BUILDING ENVELOPE THERMAL AND AIR LEAKAGE CHARACTERISTICS OF CANADIAN HOUSING

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ABSTRACT

Due to ever-changing code requirements and building practices, the Canadian housing stock has undergone significant change over the years in terms of its thermal performance. As compared to previous decades, new houses are built with higher insulation levels, better airtightness, and more efficient space heating, cooling and ventilation systems.

NRCan's flagship housing programs for both new and retrofits included field evaluations of each house. The information gathered for each participating dwelling included: house form and geometry; composition of: above and below grade walls, attics, foundation, windows and doors; airtightness data; as well as information on the type and efficiency of space heating, ventilation and hot water systems. All this collected data produced an excellent database (the so-called EGH database) of close to 0.85 million homes, representing about 6% of low-rise residential dwelling stock in Canada.

For existing homes, the database includes the pre- and post- energy retrofit information. The thermal 'picturing' of the housing stock is not only important to policy wonks and building scientists but also to building product manufacturers, and retrofit service providers. Using the EGH data, vintage-specific regional trends have been developed to show the typical insulation levels and airtightness characteristics.

For example, the data analysis showed that the airtightness of houses improved from about 8 ach at 50 Pa in early 1960s housing to an average of 2.8 ach in recently built houses. The wall insulation levels have also improved significantly from early 1960s to late 1990s.

The paper and presentation will provide details about the housing stock thermal characteristics for different regions and various vintages. One of the key elements of the database analysis is providing region and vintage specific identification of retrofit opportunities for manufacturers and retrofit contractors. An example case shows the retrofit opportunity for attic insulation identified in specific age groups of dwellings in different regions.

INTRODUCTION

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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 (2014), residential energy use was 1,481 petajoules (1 PJ = 10^6 GJ) which accounted for 16.6% of secondary energy use in Canada. It is interesting to note that since 1991, Canada's housing stock increased at 1.4%; however, the residential energy use only increased by 0.3% [NRCan 2016]. Space and domestic water heating energy requirements account for over 80% of residential energy demand in most regions. Improvements in the energy efficiency of dwellings have become, therefore, a focus of federal government agencies in order to reduce the green gas emissions and the dependence on fossil fuels.

The residential housing stock consists of 15.03 million units as per the latest data available from the Statistics Canada [NEUD 2015]. About 54.6% of this stock are detached single-family dwellings, 11.6% are low-rise row and semi-detached dwellings, 12.5% low-rise multi-unit residential buildings and the rest are mid- or high-rise apartments.

Over the years, the average size of Canadian dwellings has also steadily increased. Today's housing has, on an average, 156 m² (1,680 ft²) of conditioned floor space compared to an average of 116 m² (1,255 ft²) for houses built about 40 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.

As shown in Figure 1, about 47% of the housing stock was built prior to 1983 prior to any requirement for energy efficiency measures. Since 1985, national and provincial building codes slowly started requiring insulation and ventilation measures. Voluntary programs, such as R2000 Standard, led the introductions of proven energy efficiency measures covering insulation, airtightness, high performance windows, efficient heat recovery ventilation (HRV) systems and condensing fuel-fired space heating and domestic hot water systems. Code changes were, however, gradual over the years; and, first time in 2012 as major change, National Building Code introduced key section on energy efficiency covering the whole house.

Vintage as per major code changes	Number of Dwellings		Average Size
	(in thousands)		sq m
Before 1946	1,651	11%	126
1946–1960	1,200	8%	111
1961–1977	2,659	18%	117
1978–1983	1,550	10%	133
1984–1995	3,131	21%	137
1996–2000	1,060	7%	138
2001–2005	1,295	9%	146
2006–2010	1,344	9%	151
2011–2014	1,139	8%	156
Total	**15,029**		**133**

