Thermal and Air Leakage Characteristics of Canadian Housing

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ABSTRACT

Canadian housing stock has undergone a significant change over the years in terms of its thermal performance. The houses are being built with more thermal insulation as well as better airtightness to reduce unwanted air leakage. The thermal characterization of the housing stock is important to building scientists, engineers, architects and field energy advisors. Under Natural Resources Canada's EnerGuide for Houses program, which was cancelled in May of 2006, approximately 266,000 houses across Canada were evaluated. Of those, about 83,000 houses received post-retrofit visits. Using the data from these retrofitted houses, detailed thermal and energy use profiles have been developed for different regions. The data analysis shows that the building envelope insulation levels have significantly increased over time. Wall insulation levels have improved significantly from early 1960s to late 1990s; however, since 1995 there is no apparent change in the wall and attic insulation levels. Airtightness of houses has improved from about 8 ac/h at 50 Pa to an average of about 4 ac/h in recently built houses. This paper provides details about the housing stock thermal characteristics for different regions along with the data analyses of existing and new housing.

INTRODUCTION

Canadians use significant amounts of energy to heat, cool and ventilate their homes, to operate lights and appliances and to heat water. According to the latest data available (2005), the residential energy use was 1,481 petajoules (1 PJ = 10^{15} J) which accounted for 16.6% of secondary energy use in Canada [NRCan 2006]. Since 1991, the residential energy use has risen by about 1.1% every year. Space and domestic water heating energy requirements account for over 80% of residential energy demand in most regions. Improvement in the energy efficiency of dwellings has become, therefore, a focus of federal government agencies in order to reduce the dependence on fossil fuels.

The residential housing stock consists of 12.967 million units as per the latest data available from the Statistics Canada [Statistics Canada 2006]. About 58% of this stock consists of single family dwellings, 10% of dwellings are semi-detached housing, and the rest are low-rise row-housing and mid- or high-rise apartments. As shown in Table 1, about 50% of the housing stock was built prior to 1977. In the last ten years about 15% of stock has been built and the new housing construction has added about 220,000 dwelling units per year, making it a record period of sustained growth. Over the years, the average size of Canadian dwellings has also steadily increased. Today's housing has, on an average 142 m² (1,525 ft²) of conditioned floor space compared to an average of 119 m² (1,284 ft²) for houses built about 30 years ago. We can therefore assume that the significant growth in the number and the size of dwellings has affected the use of natural resources and the residential energy use patterns over the years.

Over the last thirty years, a number of housing surveys provided the thermal and air leakage characteristics of housing in different regions of Canada. These surveys, listed in Table 2, provided information on the architectural configurations, thermal characteristics and operating parameters of

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housing [Parekh 1996] and tracked the developments in housing construction and energy efficiency improvements. The study data provided sufficient information to develop appropriate code changes and energy efficiency programs by various stakeholders including builders, utilities and local, provincial and federal administrations. These surveys were conducted by various private and public agencies and were focused on their differing needs, thus data gathered were somewhat inconsistent and had varying degrees of accuracy. These surveys were also somewhat limited in gathering housing specific information for all regions of Canada.

Table 1. Canadian housing stock in 2004 (Statistics Canada and CMHC 2005).

	Number of Dwellings (in thousands)		Average Size sq m
Before 1946	1,832	14%	116
1946–1960	1,278	10%	102
1961–1977	3,353	26%	106
1978–1983	1,544	12%	119
1984–1995	3,019	23%	130
1996–2000	1,002	8%	139
2001–2004	938	7%	142
Total	12,967		

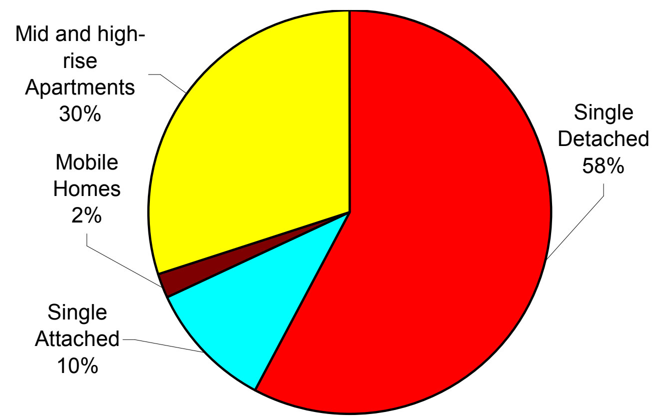

Table 2. Sources of thermal and airtightness data.

