the five contractors who monitored these houses ("Contractor A") had higher average errors, and a higher percentage of unreconcilable houses than the others, so results are shown with and without Contractor A's houses, as indicated in the first column. The next three columns show the number of houses which did not require reconciliation (average error ≤ 5% as monitored), the number which required reconciliation and could be reconciled to within 5%, and the number which could not be reconciled (average errors > 5% with applicable reconciliation factors at 100% of their limits). The fifth column shows the average of the metered energy use for each set of houses.

The columns labelled "Average Errors (%)" summarize the differences between the metered and AUDIT2000 predicted energy use for the houses in terms of minimum, mean and maximum average monthly errors, and in terms of the mean of the absolute values of the average monthly errors. The four columns labelled "As Monitored" describe each set of houses before any reconciliation was attempted. For all forty-five houses, the average monthly errors varied between -33.3% and +74.9%, the mean error is 9.4% which shows a definite tendency to over predict energy use, and the mean of the absolute values is 19.6%, indicating that most of the houses are well outside the 5% limit. The columns labelled "Reconciled, All" shows the results of reconciliation, or attempted reconciliation, on all the houses in each set. All error measurements are reduced significantly, but the minimum, maximum, and, in most cases, the mean of the absolute values, show that some of the houses cannot be reconciled. The last four columns show the results for those houses in each set which could be reconciled. The minimum and maximum values are reduced to <5% (5.1% for one house), the means are <0.2% showing that the tendency to over prediction has been virtually eliminated, and the means of the absolute values are <2.5% showing that most of these houses are reconciled to less than ±5%.

These results indicate that a substantial majority of monitored houses either require no reconciliation or can be reconciled – the percentage which cannot be varies from 28% for all new conventional houses to 13% for both new conventional and R-2000 houses with one contractor's houses removed. The result most relevant to the remainder of this report is the tendency to over predict energy use. The AUDIT2000 house files as received from contractors in the field consistently over predict energy use. The average over prediction for the forty-five houses is 9.4%, and varies from 13% for all the new conventional houses, to 3.7% for both new conventional and R-2000 houses with Contractor A's houses removed.

A general tendency to over predict is also shown by the sets of newer monitoring results in Table 10. Monitoring contractors compared results of AUDIT2000 simulations with space heat meter readings. The simulations were done with long-term weather data and corrected to the metered period by degree-days. Except for the four new conventional houses in B.C., the results are quite consistent with the reconciliation results. There is no apparent explanation why the B.C. results are so different; they may simply be a small, unrepresentative sample. The weighted averages shown in the last line of Table 10 are used as correction factors for the energy efficiency analysis in Section 5. That is, the simulated space heat energy for each house is reduced by the appropriate correction factor.

NRCan will soon have enough meter readings to reconcile a much larger set of houses, and is developing an automated reconciliation procedure. These should allow us to evaluate the apparent bias toward over prediction more accurately, and perhaps to suggest changes to field auditing techniques and/or to the HOT2000/AUDIT2000 model, which will reduce any such biases.

DataSet	Number of Houses			Metered	Average Errors (%)											
	Pre-	Recon-	Not	Energy	Original				Reconciled, All				Reconciled, Reconcilable			
	recon'd	cilable	recon'd	(GJ/day)	Min	Mean	Max	|Mean|	Min	Mean	Max	|Mean|	Min	Mean	Max	|Mean|
All Houses	14	22	9	0.334	-33.3	9.4	74.9	19.6	-20.4	2.6	34.1	5.1	-4.4	0.02	5.1	2.1
All New	8	5	5	0.348	-28.6	13.0	71.2	20.9	-3.3	3.6	26.7	4.9	-3.3	0.14	5.1	1.9
All New, less 1 contractor	8	5	2	0.367	-28.6	3.7	48.9	13.1	-3.3	1.4	10.7	2.9	-3.3	0.14	5.1	1.9
All R-2000s	6	17	4	0.325	-33.3	6.9	74.9	18.8	-20.4	1.9	34.1	5.3	-4.4	0.05	4.7	2.2
All R-2000s, less 1 contractor	6	14	3	0.340	-33.3	3.7	74.9	16.5	-20.4	0.8	21.9	4.9	-4.4	0.03	4.7	2.4

Table 9. Summary of reconciliations. The symbol |Mean| indicates the mean of the absolute values of the errors.

Source	New Conventional Houses		R-2000 Houses	
	Number	% Overprediction	Number	% Overprediction
1996 Reconciliations	18	13.0	27	6.9
Ontario Monitoring	8	12.9		
Quebec Monitoring			4	5.25
Manitoba Monitoring	15	12.4		
British Columbia Monitoring	4	-25.25		
Totals and Weighted Averages	45	9.4	31	6.7

Table 10. Correction Factors for Predicted Space Heat Energy Use.

4. Airtightness.

This section presents information on the airtightness of new conventional and R-2000 houses, with information on older houses for comparison. The airtightness database is analyzed in five ways. First, all of the data are averaged by geographical region and by broad time periods to show long-term trends and regional comparisons. R-2000 houses are treated as a separate period for comparison. Second, data on conventional houses are analyzed by shorter, more recent time periods to show recent changes in more detail. Third, the individual Prairie provinces are analyzed separately for the recent periods since there are significant differences within this region. Fourth, HOT2000 predictions of annual total air change rates for new conventional and R-2000 houses are shown. Fifth, the distribution curves for the airtightness of new conventional and R-2000 houses are presented and characterized.

4.1 Long Term Trends in Airtightness.

The results for the complete airtightness database are shown in Table 11 and Figure 3 which show average air changes per hour at 50 Pascals of depressurization (ACH @ 50 Pa) by time period and region and nationally by period. (The national averages are weighted according to the numbers in Table 7). The trend toward increasing airtightness (decreasing ACH @ 50 Pa) is clear and nearly uniform. The only significant exception is Quebec which shows a decrease in airtightness between Pre-1921 and 1921 - 1945. Atlantic Canada shows small decreases for two periods – from Pre-1921 to 1921-1945, and from then to 1961-1970 – although these may not be statistically significant. New conventional houses (1991 -) in all regions are significantly tighter than those for all earlier periods. (The definition of new conventional used here (1991 and later) is slightly different than that used in other databases (1990 and later) due to the way in which Scanada assigned specific years to houses which were originally defined in terms of a range of years). Comparing regions, the tightest new conventional houses are found in the Prairies which have had the tightest houses since 1946. The loosest new conventional houses are found in British Columbia which has generally been among the least airtight of the regions, although Quebec has been less airtight in four pervious periods, including 1981 - 1990. R-2000 houses are at least twice as airtight as new conventional houses in all regions except the Prairies where they are one-and-one-half times as airtight. As noted in Section 2.2, five of the R-2000 houses in B.C. qualified under the Quality Plus prescriptive standard. One of these houses was not required to have a blower door test, and it has an ACH @ 50 Pa of 2.10; without this house, the average for B.C. R-2000 houses would be 1.35, or virtually the same as those in the Prairies and Atlantic Canada.

Table 12 and Figure 4 show the same data set* analyzed in terms of normalized leakage area or NLA (cm^2 of equivalent leakage area per m^2 of envelope area). The same general trend toward increasing airtightness (decreasing NLA) is evident. While ACH showed three exceptions to this trend, NLA shows five. For each period, the tightest conventional houses are found in the same region, whether measured in terms of ACH or NLA. For each period, the loosest houses are found in the same region with the exception of 1921 - 1945, for which Quebec is the loosest according to ACH and B.C. is the loosest according to NLA. For all regions, new conventional houses (1991 -) are tighter than all pervious houses, and all R-2000 houses (regardless of region),

* Of the 2037 houses which were analyzed for ACH, 1874 also had values for NLA or the values of C, n, and envelope area needed to calculate NLA.

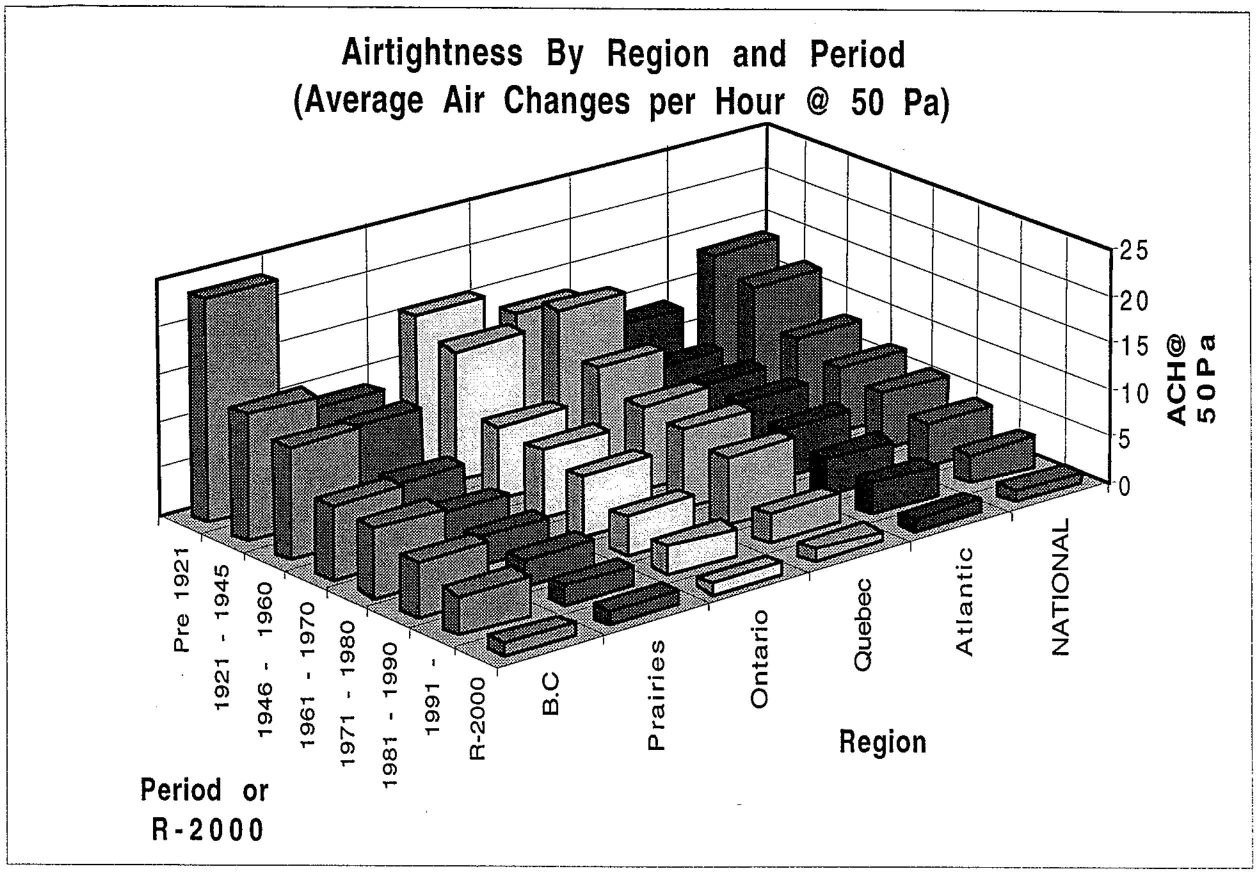

Figure 3. Airtightness (average air changes per hour at 50 Pa) by region and period, with R-2000 houses for comparison.

Region	Pre 1921	1921 - 1945	1946 - 1960	1961 - 1970	1971 - 1980	1981 - 1990	1991 -	R-2000
B.C	23.64	13.48	11.93	7.78	7.35	5.71	4.28	1.44
Prairies	9.14	9.10	4.99	3.65	3.18	2.84	1.99	1.34
Ontario	16.16	14.21	7.93	7.44	6.48	4.22	2.82	1.14
Quebec	13.51	15.63	11.21	8.94	8.40	7.23	3.27	1.22
Atlantic	9.09	6.23	6.28	6.32	5.34	3.90	3.14	1.35
NATIONAL	13.72	12.19	8.27	6.90	6.11	4.76	3.10	1.24

Table 11. Airtightness (average air changes per hour at 50 Pa) by region and period, with R-2000 houses for comparison.

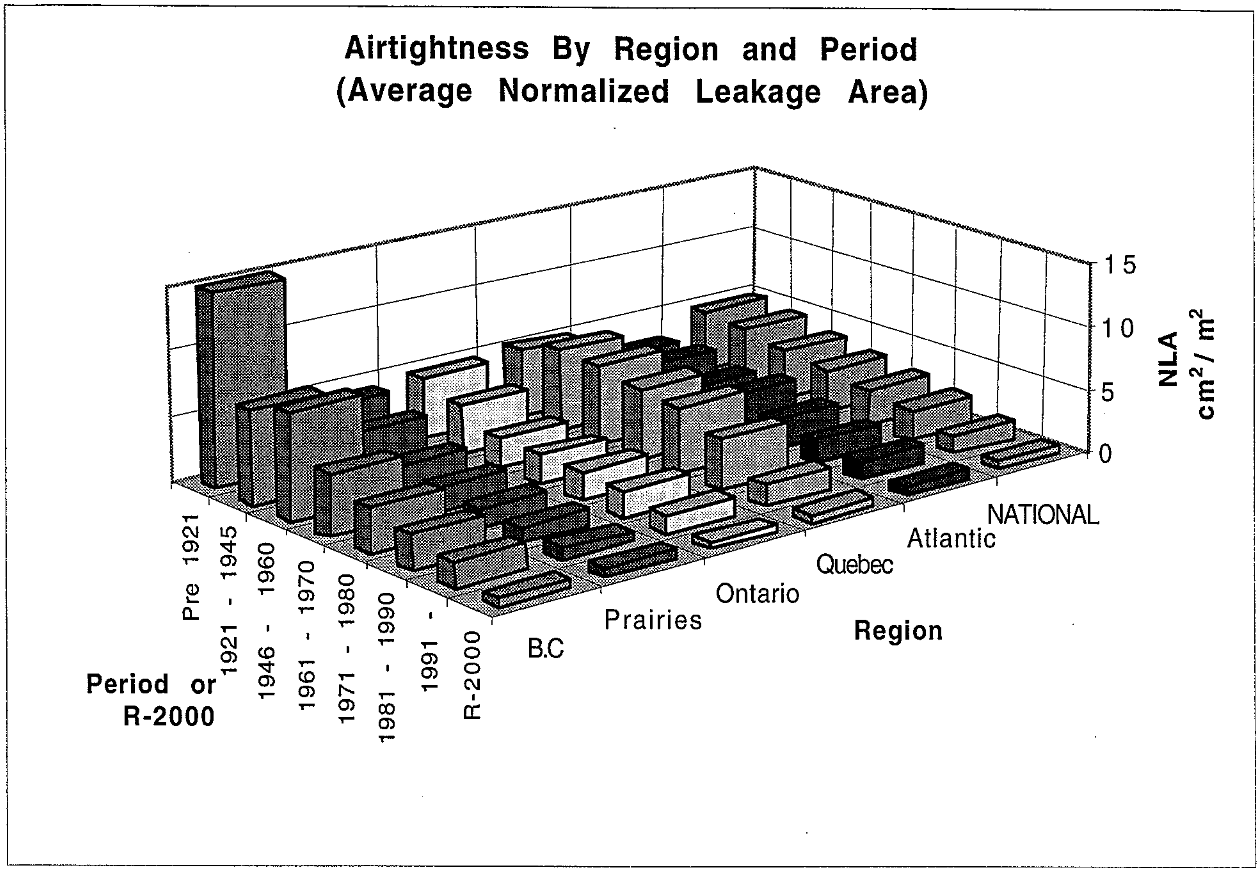

Figure 4. Airtightness (average normalized leakage areas) by region and by periods, with R-2000 houses for comparison.

Region	Pre 1921	1921 - 1945	1946 - 1960	1961 - 1970	1971 - 1980	1981 - 1990	1991 -	R-2000
B.C	14.99	7.24	8.22	4.70	3.53	2.79	1.91	0.69
Prairies	4.29	3.67	2.17	1.72	1.40	1.29	0.92	0.72
Ontario	4.79	3.89	2.50	2.21	2.10	1.92	1.35	0.53
Quebec	5.17	6.36	6.18	5.50	5.20	3.99	1.60	0.59
Atlantic	3.06	3.37	2.76	3.18	2.41	1.83	1.33	0.65
NATIONAL	4.97	4.64	3.88	3.27	2.84	2.33	1.44	0.59

Table 12. Airtightness (average normalized leakage areas) by region and period, with R-2000 houses for comparison.

are tighter than all conventional houses, according to both ACH and NLA. For conventional houses before 1991, ACH is probably the more accurate measurement, due to a change in the way house envelope area was measured. Before 1984 or 1985, the envelope area was generally defined as not including above grade basement walls, and there was considerable variation in the way tests were conducted and analyzed. Since then, the CGSB Standard[5] has specified that these walls are included, and has standardized testing. In order to make NLAs for houses surveyed before that time consistent with contemporary surveys, Scanada multiplied envelope areas by 1.5 or 1.85, depending on the number of stories. Of course, such factors can only be approximations, and must introduce some errors into the NLAs. Similar graphs and tables for equivalent leakage areas (ELAs) which are not based on envelope area are shown in Appendix II.

The Draft National Energy Code for Houses (NECH)[6] specifies that houses should have NLA of less than 2 cm^2/m^2. Table 12 shows that on average new conventional houses in all regions are within this limit. Table 13 shows the number and percentage of these houses in each region which exceed this limit, and the maximum value of NLA for new conventional houses in each region. This data indicates that all regions except the Prairies and Ontario have significant numbers of houses which exceed the 2 cm^2/m^2 limit, and that the limit is exceeded by significant amounts.

Region	Total Numbers	NLAs > 2cm^2/m^2 Number	NLAs > 2cm^2/m^2 %	Maximum NLA (cm^2/m^2)
B.C	18	6	33.3	3.66
Prairies	68	2	2.9	2.59
Ontario	20	0	0.0	1.98
Quebec	30	6	20.0	4.79
Atlantic	30	3	10.0	3.06

Table 13. New conventional houses with NLAs exceeding the NECH limit of 2 cm^2/m^2.

4.2 Recent Changes in Airtightness, Measured within Two Years of Construction.

The above data on airtightness are for fairly broad time periods, and includes tests done when houses were already several years to decades old. Figures 5 & 6 show recent changes in airtightness in more detail, and include only tests done when houses were new. The periods are 1981 to 1985, 1986 to 1990, and 1991 to 1995. This data comes entirely from three sources: The 1982 survey of airtightness,[7] the 1989 survey of airtightness,[8] and NRCan's new house dataset (Section 2.1). Thus, the data used in this section is a sub-set of the data used in the last section.

Figure 5 shows average values of ACH by region for the three periods, and Figure 6 shows average values of NLA for the same regions and periods. The two figures are very similar. There is a general trend toward greater airtightness, as shown by the national data, and by most of the individual regions. The trend is strongest in British Columbia, where 1981 -1985 houses were much looser than in all other regions, but major improvements in the second and third periods have

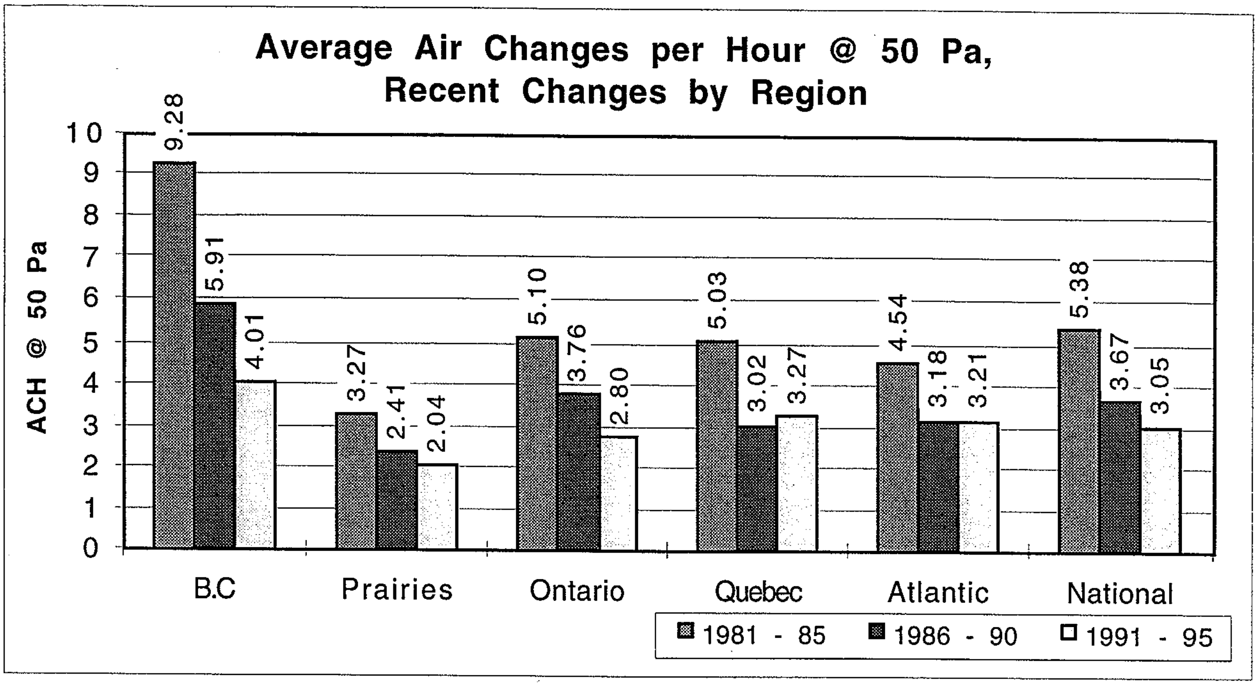

Figure 5. Average air changes per hour at 50 Pa, recent changes by region.

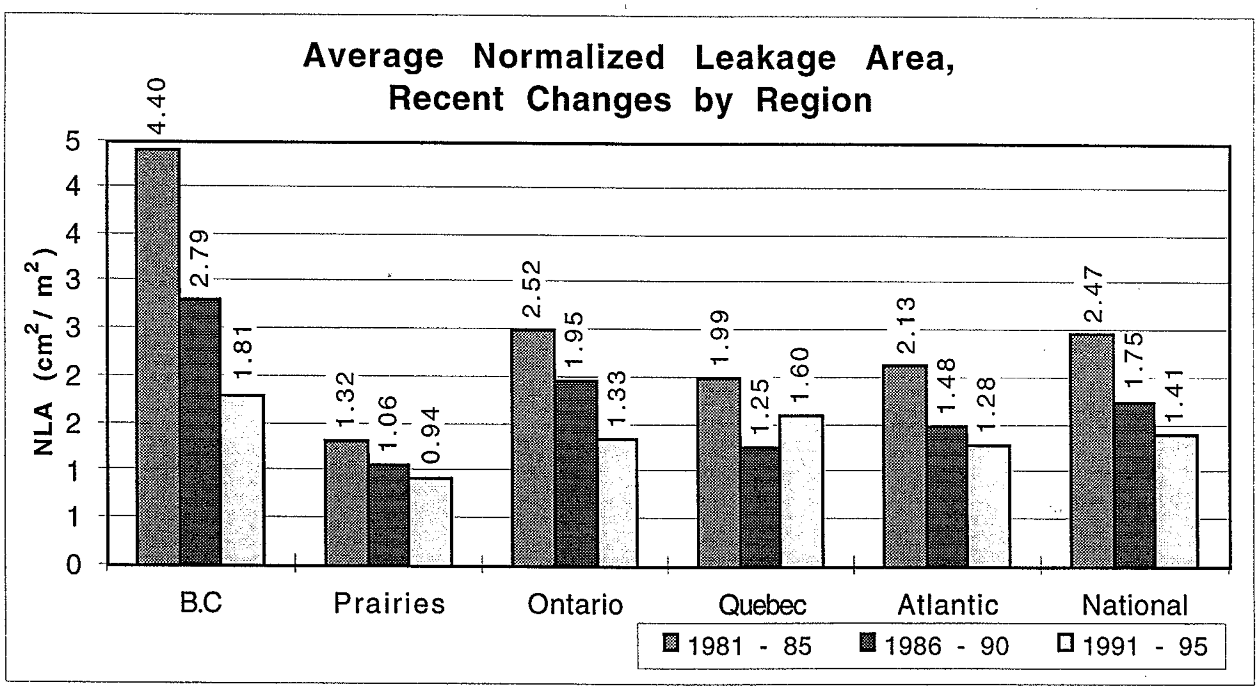

Figure 6. Average normalized leakage area, recent changes by region.

now brought BC close to the national average. In 1981 - 85, the Prairies were significantly tighter than all other regions, and small improvements have kept them the most airtight, although the differences between houses on the Prairies and those in all other regions are now much smaller. Ontario houses have shown steady progress, and are now the second tightest (according to ACH), although the differences between Ontario, Quebec and Atlantic Canada in 1991 - 95 are probably not statistically significant. Quebec and Atlantic Canada show small increases in ACH between the second and third periods, and Quebec shows an increase in NLA also. These increases are almost certainly not statistically significant, and the data should be interpreted as indicating little change in airtightness in Quebec and Atlantic Canada between 1986 - 1990 and 1991 - 1995. Also, the only data available for the last period in Quebec are for houses built in 1991 and 1992, i.e., for the early part of the last period. For all three periods, the loosest houses are found in British Columbia, and the tightest are found in the Prairies, whether measured by ACH or NLA.

These significant increases in airtightness over short time periods are probably due to a number of factors. Builders and house buyers are generally more aware of the issues of moisture damage, comfort, and energy efficiency, due to various programs for builder training and consumer awareness. The National Building Codes which were published in 1985, 1990, and 1995 may also have had some influence, although their changes in airtightness provisions are not very significant, and their adaptation by the provinces generally takes several years.

4.3 Recent Changes in Airtightness, Prairie provinces.

The Prairie region is further analyzed by province because earlier studies have shown differences between Alberta and the other two prairie provinces. Figures 7 & 8 show average values of ACH and NLA for Alberta, Saskatchewan and Manitoba for the same time periods as were used in the last section. The two graphs are generally similar. Houses in Alberta remain the least airtight on the Prairies, but the differences have been reduced by a strong improvement between 1981 - 85 and 1986 - 90 (but no significant change between the second and third periods). Saskatchewan shows steady improvements (according to ACH), and now appears to be the most airtight province in Canada (according to both ACH and NLA). In fact, the average airtightness for the seven Saskatchewan houses exceeds the R-2000 standards for both ACH and NLA. Manitoba was the most airtight in 1982, but has shown no significant changes since then.

4.4 Distributions of airtightness values.

Figures 9 & 10 show the distributions of the values of ACH and NLA for new conventional houses, and Figures 11 & 12 show these values for R-2000 houses. Only R-2000 houses which were tested within a few years of their construction are included in the distributions. Although somewhat irregular, all of the distributions seem to be closer to log-normal than to normal for the following reasons: First, all have medians that are lower than their means, and with one exception, all have peaks which occur at lower values than their means. Second, all tend to drop sharply after their peaks, and have longer right-hand tails than normal distributions do. Graphs showing both the normal and log-normal distributions are shown in Appendix III. (The means shown here are slightly different from those in Tables 11 & 12 because the former are not weighted according to the number of houses in each region).

