Building Envelope

Thermal & Air Leakage Characteristics of Canadian Housing

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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 new and retrofit housing programs included field evaluations of each house. The information gathered for each participating dwelling produced an excellent database (the so-called EGH database) of close to one million homes, representing about six per cent 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 for policy decisions 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 floor area, insulation levels, and airtightness characteristics.

This article provides details about the housing stock thermal characteristics for 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.

INTRODUCTION

Canadians use significant amounts of energy to heat, cool, and ventilate their homes, to operate lights and appliances,

and to heat water. Residential energy use was 1,481 petajoules (1 PJ = 10^6 GJ) which accounted for 16.6 per cent of secondary energy use in Canada.[1] Space and domestic water heating energy requirements account for over 80 per cent of residential energy demand in most regions. Improvements in the energy efficiency of dwellings have become 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 [NEUD 2015][2]; about 54.6 per cent of this stock are detached single-family dwellings, 11.6 per cent are low-rise row and semi-detached dwellings, 12.5 per cent are 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 m^2 (1,680 ft^2) of conditioned floor space compared to an average of 116 m^2 (1,255 ft^2) 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 (on page 32), about 47 per cent of the housing stock was built prior to 1983, and therefore 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

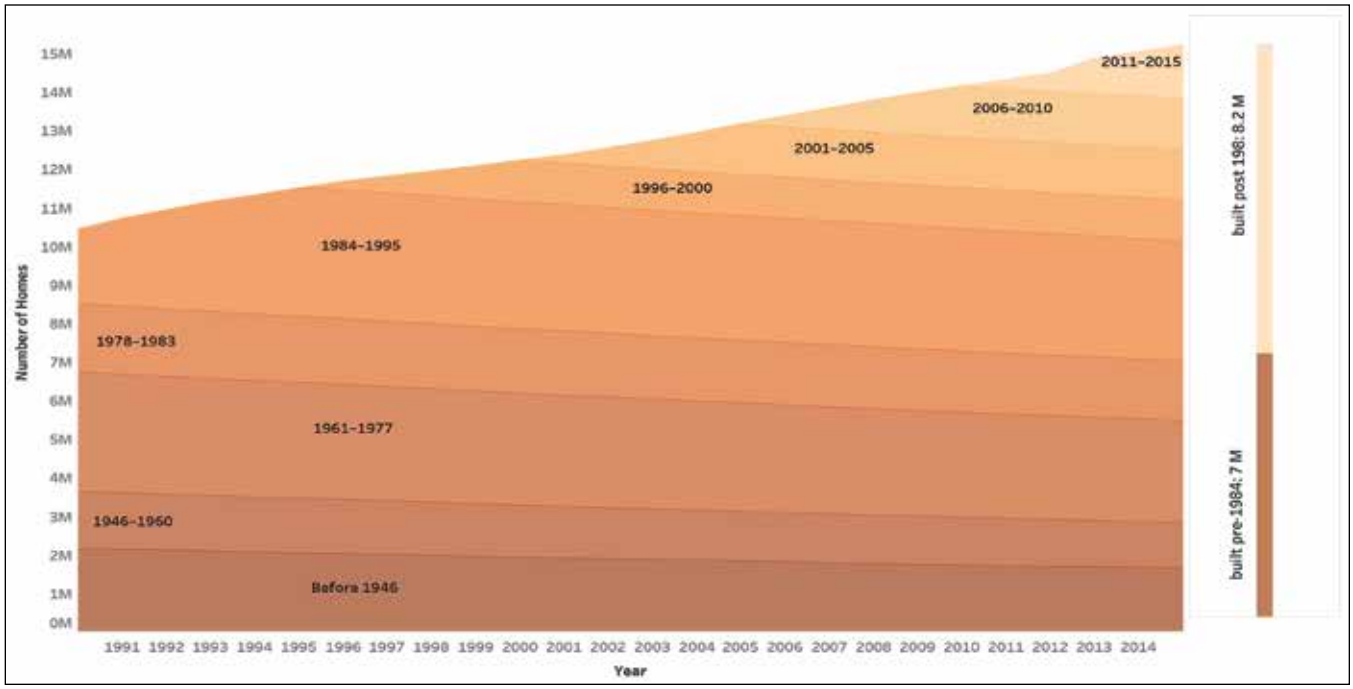

Figure 1. Canadian housing stock in 2014. Source: NRCan 2016.[3]

windows, efficient heat recovery ventilation systems, condensing fuel-fired space heating and condensing domestic hot water systems. Code changes were, however, gradual over the years; 2012 marked the first major change, the *National Building Code* introduced a key section on energy efficiency covering the whole house.

During 2007 to 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 and insulation levels for close to 682,000 houses has been collected.

The main goal of this article is to describe the analysis of the housing data for the thermal, air leakage, and energy use characteristics. This information could be used by:

- Renovators, electricity supply utilities, oil and natural gas companies, and regulators to formulate appropriate programs for homeowners;

- Building scientists, engineers, architects, and housing professionals to assess new opportunities for energy efficient construction practices in new and existing housing; and
- Construction product manufactures and supply chains.