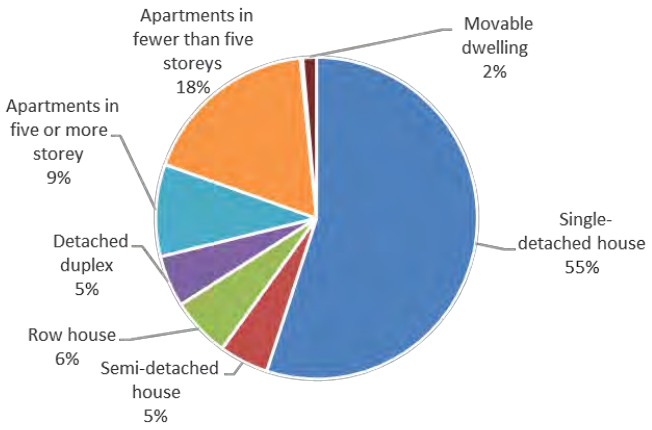

Figure 1: Canadian housing stock in 2014 [NRCan 2016].

During 2007-2013, Natural Resources Canada implemented a nation-wide program for energy efficiency retrofits of existing housing with financial incentives. The ecoENERGY-Retrofits program offered energy efficiency evaluations to homeowners for pre- and post-retrofits for more than 846,000 homes. The co-

partnering and incentives from provincial programs, natural gas and electric utilities and other stakeholders, ensured the success of the ecoENERGY-Retrofit program in retrofit uptakes.

The pre- and post-retrofits energy efficiency evaluations for the ecoENERGY-Retrofit program provided excellent quality of thermal, mechanical and energy consumption data for housing. Data on 140 specific parameters related to house geometry, insulation levels, for close to 682,000 houses has been collected.

The main goal of this paper is to describe the analysis of the housing data for the thermal, air leakage and energy use characteristics in different regions. This information could be used by: renovators, electricity supply utilities, oil and natural gas companies and regulators – to formulate appropriate programs for homeowners; by building scientists, engineers, architects and housing professionals – to assess new opportunities for energy efficient construction practices in new and existing housing; and by construction product manufactures and supply chains.

METHODS FOR DATA GATHERING AND ANALYSIS

Data Source – EnerGuide for Houses (EGH) Database

The EnerGuide for Houses (EGH) database is an information management tool and central depository for tracking residential energy evaluations and measuring the benefits from the energy evaluations delivered across Canada [Blais et al. 2005]. The process of data collection includes energy advisors (EAs) collecting house information during a detailed house energy efficiency evaluation. This data is then used for evaluating the energy consumption and recommendations for energy efficiency retrofit measures using the energy analysis software (such as HOT2000). The energy analysis software file stores the house energy model, retrofit recommendations and report information. The energy analysis software also generates a data file that contains a subset of the house characteristics and simulation results. Once the house evaluation is complete and the home modeled, the energy advisor e-mails the saved file and data file to an automated web-based file processor. The file processor performs validation and other processes on the received data file, stores the data, and saves files in the EGH Oracle database. Each database record contains information on the house's physical characteristics and its energy requirements.

The database contains files for more than 846,000 houses rated across Canada of which 681,587 have been re-evaluated after homeowners implemented energy efficiency retrofits. The concepts and database structure allow for the implementation and management of a large-scale energy efficiency program through various delivery channels. The housing database keeps house specific information gathered from field evaluations. For each house evaluation, the following data is collected:

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

Details of these items are as follows:

- **Geometric configurations** – The geometric configuration includes plan layout, dimensions of various components, volume, and orientation. For a number of field assessments, photo images were also collected. The following are main forms of low-rise housing:
    - split-level bungalows
    - 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) – 1-storey, 1½-, 2-, 2½- , and 3-storey structures;
        - the shape of the plan – rectangular, L-shape, T-shape and forms with varying number of corners and other complex structures;
        - the type of attic/roof – cathedral, sloped and flat; and
        - the foundation type – 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 follows:
    - age or the year in which the house was built (or retrofitted)
    - location and 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
    - level of depressurization if fuel burning equipment was present

- **Energy use profiles** – for each house file, there is a full energy analysis using the Standard Operating Conditions (SOCs) reporting for the heat losses for envelope components and energy use components, such as:
    - space heating
    - space cooling
    - domestic hot water
    - ventilation
    - base loads for lighting, appliances and miscellaneous electrical loads