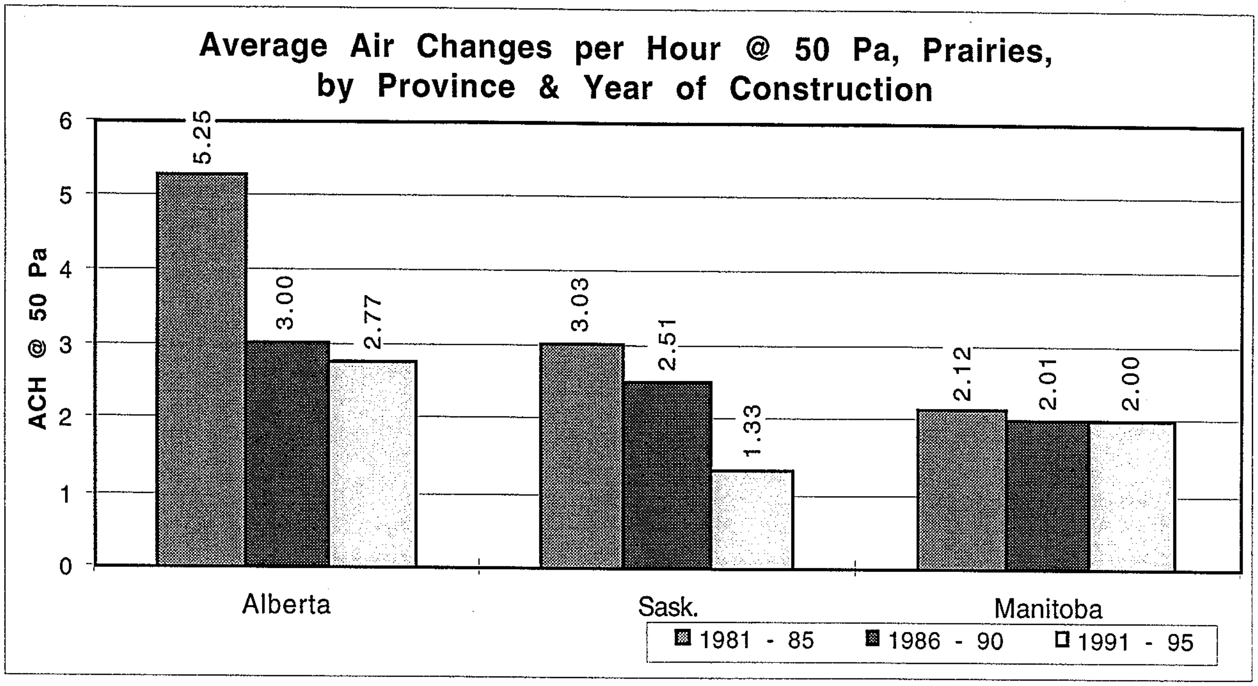

Figure 7. Average air changes per hour at 50 Pa, recent changes in the Prairie Provinces.

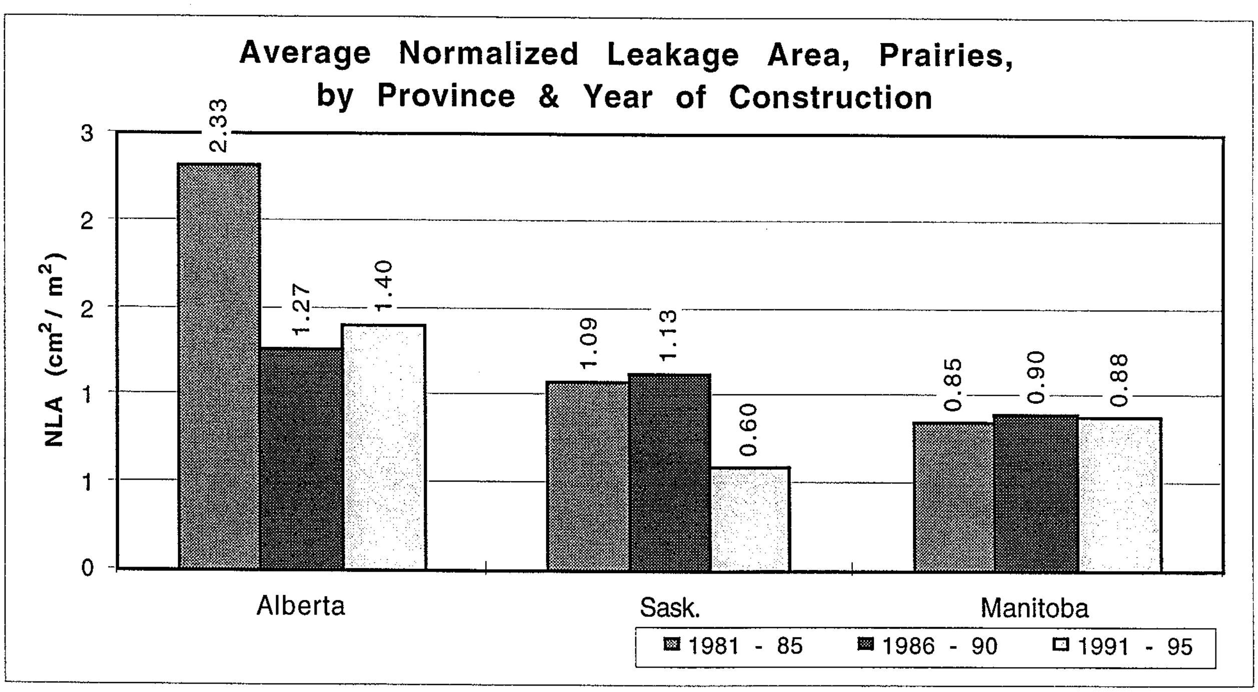

Figure 8. Average normalized leakage area, recent changes in the Prairie Provinces.

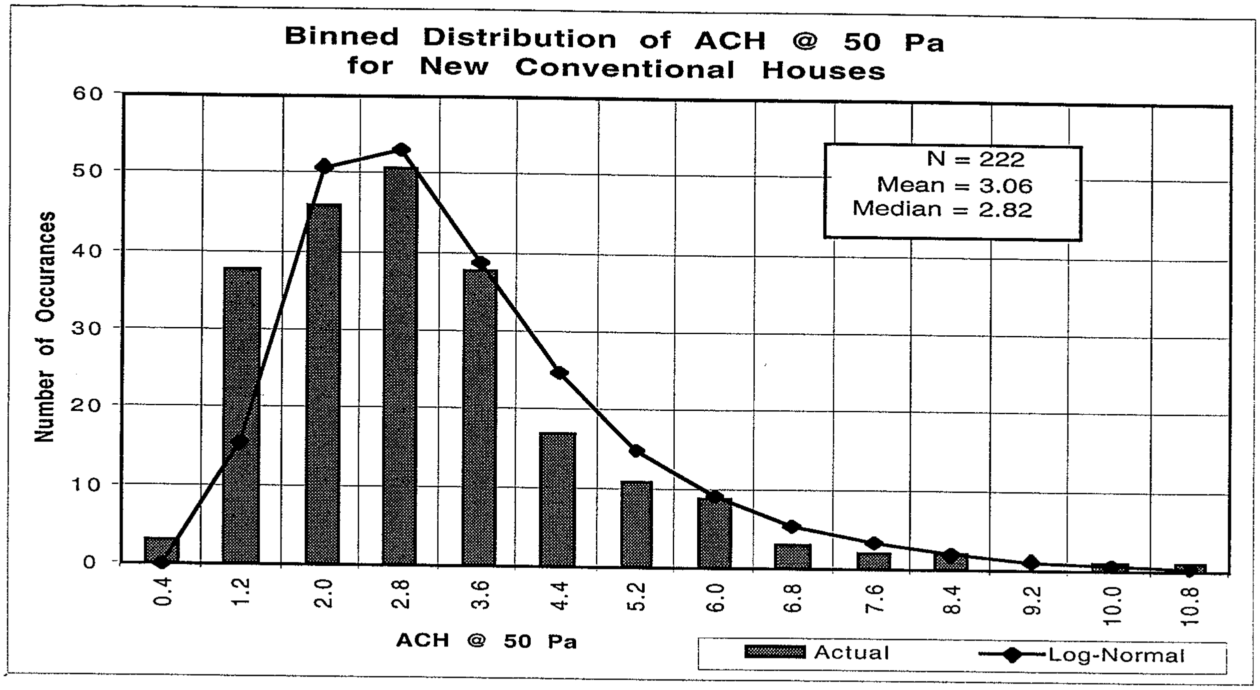

Figure 9. Binned distribution of air changes per hour at 50 Pa for new conventional houses.

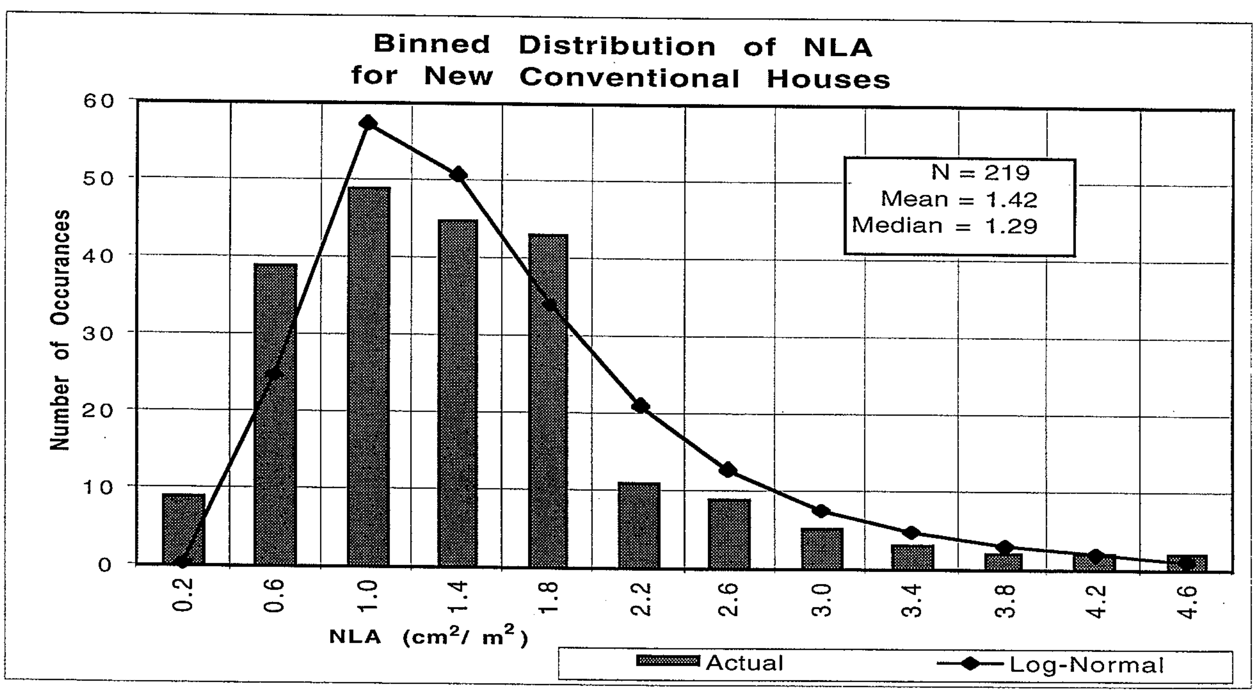

Figure 10. Binned distribution of normalized leakage areas for new conventional houses.

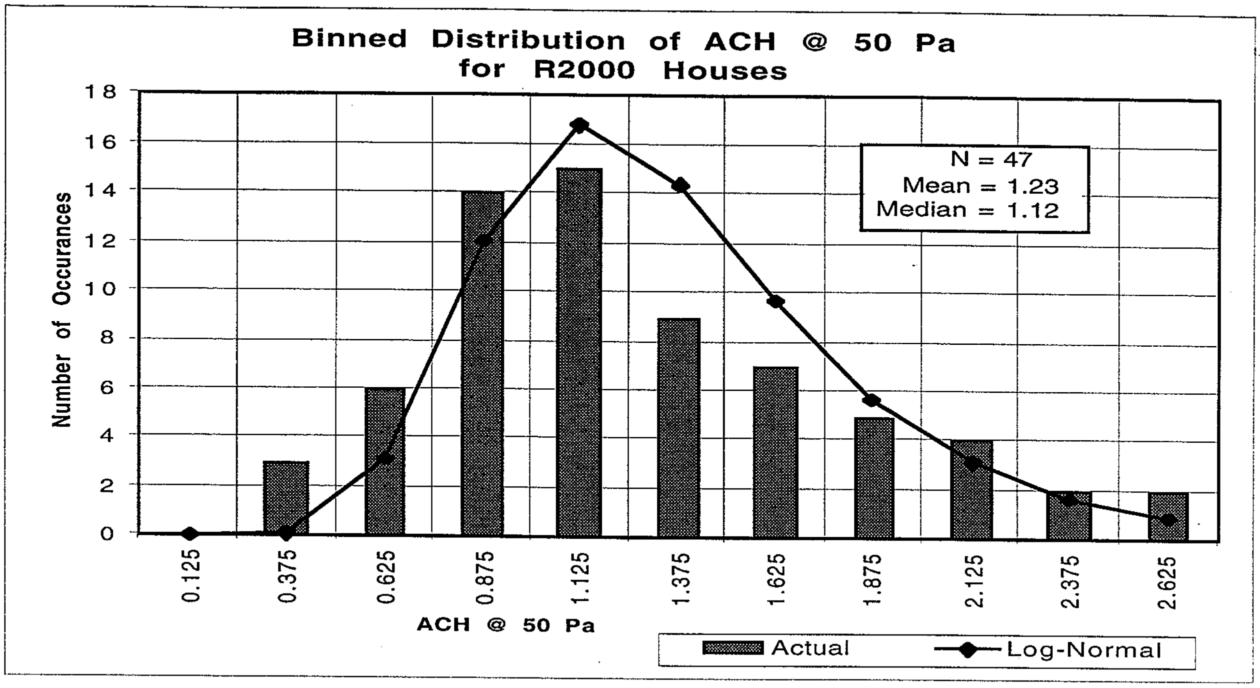

Figure 11. Binned distribution of air changes at 50 Pa for R-2000 houses.

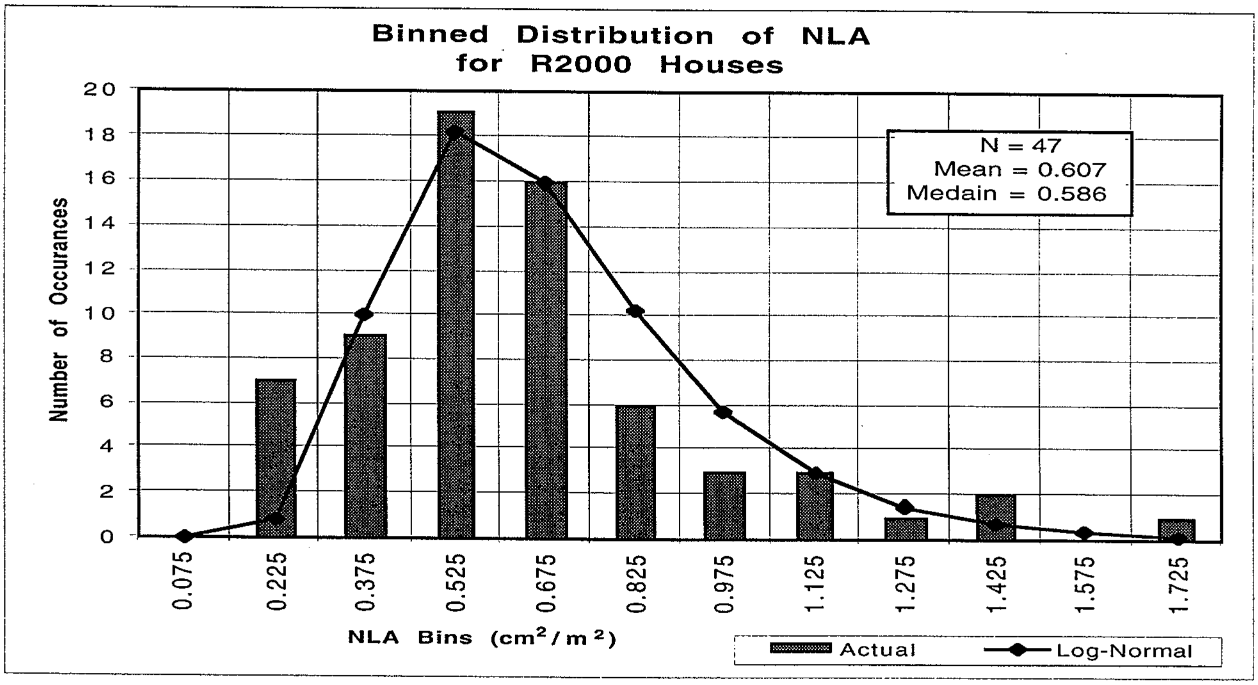

Figure 12. Binned distribution of normalized leakage areas for R-2000 houses.

4.5 Natural air change rates predicted by HOT2000.

Houses with natural air change rates of less than 0.35 air changes per hour (ach) are likely to have indoor air quality (IAQ) problems,[9,10,11] unless they have enough mechanical ventilation to bring their total ventilation rates up to that amount.* In houses with natural ventilation rates less than 0.20 ach the potential for IAQ problems is more severe. These ventilation rates should be achieved in the heating season month with the lowest natural ventilation rate which is generally October. A comparison of monthly and annual rates (Section 5) indicates that an annual average of 0.364 ach correlates with an October rate of 0.35. Using the same proportions, an annual rate of 0.208 should correspond to an October rate of 0.20. In houses with air conditioning, the summer months are the worst case, but they are not investigated here because most of the houses in this study do not have air conditioning.

In order to investigate the potential for IAQ problems due to low ventilation rates, we used HOT2000 to predict the annual average of the natural air change rate for the new conventional houses. BATCH HOT2000 was run on files for each of the houses as received from the field monitors, i.e., as built and as operated, and produced a spreadsheet output file containing the location, type of ventilation system, and natural air change rate for each house. This data was analyzed by region, and the results are shown in Table 14. Between 80 and 97% of the new conventional houses have natural ach's which are low enough to cause potential IAQ problems, i.e., annual averages < 0.364, corresponding to averages <0.35 for the lowest heating season month (see next section). In 50 to 75% of them the potential is more severe (annual averages < 0.208, corresponding to< 0.20 for the lowest heating month). However, many of these houses have mechanical ventilation systems which can prevent IAQ problems if used properly.

Region	Number of Houses	Natural Air Change Rates (ach)			House with Natural ach less than:					
					All Houses		No HRVs		No Mech. Vent.	
		Min	Mean	Max	<0.35	<0.20	<0.35	<0.20	<0.35	<0.20
B.C.	12	0.015	0.153	0.390	92%	75%	83%	67%	83%	67%
Prairies	69	0.017	0.156	0.426	97%	68%	80%	51%	22%	13%
Ontario	20	0.063	0.221	0.452	85%	55%	45%	25%	45%	25%
Quebec	30	0.059	0.226	0.605	80%	50%	73%	43%	67%	40%
Atlantic	24	0.060	0.212	0.496	83%	63%	13%	8%	0%	0%
National	155	0.015	0.186	0.605	90%	63%	64%	41%	35%	22%

Table 14. The natural air change rates, and potentials for IAQ problems, of new conventional houses.

* Despite differences in methodology, there is a general consensus that the minimum acceptable air change rate is in the range of 0.30 to 0.35.

Houses with heat recovery ventilators (HRVs) which are properly sized and installed are unlikely to have IAQ problems, since the HRVs are quiet and energy efficient, and so are likely to be run whenever windows are closed for the heating season. However, the majority (64%) of the new houses have both natural ach's of less than 0.364 and no HRV. These figures range from 13% in Atlantic Canada to 83% in British Columbia. Forty-one percent of the houses have natural ach's below 0.208 and no HRVs, and these figures range from 8% in the Atlantic provinces to 67% in B.C.. Central fans other than HRVs may prevent IAQ problems if they are properly sized and installed, but they are often not run throughout the heating season because they increase heating costs and may be noisy. In any case, a substantial number of the new conventional houses have low natural air change rates and no fans other than kitchen and bathroom exhausts which are seldom if ever used continuously. The conclusion to be drawn from these figures is that homes built according to current practice for airtightness should at least have central ventilation systems which are adequately sized for the house, and suited for continuous operation. Such systems are defined by the F326 Standard (Ref 11), and by Section 9.32 of the *National Building Code of Canada.*[12] HRVs can be used to minimize energy costs and increase comfort. Controls should also be provided to increase ventilation rates during periods of high humidity or occupancy, or low air leakage due to low indoor-outdoor temperature differences.

Table 15 shows similar data for R-2000 houses. As might be expected, all the R-2000 houses in this study have natural air change rates below 0.364, and approximately 90% in all regions have natural ach's below 0.204. However, all of the R-2000 houses have HRVs, and so are unlikely to have IAQ problems as long as the HRVs are run throughout the heating season.

Region	Number of Houses	Natural Air Change Rates (ach)			Houses with natural ach less than			
					All Houses		No HRVs	
		Min	Mean	Max	<0.35	<0.20	<0.35	<0.20
B.C.	8	0.044	0.122	0.276	100%	88%	0%	0%
Prairies	16	0.076	0.139	0.331	100%	88%	0%	0%
Ontario	12	0.008	0.093	0.207	100%	100%	0%	0%
Quebec	14	0.054	0.145	0.279	100%	86%	0%	0%
Atlantic	13	0.024	0.138	0.279	100%	92%	0%	0%
National	63	0.008	0.129	0.331	100%	90%	0%	0%

Table 15. The natural air change rates of R-2000 houses.

5. Energy Efficiency.

Energy efficiency is analyzed according to the Energy Efficiency Rating (EER) system developed for the EnerGuide for House Program. This system gives houses ratings based on total energy use under standard operating conditions.[13] This section traces the derivation of the EERs through five stages, beginning with un-normalized energy use for space heat, and comparing three methods of normalization. Data on energy use by each house is based on HOT2000 predictions under standard EnerGuide operating conditions. In order to simulate these conditions, each house file is processed as follows:

For each of the new conventional and R-2000 houses in this study, the interactive version of HOT2000 was used to set the parameters dealing with occupancy effects and location to the EnerGuide standard values as follows:

Main floor heating set point:	21.0 °C
Basement Heated:	Yes
Basement Cooled:	No
Basement heating set point:	21.0 °C
Basement separate thermostat:	No
Allowable daily temperature rise:	3.5 °C
Average interior loads, Lighting:	3.0 kWh/day
Average interior loads, Appliances:	14.0 kWh/day
Average interior loads, Other:	3.0 kWh/day
Average exterior use:	4.0 kWh/day
Hot water load:	225 L/day
Hot water temperature:	55.0 °C
Adult Occupants:	2 at home 50% of time
Child Occupants:	2 at home 50% of time
Infant Occupants:	0 at home 0% of time
Air Conditioner:	Not installed
Terrain Description @ Building site:	Suburban, forest
Local shielding, Walls:	Very heavy
Local shielding, Flue:	Light local shielding

Mechanical ventilation rate were adjusted so that total air change rate during the warmest month when windows are normally closed will be 0.35 ach ±0.005. This "shoulder season" month is considered to be October in all parts of Canada, except for the Vancouver and Victoria B.C. areas in which November is used. Meeting the desired air change rates is done by adjusting mechanical ventilation to achieve an annual total air change rate of 0.364 ±0.005, or 0.335 ±0.005 for houses around Vancouver and Victoria. The mechanical ventilation rates were calculated as balanced, i.e., supply equals exhaust. Houses without a central ventilation system are treated as follows: If their natural air change rate meets or exceeds the target, then no change is made; if they require mechanical ventilation, then continuous fans without heat recovery are added.

Once the above changes have been made for all the houses in a dataset, HOT2000's translation utility was used to create ASCII house files (.V71 files) which can be read by BATCH HOT2000. BATCH HOT2000 was then run on the files in each database to produce a spreadsheet output with the following variables: region, year of construction, space heat energy, space heat and DHW energy, energy used for space heat and ventilation fans during furnace operation, fuel types for space heat and domestic hot water, house volume, and degree days and average deep

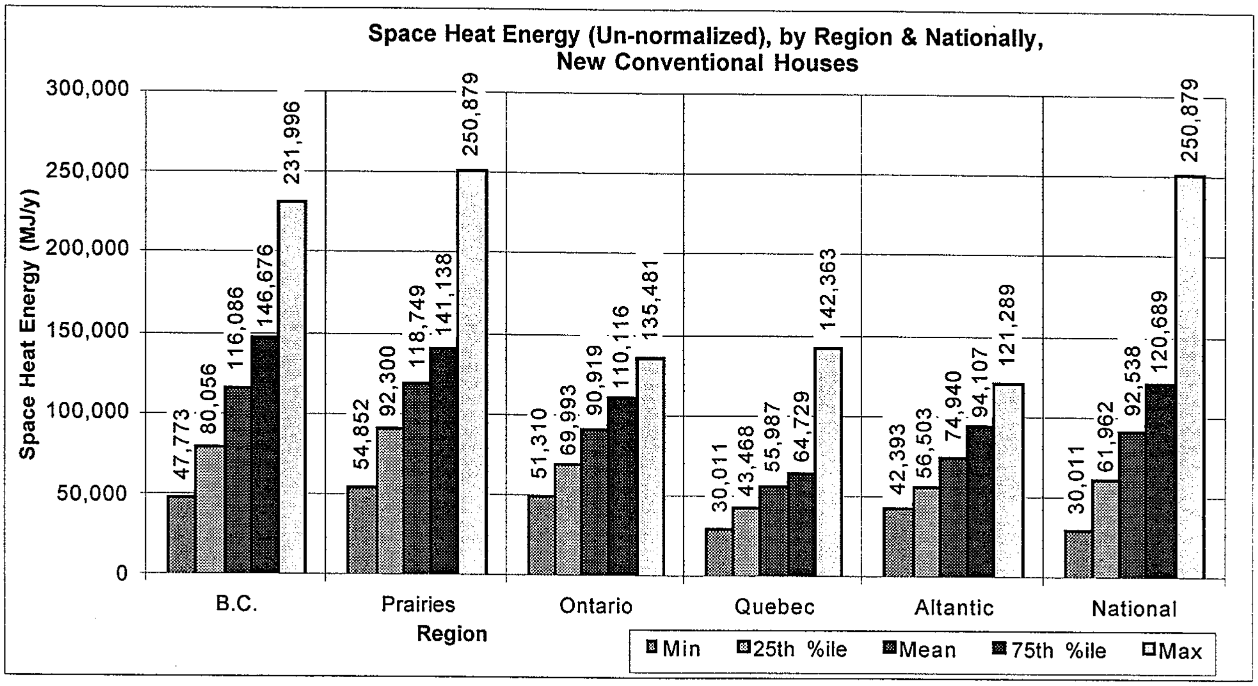

Figure 13. Space heat energy use (un-normalized) for new conventional houses, by region and nationally.