Source of Data	Number of Records
1. 1982 Airtightness Tests on 200 New Houses (SRC) 1982, Canada	200
2. 1989 Airtightness Survey of New Merchant Homes (NRCan) 1989, Canada	194
3. Airtightness and IAQ of 78 Winnipeg Houses (CMHC) 1989	78
4. Airtightness Measurements in Saskatoon Houses (NRC-DBR) 1982, SK	176
5. Airtightness Tests on 108 Ontario Houses 195, ON	108
6. Appin – Manitoba Houses 1989	73
7. CMHC STAR Housing Database (1993), Canada	1,100
8. Nova Scotia Report (NRCan) 1993	54
9. Efficiency Housing Database - Alberta (NRCan) 1993	55
10. Elliott Lake, Scanada 1992, ON	26
11. Espanola data, Scanada 1991, ON	29
12. Eval-Iso Project - Hydro Quebec (1995), Quebec	1,081
13. Field Energy Audit Survey (NRCan) 1994, BC	90
14. Field Testing (CMHC) and Aereco Houses, Scanada 1992, ON	24
15. Healthy Homes (NRCan) 1994, NS	20
16. MAPP Data, Scanada 1987, NF, MB, ON, QU, NS	125
17. Ontario Hydro, Scanada 1989, ON	85
18. Summary of Airtightness New Conventional Homes (NRCan) 1989	68
19. Survey of 28 Homes, Bowser Tech 1990, ON	28
20. Survey of Airtightness of 40 New BC Homes (NRCan) 1993	40
21. Ventilation Control (SRC) 1994, SK (CMHC publication)	20
22. Airtightness and Energy Efficiency of New Conventional and R2000 Housing in Canada (NRCan) 1997	162
Total	**3,836**

Under Natural Resources Canada's EnerGuide for Houses program, which was cancelled in May of 2006, approximately 266,000 houses across Canada were evaluated. Of those, about 83,000 houses received post-retrofit visits. Over 150 specific items on 83,000 houses that have been retrofitted have been stored in a database. The main goal of this paper is to provide analysis of the housing data for the thermal and air leakage characteristics of housing in different regions. This information should be useful to builders, electricity supply utilities, oil and natural gas companies and regulators to formulate appropriate programs for homeowners. For building scientists, engineers, architects and housing professionals, this information would be very useful in assessing the new opportunities for energy efficient construction practices in new and existing housing.

METHODS FOR DATA GATHERING AND ANALYSIS

DATA SOURCES

The housing database keeps house specific information gathered from field evaluations. For each house evaluation, the following data is gathered:

1. House configuration including overall dimensions, orientation, type of house and number of storeys
2. Insulation levels for the attic, walls, foundation, windows and exterior doors
3. Airtightness data including the calculated normal air change rates
4. Energy analysis data showing components of heat losses, estimates of space heat and hot water energy use and the energy ratings.

This paper will focus more on the items 2 and 3 of above. Details of these items are as follows:

- House configurations – The house configuration includes plan layout, dimensions of various components, volume, and orientation. The following are main forms of low-rise housing:
    - detached or single-family homes
    - semi-detached (two attached houses)
    - row houses (more than two attached and vertically separated)
    - walk-ups (more than two dwellings vertically and horizontally separated)

  House formation defines the size and volume. There are:
    - the number of levels (storeys) which includes one-storey, one and half, two, two and half, and three storey structures;
    - the shape of the plan which includes rectangular, L-shape, T-shape and forms with varying number of corners and other complex structures;
    - the type of attic/roof which includes cathedral, sloped and flat; and
    - the foundation types including slab-on-grade, full basement, shallow basement, walk-out basement, and crawlspace.
- Thermal characteristics – The thermal characteristics include the make and composition of envelope components (size and insulation values), predominant heating and hot water equipment data (type and steady state efficiencies), and, in particular, airtightness and ventilation parameters. The data classifications were as per the following:
    - age or the year in which the house was built (or retrofitted)
    - location and the region
    - thermal insulation levels of building envelope components
        - above-grade walls,
        - attic/roof
        - windows and doors
        - foundation walls and floor
    - measurements of airtightness using the blower door

- space heating, hot water and ventilation systems
    - primary and secondary fuels used for space heating and hot water
    - type of space heating and hot water systems and steady state efficiencies
    - type of ventilation system and typical airflows (estimated)

PROCEDURES FOR THE DATA ANALYSIS

For the comprehensive data analysis, we selected data files which consisted of pre and post retrofit evaluations. These data sets consisted of about 82,933 house files. Table 3 and 4 shows the sample size for each province and territory and for each age group. The sample size represents from 0.3% to 2.5% of regional stock with an overall weighted average of about 1.1% of the low-rise housing stock. This representation is far superior in size than any of previous studies. On a regional basis, these evaluations are taken from both urban and rural settings.

Though the majority of the information available in the NRCan database is obtained from direct observations (quality assurance guidelines were put in place to ensure appropriate levels of accuracy), certain situations such as inaccessible attics, required the use of default data. To establish relevant defaults, a profile of thermal archetypes was developed using survey data, and defined by locations and years of construction (or the year of major renovation). As construction practices heavily depend on the requirements of codes and standards, the vintage periods of when the house was constructed become a primary factor. Based on these and other primary inputs, all required thermal insulation and equipment specifications were generated.

Table 3. Number of evaluations used for stock representation.

Provinces and Territories	Sample Size	Sample Size Representation of Housing Stock, %
BC	13,029	1.4%
AB	15,348	2.1%
SK	8,232	2.8%
MB	6,271	2.1%
ON	28,060	1.0%
QC	7,936	0.5%
NB	1,003	0.5%
NF	437	0.3%
NS	2,180	0.9%
PE	151	0.4%
NT	109	1.8%
YK	177	2.5%
Total	**82,933**	**1.1%**

Table 4. Number of evaluations used for each age groups used for stock representation.