Procedures for the Data Analysis

For the comprehensive data analysis, we selected data files containing both pre- and post-retrofit evaluations, a total of 681,587 house files. Table 1 and 2 show the sample size for each province and territory and for each age group. The sample size represents from 1.1% to 9.7% of regional stock with an overall weighted average of about 4.8% of low-rise housing stock. This is an excellent representation and is superior in size. On a regional basis, these evaluations are taken from both urban and rural settings. It should be noted that the EnerGuide for Houses database contains information from homes that participated in the federal/provincial, or utility supported incentive programs; these homes were not randomly selected. This a large database covering all climate zones of Canada including specific regions and different vintages. Such a large database mimics and represents Canada's existing housing stock, specifically built prior to year 2010.

The survey data was used to develop a profile of thermal archetypes based on the location and the year of construction (or the year of major renovation). As construction practices heavily depend on the requirements of codes and standards, the vintage of house construction became a primary factor. Data collation included the development of representative numeric rules and co-relation-based formulas for various components. The required primary inputs were the age of the house and the location. Based on these, all required thermal insulation and equipment specifications were generated.

Table 1: Number of evaluations used for stock representation.

Provinces	Sample Size, thousands	Representation of Housing Stock %
BC	74.7	4.0%
AB	34.9	2.3%
SK	41.0	9.7%
MB	20.9	4.4%
ON	421.7	8.1%
QC	39.8	1.1%
NB	21.7	6.9%
NF	2.6	1.2%
NS	21.3	5.3%
PE	1.9	3.3%
NT	0.4	2.7%
YK	0.6	4.1%
NU	0.2	2.4%
Total	**682**	**4.8%**

Table 2: Number of evaluations used for each age groups used for stock representation.

Vintage as per major code changes	Sample Size, thousands	Representation of Housing Stock %
Before 1946	111.5	7.2%
1946–1960	117.6	10.5%
1961–1977	180.5	7.3%
1978–1983	79.1	5.5%
1984–1995	158.8	5.4%
1996–2000	19.7	2.0%
2001–2005	9.2	0.8%
2006–2010	5.0	0.4%
2011–2014	0.2	0.0%
Total	**682**	**4.8%**

The data analysis included sorting for the vintage, type and thermal indicators, and then 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 must be noted that the analyses presented here deal strictly with thermal insulation, air leakage and estimates of energy consumptions. 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. It is 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

Data sets for each province and territory were categorized by vintage and housing type. All evaluations were combined together to represent the national characteristics. The data analysis showed that over the years, the housing stock has become more airtight and better insulated; and of course, much more energy efficient. These changes have reduced the overall annual space heating and total energy consumption for houses significantly. Some of these interesting trends are presented in the following figures.

Figure 2 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; code changes since the year 2000 have raised the minimum insulation levels.