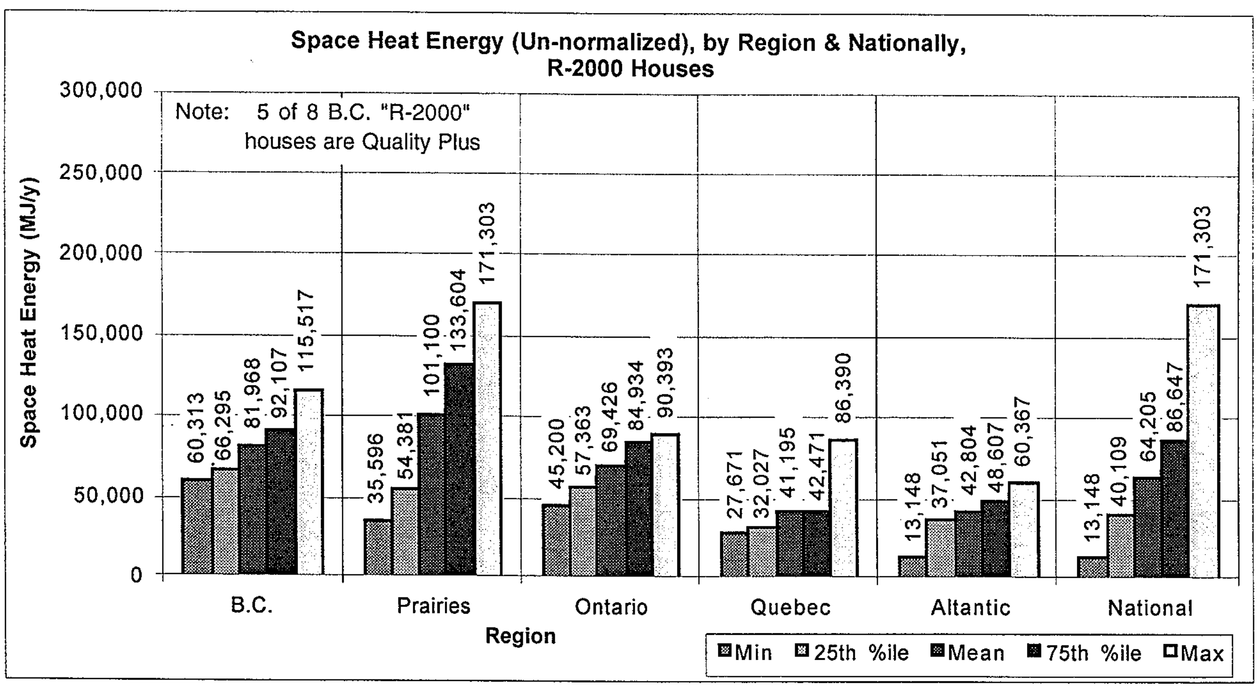

Figure 14. Space heat energy use (un-normalized) for R-2000 houses, by region and nationally.

ground temperature from the house's HOT2000 weather file. (Other variables which are used to calculate depressurization potential (below) are also written). The space heat data for each individual new conventional or R-2000 house in this section is reduced according to the correction factors show in Table 10.

5.1 Un-normalized Space Heat Energy under EnerGuide Operating Conditions.

Figures 13 & 14 show the actual (un-normalized) space heat energy by region and nationally for new conventional and R-2000 houses. Space heat energy is the sum of fuel or electricity used for space heat, and electricity for space heat and ventilation fans during furnace operation. The energy content of both fossil fuels and electricity are used with no fuel factors, e.g., one cubic meter of natural gas equals 37.26 MJ, and one kiloWatt-hour of electricity is 3.6 MJ. Appendix IV shows these results separately for fossil fuels and electricity, and Section 5.7 discusses fuel efficiencies. For each region, and nationally, the houses with the minimum and maximum energy use for space heat are shown, along with the twenty fifth percentile, mean, and seventy fifth percentile of each set. The national means are weighted by the number of houses in each region. For both new conventional and R-2000 houses, the highest means and maximums are found in the Prairies, as might be expected since the coldest climates occur there. However, the second highest means and maximums occur in the mild climate of British Columbia. Thus, new conventional houses in B.C. locations with annual degree days from 3007 in Vancouver (where thirteen of the twenty are located) to 3756 in Kamloops, use significantly more energy than those in Ontario and Quebec where degree days range from 4068 in London to 5080 in Quebec City. Similarly, the eight R-2000 houses in Vancouver use more energy for space heat than those in central Canada. In every region, the R-2000 houses use less space heat energy than the new conventionals; the only exception is the minimum in B.C..

5.2 Space Heat Normalized by Degree Days and Floor Area.

In the first stage of normalization, energy for space heat as calculated above is divided by the product of degree days and approximate house floor area. Degree days are taken from HOT2000's long-term weather data for the location closest to each house, and nominal floor area is defined as house volume in cubic meters divided by 2.5 metres. Thus, normalized space heat energy S_n for each house is:

$$S_n = \frac{S}{DD * (V/2.5m)},$$

where S is Space heat as defined in Section 5.1 (MJ/y),
DD is heating degree days, and
V is the heat volume of the house (m^3).

The normalized space heat energies for new conventional houses are shown in Figure 15 while those for R-2000s are shown in Figure 18. For both house types, and for all points in the distribution, B.C. houses are the least energy efficient in the country. Houses in the Prairies are very close to those in central and atlantic Canada. In all regions, and for all points of the distributions, R-2000 houses are more energy efficient than new conventionals, and, with the exception of B.C., R-2000 houses show less variation in their distributions. For all stages of normalization, the B.C. R-2000 houses are much less energy efficient than those in the rest of Canada. This is because, as noted in Section 2.2, five of the eight B.C. R-2000 houses are actually Quality Plus houses which do not meet the normal R-2000 criteria.

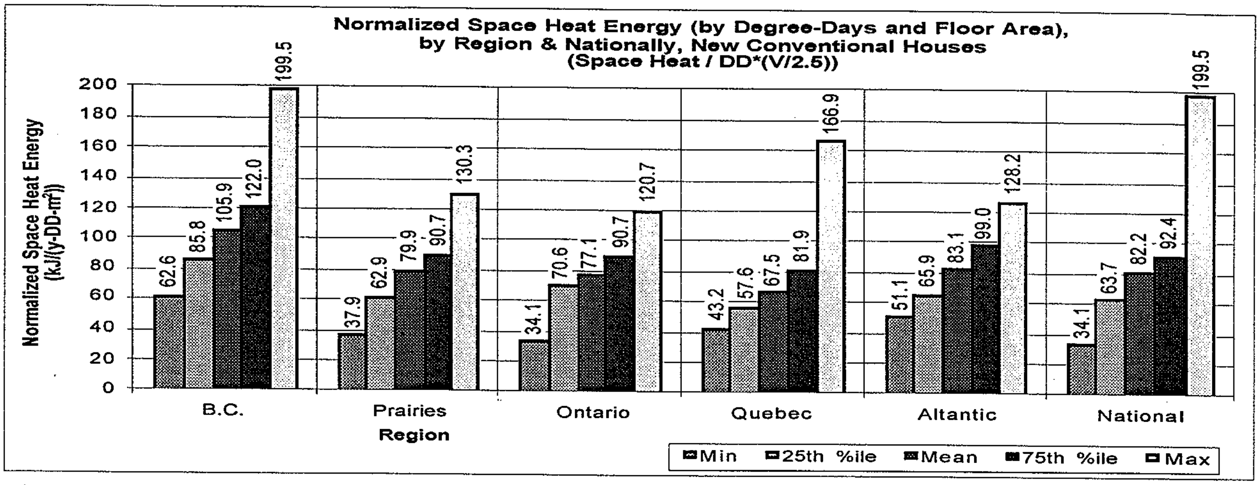

Figure 15. Space heat energy normalized by degree days and floor area, new conventional houses.

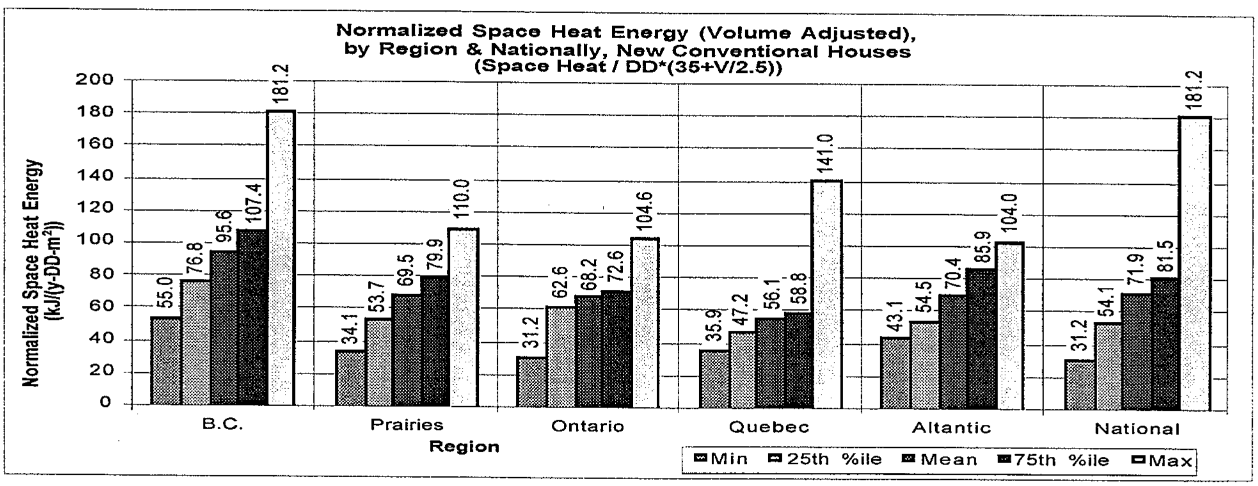

Figure 16. Space heat energy normalized with volume adjustment, new conventional houses.

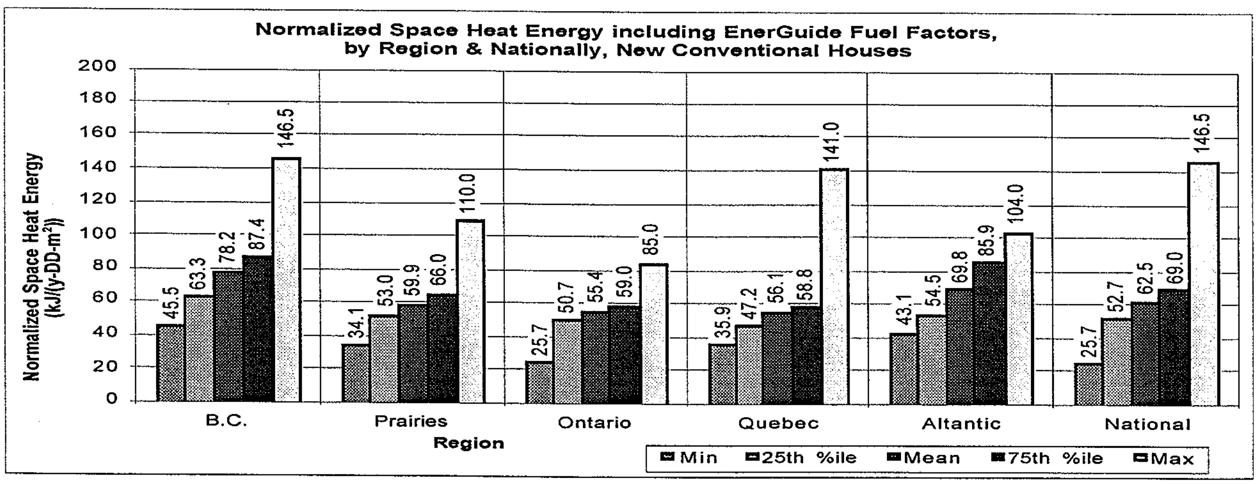

Figure 17. Space heat energy normalized with EnerGuide fuel factors, new conventional houses.

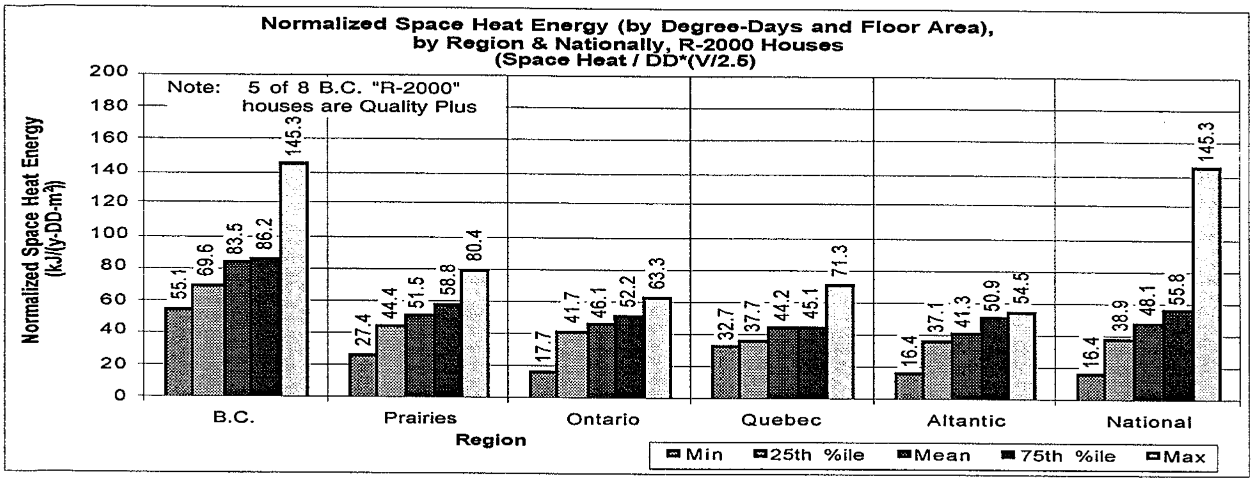

Figure 18. Space heat energy normalized by degree days and floor area, R-2000 houses.

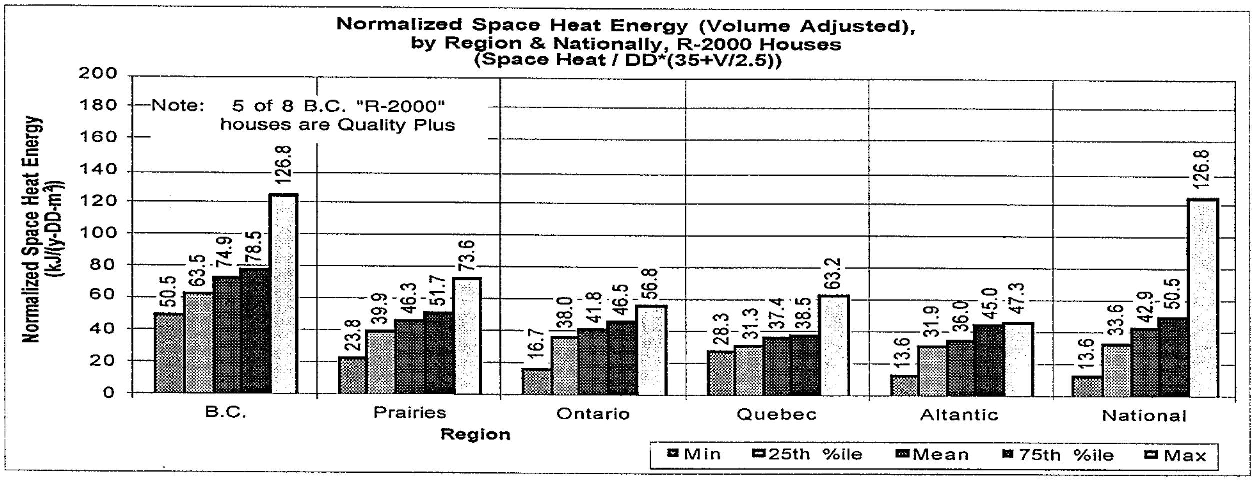

Figure 19. Space heat energy normalized with volume adjustment, R-2000 houses.

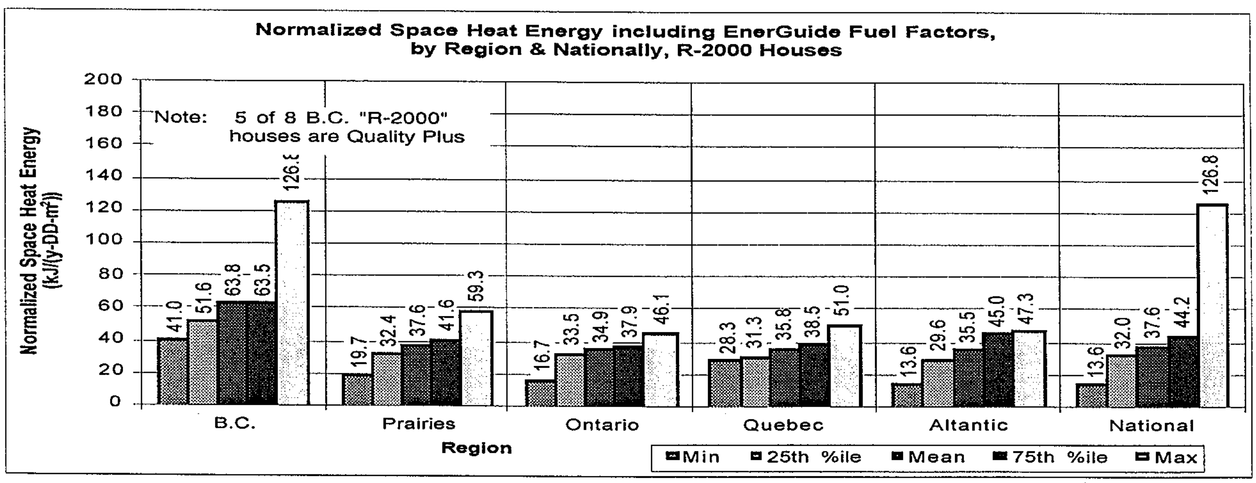

Figure 20. Space heat energy normalized with EnerGuide fuel factors, R-2000 houses.

5.3 Space Heat Normalized by Degree Days and Adjusted for Volume.

The method of normalization in the last section give an advantage to larger houses. Due to their lower surface area to volume ratios, larger houses with the same levels or insulation and ventilation rates will appear to be more energy efficient than smaller ones when normalized by volume or floor area. To compensate for this advantage, the R-2000 Technical Requirements[14] developed the practice of including a "basic floor area allowance" of 35 m^2 in the formula for normalization. Thus, volume adjusted normalized space heat energy S_v is defined as:

$$S_v = \frac{S}{DD * (35m^2 + V/2.5m)}.$$

Normalized energies defined in this way are shown in Figures 16 (new conventional houses) and 19 (R-2000 houses). All figures are slightly lower than those in the last section, but there are no significant differences in terms of relationships between house types or regions, nor in the shapes of the distributions. However, as Figure 21 shows, the two methods are significantly different for smaller houses. The solid regression line shows that larger new conventional houses in this study are not generally more energy efficient than the smaller ones; in fact, there is a very weak increase in normalized energy with volume, although this may be due largely to the four houses with volumes much larger than the average of 616 m^3 which also have very high normalized energies. In any case, adding the floor area allowance does give smaller houses an advantage, as shown by the two regression lines, and by pairs of individual points. For houses with large volumes, the pairs of points for each house are generally very close together indicating that including the volume adjustment make little difference to their normalized energies, while for smaller houses, the differences are generally larger. With the four large high energy houses removed, the solid regression line become almost flat (slope = +0.0068) and the r^2 is decreased to 0.0039. However, the relationships between the regression lines and pairs of points is not changed significantly. A similar figure for R-2000 houses is found in Appendix IV.

5.4 Normalized Space Heat Energy Including EnerGuide Fuel Factors.

The normalizations in the previous two sections do not take into account the fact that losses in the use of electricity occur in generation and transmission whereas fossil fuel losses occur mainly on site. For this reason, EnerGuide ratings include fuel factors of 1.0 for electricity and 0.8 for fossil fuels. That is, electrical energy used for space heat, including fan energy, is not changed, while fossil fuel energy for space heat is multiplied by 0.8. The purpose of the fuel factors is to make EnerGuide for Houses fuel neutral, i.e., "to make houses of the same insulation levels and thermal envelope characteristics equal in their rating assuming the most commonly available replacement equipment of each type. Credit is given if higher efficiency equipment is used and penalties for lower efficiency equipment" (Ref 13, p. 28). Normalized space heat energy including fuel factors S_f is calculated as:

$$S_f = \frac{S_F *0.8 + S_E}{DD * (35m^2 + V/2.5m)}.$$

where S_F is fossil fuel use for space heat (MJ/y), and
S_E is electrical energy for space heat, including furnace and ventilation fans during furnace operation (MJ/y).

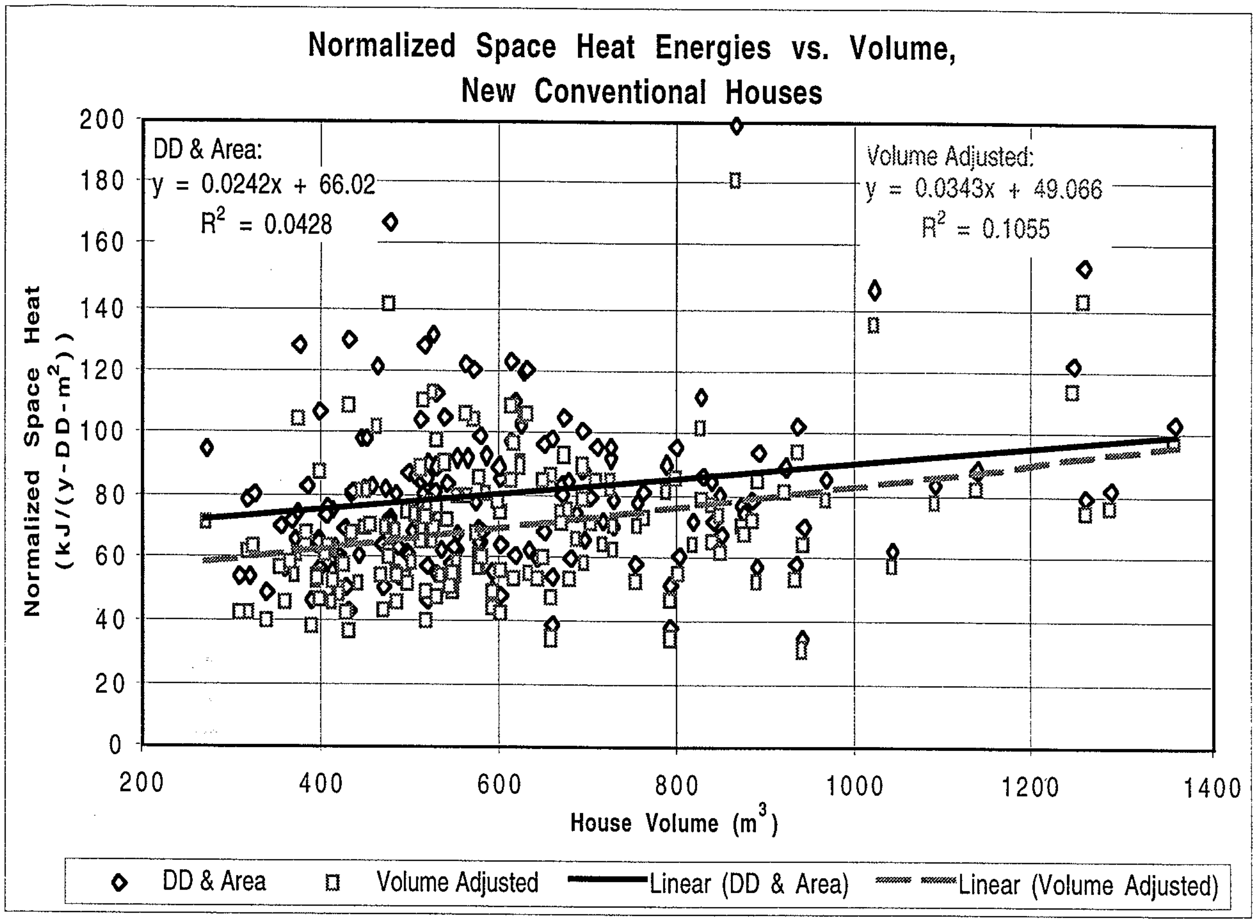

Figure 21. Normalized space heat energy by two methods vs. house volume.

The results of including the fuel factors in the normalization procedures are shown in Figure 17 for new conventional houses and Figure 20 for R-2000 houses. In most cases, the fuel factors significantly reduce normalized energy consumption figures, but there are three main exceptions: 1) new conventional houses in Quebec, where all thirty of the houses are electrically heated, so the fuel factors make no difference, 2) new conventional houses in Atlantic Canada where twenty-three of the twenty four houses are electric, and only the mean is changed, and 3) R-2000 house in Quebec where twelve of the fourteen houses are electric, and only the mean and maximum are changed. Adding fuel factors to the normalization procedure does not significantly affect the distributions of normalized energies, but it does have a strong effect of the space heating efficiency of houses heated with fossil fuels, as shown in Figures 22 & 23. When fuel factors are applied to all houses, normalized space heat is reduced by 11 to 12%. The fuel factors make no difference to electrically heated houses, but they reduce the normalized space heat of fossil fuel houses by 19%. Before fuel factors are applied, the average normalized space heating energy of fossil fuel heated houses is 35% greater than that of electrically heated houses. With fuel factors, this difference is reduced to 10%. (The last three percentages are for both new conventional and R-2000 houses). The lower energy efficiency of fossil fuel houses may be due to the low cost of natural gas.