Age Groups	Sample Size	Representation of Housing Stock, %
1945 or older	15,989	1.5%
1946 - 1960	16,004	2.2%
1961 - 1970	14,062	1.2%
1971 - 1980	21,888	1.5%
1981 - 1990	9,746	0.9%
1991 - present	5,244	0.3%
Total	**82,933**	**1.1%**

The data analysis included sorting for the vintage, type and thermal indicators. Analysis included gathering the minimum, 25th percentile, median, average, 75th percentile and maximum values for each age group and region. The resultant values were further compared with the available data from other surveys.

It should be noted that the analyses presented here strictly deal with thermal insulation, air leakage and estimates of energy consumption. The energy consumption estimates were not verified against actual house energy billing. The field data did not include any information on the moisture performance and durability of building envelope components.

THERMAL AND AIR LEAKAGE CHARACTERISTICS

The data analysis contained significant information for each province and territory. Table 5 shows the summary of data analysis results for the province of Alberta. It is somewhat beyond the scope of this paper to include all details for all regions. Therefore, we selected representative analytic results to show the overall 'thermal' picture of dwelling in different regions. The following sections describe these results.

PROFILES OF BUILDING ENVELOPE CHARACTERISTICS AS PER AGE GROUPS

All evaluations were combined together to represent the national characteristics. The data analysis showed that over the years, the housing stock has become more air-tight and better insulated. These changes have reduced the overall annual space heating energy consumption for houses.

Figure 1 shows the profile of attic/ceiling and above-grade wall insulation levels for dwellings. Figure 3 shows the summary of effective insulation levels for below-grade components. Each bar represents a range of values for the 25th and 75th percentiles with a median value. Over the years, the overall insulation levels have significantly improved.

Figure 2 shows the airtightness profiles of housing. We can see that over the years, houses have become more airtight. The "normal" house infiltration rate ranges from 0.15 to 0.67 air changes per hour during the heating months. As these houses become more airtight, the need for mechanical ventilation becomes imperative. Recent code changes in the provinces mandate mechanical ventilation capable of providing at least 0.25 to 0.30 air changes per hour.

Figure 4 shows the weighted average for the annual space heating requirements for houses, based on the energy simulations performed. The space heating requirement for new housing is about 436 MJ/m^2 of floor area. The improvement results from the combined effects of increased insulation values, better airtightness, efficient space heating equipment and, overall, increased average floor area. Houses built today consume about 34% less energy per square metre of floor are than those built during 1960 to 1980s. In addition, houses built today are about 18% better in energy efficiency than those built during the 1985 to 1990s.

Table 5. Data analysis results of house evaluations from Alberta.

Age Group	Sample Size	25th Percentile	Median	75th Percentile	Average
Heated Floor Area (m^2)					
1945 or older	1,001	145	179	231	199
1946 - 1960	3,019	164	187	217	197
1961 - 1970	3,160	181	204	241	219
1971 - 1980	6,012	181	214	262	229
1981 - 1990	1,903	186	239	303	256
1991 - present	253	223	267	322	280
Heated Volume (m^3)					
1945 or older	1,001	361	448	577	497
1946 - 1960	3,019	410	467	542	492
1961 - 1970	3,160	451	510	601	546
1971 - 1980	6,012	452	535	655	572
1981 - 1990	1,903	465	599	757	640
1991 - present	253	557	667	805	700
Attic/Ceiling Insulation (Effective RSI, m^2K/W)					
1945 or older	1,001	1.99	3.18	4.61	3.31
1946 - 1960	3,019	2.38	4.23	5.81	4.21
1961 - 1970	3,160	2.29	4.41	6.07	4.29
1971 - 1980	6,012	2.78	3.95	5.55	4.12
1981 - 1990	1,903	4.28	5.20	6.16	5.15
1991 - present	253	4.59	5.30	6.41	5.37
Above-grade Wall Insulation (Effective RSI, m^2K/W)					
1945 or older	1,001	0.87	1.56	1.77	1.41
1946 - 1960	3,019	1.61	1.69	1.88	1.71
1961 - 1970	3,160	1.68	1.83	1.91	1.84
1971 - 1980	6,012	1.86	1.90	1.94	1.97
1981 - 1990	1,903	1.92	2.55	2.68	2.34
1991 - present	253	2.58	2.64	2.70	2.62
Foundation Wall and Other Components Insulation (Effective RSI, m^2K/W)					
1945 or older	1,001	0.06	0.52	1.33	0.74
1946 - 1960	3,019	0.23	0.78	1.55	0.91
1961 - 1970	3,160	0.40	1.06	1.66	1.04
1971 - 1980	6,012	0.64	1.49	1.83	1.30
1981 - 1990	1,903	1.58	1.83	1.94	1.80
1991 - present	253	1.82	1.94	2.88	2.19
Airtightness, Air Change per Hour at 50 Pa pressure difference					
1945 or older	1,001	6.4	8.1	10.8	9.0
1946 - 1960	3,019	4.2	5.4	7.0	6.0
1961 - 1970	3,160	3.3	3.9	4.8	4.4
1971 - 1980	6,012	3.4	4.2	5.3	4.7
1981 - 1990	1,903	3.4	4.2	5.1	4.5
1991 - present	253	2.8	3.6	4.6	3.9
Equivalent Leakage Area at 10 Pa pressure difference (sq cm)					
1945 or older	1,001	1,068	1,449	1,985	1,633
1946 - 1960	3,019	743	957	1,264	1,077
1961 - 1970	3,160	604	775	1,016	886
1971 - 1980	6,012	657	856	1,124	981
1981 - 1990	1,903	691	929	1,245	1,031
1991 - present	253	692	892	1,129	974
Annual Space Heating Energy Use Index (MJ/m^2)					
1945 or older	1,001	961	1,234	1,567	1,317
1946 - 1960	3,019	729	901	1,106	955
1961 - 1970	3,160	672	794	955	838
1971 - 1980	6,012	657	761	895	798
1981 - 1990	1,903	574	653	765	683
1991 - present	253	446	516	601	539
Average Annual Energy Consumption (GJ/year)					
1945 or older	1,001	236	293	362	310
1946 - 1960	3,019	199	232	275	245
1961 - 1970	3,160	199	231	272	243
1971 - 1980	6,012	196	230	274	242
1981 - 1990	1,903	190	224	265	232
1991 - present	253	174	200	233	209