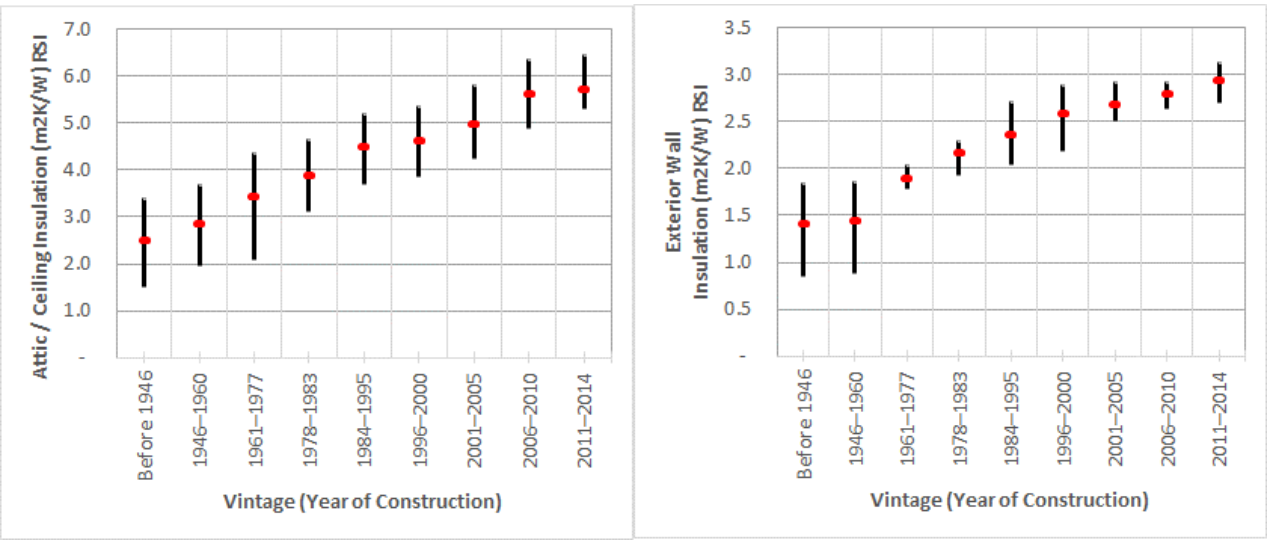

Figure 2: Attic/ceiling and exterior above-grade wall insulation levels (effective thermal insulation value in m^2K/W).

Figure 4 shows the airtightness profiles of housing. Over the years, houses have become more airtight. The normal natural and mechanical air change rates for these houses ranges from 0.12 to about 1.2 air changes per hour during the heating months (not to be confused with the measured air change rate at 50 Pa (ac/hr@50Pa). As these houses become more airtight, the need for mechanical ventilation becomes imperative. Recent code changes in all provinces mandate the installation of mechanical ventilation to bring up the normal air change rate to about 0.25 to 0.30 per hour. As shown in Figure 4, more than 62% of the stock fails to meet the minimum requirements for ventilation and requires mechanical ventilations system retrofits.

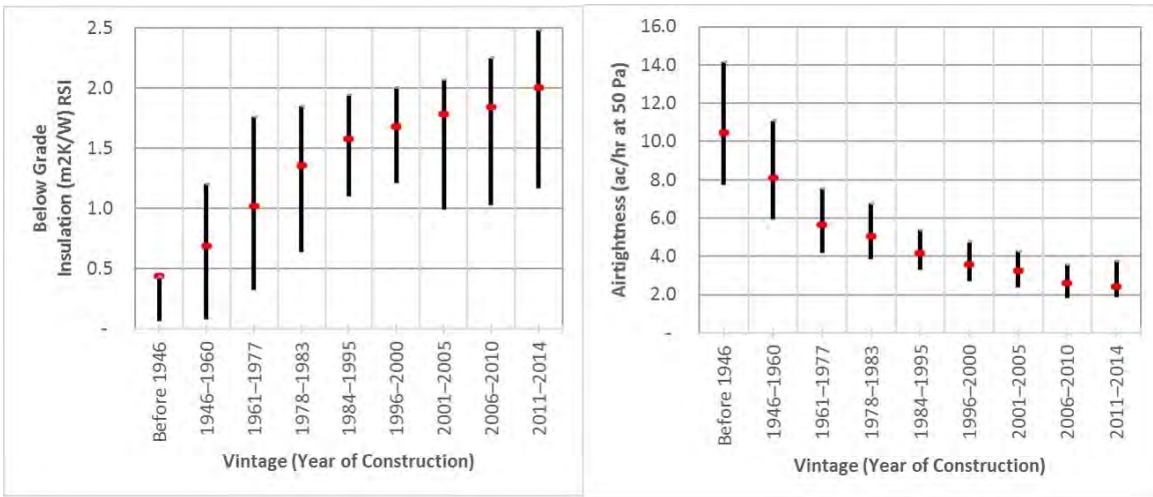

Figure 3: Below grade foundation insulation and average airtightness of dwellings.