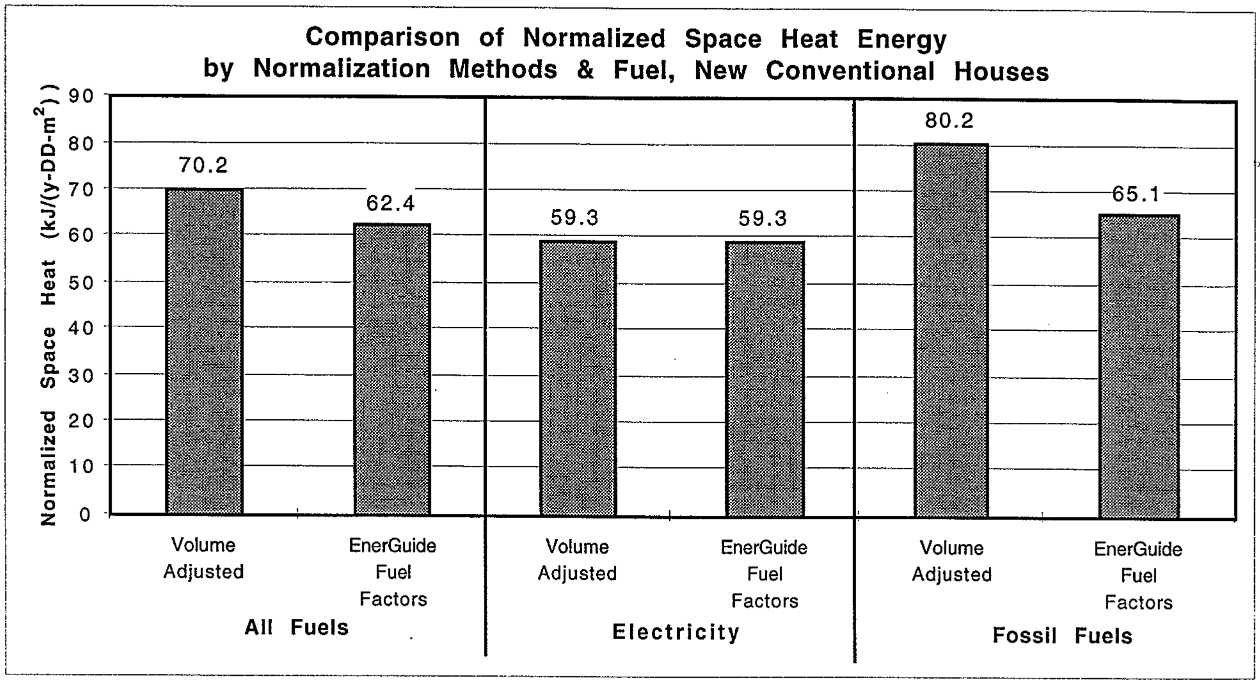

Figure 22. Comparison of normalized space heat energy by normalization methods & fuels, new conventional houses.

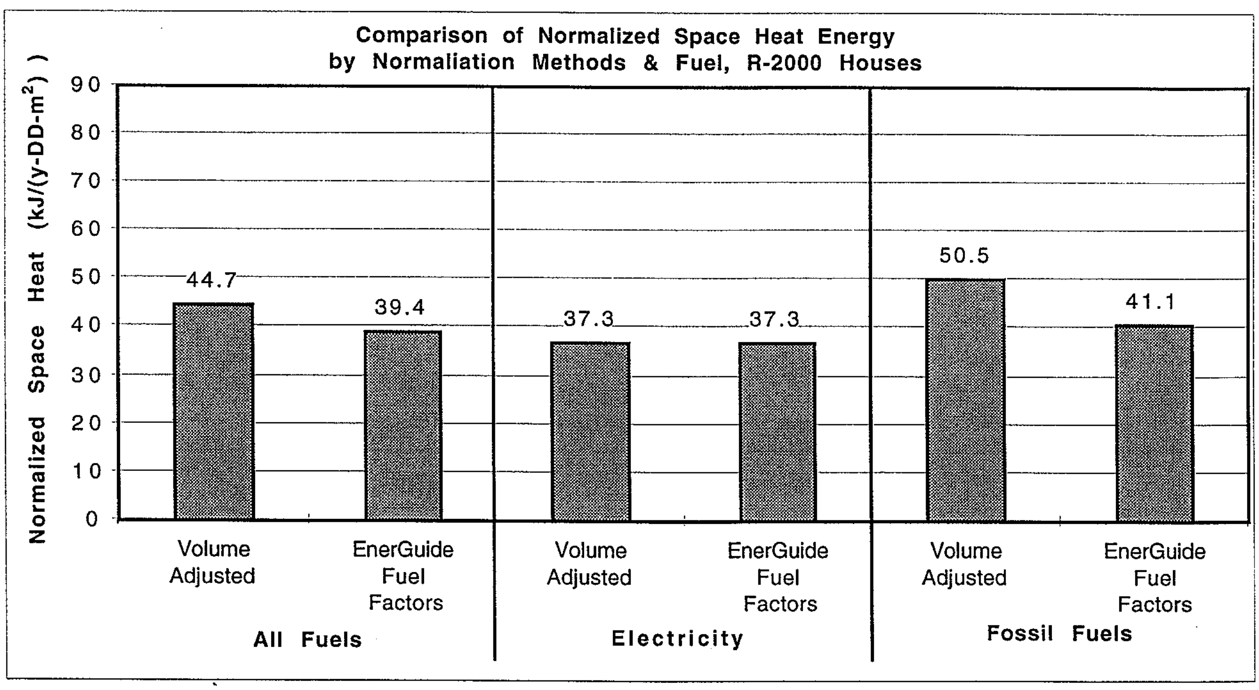

Figure 23. Comparison of normalized space heat energy by normalization methods & fuels, R-2000 houses.

5.5 The EnerGuide for Houses Ratings.

The EnerGuide for Houses Energy Efficiency Rating (EER) includes all of the space heat normalization proceedings of the last section, and also includes standardized amounts of energy use for hot water and other uses such as lights and appliances. The energy use of a specific house with standardized occupancy and ventilation factors is compared with a reference house to produce a unitless rating number which increases with energy efficiency. For each house, the EER is calculated as follows:

$$EER = 100 - (E_{ff} / R_{ef}) \times 20$$

where

$$E_{ff} = S_E \times B_{SE} + S_F \times B_{SF} + 1.136\,(D_E \times B_{DE} + D_F \times B_{DF}) + L$$

$$R_{ef} = 3.6\ \text{MJ/(y-DD-m}^3) \times (60 \times DD/6000) \times (35\ \text{m}^3 + V/2.5) + 1.136 \times 17082\ \text{MJ/y} \times (55^\circ\text{C} - T_w)/(55^\circ\text{C} - 9.5^\circ\text{C}) + 31536\ \text{MJ/y}$$

and

E_{ff} = Effective Total Energy Consumption (MJ/y),
R_{ef} = Reference Consumption (MJ/y),
S_E = Electrical energy consumption for space heat, including furnace and ventilation fans during furnace operation (MJ/y),
B_{SE} = Base efficiency, electrical energy for space heat = 1.0,
S_F = Fossil fuel energy consumption for space heat (MJ/y),
B_{SF} = Base efficiency, fossil fuel energy for space heat = 0.8,
D_E = Electrical energy consumption for DHW (MJ/y),
B_{DE} = Base efficiency, electrical energy for DHW = 0.88,
D_F = Fossil fuel energy consumption for DHW (MJ/y),
B_{DF} = Base efficiency, fossil fuel energy for DHW = 0.57,
L = Energy for lighting and appliances (MJ/y),
DD = Degree days, from HOT2000 climatic data for site,
T_w = Average water main temperature = HOT2000 deep ground temp. (°C),
V = Heated volume of the house (m^3).

The results for new conventional and R-2000 houses are shown in Figures 24 & 25, while Figure 26 compares the new conventional and R-2000 ratings. With the exception of houses in British Columbia, the average EERs for both new conventional and R-2000 houses show very little variation by region, although the new conventional houses show a high degree of variation within regions. R-2000 houses are much more uniform within regions, and more efficient than new conventional houses. The weighted national average for R-2000 houses is 80.0, while for new conventional houses it is 72.0. As noted in Sections 2.2 & 5.2, the B.C.

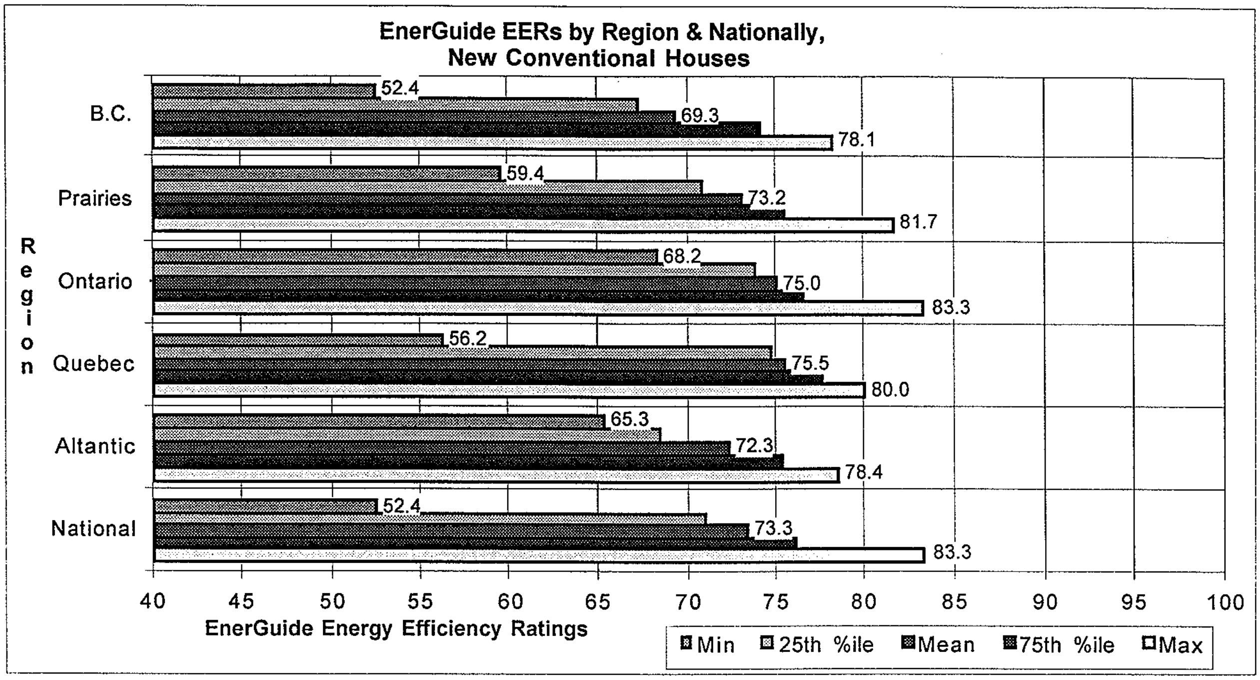

Figure 24. Average, minimum and maximum EnerGuide Energy Efficiency Ratings, new conventional houses, by region and nationally..

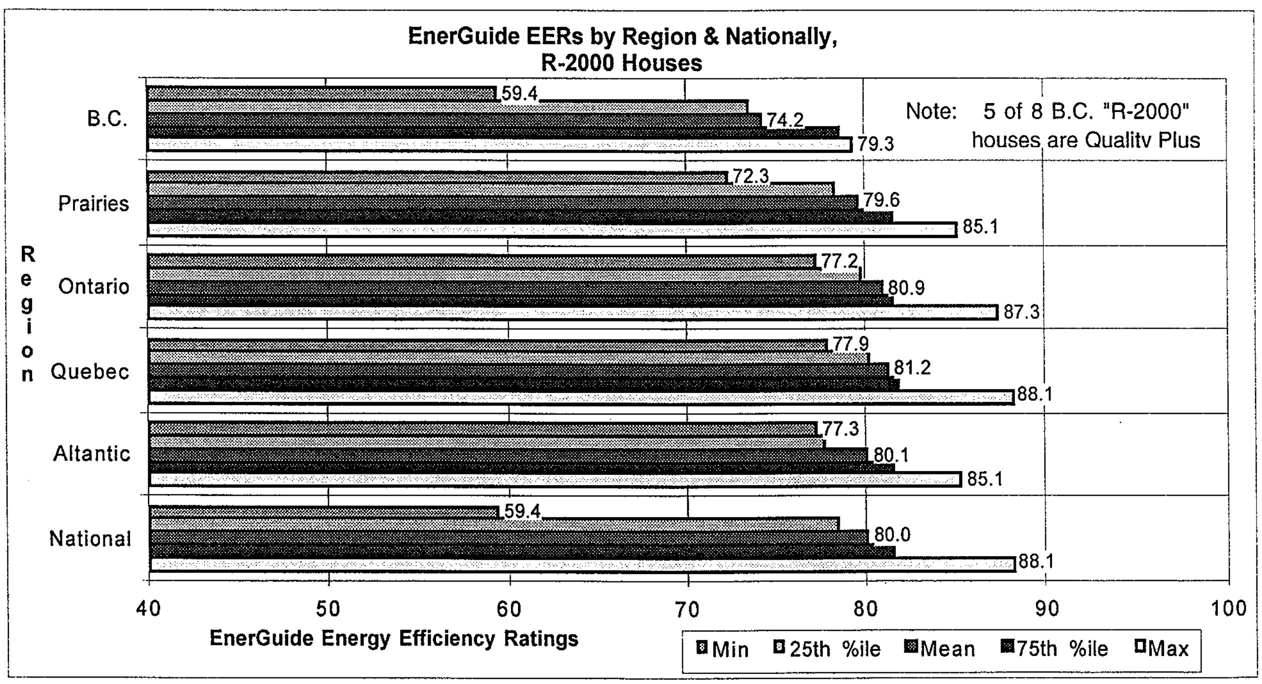

Figure 25. Average, minimum and maximum EnerGuide Energy Efficiency Ratings, R-2000 houses, by region and nationally.

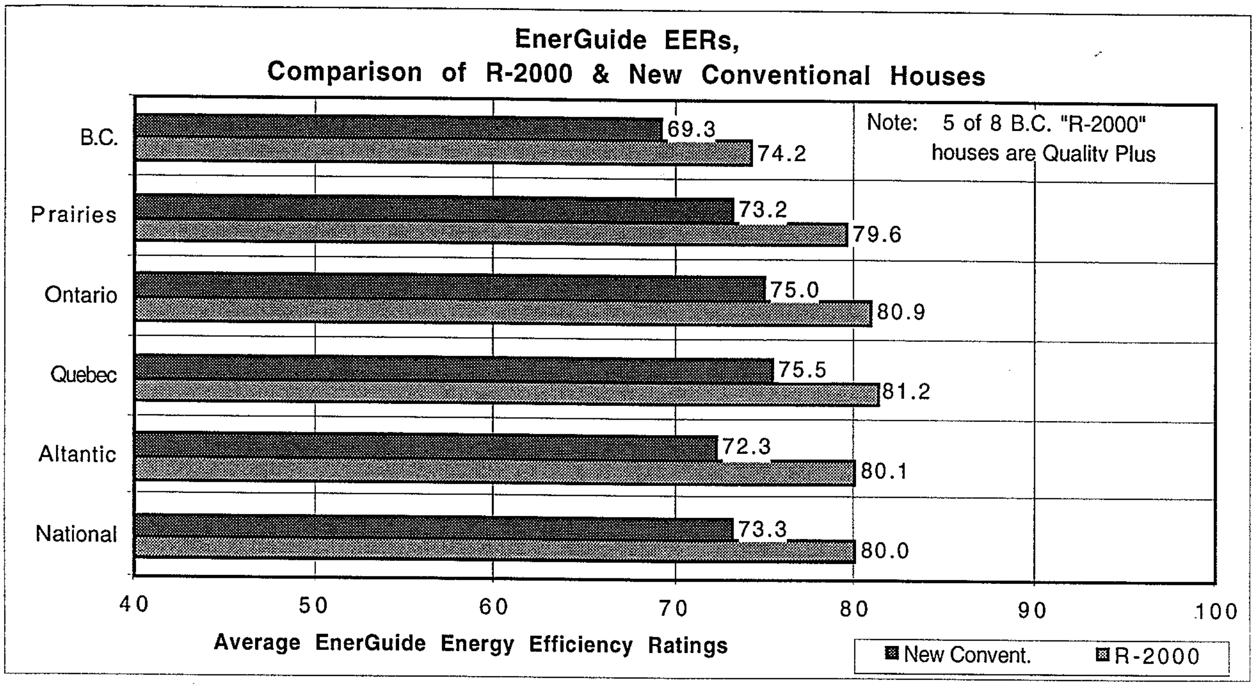

Figure 26. Average EnerGuide Energy Efficiency Ratings, comparisons of R-2000 & new conventional houses, by region and nationally.

R-2000 houses are mostly Quality Plus houses which clearly do not meet the same standards for energy efficiency as other R-2000 houses. Their average EnerGuide rating of 74.2 is lower than the ratings for new conventional houses in Ontario (75.0) and Quebec (75.5).

Thus, whether new conventional and R-2000 houses are compared by normalized space heat or by EnerGuide energy efficiency ratings, the results are reasonably consistent. In each region, R-2000 houses are significantly more efficient than conventional houses of the same region, and with the exception of B.C., R-2000 houses are more energy efficient than new conventionals in all regions. The B.C. R-2000 houses are less energy efficient than the new conventional houses in some regions, although which regions this is true of depends on the measurement of energy efficiency.

Figures 27 & 28 show the EnerGuide ratings of individual houses along with proposed EnerGuide Levels. With the exception of seven houses (four in B.C., two in the Prairies and one in Quebec) all the new conventional houses have EnerGuide Ratings of 65 or greater, and so are at least Level Threes, the minimum level for new houses. Thus, 96% of the new houses in the dataset are in the appropriate level or better. Sixty-seven (41%) of the new houses have EnerGuide Ratings of 75 or better, making then Level Fours, "Better New Homes." Four of the 163 new houses (2.5%) have ratings of 80 or more, making them equivalent to new R-2000 houses. Figure 28 shows that one of the Quality Plus R-2000 houses from B.C. does not qualify as a Level Three, and three others are below Level Four. When these four are eliminated, and the remaining fifty-nine R-2000 houses are considered, all but one (98%) qualify as at least Level Four

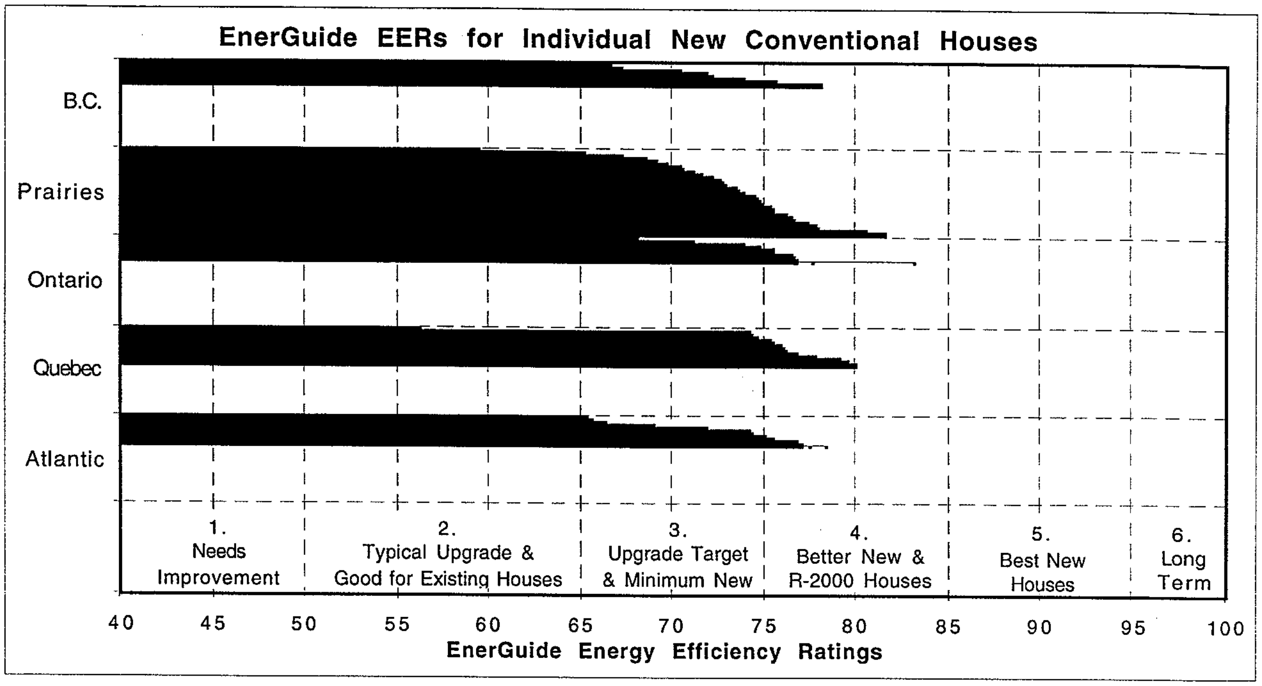

Figure 27. EnerGuide ratings for individual new conventional houses, with the EnerGuide levels shown.

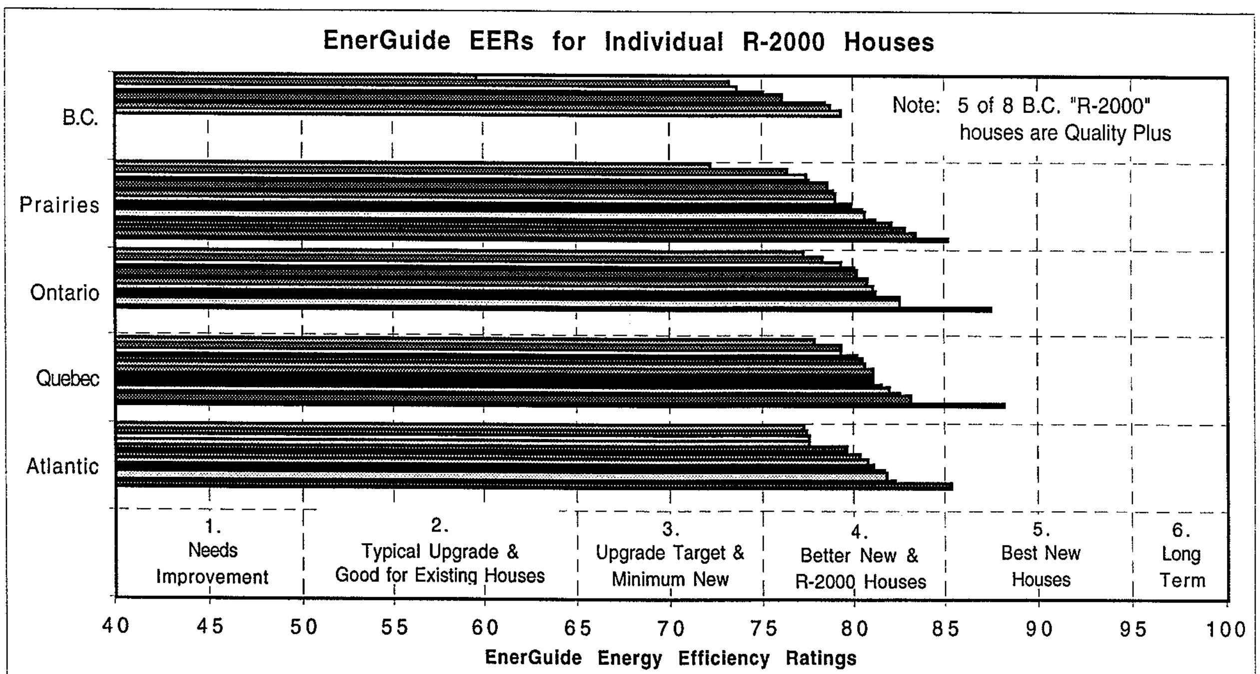

Figure 28. EnerGuide ratings for individual R-2000 houses, with the EnerGuide levels shown.

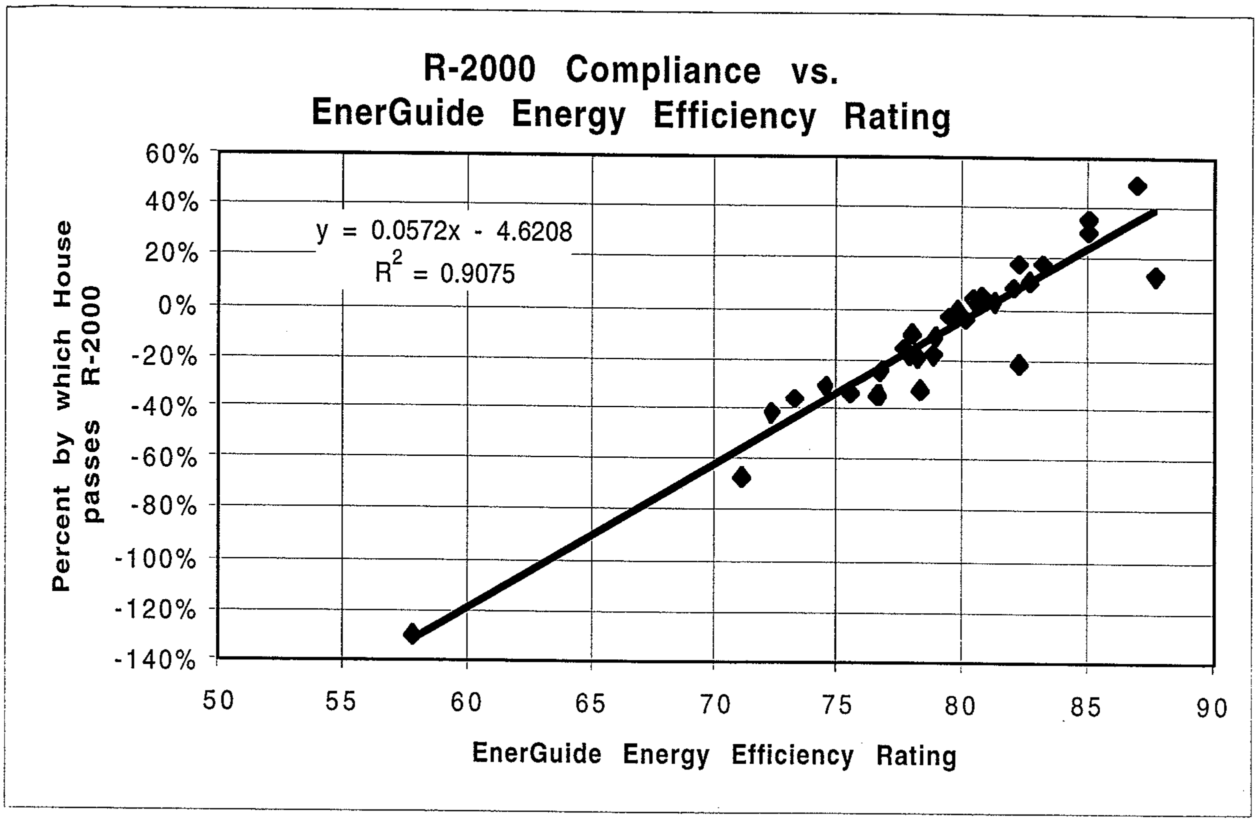

Figure 29. R-2000 compliance vs. EnerGuide ratings for selected R-2000 houses.

"Better New Homes." Thirty-three (56%) have ratings of 80 or better, and so meet current standards for R-2000, and four (7%), are Level Fives, "Best New Houses." Thus, the proposed EnerGuide Levels are consistent with current practice in new conventional and R-2000 housing.

Figure 29 compares the current R-2000 standard with the EnerGuide energy efficiency ratings as follows: a set of the R-2000 houses which spans the range of their EnerGuide ratings was selected, and run in HOT2000 with their parameters set to R-2000 defaults. These defaults are the same as the EnerGuide standard conditions shown above, except that the basement temperature is set to 20 °C, and the flow rates for the HRV are set to the F326 minimum ventilation rates. The percentage by which each house passes its R-2000 target is compared with its EnerGuide rating. Failure to meet the target is indicated by a negative percentage. There are several reasons why many of the R-2000 houses in Figure 29 do not meet their targets: First, the houses were selected to include their entire range of EnerGuide ratings, including those of the B.C. Quality Plus houses. Second, many of these houses qualified as R-2000 under earlier standards which were less rigorous. Third, the HOT2000 files received from field contractors may tend to overestimate energy use, as shown in Section 3; since the purpose of this figure is to compare HOT2000 based compliance with HOT2000 based EnerGuide ratings, the correction factors from that section are not applied. The correlation between R-2000 target and EnerGuide ratings is strong ($r^2 = 0.9075$) but there are significant outliers which have been checked for errors. The regression line crosses the R-2000 target line (0%) at a EnerGuide rating of 80.78. Houses with a EnerGuide rating below 80 are very unlikely to pass the R-2000 target. As shown above, only 2.5% of the new conventional houses meet this criteria. Thus, this analysis confirms the significant gap between R-2000 and new conventionals which is also apparent from the normalized space heat energy and EnerGuide for Houses analyses.