The data analyses based on various age groups showed that there are significant improvements in the energy efficiency of housing in Canada. The increased insulation levels and airtightness would indicate recent construction is producing more energy efficient houses.

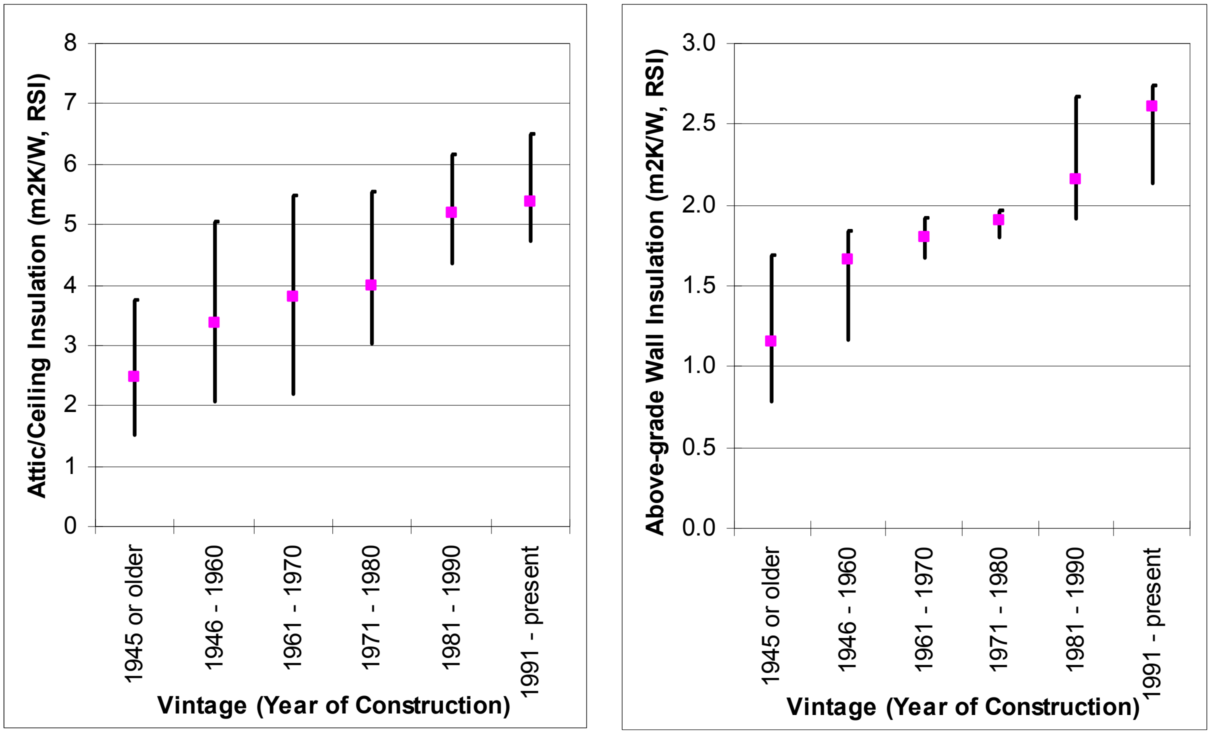

Figure 1. Attic/ceiling and above-grade wall insulation levels (effective RSI).