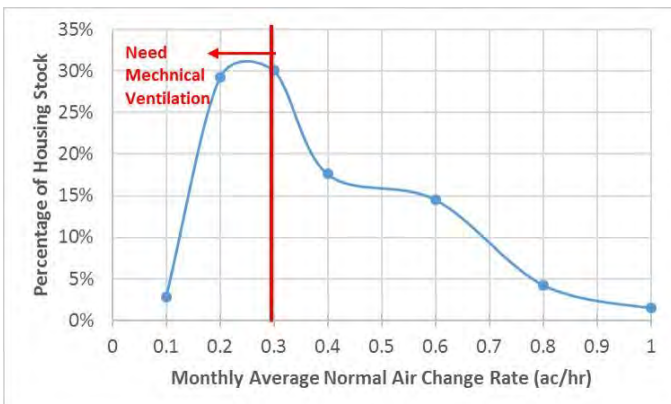

Figure 4: More than 62% of stock is below recommended normal air change rate of 0.3 and need mechanical ventilation.

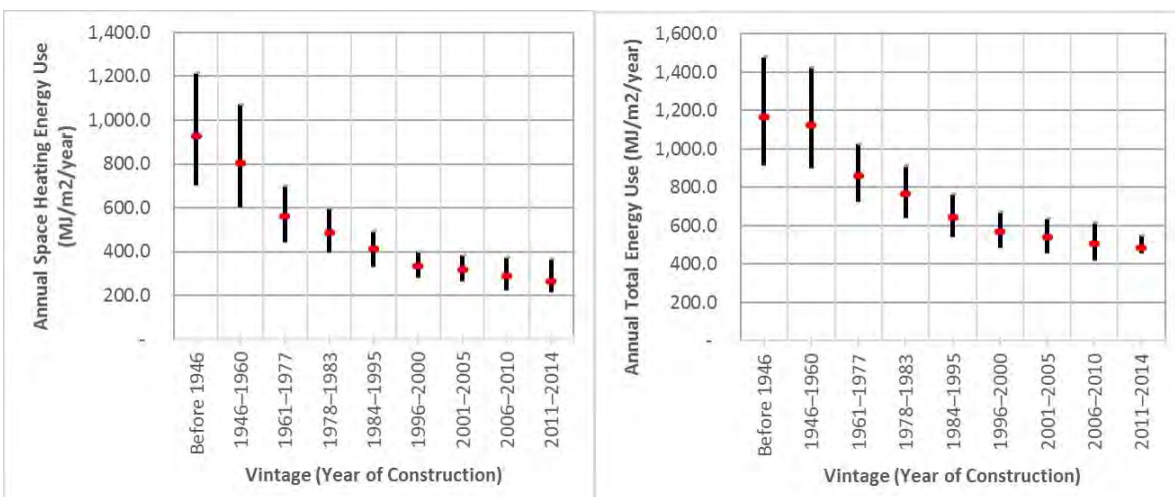

Figure 5: Profile of annual space heating and total energy use for dwellings.

Figure 5 shows the weighted average data for the annual space heating requirements and total energy use

profiles. The median value for space heating requirements for new housing (2014) is about 264 MJ/m²/year compared to 335 MJ/m²/year for house built about 15 years ago during 1995-2000. Combined effects of increased insulation values, lower airtightness and higher average floor area show these improvements.

Figure 6 shows the reduction in space heating and total energy consumption based on the year of construction. Significant improvements in insulation levels, more airtight construction practices, and improved efficiencies in mechanical equipment have led to better overall energy efficiency.