5.5.1 B.C. PowerSmart Houses

Of the twenty new conventional houses in B.C., five are PowerSmart houses. The PowerSmart program has more energy efficient windows than those specified in the B.C. housing code, as well as some water and electricity saving features. All of the PowerSmart houses in the dataset were constructed in 1995. When compared with the other new conventional houses in B.C., the PowerSmart houses have significantly higher EnerGuide Ratings as shown in Table 16, which also shows that this difference cannot be explained by the fact that the PowerSmart houses are newer than many of the other B.C. houses. Table 17 shows that this difference is not due to airtightness; the PowerSmart houses are significantly less airtight than other new conventional houses in B.C..

EnerGuide Ratings	PowerSmart	Non-PowerSmart	
		1990-96	1994-96
Minimum	69.2	52.4	52.7
Mean	73.8	67.8	69.2
Maximum	78.1	75.6	75.6

Table 16. EnerGuide Ratings for PowerSmart and non-PowerSmart new conventional houses in B.C.

ACH @ 50 Pa	PowerSmart	Non-PowerSmart	
		1990-96	1994-96
Minimum	3.94	1.85	1.85
Mean	4.85	3.43	3.14
Maximum	6.89	5.85	4.86

Table 17. Air changes per hour at 50 Pa, PowerSmart and non-PowerSmart B.C. houses.

Houses with CHEERS Ratings in		Heat Losses as % of Total					Solar Gains as % of Window Losses
		Non-Window			Windows	Leakage & Ventilation	
		Ceilings	Main Floors	Basements			
Lowest 10th %ile:	Min	2.4	7.2	17.9	9.1	11.6	49.7
	Mean	3.5	16.5	43.3	18.7	18.1	61.0
	Max	4.6	21.6	61.6	34.6	27.6	79.6
Highest 10th %ile:	Min	2.9	11.2	15.4	12.7	8.6	41.4
	Mean	6.1	18.0	27.3	25.0	23.6	61.9
	Max	9.3	33.2	41.1	39.2	32.7	78.9

Table 18. Summary of heat losses by component in least and most energy efficient new conventional houses.

5.5.2 Heat Losses by House Components.

Given the differences in energy use between new conventional and R-2000 houses, and the wide variation between the most and least energy efficient new conventional houses, it may be useful to determine where these houses are losing most of their energy. Figure 30 compares the average heat losses through various parts of house envelopes for new conventional and R-2000 houses. These values are not normalized in any way. Losses by ventilation include natural air infiltration and mechanical ventilation. The total of the losses in the figure is the average space heat load for the two types of houses: 126.9 GJ/year for new conventionals, and 113.6 GJ/year (10.5% less) for R-2000s. R-2000 houses lose less through each component except that they lose more through window, due to their larger size and window areas. The largest difference is in the basements where new conventional houses lose 38% more heat than R-2000 house do. In new conventional houses, an average of 29% of total heat losses occur through the basement; for R-2000 houses, the figure is 23%.

Table 18 compares the least and most energy efficient ten percent of new conventional houses in terms of percentage of total space heat lost through the five house components. For all elements except the basement, the differences between the two sets of houses is small, but the means and maximums of heat loss through the basements are much larger for the inefficient houses. The least efficient houses seem to be characterized by poorly insulated basements which are responsible for forty to sixty percent of total heat losses. Thus, whether one compares new conventional and R-2000 houses, or the most and least efficient new conventional houses, it seems that less efficient houses are characterized by poorly insulated basements which account for a large percentage of total heat loss. This indicates that greater attention should be given to basement insulation in new conventional houses.

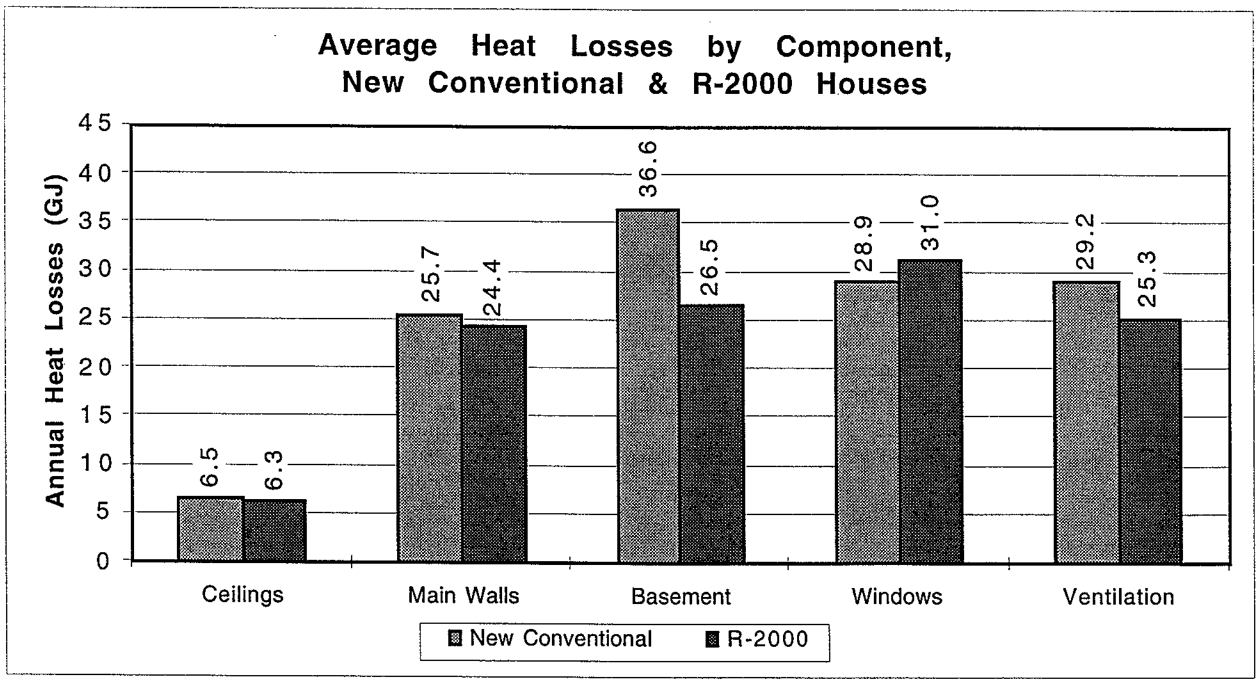

Figure 30. Average heat losses by component, new conventional and R-2000 houses.

5.6 Effects of House Volume.

Section 5.3 showed normalized energy consumptions with and without volume adjustments. The effects of volume are further analyzed here by showing the relationships between volume and both un-normalized space heat energy and EnerGuide ratings. Figure 31 shows the relationship between un-normalized space heat energy and volume for the 163 new conventional houses. As would be expected, energy use generally increases with volume, although there is a high degree of scatter ($r^2 = 0.4787$) due to the effects of fuel efficiency and climate as well as individual house characteristics. Houses in the Prairies are generally above the regression line, due to their severe climate. Houses in B.C. are on both sides of the line despite being located in the mildest climate. Those in Quebec are almost all below the line which is consistent with their higher than average energy efficiency. Figure 32 shows the relationship between EnerGuide Energy Efficiency Ratings and volume. Energy efficiency declines slightly with increased volumes, but the slope is shallow and the relationship is weak ($r^2 = 0.1152$). Without the four B.C. houses with volumes greater than 800 m^3 and EERs less than 75, the slope of the regression line would be 43% less steep. Most Quebec houses are above the line, but without them the slope would only decrease by 16%.

Figure 33 shows un-normalized space heat energy versus volume for R-2000 houses. The pattern is similar to that for conventional houses. The correlation is slightly better ($r^2 = 0.5694$) indicating that the characteristics of R-2000 houses are more uniform than those of conventionals. Most Prairie houses are above the regression line while most houses in Quebec and Atlantic Canada are below it. Figure 34 shows the relationship between EnerGuide ratings and volume for these houses. The regression line is almost flat, indicating that the effects of volume have been virtually eliminated by normalization. Comparing Figures 33 & 34 shows that houses whose energy consumption for space heat varies by thirteen to one have virtually the same EnerGuide ratings. Even within single regions, the energy use varies by 4.6 : 1 (Atlantic Canada) and 4.8 : 1 (the Prairies). This raises the question whether a house rating system designed to promote energy efficiency and help reduce national energy consumption should give the same rating to two houses, one of which consumes almost five times as much energy as the other.

5.7 Fossil Fuel and Electric Space Heating.

Section 5.4 showed that electrically heated houses tend to be more energy efficient than those heated by fossil fuels, even when the EnerGuide fuel factors are included. This section looks at heating systems in more detail. Fossil fuel systems are examined according to their steady-state efficiency: high efficiency is defined as 90% or greater, mid efficiency is from 80% to less than 90%, and low efficiency is less than 80% efficient. Electric space heat systems are divided into all electric space heat systems, and those with forced air circulation; both are considered to be 100% efficient. The percentages of new conventional house with each type of system are shown in Table 19 which also shows the percentages with fossil fuel and electric hot water systems. Nationally, the majority of these houses use fossil fuels for both space heat and domestic hot water. Almost half of the fossil fuel space heat systems are mid efficiency, with high efficiency systems making up just over half of the remainder. In Ontario, all houses in the dataset are heated by fossil fuels, and more than half of them have high efficiency furnaces. In B.C., 95% of houses are fossil fuel heated, and mid efficiency units predominate. Electrically heated houses make up 100% of the Quebec sample, and over 95% of those from Atlantic Canada. Electrically heated houses with forced air circulation are only found in significant numbers in the Prairies; Quebec and the Atlantic region each have only one house of this type.

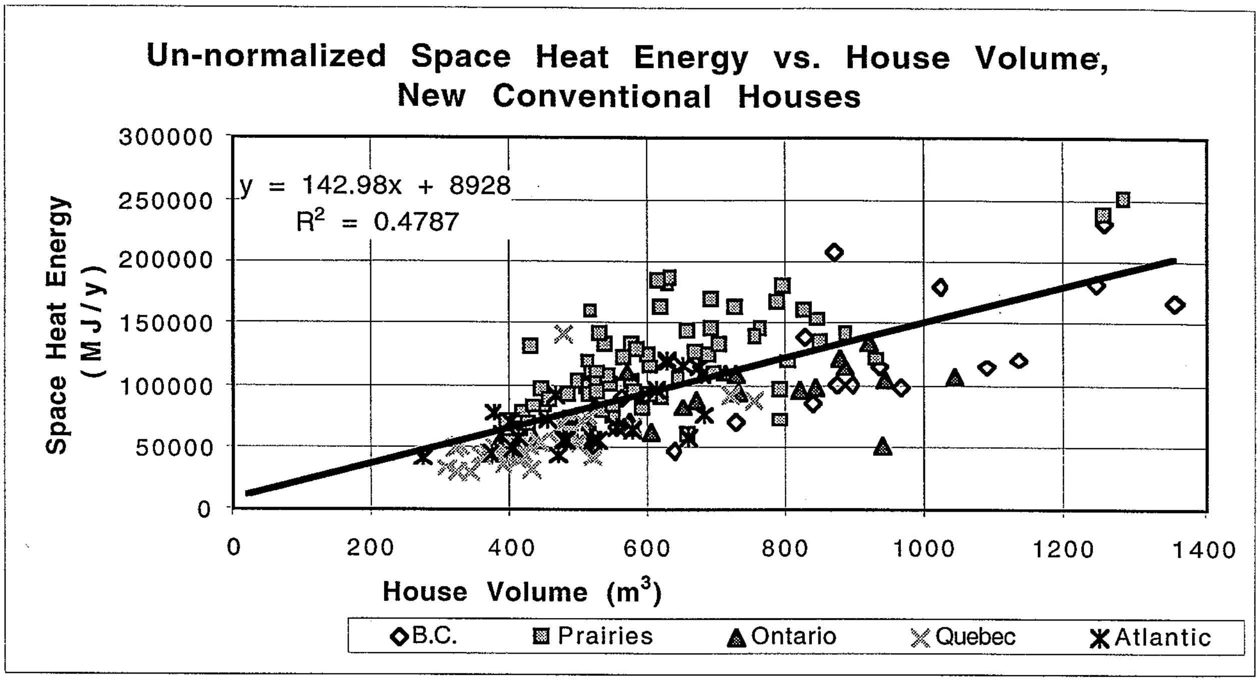

Figure 31. Un-normalized space heat energy vs. house volume, new conventional houses.

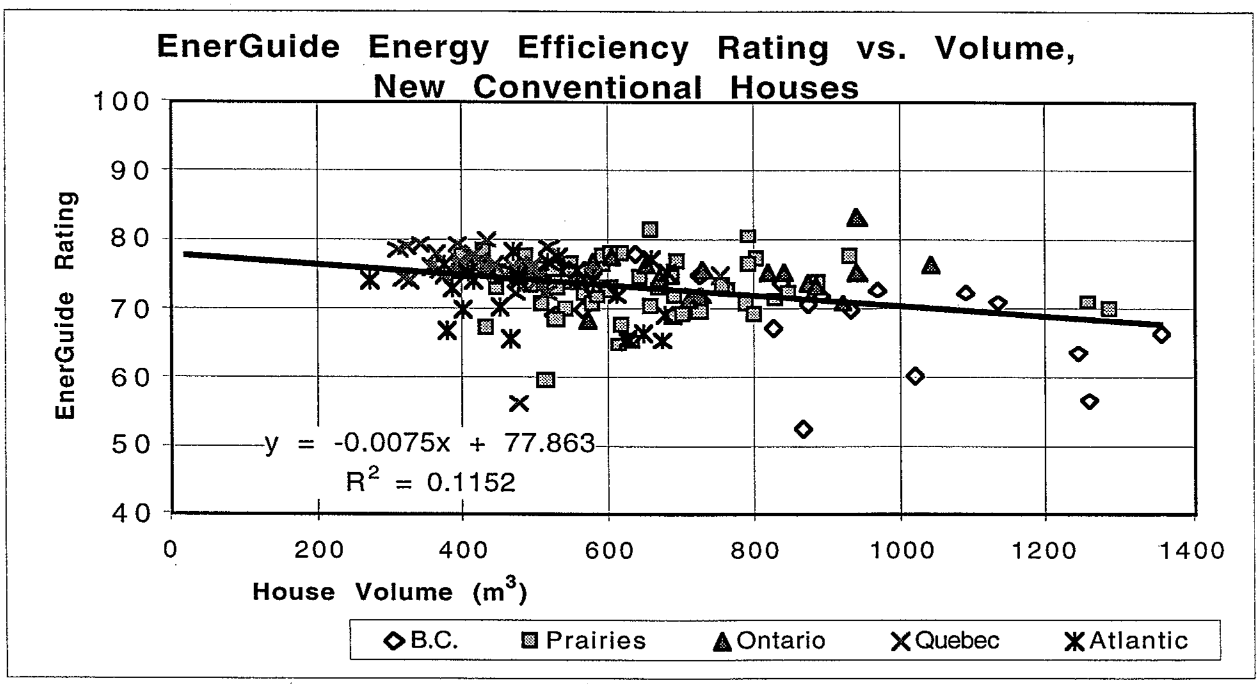

Figure 32. EnerGuide Ratings vs. house volume, new conventional houses.

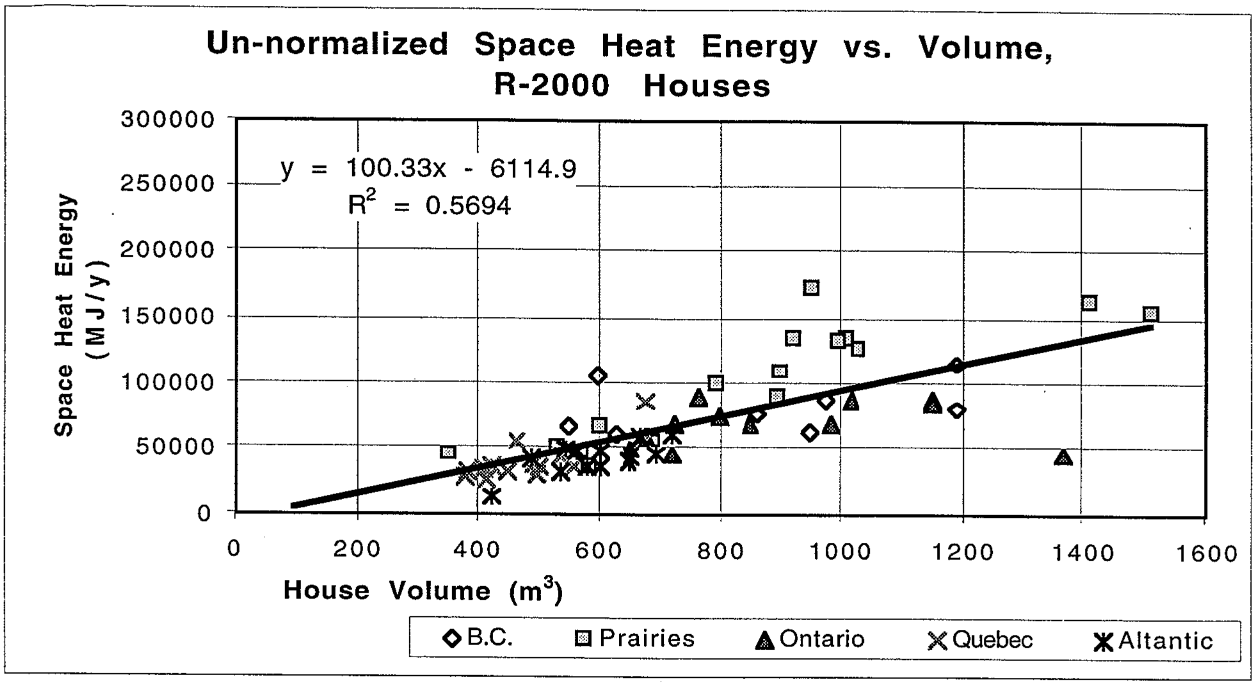

Figure 33. Un-normalized space heat energy vs. house volume, R-2000 houses.

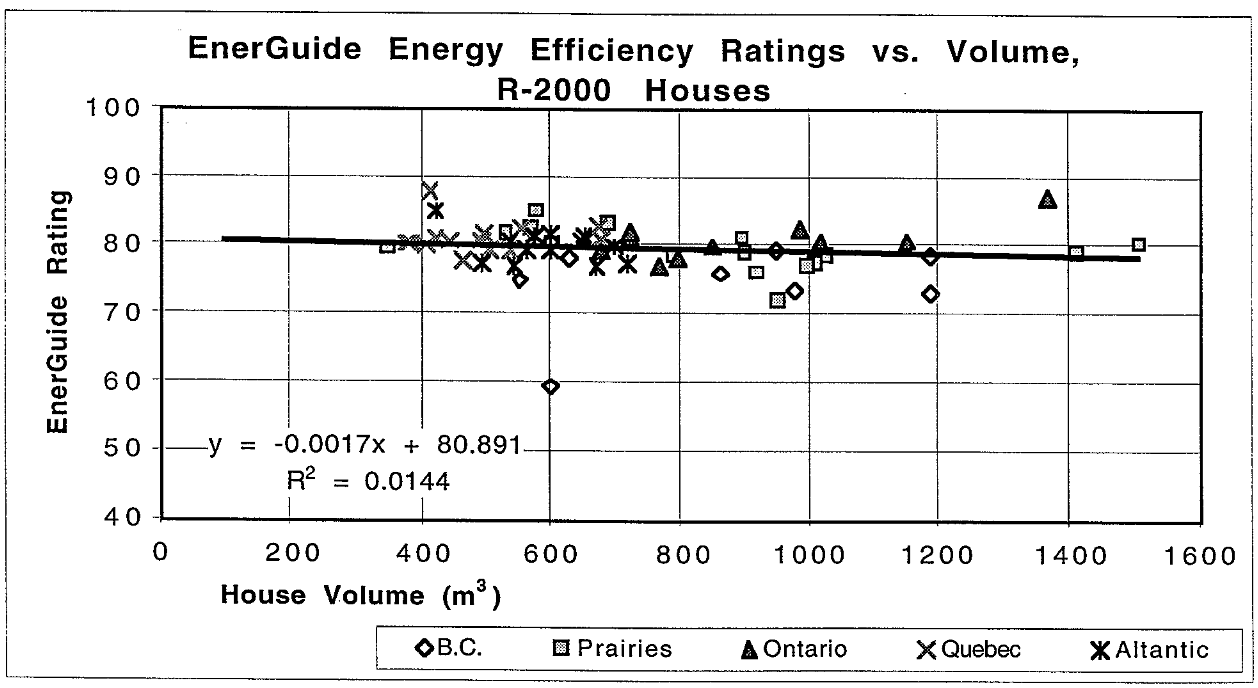

Figure 34. EnerGuide Ratings vs. house volume, R-2000 houses.

Region	Number of Houses	Percentage of houses with							
		Fossil Fuel Space Heat				Electric Space Heat		DHW	
		All	Efficiency			All	Forced Air	Fossil Fuel	Electric
			Low	Mid	High				
B.C.	20	95.0	25.0	65.0	5.0	5.0	0.0	90.0	10.0
Prairies	69	65.2	34.8	29.0	1.4	34.8	29.0	65.2	34.8
Ontario	20	100.0	10.0	35.0	55.0	0.0	0.0	100.0	0.0
Quebec	30	0.0	0.0	0.0	0.0	100.0	3.3	0.0	100.0
Atlantic	24	4.2	0.0	4.2	0.0	95.8	4.2	4.2	95.8
NATIONAL	163	62.8	14.7	30.0	18.1	37.2	6.4	61.8	38.2

Table 19. Space heat and DHW systems, new conventional houses.
National figures are regionally weighted

Space Heat Type	Average Values			
	Volume (m^3)	Space Heat Efficiency (%)	Un-normalized Space Heat (MJ/y)	EnerGuide Rating
ALL	612.8	90.2	97,006	73.2
FOSSIL FUEL				
All	704.4	81.3	119,333	72.2
Low Efficiency	646.6	77.3	121,851	72.4
Mid Efficiency	747.1	80.9	128,456	70.8
High Efficiency	707.3	92.0	84,555	75.8
ELECTRIC				
All	512.9	100.0	72,675	74.4
Forced Air Circulation	608.7	100.0	87,355	76.1

Table 20. Statistics by space heat systems, new conventional houses.

Table 20 summarizes some of the characteristics of new conventional houses by their heating systems. As noted in Section 5.4, electrically heated houses are more energy efficient than fossil fuel houses, even when fuel factors are applied. This is again evident from their EnerGuide ratings. Within fossil fuel heated houses, it is interesting to note that those with low efficiency furnaces have higher average EnerGuide ratings than those with mid efficiency furnaces. This must simply be due to differences in insulation levels and/or airtightness which predominate over the 3.6% difference in average efficiencies. Houses with high efficiency furnaces have the highest ratings of all fossil fuel houses, by a significant margin. Electrically heated houses with forced air circulation have the highest EnerGuide rating of all, 76.1 which is 2.3% higher than the average for all electric houses, and 4% higher than the average for all houses. In terms of un-normalized space heat energy, fossil fuel houses use 64% more electrical houses, but they are 37% larger which accounts for most of this difference.

Table 21 analyzes R-2000 houses by types of space heat and hot water systems. Nationally, just over 60% of the R-2000 houses in the dataset are heated by fossil fuels, and most of these have high efficiency furnaces. There are only two houses in the sample with low efficiency furnaces. The Prairie sample is 100% fossil fuel heated, and those from Ontario and B.C. are over 80% fossil fuel. The Prairies have the highest percentage of mid efficiency furnaces, but they are still outnumbered by high efficiency units. Electric space heat dominates in Atlantic Canada and Quebec, and Quebec has the highest percentage of electric systems with forced air circulation. The main differences between R-2000 and conventional houses are the higher percentages of high efficiency furnaces in R-2000s, the higher percentage of electrically heated conventional houses on the Prairies, and the higher percentages of electrically heated R-2000s which have forced air circulation.

Region	Number of Houses	Percentage of houses with							
		Fossil Fuel Space Heat				Electric Space Heat		DHW	
		All	Efficiency			All	Forced Air	Fossil Fuel	Electric
			Low	Mid	High				
B.C.	8	87.5	0.0	12.5	75.0	12.5	0.0	100.0	0.0
Prairies	16	100.0	6.3	43.8	50.0	0.0	0.0	100.0	0.0
Ontario	12	83.3	0.0	8.3	75.0	16.7	16.7	83.3	16.7
Quebec	14	14.3	7.1	7.1	0.0	85.7	35.7	0.0	100.0
Atlantic	13	7.7	0.0	7.7	0.0	92.3	7.7	7.7	92.3
NATIONAL	63	60.3	0.7	11.3	48.3	39.7	11.9	60.9	39.1

Table 21. Space heat and DHW systems, R-2000 houses.
National figures are regionally weighted

Table 22 shows some of the average characteristics of R-2000 houses by space heat system. The patterns are similar to those for new conventional houses, but the space heat energy values are smaller (except for high efficiency furnaces), and the EnerGuide ratings are lower in all cases. Again, electrically heated houses are more energy efficient than those heated by fossil fuel, and electrical houses with forced air circulation are the most efficient of all. Within fossil fuel heated houses, those with low efficiency heaters have higher average EnerGuide ratings than those with mid efficiency, and the mid efficiencies have higher ratings than the high efficiencies. There are three explanations for this paradoxical result. First, as mentioned, there are only two R-2000 houses with low efficiency houses, so their results are not statistically significant. Second, meeting the R-2000 target for energy efficiency involves trade-offs, e.g., a house with a more efficient furnace can have less insulation. Third, the three least energy efficient B.C. R-2000 houses have high efficiency fossil fuel heaters, and they may bring the average down significantly. The un-normalized space heat energy of fossil fuel heated R-2000 houses is 109% greater than that of electrically heated R-2000 houses, and the fossil fuel heated houses are 50% larger which accounts for almost one-half of the difference.

Space Heat Type	Average Values			
	Volume (m^3)	Space Heat Efficiency (%)	Un-normalized Space Heat (MJ/y)	Energuide Rating
ALL	731.7	93.7	67,296	79.6
FOSSIL FUEL				
All	853.2	89.0	86,623	78.7
Low Efficiency	709.1	76.0	55,807	80.6
Mid Efficiency	907.3	81.5	83,861	79.3
High Efficiency	839.9	93.7	90,624	78.2
ELECTRIC				
All	569.6	100.0	41,526	80.9
Forced Air Circulation	578.9	100.0	34,440	82.8

Table 22. Statistics by space heat systems, R-2000 houses.