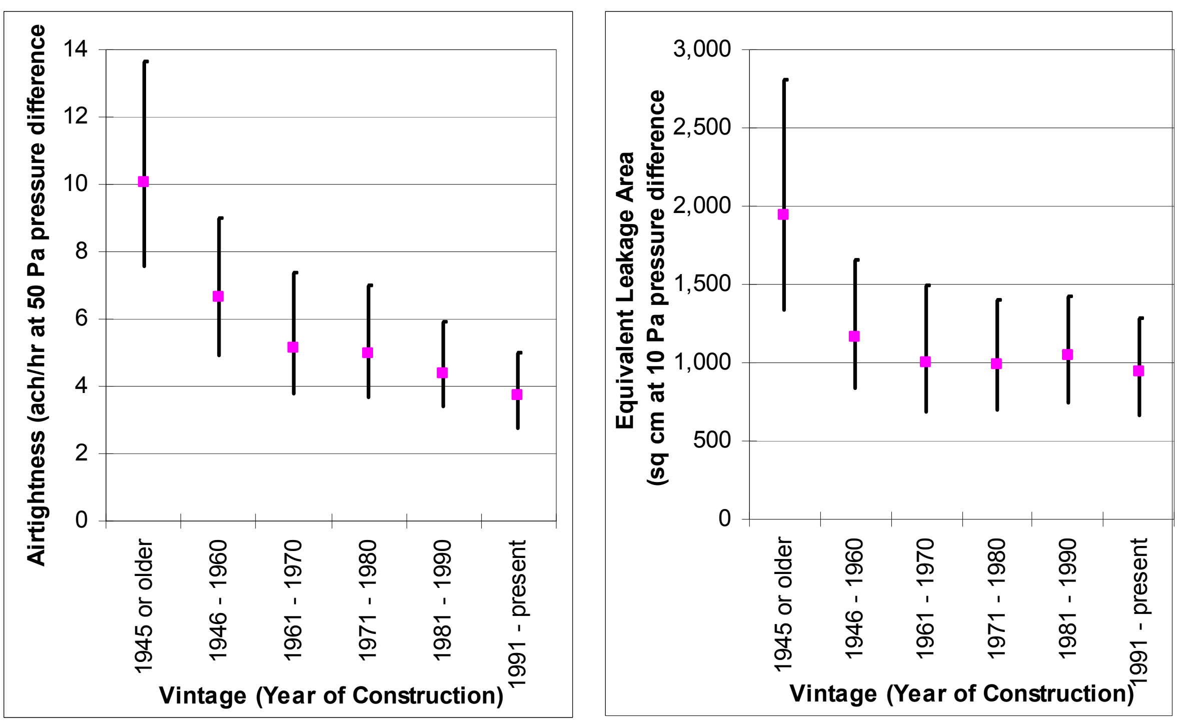

Figure 2. Airtightess and equivalent air leakage area profiles for Canadian housing.

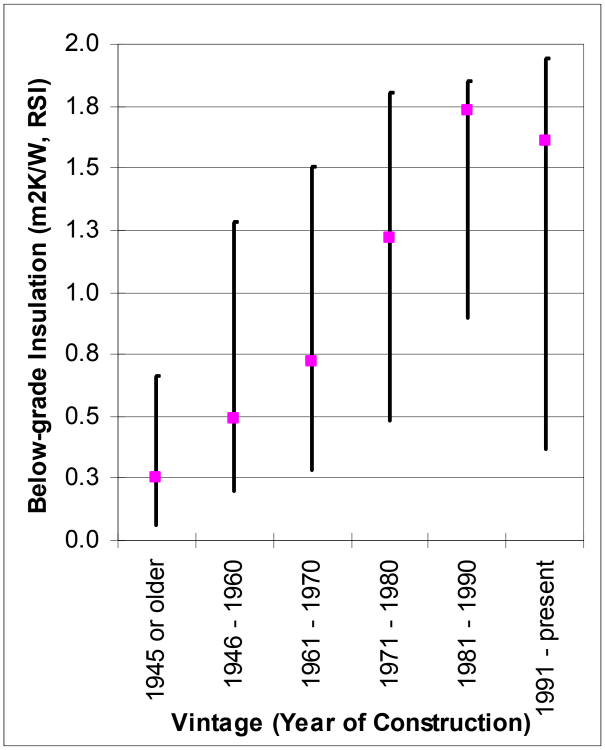

Figure 3. Below-grade insulation levels.

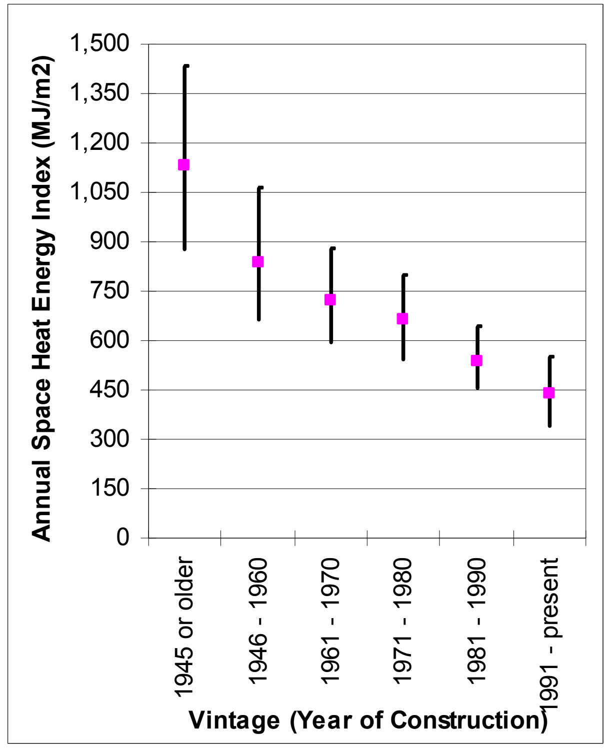

Figure 4. Profile of annual space heating energy requirement for dwellings.

COMPARISONS OF WEIGHTED-AVERAGE CHARACTERISTICS FOR EACH REGION

Each province and territory has its own building codes and region specific construction practices. There is a wide range of energy efficiency options that can be employed to reduce the overall energy consumption.