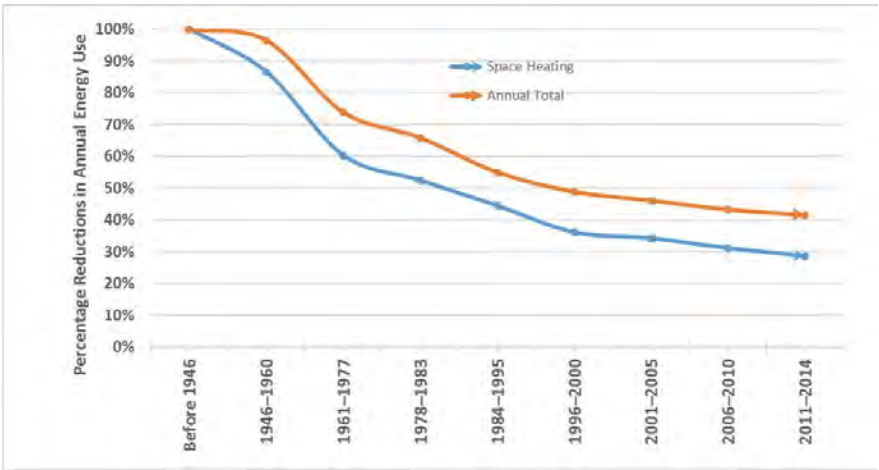

Figure 6: Profile of reductions in space and total energy use in different vintages of dwellings.

Comparisons of Weighted-Average Characteristics for Each Region

Each province and territory has its own building codes and region-specific construction practices. Even so, there are wide ranges of energy efficiency options that can reduce the overall energy consumption.

Figure 7 shows the comparison of 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 8 shows the airtightness for housing across Canada. The data shows the average values of airtightness both pre- and post-retrofit. Overall, 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 one reason for this observation. This graph also shows the achieved airtightness after retrofitting these houses. As shown in Figure 8, opportunities for air-sealing retrofits diminish when we start with a more airtight house. Figure 9 shows the comparison of the space heating index and the average annual total energy consumption.

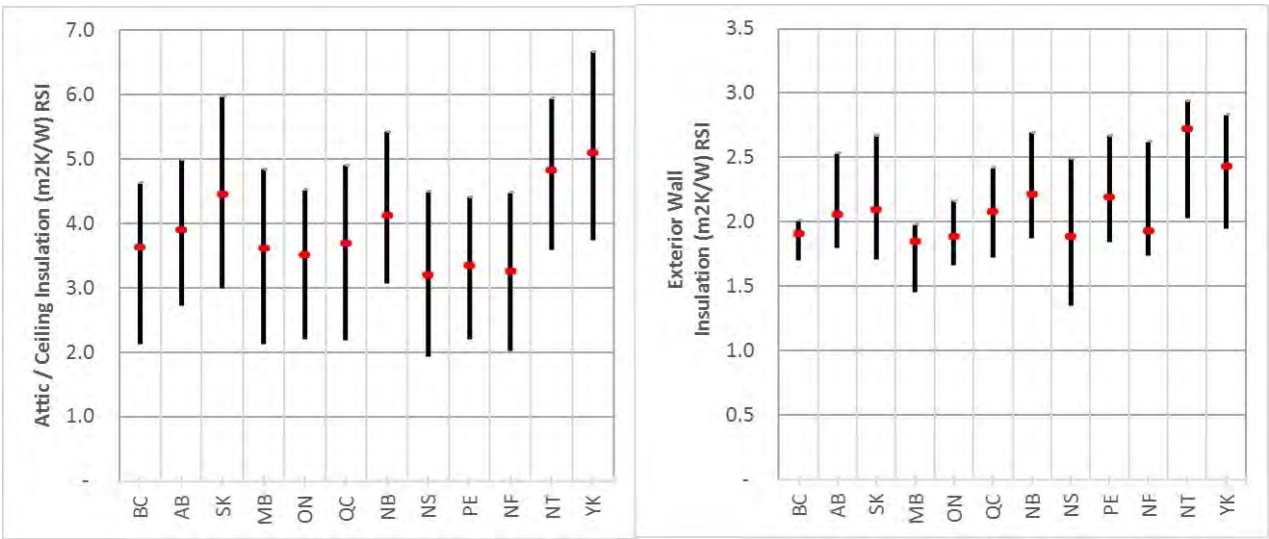

Figure 7: Comparisons of weighted average insulation levels for attic/ceiling and above-grade walls.