For both R-2000 and conventional houses, electrically heated houses are more energy efficient than fossil fuel houses, and electrically heat houses with forced air circulation are the most energy efficient of all. As mentioned in Section 5.4, the lower efficiency of fossil fuel houses is probably due to the low cost of natural gas. The difference which forced air makes in electrically heated houses cannot be explained by its regional distribution. Twenty of the twenty-two new conventional houses with forced air electric heat are located on the Prairies, and the average EnerGuide rating for houses on the Prairies is just below the national average. Five of the eight R-2000 houses with forced air electric heat are in Quebec, and the average EnerGuide rating for Quebec R-2000s is 81.2 which is higher than the national average, but lower than the 82.1 of its forced air electric houses. A possible explanation is that baseboard electric heating has the lowest initial cost of all heating systems, and is often found in the lowest cost housing which also has less insulation and airtightness.

5.8 Solar Gains.

This section analyzes HOT2000's simulations of useable solar gains through the windows of the new conventional and R-2000 houses. HOT2000 does not treat all solar gains as useable for two reasons. First, each house model includes an "allowable daily temperature rise", the maximum number of degrees by which the house temperature is allowed to exceed the heating set point. Above that point, it is assumed that occupants will open windows to prevent further temperature rises. As stated in Section 5, all houses in this study are modelled with set points of 21.0 °C, and an allowable temperature rise of 3.5 °C, so any solar gains which would raise a house's internal temperature above 24.5 °C are not considered useable. Second, HOT2000 calculates internal gains from non-space heating uses of energy (baseloads and DHW tanks) before calculating solar gains. This means that if there are enough internal gains from lighting, appliances, the DHW tank, etc. to raise the internal temperature above 24.5 °C, then no solar gains are considered useable.

Giving internal gains priority over solar gains is somewhat arbitrary. One the one hand, it makes sense to say that since internal gains are by-products of energy use which will occur in houses regardless of their potential for solar gains, the internal gains do prevent the solar gains from being useful. On the other hand, the use of energy by most lighting and appliances is very inefficient in terms of the end-use energy delivered. For example, incandescent lights are 5% efficient while compact flourescents are 20%. Baseloads continue to be used during the non-heating season when their waste heat is either of no values, or has a negative effect due to overheating or increased cooling load. Thus, it also makes sense to calculate useable solar gains with baseloads reduced to the approximately 10% of their gross energy which is delivered as net, useful work. Whether gross or net baseloads are used will not change energy ratings, but giving more credit to solar gains may be appropriate as baseloads may be purchased. We used simulations of useable solar gains with both gross and net baseloads, as follows:

For gross baseloads, BATCH HOT2000 simulated each house under standard EnerGuide conditions, and wrote the monthly values of solar gains, window losses and space heat load to a file. (Space heat load is the total amount of space heat required, including the amounts which are supplied by internal gains and solar energy, as well as the output of the furnace). These quantities are summed for the heating season (September through May), and compared. For net baseloads, the same procedure is used, except that BATCH HOT2000's Global Editor is used to reduce baseloads to ten percent of their EnerGuide values, and to eliminate the DHW tank. The net baseload is 2.0 kWh per day, plus 0.4 kWh used outside. Since HOT2000 allows a maximum internal gains utilization of 95% when monthly internal gains are less than 5% of monthly space heat load,[15] the change from gross to net baseloads makes a maximum difference of 17.1 kWh/day of useable internal gains.

The resulting useable solar gains are shown in Table 23, and in Figures 35 & 36. The table shows that the differences between useable solar gains with gross and net baseloads are significant but not very large. For both new conventional and R-2000 houses with the smallest solar gains, the difference is less than half a percent, and the effect on solar gains as percentages of window losses and space heat load are less than 0.1%. However, for the average new conventional house, reducing the baseload increases useable solar gains by 6.5% with significant increases in percentage of window losses and total heat load supplied by solar gains. For R-2000 houses, the increase in useable solar gains is 9.1%. For houses with the largest solar gains, the increases are smaller: 2.9% for conventional and 3.3% for R-2000 houses. Figure 35 shows the distribution of solar gains (with net baseloads) as a percentage of heat losses through windows for both new conventional and R-2000 houses. There is only one house (an R-2000) with windows which gain more heat than they lose. There are six R-2000s and ten new conventionals with gains equal to or greater than 80% of their losses. R-2000 houses generally outperform the conventionals – due to higher gains, not smaller losses – but there are two R-2000 houses which are outperformed by all the new conventionals. Both are located in southern Ontario, the worst has no south facing windows, and the other has a few southeast and southwest facing windows most of which have significant overhangs.

Figure 36 shows useable solar gains with net baseloads as a percentage of space heat loads. Forty percent of new conventional houses get at least 15% of their space heat from the sun while 79% of R-2000 houses get at least that much. Only one conventional house gets 25% or more of its heat from solar energy while seven R-2000 houses do. R-2000s generally get more of their space heat from the sun due both to higher solar gains and smaller space heat loads. The main exceptions are the same two R-2000 houses with very small solar gains as percentages of window losses, and the new conventional house which gets 40% of its heat from the sun. This house is located in southern Ontario, and both its HOT2000 energy use and airtightness meet the R-2000 standards.

	New Conventional Houses						R-2000 Houses					
	Gross Baseloads			Net Baseloads			Gross Baseloads			Net Baseloads		
	(MJ/y)	% Window Losses	% Space Heat Energy	(MJ/y)	% Window Losses	% Space Heat Energy	(MJ/y)	% Window Losses	% Space Heat Energy	(MJ/y)	% Window Losses	% Space Heat Energy
Minimum	6,322	29.5	4.7	6,326	29.5	4.7	1,953	7.2	2.0	1,960	7.2	2.0
Mean	16,434	55.4	12.9	17,494	59.1	13.9	17,691	57.3	17.0	19,295	63.0	18.8
Maximum	63,180	91.2	34.9	65,028	97.2	40.0	46,694	100.8	28.1	48,253	104.7	29.3

Table 23. Useable solar gains compared with window losses and space heat load.

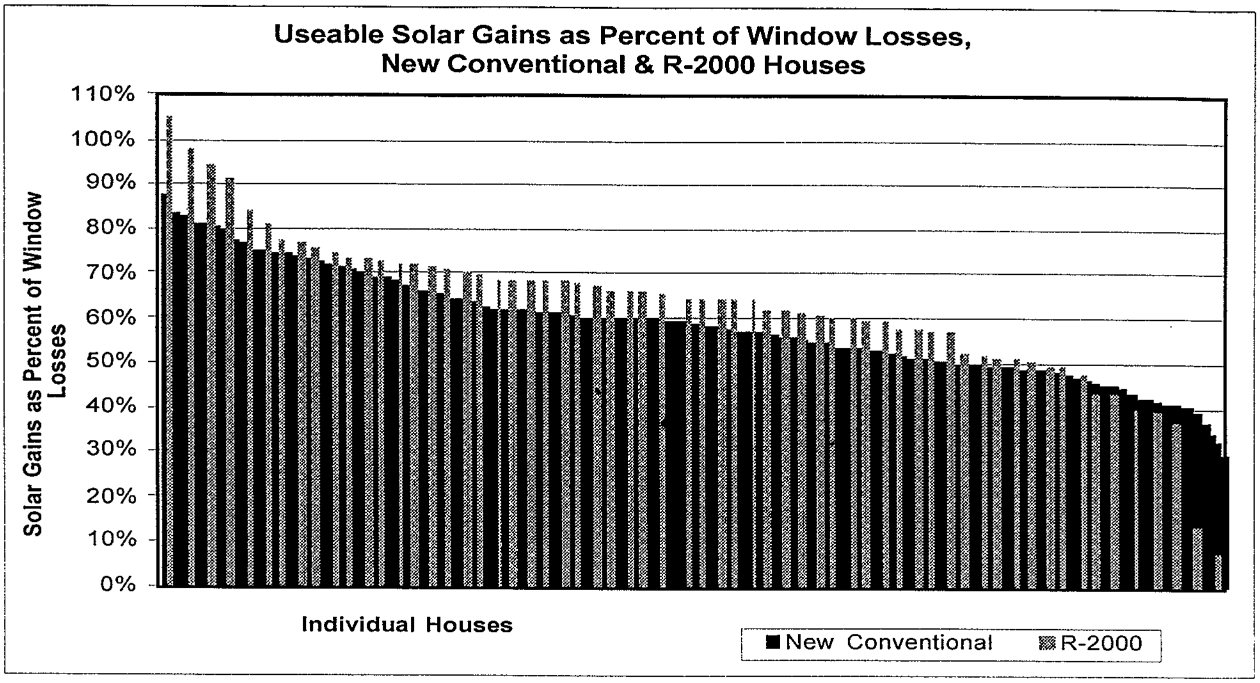

Figure 35. Useable solar gains as percent of window losses, internal gains from net baseloads.

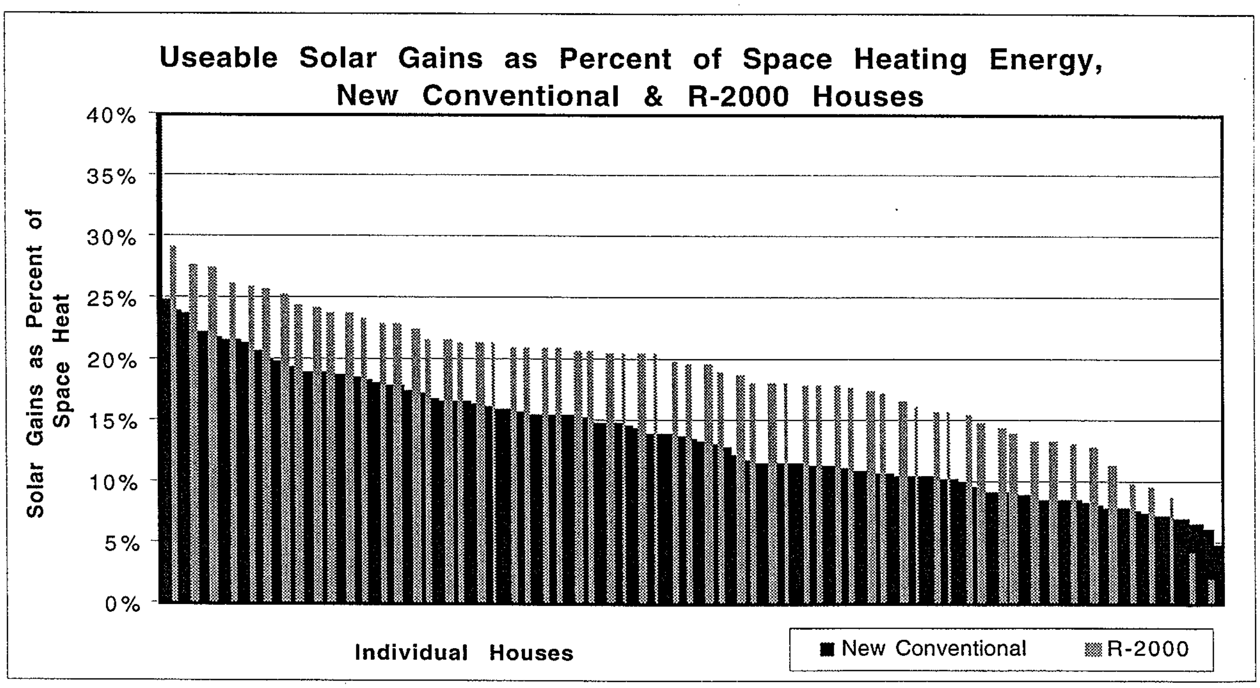

Figure 36. Useable solar gains as percent of space heat energy, internal gains from net baseloads.

6. Potential Depressurization in New Conventional Houses.

As houses become more airtight, they have a greater potential to be depressurized by exhaust fans. Such fans may include exhaust only ventilation systems, clothes dryers, kitchen and bathroom fans, and central vacuums. Depressurization can be a problem because it can cause fuel burning appliances such as furnaces, DHW tanks, and wood stoves or fireplaces to backdraft, or spill, releasing pollutants into the house instead of up the flue. Systems identified in Section 9.32 of the National Building Code (Ref 12), and systems in compliance with the F326 Standard (Ref 11) should have adequate air supply to minimize depressurization. This study is based on the F326 standard because the data collection method (HOT2000 house files) include information on F326 compliance, and we do not have adequate data to determine how many of the houses could comply with the alternative requirements described in the building code.*

The Canadian national standard *Residential Mechanical Ventilation Systems* (F326) (Ref 11) specifies that

> For dwelling units incorporating vented combustion appliances other than Direct Vent appliances, operation of the ventilation system under reference exhaust flow conditions shall not contribute to decreasing the pressure in the dwelling unit relative to the outside by more than the value for which the appliance has been certified by an accredited certification agency or the value specified by the manufacturer or, in the absence of such a certification or specification, 5 Pa (Ref 11, p. 22).

The "Reference Exhaust Flow-Rate Condition" for which the depressurization of a house is calculated is the sum of:

(a) the net exhaust flow rate of the ventilation system under the minimum ventilation capacity condition; and
(b) the net exhaust flow rate of the clothes dryer, or, if one is not installed, a default value of 75 L/s; and
(c) the net exhaust of any exhaust appliance or appliances having a net exhaust flow rate of 75 L/s or greater, whether or not they are part of the ventilation system (Ref 11, p. 22).

The amount of depressurization which the sum of the above air flows can cause in a particular house is called the *F326 depressurization potential*, and was calculated for each new conventional house in the dataset, as follows (see Appendix VI for details): All HRVs are set to the F326 minimum for the house they are installed in, and all non-HRV, non-balanced systems are set to the F326 minimum rate for their house, or to their maximum capacity, whichever is less. Two separate spreadsheets were used; in the first, all HRVs are assumed to be operating with balanced flows, while in the second all HRVs which can have an exhaust only defrost mode are set to exhaust only at the F326 minimum. Thus, two sets of depressurization results are created. One with all HRVs in balanced flows, and the second with all HRVs which can have an exhaust only defrost mode in their defrost modes. Of the 163 houses, 47 have HRVs, and 35 of the HRVs can

* Of the 163 new conventional houses which are investigated for potential depressurization, any of the 108 which have central ventilation but no HRV could be in compliance with Section 9.32 of the National Building Code. However, almost all of these houses were built before adoptation of the code.

have an exhaust only defrost mode; of these 35, 16 use partial recirculation in exhaust mode, and 6 are programable, i.e., their defrost mode can be set to exhaust only or to another type. In the second set, all programable HRVs are considered to be exhaust only, and the partial recirculation HRVs are set to exhaust only at 75% of their normal (F326) rates.

The airtightness parameters C and n which are written from HOT2000 are based on the CGSB standard blower door test. Where necessary and possible, these were replaced by values from a blower door test done with the F326 sealing protocol (Ref 11, Clause 10 including Table 6) as follows: For houses in which the two blower door tests would be different, results from an F326 test were used if available. For houses for which they were not available, they were estimated from the diameter of the ventilation air intake according to *Treatment of Flues in HOT-2000.*[16] In 10 of the 163 houses F326 tests were not available and there was no data on ventilation air intakes, so CGSB results were used. If any of these houses do have intakes, then their potential for depressurization is overestimated.

For each house, the exhaust flow rates are summed as described above to get the Reference Exhaust Flow-Rate Condition Q_R, and the F326 depressurization potential P_F is calculated as

$$P_F = \exp\{ \ln(Q_R / C) / n \}.$$

The houses in the database were separated into those which have "vented combustion appliances other than Direct Vent appliances," and those which do not. The former are referred to as spillage-susceptible and were defined in the spreadsheet as those which met any of the following conditions:

1. Furnace flue diameter is greater than zero. HOT2000 will not allow the flue diameter to be greater than zero for direct vent furnaces, i.e., induced draft or condensing furnace/boilers,

2. DHW flue size is greater than zero, and the DHW system is not a direct venting type. Direct venting types include those which are called Direct vent, and also Condensing, and Induced draft fan. Thus, only non-electric conventional DHW tanks are considered spillage-susceptible. It is possible for induced draft DHW tanks to be co-vented through a B-vent with a conventional or induced draft furnace. In such a case, spillage could occur through the flue. Among the houses in this study, there is one with an induced draft DHW heater and a conventional furnace; it is counted as spillage-susceptible because the conventional furnace is. Six, or 3.7%, of the houses have induced draft DHW and induced draft furnaces. Since it is considered possible but not likely that they would be co-vented through an unsealed flue, they are not counted as spillage-susceptible. Of these six, four have potential depressurizations greater than 5 Pa, and they range from 5.9 to 31.4 Pa.

3. Solid fuel burning equipment flue diameters are greater than zero. For the purpose of this analysis, the presence of any wood stove or fire place is considered to make the house spillage-susceptible.

A house which meets any of the above criteria is considered to be spillage-susceptible, and to have a depressurization limit of 5 Pa; a house which does not meet any of the criteria is considered not to have a depressurization limit nor to be spillage-susceptible.

The results are shown in Table 24 and in Figures 37 through 40. Of the total of 163 houses, 76 are spillage-susceptible. The table presents depressurization potential in two columns. The first shows the results with all HRVs operating with balanced supply and exhaust flows. In the second, all HRVs which can have an exhaust only defrost mode are set to exhaust only as described above. The results for the two cases are substantially different. With balanced flows, 82 or 50% of the 163 houses have the potential to be depressurized to 5 Pa or more, and this includes 24 or 32% of the spillage-susceptible houses. Twenty-four percent of all houses, and 13% of spillage-susceptible houses, have the potential to be depressurized to 10 Pa or more. Eight percent of all houses, and one percent of susceptible houses, could be depressurized to 20 Pa or more. With HRVs in defrost mode, 56% of all houses, and 39% of all susceptible houses can be depressurized to 5 Pa or more. Thirty-one percent of all houses, and 17% of susceptible houses, can be depressurized to 10 Pa or more. Twelve percent of all, and three percent of susceptible, houses can be depressurized below 20 Pa.

The maximum potential depressurizations in both columns are 76.0 Pa in all houses, and 34.7 Pa in spillage-susceptible houses. Such high levels of depressurization are unlikely to be achieved in practice because actual fan flow rates will be decreased by the depressurization. Fan flow rates are measured or estimated individually; when working against the negative pressure created by other fans their flows can be reduced significantly. Nevertheless, they do represent very significant, and potentially hazardous levels of depressurization. The potential for depressurization is consistently lower in spillage-susceptible houses than in others. This indicates that there may be some awareness of the hazards involved in depressurizing vented combustion appliances, even if the resulting precautions fall far short of the F326 guidelines.

Figure 37 shows the relationship between F326 depressurization and airtightness for balanced HRV flows. There is an apparent decrease in potential depressurization with decreasing airtightness. This is to be expected since depressurization is a function of airtightness and exhaust flows. The highest potential depressurization for all houses is in a house with an ACH @ 50 Pa of 1.22, while for spillage-susceptible houses, the highest is in a house with an ACH @ 50 Pa of 0.98. The average ACH @ 50 Pa for all the houses is 2.71.* However, the best correlation coefficients – which are achieved with a power law regression ($y = ax^{-n}$) – are low: $r^2 = 0.3779$ for all houses, and $r^2 = 0.3216$ for spillage-susceptible houses. Figure 38 shows the relationship between F326 depressurization and Reference Exhaust Flow-Rate Conditions (F326 exhaust flow rates) with balanced HRV flows. There is an apparent increase in potential depressurization with increasing exhaust flow, as would be expected. The highest potential depressurization for all houses occurs in the house with the second highest exhaust rate. However, the highest potential depressurization for spillage-susceptible houses occurs in a house with 75.0 L/s of exhaust flow, which is just below the average of 78.4 L/s. This is not surprising since 79% of all houses have exhaust flows equal to 75.0 L/s. The best correlation coefficients are low: $r^2 = 0.3057$ (linear) for all houses, and $r^2 = 0.2145$ (power law) for spillage-susceptible houses. Figures 39 & 40 show the results with all HRVs in defrost mode. The results and correlations are similar, except that 35 of the points are shifted upward to significantly higher depressurization levels.

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* This number is different from the 3.10 given in Table 6, Section 4.1 because it is averaged from fewer houses, and does not include regional weighting.

		Assuming Balanced Flows in all HRVs	Assuming all HRVs in Defrost Mode
Total Number of Houses		163	163
Number of Spillage-susceptible Houses		76	76
Houses Exceeding 5 Pa Depressurization:			
Of All Houses:	Number	82	91
	Percentage	50.3%	55.8%
Of Spillage-susceptible Houses:	Number	24	30
	Percentage	31.6%	39.5%
Maximum Depressurization (Pa):			
In All Houses		76.0	76.0
In Spillage-susceptible Houses		34.7	34.7
Number of All Houses in which Depressurization			
is greater than:	5 Pa	82	91
	10 Pa	39	51
	20 Pa	13	19
	30 Pa	6	11
	40 Pa	1	4
Number of Spillage-susceptible Houses in which			
Depressurization is greater than:	5 Pa	24	30
	10 Pa	10	13
	20 Pa	1	2
	30 Pa	1	1
	40 Pa	0	0
Houses with Exhaust Only Ventilation:			
Number		14	
Number Exceeding 5 Pa Depressurization		11	
Percent Exceeding 5 Pa Depressurization		78.6%	
Average Depressurization (Pa)		11.3	

Table 24. Potential depressurization of new conventional houses.

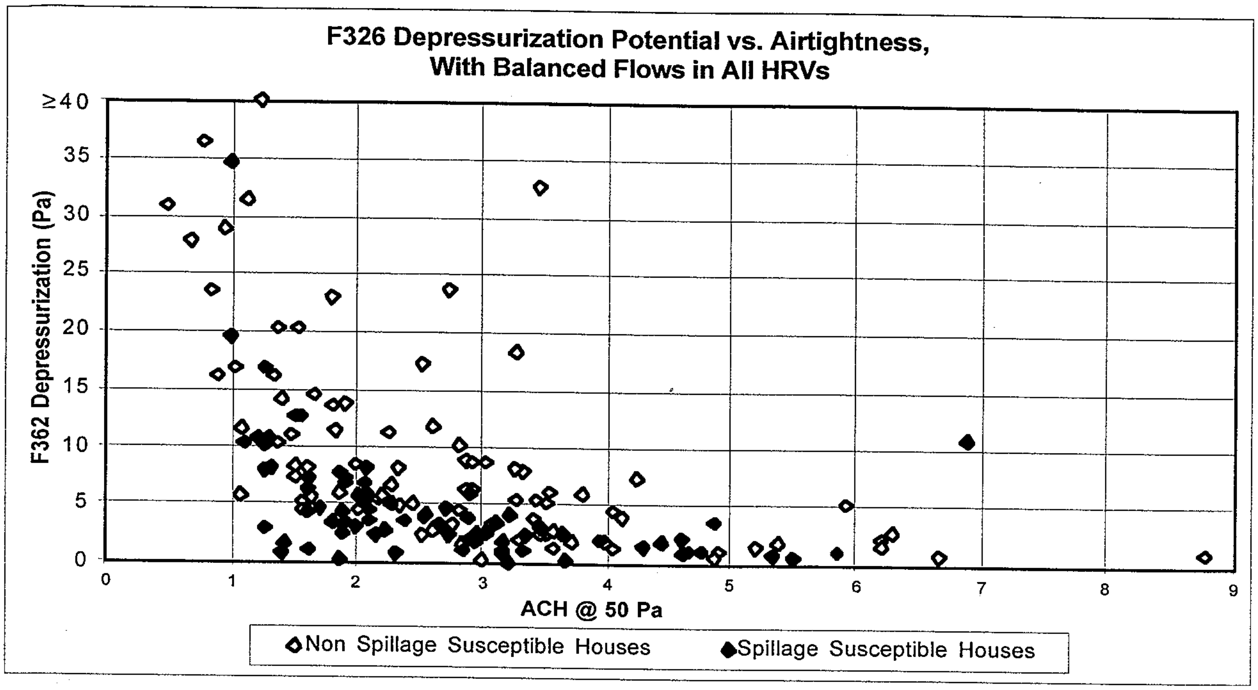

Figure 37. F326 depressurization potential vs. airtightness, balanced flows in HRVs.

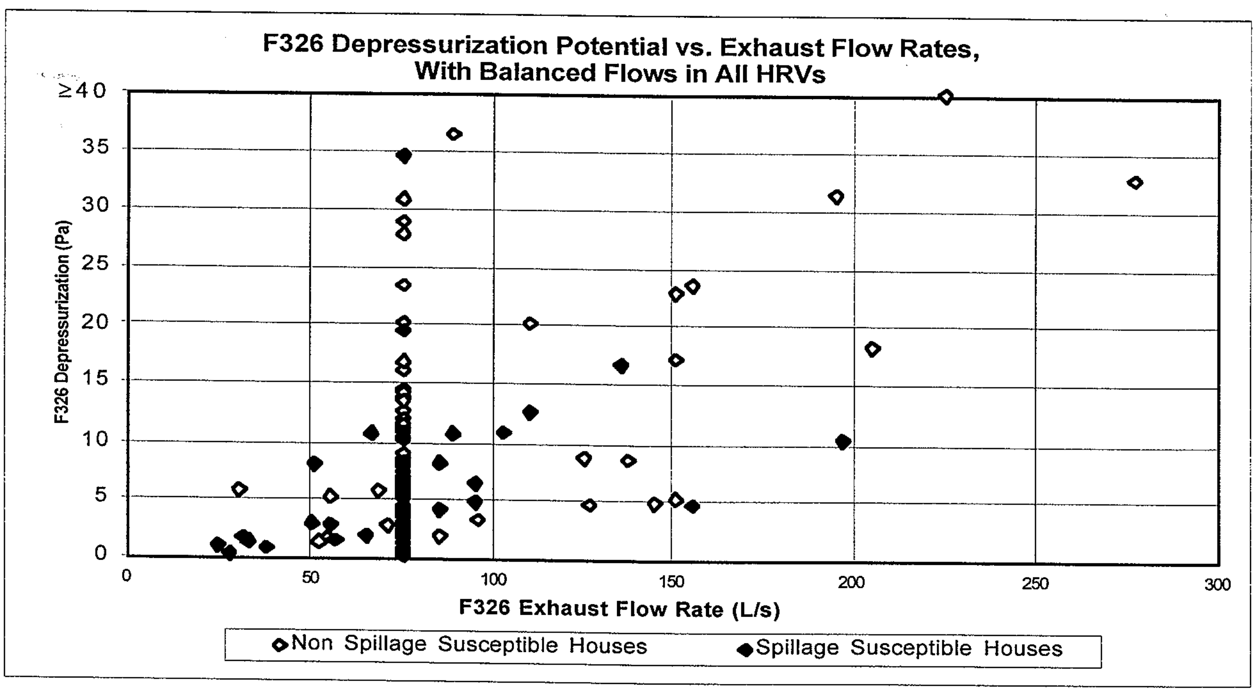

Figure 38. F326 depressurization potential vs.exhaust flow rates, balanced flows in HRVs.