Figure 5 shows the comparison of housing stock weighted average insulation levels for attic/ceiling and above-grade walls. Overall, prairie housing (AB, SK and MB) has higher levels of insulation compared to other regions (except NT and YK territories).

Figure 6 shows the airtightness for housing across Canada. The data shows the average values of airtightness both pre and post retrofit. Overall, the prairie housing (AB, SK and MB) is much more airtight than other regions. The increased occurrence of stucco-clad housing in the prairies and the better airtightness that this type of cladding provides could be a reason for this observation. This graph also shows the achieved airtightness after retrofitting these houses. As shown in Figure 7, opportunities for air-sealing retrofits are diminished when we start with a more airtight house. For example, a house starting at 15 ac/h would have a potential reduction to about 10 ac/h (a 33% decrease), whereas a house starting at 6 ac/h would have a potential reduction to about 5 ac/h (a 17% decrease) and a start of 3 ac/h has a potential reduction of about 2.8 ac/h (less than a 7% decrease). Figure 8 shows the comparison of the space heating index and the average annual total energy consumption for houses.

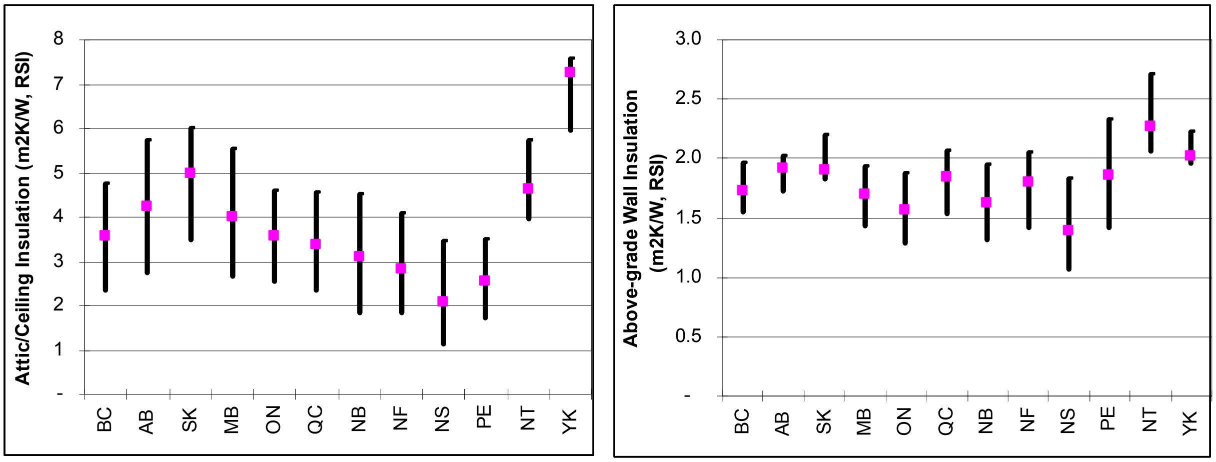

Figure 5. Comparison of sample-size weighted average insulation levels for attic/ceiling and above-grade walls.

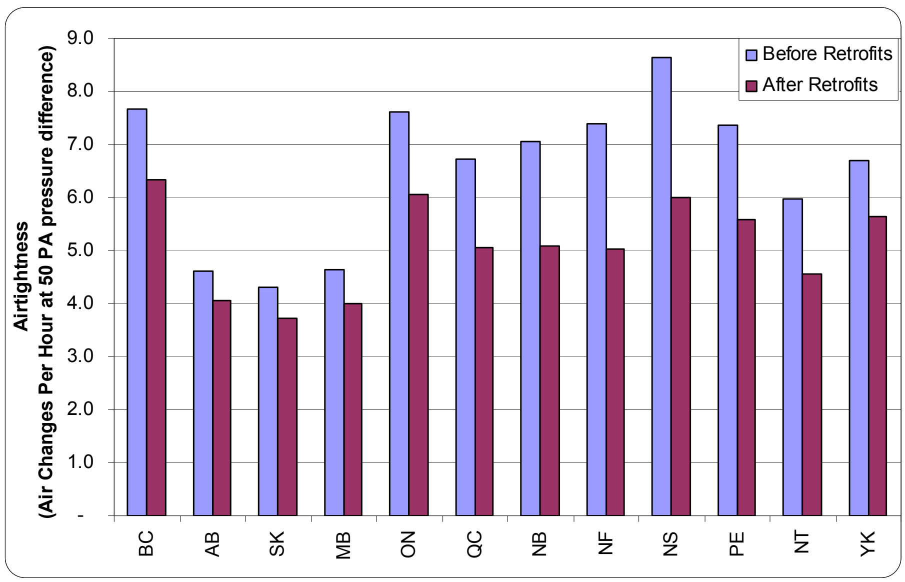

Figure 6. Average air tightness characteristics of dwellings in Canada.