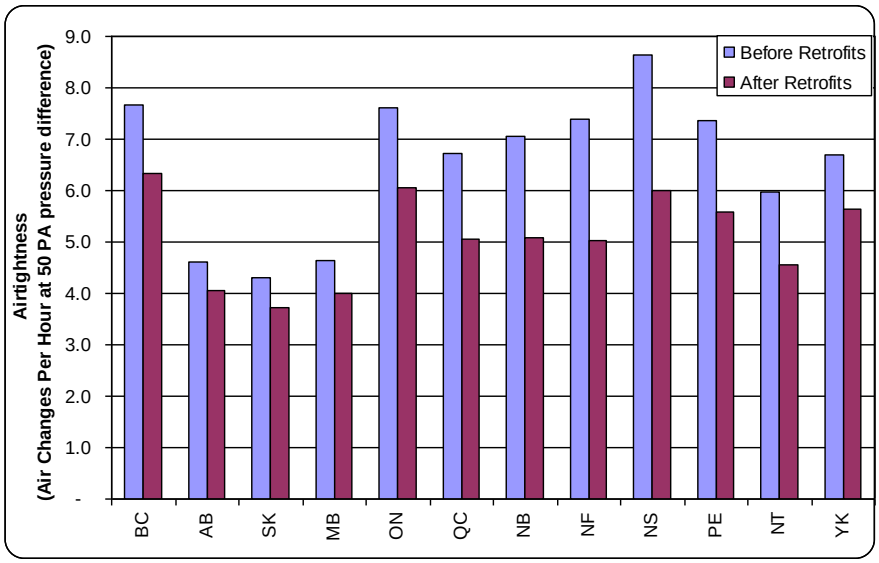

Figure 8: Airtightness characteristics of dwellings in Canada.

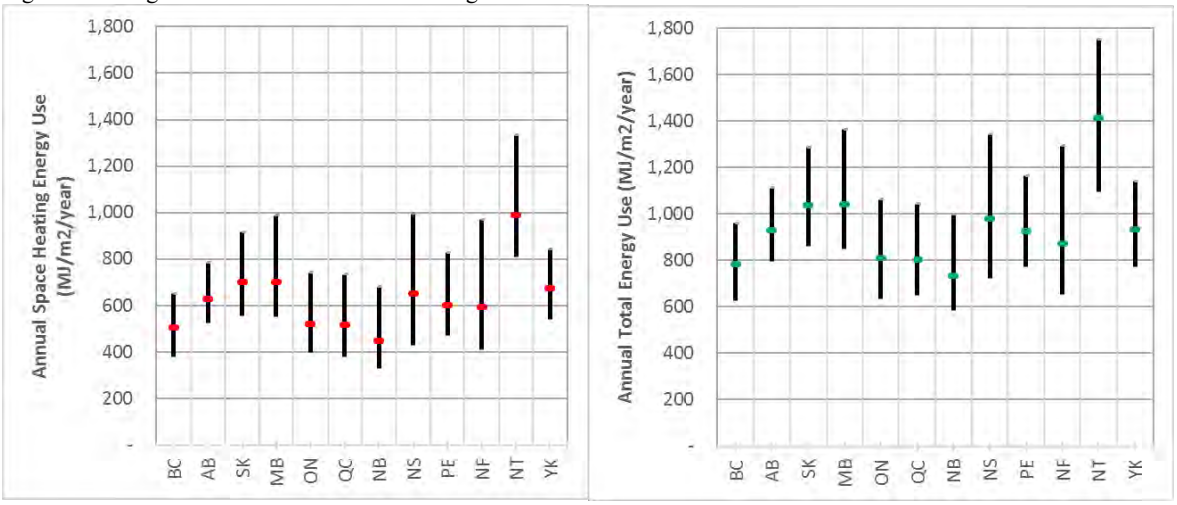

Figure 9: Comparisons of space heating energy index and the total annual energy use for dwellings.