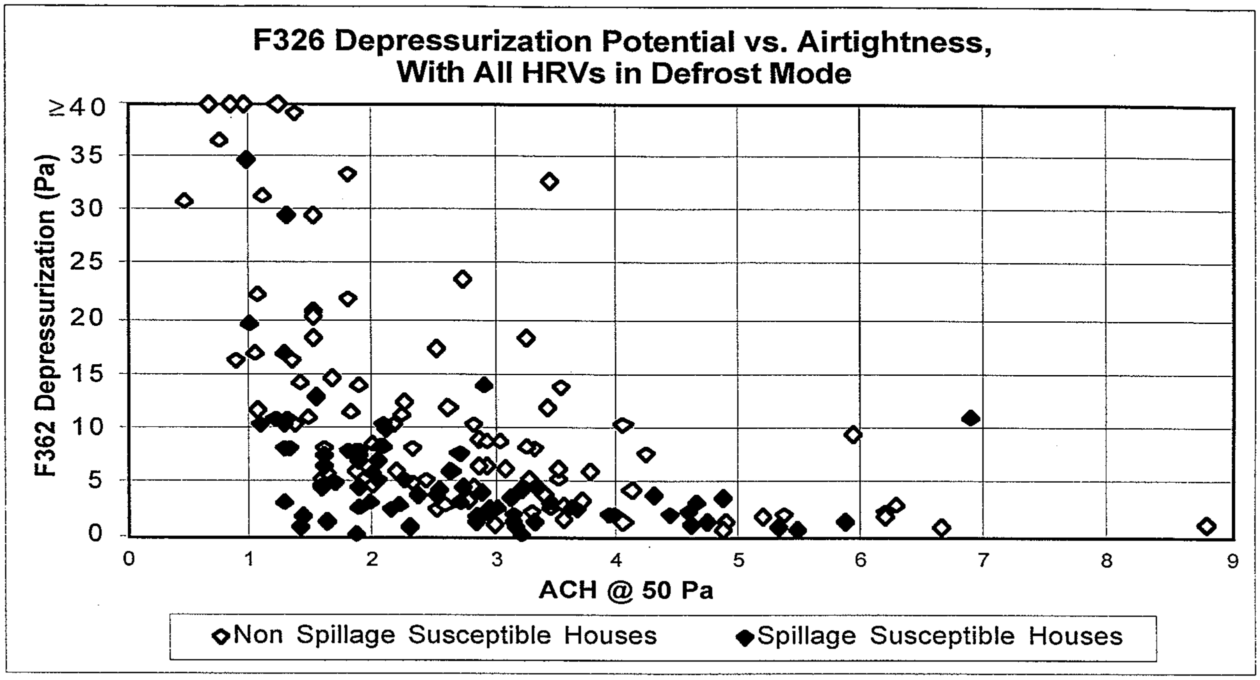

Figure 39. F326 depressurization potential vs. airtightness, all HRVs in exhaust mode.

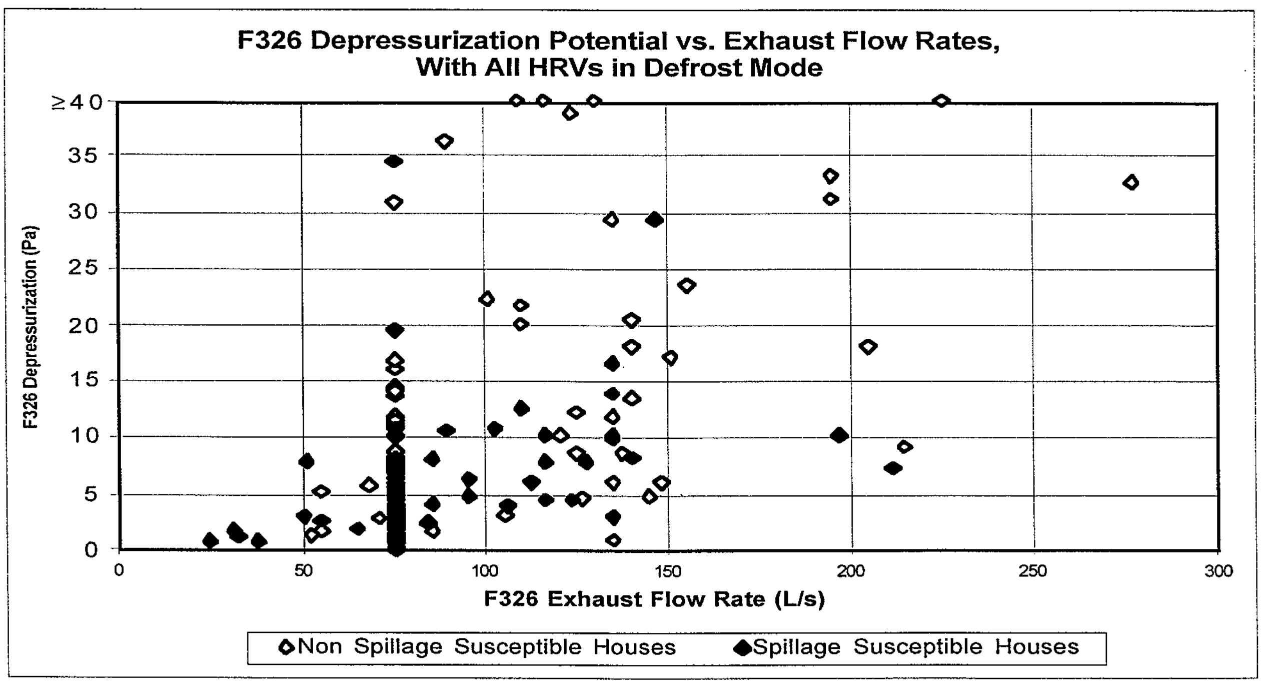

Figure 40. F326 depressurization potential vs.exhaust flow rates, all HRVs in exhaust mode.

There is some disagreement as to whether the results with balanced flows in HRVs or those with HRVs in exhaust mode are more significant. Some[17,18] contend that an HRV in exhaust only mode is no different than any other intermittent exhaust fan, and should be counted. Others[19] argue that exhaust mode occurs for infrequent and short periods which are unlikely to coincide with time when vented appliances are likely to backdraft, and do not persist long enough to cause significant problems. Both methods of dealing with HRVs result in a significant percentage of houses, including spillage-susceptible houses, which are subject to high levels of depressurization.

These results on potential depressurization are subject to four sources of error: First, as mentioned above, F326 values for the airtightness parameters C and n had to be estimated for a number of houses, and could not be estimated for others. Use of CGSB parameters results in some overestimation of potential depressurization in six percent of houses. Second, some flow rates for exhaust fans may have been estimated or taken from manufactures' data rather than measured in the field. This probably results in some overestimation of exhaust flow rates, and thus, of potential depressurization, since improper installation or long duct lengths can substantially decrease flow rates. Third, no attempt is made to estimate the effects of exhaust fans on each other. Since the depressurization caused by one fan will decrease the flow through others, this factor also results in probable overestimates of total exhaust rates, and thus depressurization, although it is not likely to be significant until depressurization is well above the 5 Pa limit. Thus, the first three sources of error all result in conservative results, i.e., they all tend to overestimate the potential for depressurization, and thus to indicate the need for measures to reduce depressurization and its potential hazards.

The final source of potential error is the four houses which have induced draft DHW tanks, induced draft furnaces, and potential depressurizations of over 5 Pa. If all four were co-vented through unsealed B-vents, they would increase the number of spillage-susceptible houses with depressurization potentials by five percent. Thus, not classifying them as spillage-susceptible may result in a slight underestimation of the potential for depressurization.

A previous study,[20] used statistical methods to determine the probability of depressurization in a sample of 192 houses built in 1989 which had an average airtightness of 3.44 ACH @ 50 Pa. Exhaust flows of dryers, kitchen and bathroom fans were measured in a separate sample of 205 houses done in 1988.[21] These indicated that the average house would have a combined exhaust flow of 113 L/s. At this flow rate, approximately 48% of the 1989 houses would be depressurized by 5 Pa or more. However, if the exhaust rates had been summed according to the F326 method, the average would almost certainly have been lower. The average measured exhaust flows (L/s) were: dryers: 37, kitchen fans: 59, bathroom fans: 17, and central vacuums: 24 (see Table 25). Thus, the sum of the dryer (or 75 L/s) plus the few other devices of 75 L/s or more would probably be less than 75 L/s. At 75 L/s, only about 30% of the 1989 houses would have been depressurized to 5 Pa or more. These results are not directly comparable with those in this report because the former are based on a statistical combination of two samples and cannot distinguish between houses which do and don't have appliances which can be backdrafted. However, they do indicate that the percentage of houses which can have excess depressurization has remained between 30 and 50% despite a 21% increase in airtightness.

Device	Number Tested	Flows (L/s)		
		Mean	Minimum	Maximum
Clothes Dryer	61	37	10	83
Kitchen Fans	62	59	3	155
Bathroom Fans	103	17	2	98
Central Vacuums	24	24	10	41

Table 25. Measured exhaust air flows from a 1982 survey (from Ref 20 & 21).

The F326 standard may be conservative, and small amounts of excess depressurization do not necessarily constitute dangerous situations (Ref 19). Nevertheless, the general conclusion to be drawn from this study of potential depressurization is that new conventional houses are airtight enough to be subject to severe depressurization and spillage problems unless proper measures are taken to prevent them. Such measures could include restrictions on combustion appliances other than direct vent appliances, and on the installation of exhaust only ventilation system. The tendency of occupants to install wood stoves or fireplaces after a house has been completed may present a special hazard. As trends toward greater airtightness continue, both in building codes and in practice, conventional houses appear to require improvements of guidelines on combustion and ventilation equipment.

7. Summary and Conclusions.

Canadian housing continues to become more airtight and more energy efficient in all regions of the country. Although R-2000 houses continue to be significantly tighter and more efficient than new conventional houses, the gap is narrowing. Conventional houses built in the last five years are thirty-five percent tighter than those from the previous five years. Greater airtightness creates a need for mechanical ventilation, and creates the potential for hazardous depressurization and spillage of pollutants. This study shows that approximately 35% of new conventional houses which require mechanical ventilation to prevent IAQ problems have none, and that 64% have either no ventilation systems or systems which may be inadequate. The figures for houses with the potential for low air change rates and more severe IAQ problems are 21% no mechanical ventilation and 40% none or possibly inadequate. Fifty to 55% of new conventional houses are subject to depressurization of greater than the F326 limit of 5 Pa. This includes 30 to 40% of houses which have combustion devices which can spill pollutants when depressurized. These conclusions are based on databases of reasonable size and accuracy which are representative of all regions of the country. Although subject to some errors and uncertainty, they are strong enough to indicate that these problems do occur in significant numbers of new Canadian houses.

Increasing airtightness is an important aspect of the ongoing increase in energy efficiency which has made Canada a world leader in cold climate housing. Airtightness is also required to avoid moisture damage, and for comfort. These benefits can be achieved without causing IAQ problems due to inadequate ventilation or depressurization and spillage through improved ventilation equipment and depressurization tolerant combustion appliances.

Based on this sample, new conventional houses consume an average of 93 giga-joules per year (GJ/y) for space heating. By comparison, R-2000 houses consume 70 GJ/year. Normalized fuel neutral results are 63 kilo-Joules per year per degree-day per square meter of nominal floor area (kJ/(y-DD-m^2)) for new conventional houses and 42 kJ/(y-DD-m^2) for R-2000. Under the EnerGuide for Houses energy efficiency ratings, new conventional houses average 73 out of 100, and R-2000 houses have an average rating of 79.

Appendix I: Detailed Tables of Characteristics of the New Conventional & R-2000 House Datasets.

The tables in this appendix use bold type to indicate the maximum value in each category, and italic type to indicate the minimum.

I-1. The New Conventional House Dataset.

Above grade insulation values are shown in Table I-1. Generally the highest values of ceiling insulations are found in the Prairies, but the single house with the lowest value is also there. The houses with lowest mean value of ceiling insulation are in Ontario. Quebec has the highest values of main (non-basement or crawl space) walls, and B.C. has the lowest. For basement walls above ground, the highest average insulation values are found in Ontario, while the Prairies have the highest values at the ninetieth percentile and maximum, and the lowest average values are in Atlantic Canada. Table I-2 shows insulation values for basement walls below grade; the highest values are found in Quebec and the Prairies, and the lowest in Atlantic Canada and B.C.. Table I-3 shows the average thermal resistance of windows in the main wall (excluding windows in basements and crawl spaces); those with the highest resistance are found in the Prairies, and those with the lowest are in Ontario and B.C.. In all cases, B.C. is below the national average for insulation values. This is partly due to the milder climate of the west coast, but as Section 5 (Energy Efficiency) shows, the efficiency of B.C. houses is low when climate is taken into account.

I-2 The R-2000 House Dataset.

Table I-4 shows above ground insulation levels. The best insulated ceilings are generally found in the Prairies while Quebec has the lowest values. Quebec has the highest values for main wall insulation, and B.C. has the lowest. Quebec also has the most insulated basement walls above ground, while Ontario's are the least insulated. On average, this is also true of basement walls below ground, as shown in Table I-5. The windows with the highest thermal resistances are found the Prairies and Ontario, and those with the lowest are found in B.C., as shown in Table I-6.

Region	Number of Houses	Minimum	10th %ile	Mean	90th %ile	Maximum
	Ceiling R-values (RSI)					
B.C	20	4.17	*4.39*	5.81	6.72	7.22
Prairies	69	*3.58*	**5.78**	**6.73**	**7.38**	**9.80**
Ontario	20	4.47	4.66	*5.38*	*6.54*	7.05
Quebec	30	**4.79**	4.99	5.63	6.63	*6.89*
Atlantic	24	**4.79**	5.54	6.12	6.90	7.25
NATIONAL	163	3.58	4.97	5.84	7.02	9.80
	Main Wall R-Values (RSI)					
B.C	20	*1.86*	*1.97*	*2.56*	*2.92*	*3.27*
Prairies	69	1.94	2.62	2.77	2.95	3.99
Ontario	20	2.55	2.60	2.92	3.23	3.35
Quebec	30	**2.64**	**2.85**	**3.15**	**3.47**	**4.20**
Atlantic	24	2.31	2.31	2.72	2.94	4.14
NATIONAL	163	1.86	2.50	2.85	3.23	4.20
	Basement Walls Above Ground, R-Values (RSI)					
B.C	20	0.51	1.20	1.85	2.75	3.03
Prairies	69	*0.27*	0.64	2.09	**3.54**	**5.50**
Ontario	20	**1.42**	**1.65**	**2.20**	2.69	*2.90*
Quebec	30	0.28	1.46	1.90	*2.43*	3.03
Atlantic	24	0.35	*0.41*	*1.77*	2.97	3.65
NATIONAL	163	0.27	0.77	2.00	2.98	5.50

Table I-1. Above grade insulation levels of new conventional houses.

Region	Number of Houses	Minimum	10th %ile	Mean	90th %ile	Maximum
	Upper Basement Walls Below Ground, R-Values (RSI)					
B.C	13	**0.24**	0.25	1.46	*1.93*	*2.65*
Prairies	62	**0.24**	0.26	1.96	**3.35**	**4.79**
Ontario	20	**0.24**	1.36	1.86	2.34	4.05
Quebec	30	**0.24**	**1.54**	**1.90**	2.43	3.00
Atlantic	17	*0.20*	*0.24*	*1.15*	2.16	3.17
NATIONAL	142	0.20	0.24	1.74	2.70	4.79
	Lower Basement Walls Below Ground, R-Values (RSI)					
B.C	13	**0.24**	*0.24*	1.45	*1.93*	*2.65*
Prairies	62	**0.24**	0.25	**1.91**	**3.35**	**4.79**
Ontario	20	**0.24**	1.36	1.86	2.34	4.05
Quebec	30	**0.24**	**1.42**	1.79	2.29	2.70
Atlantic	17	*0.20*	*0.24*	*1.15*	2.16	3.17
NATIONAL	142	0.2	0.24	1.70	2.69	4.79

Table I-2. Below grade insulation levels of new conventional houses.

Region	Number of Houses	Main Wall Window R-Values (RSI)				
		Minimum	10th %ile	Mean	90th %ile	Maximum
B.C	20	*0.23*	*0.24*	0.36	0.45	0.51
Prairies	69	**0.33**	**0.34**	**0.46**	**0.52**	**0.61**
Ontario	20	0.30	0.32	*0.33*	*0.34*	*0.36*
Quebec	30	0.32	**0.34**	0.37	0.41	0.43
Atlantic	24	0.30	0.32	0.36	0.46	0.47
NATIONAL	163	0.23	0.33	0.37	0.51	0.61

Table I-3. Insulation levels of windows in main walls, new conventional houses.

Region	Number of Houses	Minimum	10th %ile	Mean	90th %ile	Maximum
	Ceiling R-Values (RSI)					
B.C	8	4.88	5.51	6.59	*7.48*	*8.09*
Prairies	16	5.27	**7.12**	**8.67**	9.96	**10.83**
Ontario	12	4.85	5.51	6.83	8.63	9.03
Quebec	14	*2.65*	*3.82*	*6.27*	7.67	10.34
Atlantic	13	**6.00**	6.00	7.89	**10.46**	10.50
NATIONAL	63	2.65	5.41	7.26	9.93	10.83
	Main Wall R-Values (RSI)					
B.C	8	*2.44*	*2.57*	*2.90*	*3.56*	*3.62*
Prairies	16	2.68	2.74	3.57	4.58	5.73
Ontario	12	2.86	2.92	3.46	3.87	5.88
Quebec	14	**3.76**	**3.96**	**5.13**	**6.02**	**6.64**
Atlantic	13	2.72	2.74	3.82	5.48	5.93
NATIONAL	63	2.44	2.72	3.58	5.72	6.64
	Basement Walls Above Ground, R-Values (RSI)					
B.C	6	2.01	2.23	2.95	3.58	3.93
Prairies	16	**2.32**	2.32	3.09	4.29	**5.93**
Ontario	12	*1.37*	*1.43*	*2.35*	*3.29*	*3.76*
Quebec	14	2.17	2.45	**3.66**	4.67	4.76
Atlantic	12	**2.32**	**2.50**	3.51	**4.91**	5.46
NATIONAL	60	1.37	2.15	2.84	4.60	5.93

Table I-4. Above grade insulation levels of R-2000 houses.

Region	Number of Houses	Minimum	10th %ile	Mean	90th %ile	Maximum
	Upper Basement Walls Below Ground, R-Values (RSI)					
B.C	4	1.93	2.19	2.82	3.38	3.54
Prairies	13	**2.32**	**2.32**	2.82	3.27	**5.56**
Ontario	12	1.78	1.82	*2.21*	*3.01*	*3.14*
Quebec	14	1.93	2.06	**3.28**	4.30	4.65
Atlantic	10	*1.17*	*1.31*	3.08	**4.43**	4.90
NATIONAL	53	1.17	1.86	2.60	4.30	5.56
	Lower Basement Walls Below Ground, R-Values (RSI)					
B.C	4	1.93	2.19	2.82	3.38	3.54
Prairies	13	**2.32**	**2.32**	2.72	3.27	4.21
Ontario	12	1.78	1.82	*2.21*	*3.01*	*3.14*
Quebec	14	1.93	2.06	**3.28**	4.30	4.65
Atlantic	10	*1.17*	*1.31*	3.08	**4.43**	**4.90**
NATIONAL	53	1.17	1.86	2.59	4.23	4.90

Table I-5. Below grade insulation of R-2000 houses.

Region	Number of Houses	Main Wall Window R-Values (RSI)				
		Minimum	10th %ile	Mean	90th %ile	Maximum
B.C	8	*0.24*	*0.24*	*0.34*	*0.43*	*0.44*
Prairies	16	0.31	0.34	**0.53**	**0.70**	**0.78**
Ontario	12	**0.34**	**0.38**	0.43	0.46	0.50
Quebec	14	0.28	0.31	0.40	0.54	0.57
Atlantic	13	0.33	0.34	0.43	0.51	0.52
NATIONAL	63	0.24	0.34	0.43	0.61	0.78

Table I-6. Insulation values of windows in main walls, R-2000 houses.

Appendix II: Equivalent Leakage Areas.

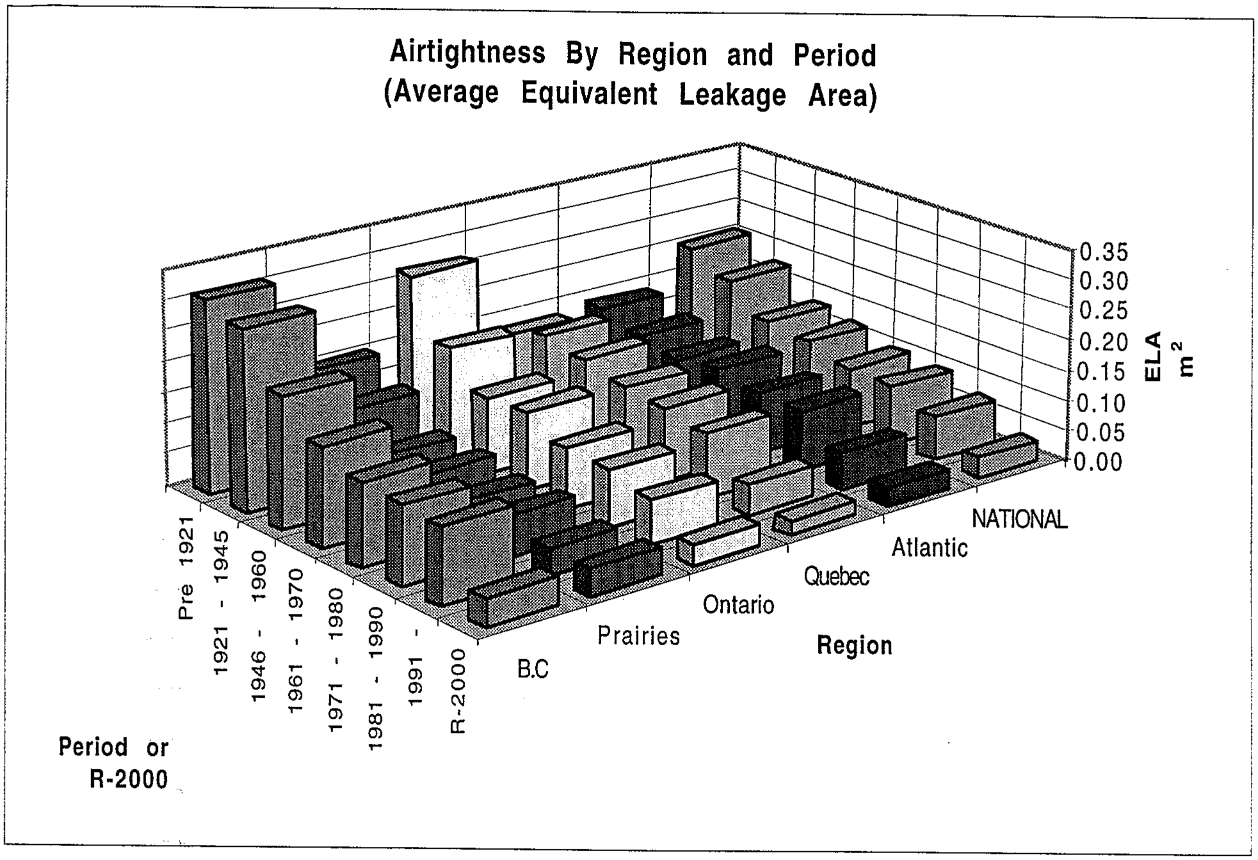

Figure II-1. Airtightness (average equivalent leakage areas) by region and period, with R-2000 houses for comparison.

Region	Pre 1921	1921 - 1945	1946 - 1960	1961 - 1970	1971 - 1980	1981 - 1990	1991 -	R-2000
B.C	0.314	0.294	0.212	0.162	0.135	0.127	0.124	0.046
Prairies	0.156	0.122	0.076	0.072	0.062	0.064	0.045	0.043
Ontario	0.273	0.179	0.125	0.129	0.099	0.093	0.074	0.033
Quebec	0.135	0.160	0.147	0.129	0.121	0.106	0.052	0.024
Atlantic	0.141	0.121	0.105	0.115	0.100	0.100	0.056	0.030
NATIONAL	0.208	0.174	0.129	0.121	0.101	0.096	0.073	0.034

Table II-2. Airtightness (average equivalent leakage areas (m^2)) by region and period, with R-2000 houses for comparison.

Appendix III: Graphs of Airtightness Distributions.

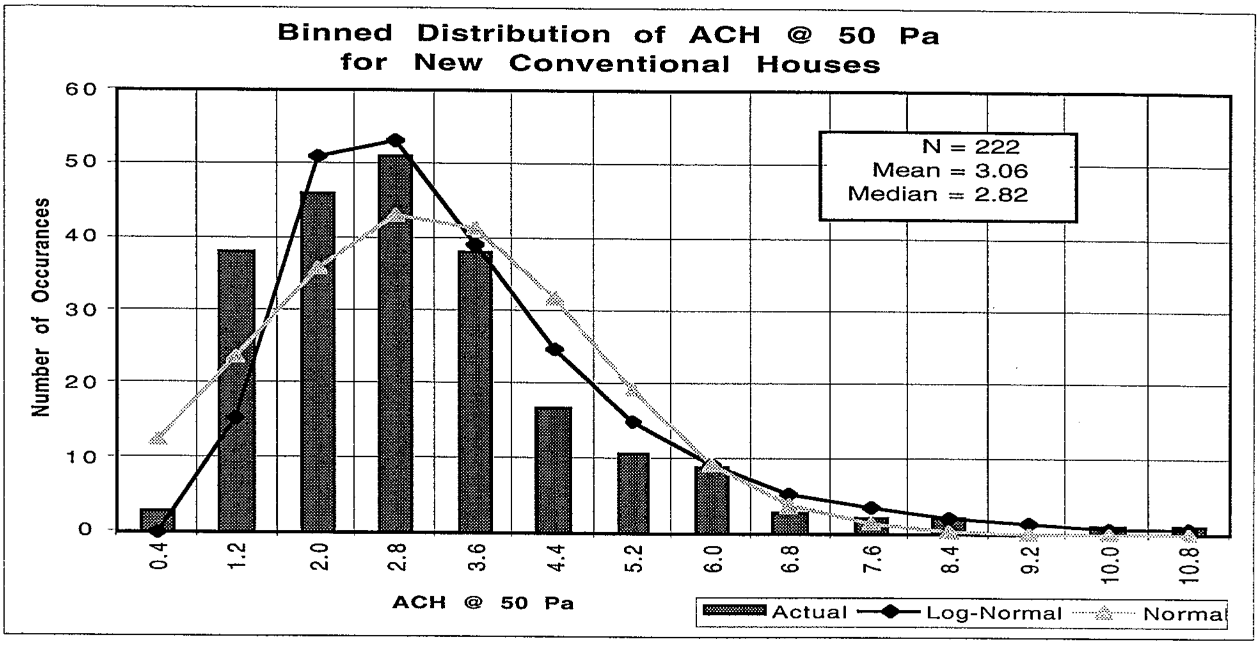

Figure III-1. Binned distribution of air changes per hour at 50 Pa, showing normal and log-normal distributions, for new conventional houses.