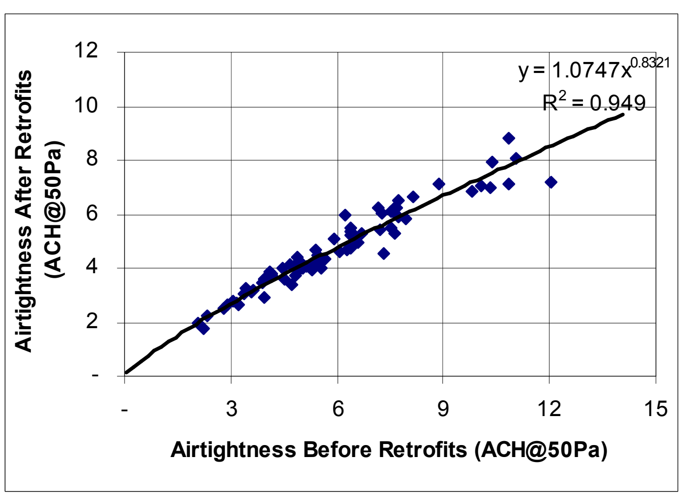

Figure 7. Opportunities for airtightness improvements.

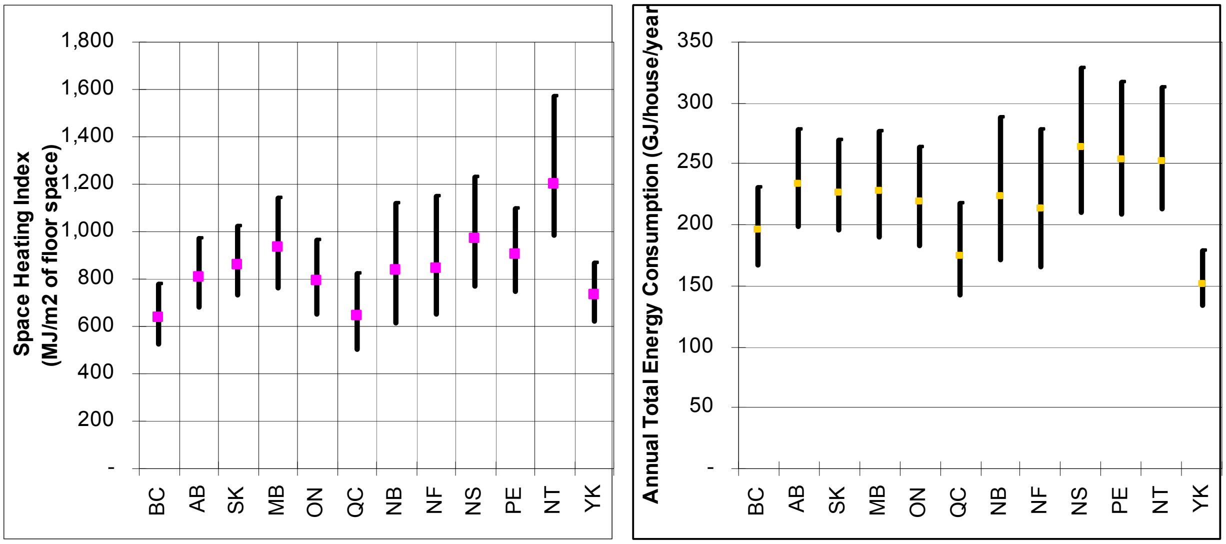

Figure 8. Comparisons of space heating energy index and the total annual energy use for dwellings.

Figure 8 shows that Quebec generally has the lowest energy index and annual energy index, despite having only average insulation levels and airtightness levels, according to the assessed data. This may be due to smaller house sizes and efficiency of heating systems. The electrically heated houses in Quebec use 100% efficient electric power when compared to the 70-95% efficient fuel-fired furnaces everywhere else, and the efficiencies are a factor in the calculation.

HOUSING CHARACTERISTICS OF RECENTLY BUILT HOUSING STOCK

How is current housing in terms of thermal and energy performance? This analysis was performed using the data gathered for the housing built in last ten years (1996 to 2005). It should be noted that the sample size included only about 3200 houses, roughly 0.5% of what was built during these years. The sample size is sufficiently representative and it covered all provinces.

Figure 9 shows the above-grade insulation values and the airtightness data. In general, all across Canada, houses built today consist of 2x6" framing with RSI 3.52 (R-20) insulation batt as a minimum. Attic insulation levels also range from RSI 5.6 to 6.7 (R-32 to 38) across Canada. Airtightess ranges from 2.0 to about 4.5 ac/h at a 50 Pa pressure difference.

Figure 10 shows the summary profiles of space heating and total energy consumption for the housing. On average, the space heating index is about 436 MJ/m^2 of floor space. In comparison, the R-2000 houses have an average space heating index of about 280 MJ/m^2 [NRCan 1999]. The current new housing still lags by about 35% in space heating energy efficiency.