Application EGH Data Analysis for Insulation Retrofit Opportunities

One key element of the database analysis is to use the region and vintage specific housing stock data in work with industry partners. One such project, by North American Insulation Manufacturers' Association (NAIMA) Canada, calculates the potential benefits of selective improvements to the insulation levels in Canada's existing housing stock.

This project focused on identifying opportunities for upgrading insulation levels in existing houses. The objective was to determine how many homes in Canada are under-insulated and to estimate, both regionally and nationally, the energy and cost savings by upgrading under-insulated homes to contemporary standards (The "Retrofit Potential").

The provincial/territorial information from the EGH database was categorized based on the type of heating fuel (natural gas, electricity and oil), climate zone (region) and house age (vintage). The existing insulation levels were then compared to those specified in section 9.36 of the National Building Code (NBC) of Canada.

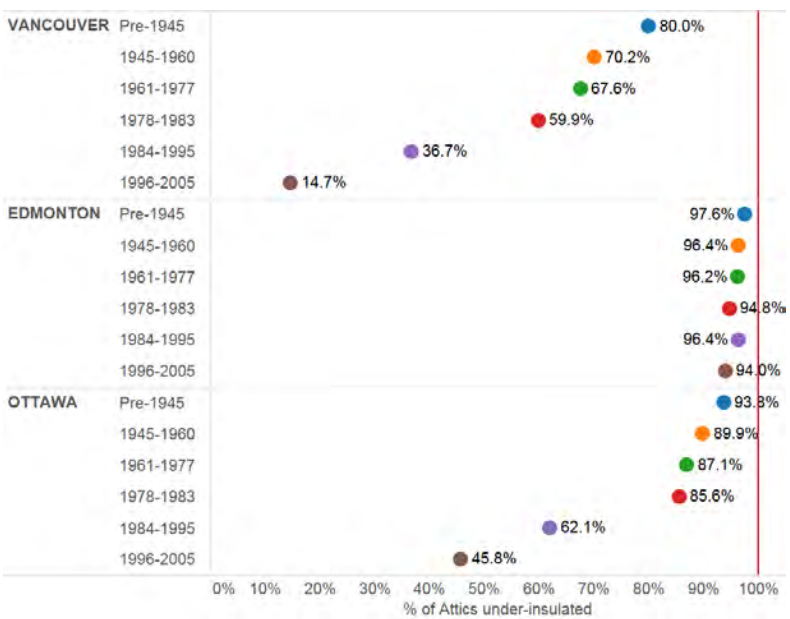

Figure 10: % of the attics under-insulated (9.36 limit - R-20)

One findings of this analysis was: the bulk of the Retrofit Potential of Canada's existing housing stock occurs in just one of the five building components studied - ceilings with attics (Proskiw, 2016). Figure 10 shows the % of homes with "under-insulated" attic spaces for selected cities and vintage. For this particular analysis, the definition of under-insulated was: R-20 below the 9.36 requirement, and was limited to detached and semi-detached homes.

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 682,000 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 this analysis. With the increase in insulation levels and more airtight construction practices, it is now necessary to provide mechanical ventilation in 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.

The information generated from this analysis has been used to develop a series of house archetypes; useful for code and policy analysis, evaluating the impact of new technologies, etc.

CONCLUSIONS/RECOMMENDATIONS

The EnerGuide for Houses (EGH) database is a collection of comprehensive information for close to 4.8% of Canadian housing stock and is available for research purposes. Such a large database provide excellent 'thermal picturing and energy use profiling' of the Canadian housing stock. The large data set analyses aid in identifying the potential targeted opportunities for (1) energy efficiency retrofits for existing houses, and (2) incorporating necessary changes to the codes and standards for 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. More than 62% of housing stock has much lower normal ventilation rates and may need mechanical ventilation retrofits to meet the recommended fresh air requirements.

The overall energy efficiency of tract housing is improving steadily. It is recommended to enhance, populate and maintain the EGH database on a continuous basis to assist future opportunities for energy efficiency and higher performance of Canadian housing to keep Canada world leader in high performance housing.

ACKNOWLEDGEMENTS

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