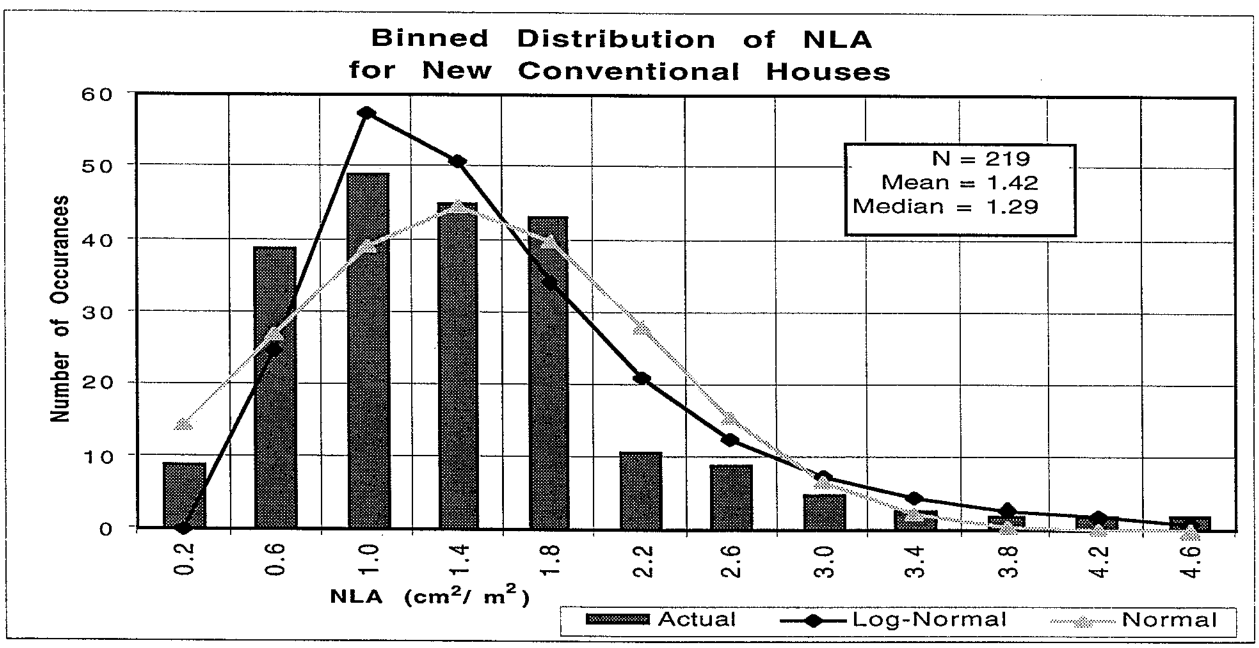

Figure III-2. Binned distribution of normalized leakage areas, showing normal and log-normal distributions, for new conventional houses.

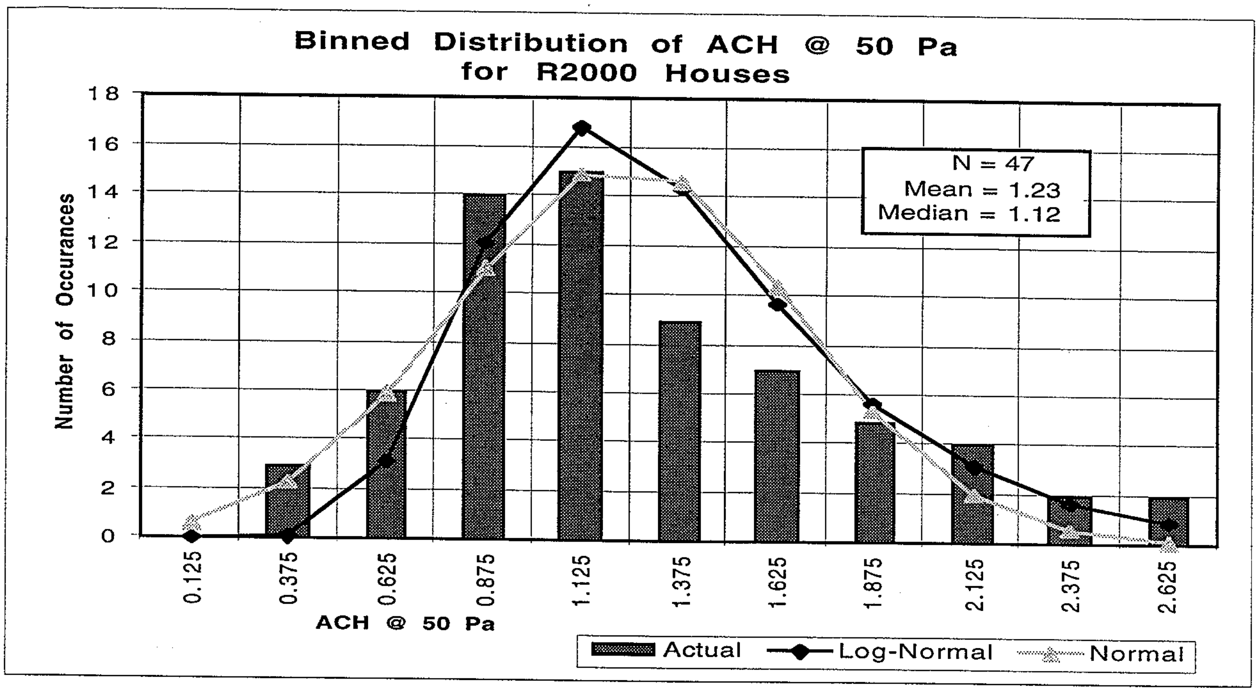

Figure III-3. Binned distribution of air changes per hour at 50 Pa, showing normal and log-normal distributions, for R-2000 houses.

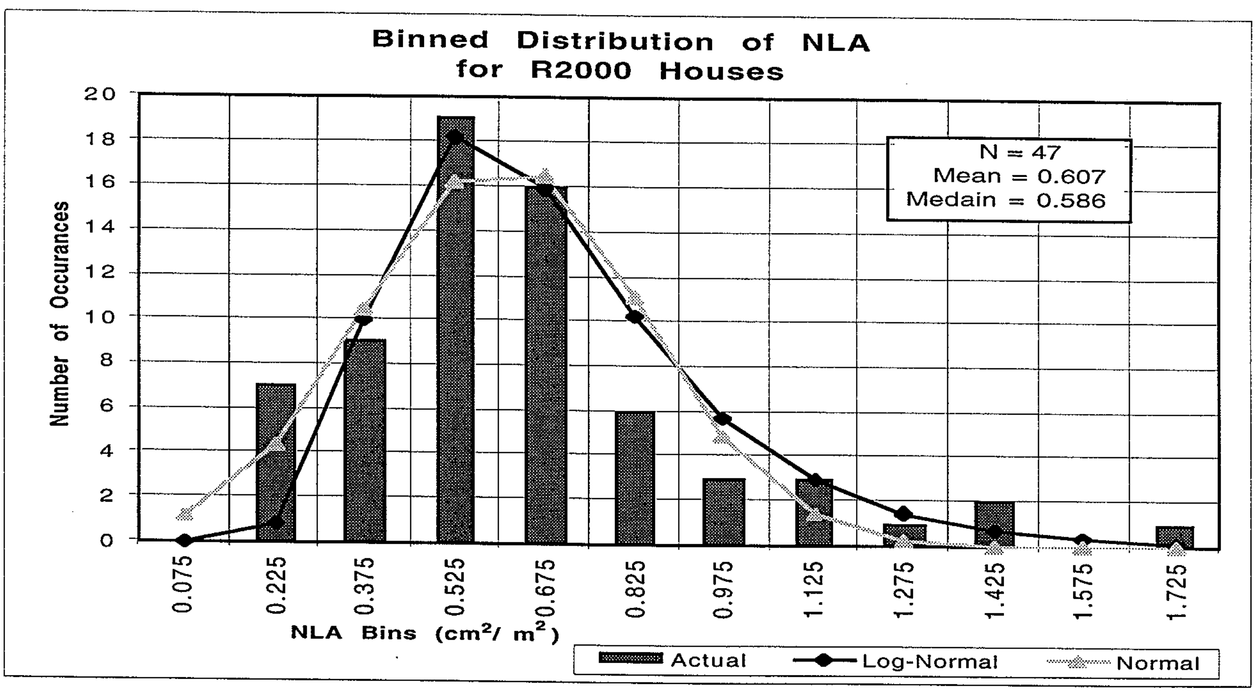

Figure III-4. Binned distribution of normalized leakage areas, showing normal and log-normal distributions, for R-2000 houses.

Appendix IV: Un-normalized Space Heat Energy for Fossil Fuel & Electrically Heated Houses.

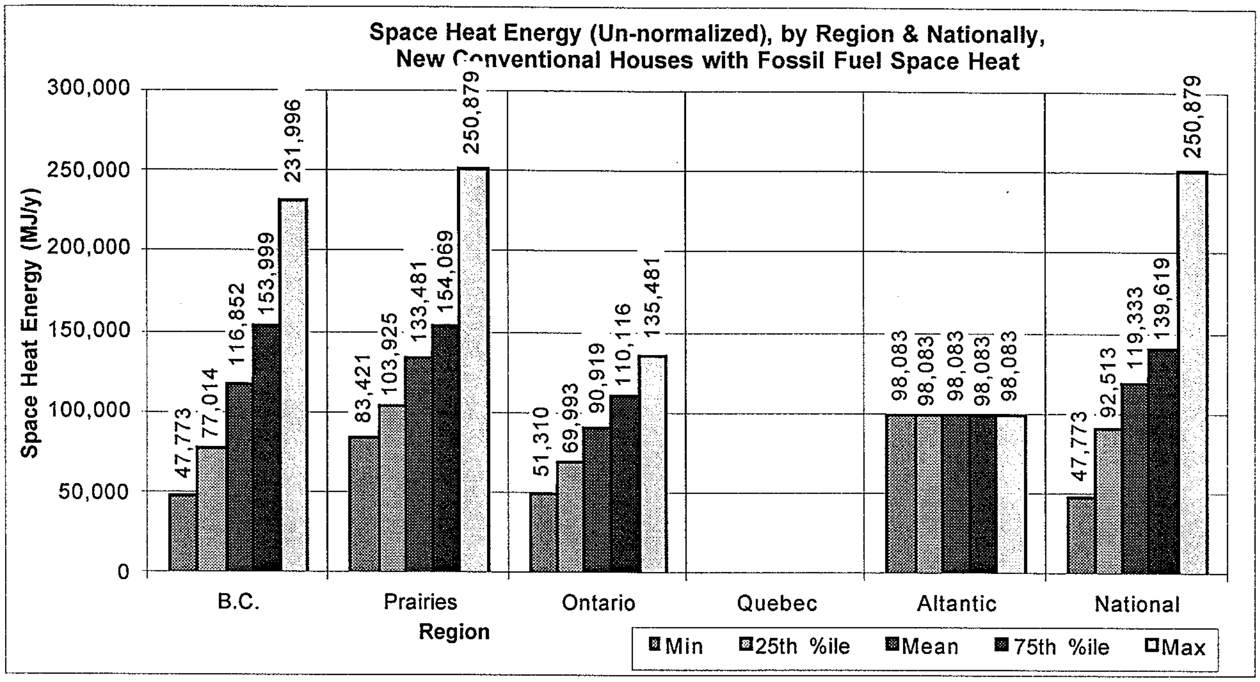

Figure IV-1: Space heat energy use (un-normalized) for new conventional houses with fossil fuel space heat, by region and nationally.

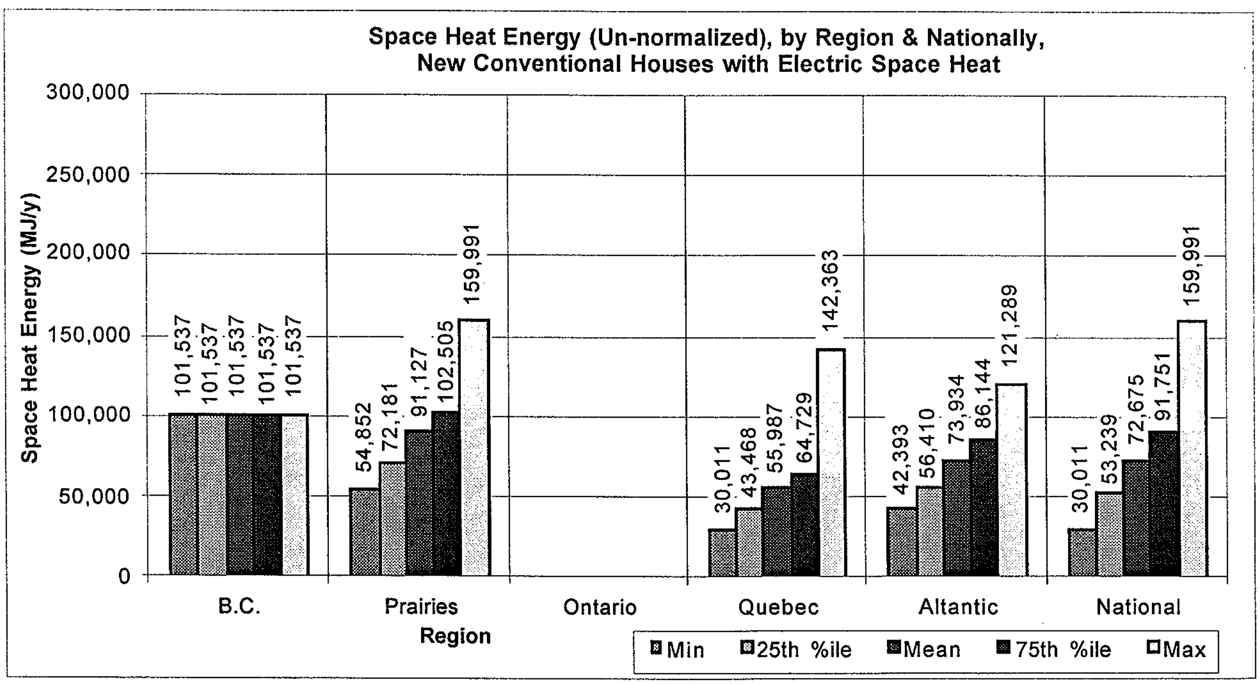

Figure IV-2: Space heat energy use (un-normalized) for new conventional houses with electric space heat, by region and nationally.

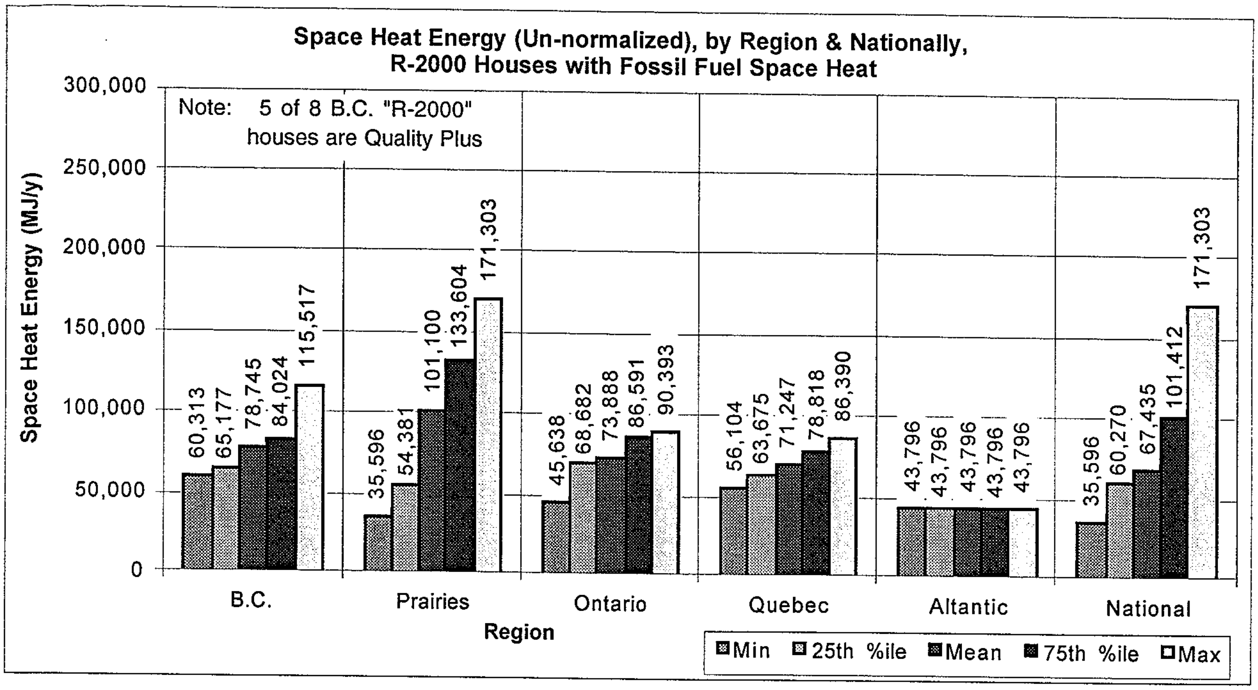

Figure IV-3: Space heat energy use (un-normalized) for R-2000 houses with fossil fuel space heat, by region and nationally.

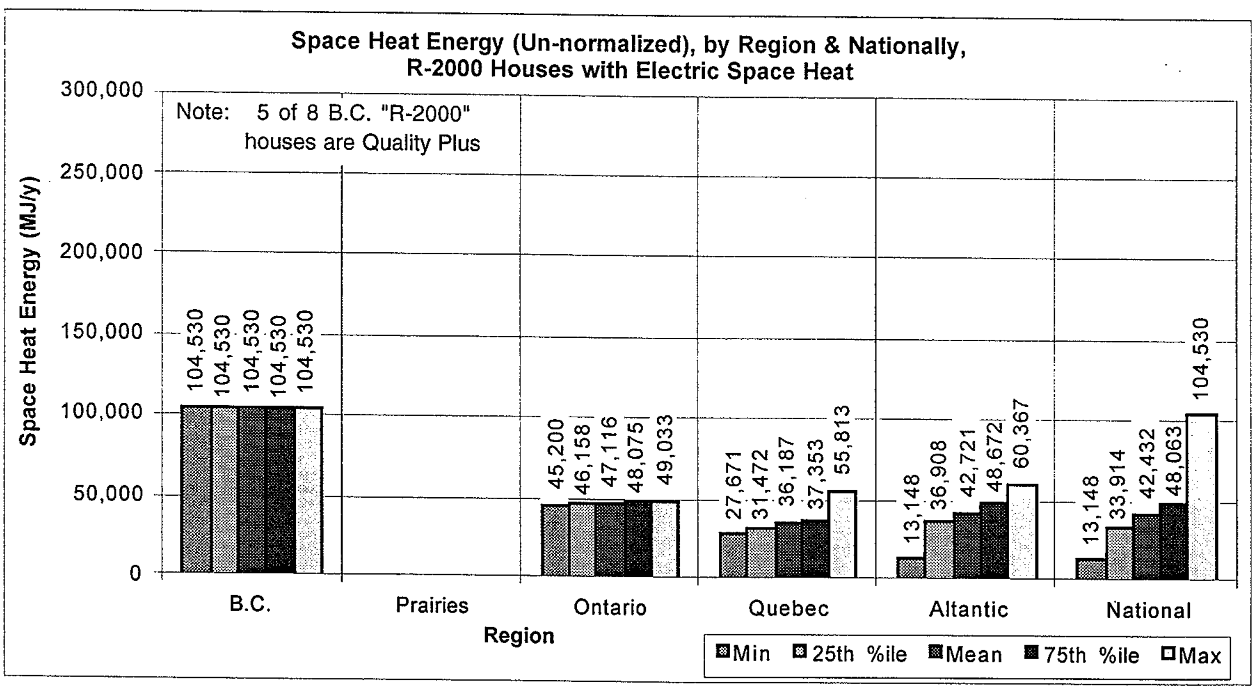

Figure IV-4: Space heat energy use (un-normalized) for R-2000 houses with electric space heat, by region and nationally.

Appendix V: Normalized Space Heat vs. Volume, R-2000 Houses.

Figure V-1 shows the effect of normalization with and without volume adjustment for the sixty-three R-2000 houses in this study. It is similar to Figure 21 (Section 5.3) in that larger houses do not appear to be more energy efficient even before being adjusted for volume. It also shows that adding the floor area allowance gives smaller houses an advantage. The high degree of scatter in the plot is due to the fact that it includes houses which were certified under a number of different R-2000 Technical Guidelines, and the five B.C. Quality Plus houses.

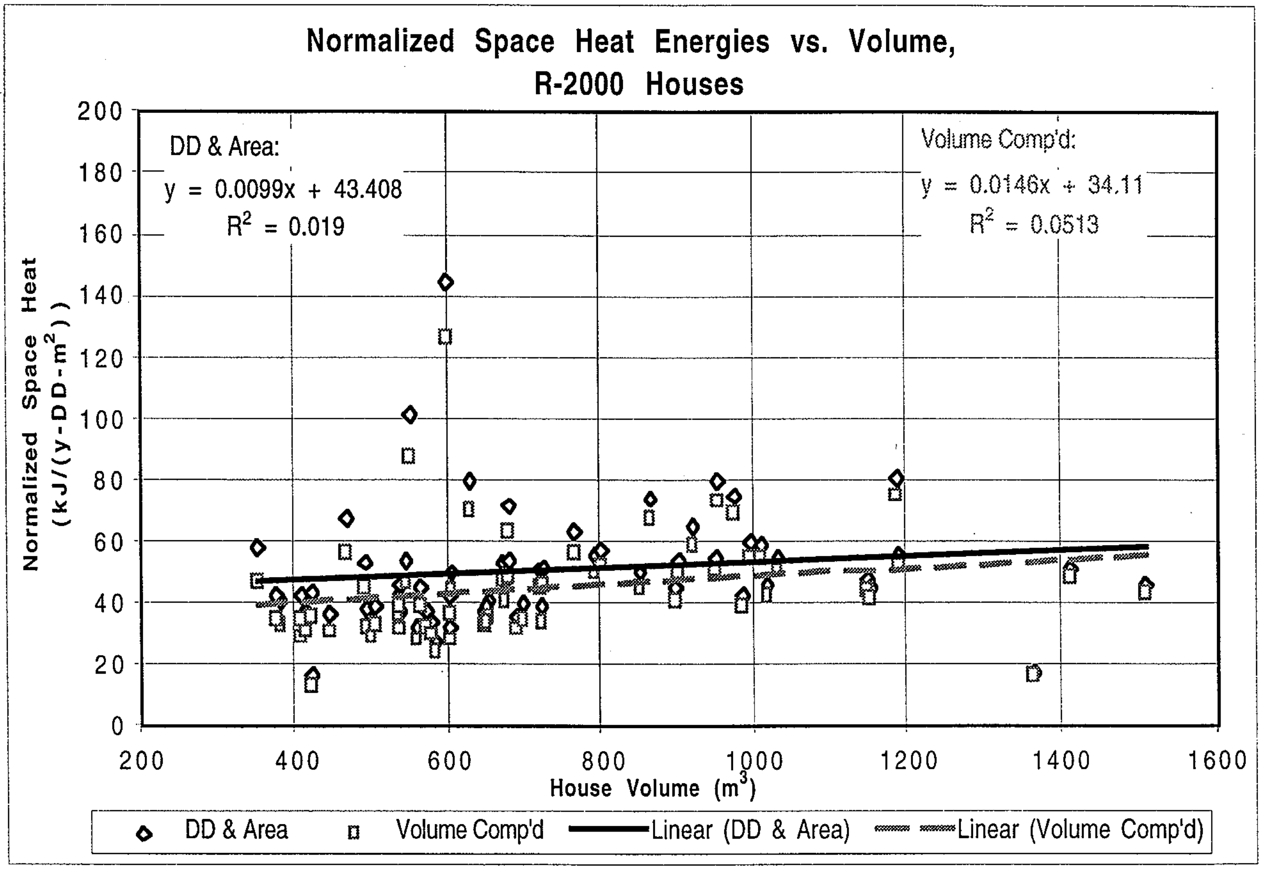

Figure V-1: Normalized space heat energy by two methods vs. house volume, R-2000 houses.

Appendix VI: Detailed Methodology for Calculating Potential Depressurization.

For each of the 163 houses in the new conventional dataset, the F326 depressurization potential (Section 6) was calculated as follows:

1. BATCH HOT2000 was run (see Section 5.) with the following spreadsheet outputs: the supply and exhaust air flow rates of the central ventilation system, the space heating system type, fuel and flue diameter, the DHW system type and fuel, and the combined appliance depressurization limit.

2. A specially written FORTRAN program was used to produce the following spreadsheet outputs, which BATCH HOT2000 cannot write, for each house: the house airtightness coefficients C and n, the intermittent exhaust air flow rates for the clothes dryer, kitchen and bathroom exhaust fans, central vacuum and "other," the DHW system flue diameter, and the types and flue diameters of solid fuel burning equipment.

3. The results of steps 1. and 2. are loaded into two spreadsheets, and the following changes are made:

   a. Central ventilation flow rates are adjusted as follows: In both spreadsheets, flows through non-HRV, non-balanced systems are set to the F326 minimum ventilation rate for their house, or to the their maximum capacity, which ever is less. In the second spreadsheet only, all HRVs which can have an exhaust only defrost mode are set to exhaust only at the F326 minimum flow rate for their house. Thus, two sets of depressurization results are created. One with all HRVs in balanced flows, and the second with all HRVs which can have an exhaust only defrost mode in their defrost modes.

   b. The airtightness parameters C and n which are written from HOT2000 are based on the CGSB standard blower door test. Where necessary and possible, these were replaced by values from an F326 blower door test as follows: For houses in which the two blower door test would be different, results from a blower door test done with the F326 sealing protocol (Ref 11, Clause 10 including Table 6) were used if available. For houses for which they were not available, they were estimated from the diameter of the ventilation air intake according to *Treatment of Flues in HOT-2000* (Ref 16). Neither F326 blower door results, nor intake diameters were available for 10 of the 163 houses, so CGSB values of C and n were used. If any of these houses do have ventilation air intakes, then their potentials for depressurization will be overestimated.

4. The spreadsheets calculates the Reference Exhaust Flow-Rate Condition Q_R for each house as the sum of:

   a. The central ventilation system supply rate subtracted from the exhaust rate to get the net exhaust rate (L/s).

   b. The specified intermittent exhaust rate for a clothes dryer (L/s) if one is given, or else 75 L/s.

c. The sum of each of the non-dryer intermittent exhaust flow rates that are ≥ 75 L/s. That is each of the kitchen fan, bathroom fan(s), others, and central vacuum that are ≥ 75 L/s is summed while those which are < 75 L/s are ignored.

4. The Reference Exhaust Flow-Rate Condition is used to calculate the F326 depressurization potential P_F for each house as

$$P_F = \exp\{ \ln(Q_R / C) / n \}.$$

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