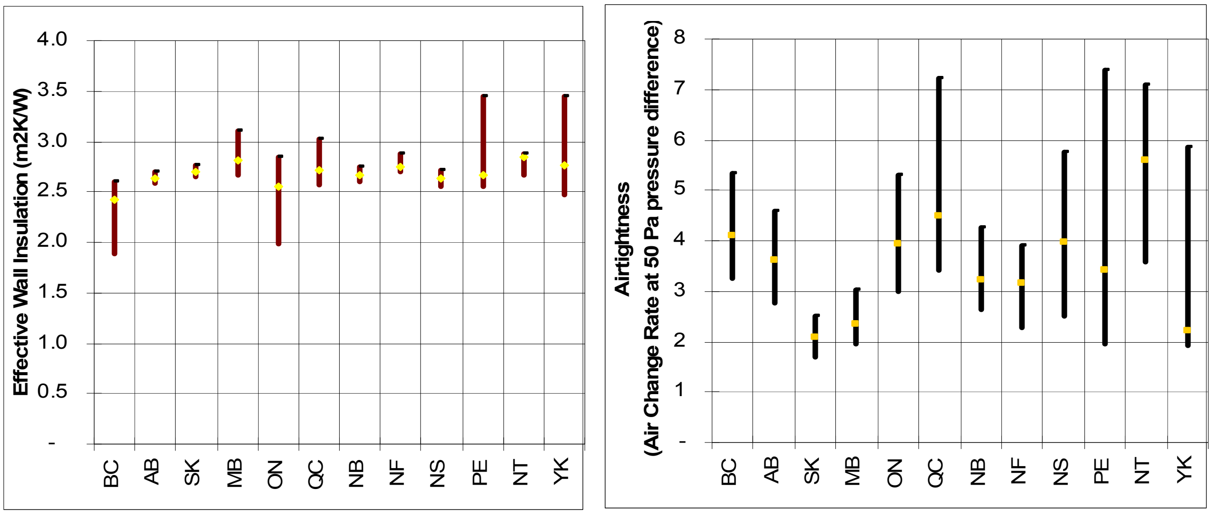

Figure 9. Data analyses of the recently built housing in Canada.

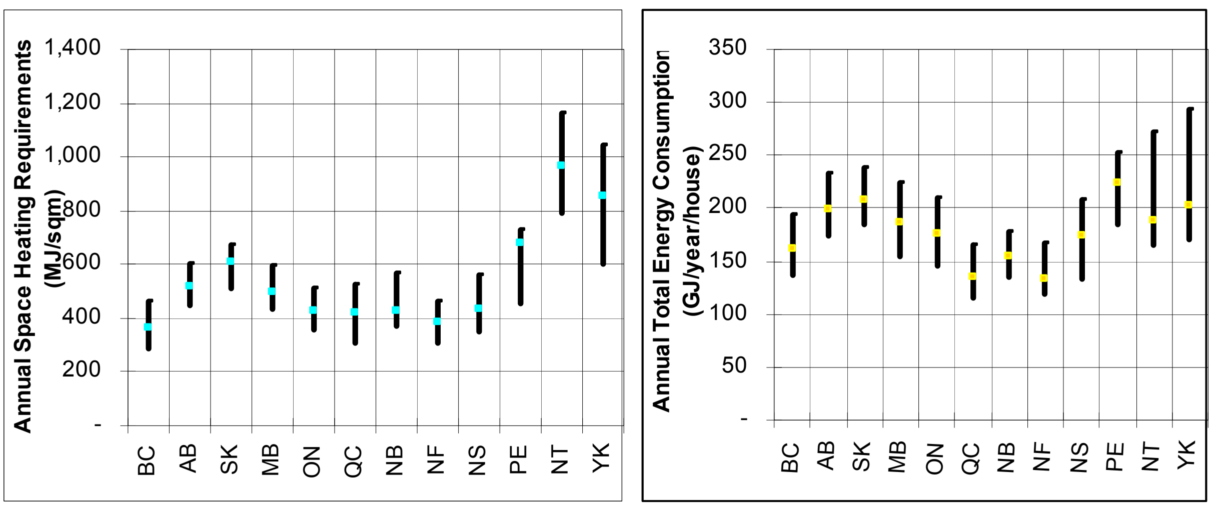

Figure 10. Space heating and total energy use profiles of recently built housing.

DISCUSSIONS

The housing database provides an excellent resource for evaluating the thermal, airtightness and energy efficiency performance parameters of Canadian housing. The database contains detailed information on more than 83,000 houses representing all regions in both the urban and rural areas. There is no attempt to qualify these data sets on the basis of statistical representation; however, the large number of house-files make it sufficiently representative of existing and new housing stock.

The field data presented here solely reflects the thermal and energy use profiles. The moisture performance or durability aspects including the indoor air quality aspects are not considered in the present analysis. With the increase in insulation levels and more airtight construction practices, it is now necessary to provide mechanical ventilation in new houses. It is perceived that the overall ‘house as a system’ approach would lead to better energy efficiency, improved durability of the building envelope and acceptable indoor-air quality.

CONCLUSIONS/RECOMMENDATIONS

The 'thermal characterization' of the Canadian housing stock helps in identifying the potential opportunities for further energy efficiency gains through retrofitting the existing houses and incorporating necessary changes to the construction of new housing.

Over the years, there has been significant increase in the effective insulation levels of houses. Overall, the building envelope insulation levels are much better for above-grade and attic/ceiling components. There are still more opportunities for increasing the insulation levels for the foundation (below-grade) components.

Houses are becoming more air-tight and construction practices have changed significantly. These changes are now requiring mechanical ventilation to meet the fresh air requirements in houses.

The overall energy efficiency of tract housing is improving steadily. There are still further opportunities to 'catch-up' with the R2000 levels of energy efficiency.

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