METHODS FOR DATA GATHERING AND ANALYSIS

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].[5]

The process of data collection includes energy advisors collecting house information during a detailed house energy efficiency evaluation.

This data is then used to evaluate 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 is modelled, 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 configurations:** The geometric configuration includes plan layout, dimensions of various components, volume, and orientation, like:
  - > Number of levels (storeys);
  - > Plan shape;
  - > Type of attic/roof; and
  - > Foundation type.
- **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 are as follows:
  - > Age or the year in which the house was built (or retrofitted);
  - > Location and region;
  - > Thermal insulation levels of building envelope components;
  - > Measurements of airtightness using the blower door; and
  - > Space heating, hot water, and ventilation systems.
- **Energy use profiles:** For each house file, there is a full energy analysis using

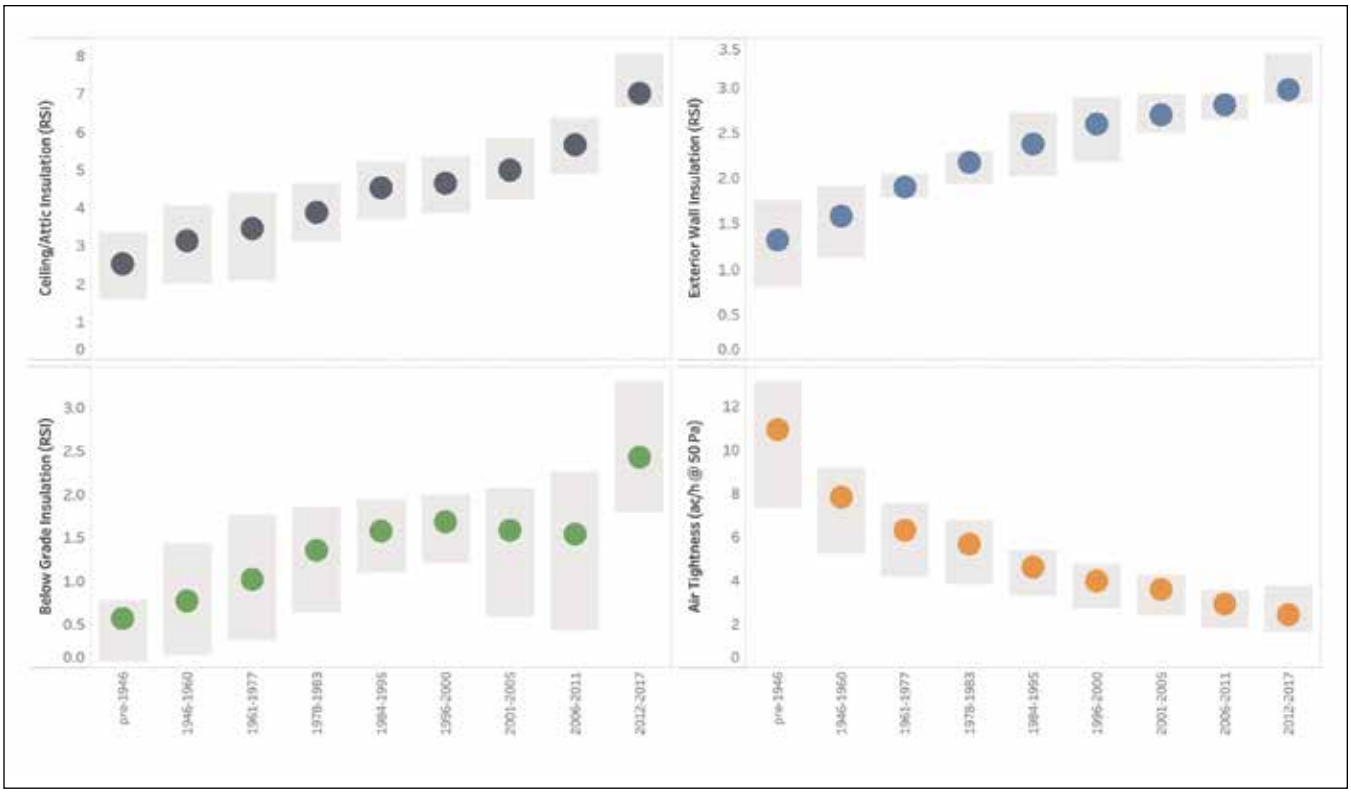

Figure 2. Envelope insulation levels (effective thermal insulation value in m^2K/W) and average air-tightness of dwellings.[4]

the Standard Operating Conditions (SOCs) reporting for the heat losses for envelope components and energy use components, like:

> Space heating and cooling;
> Domestic hot water;
> Ventilation; and
> Base loads for lighting, appliances, and miscellaneous electrical loads.

PROCEDURES FOR DATA ANALYSIS

For the comprehensive data analysis, data files containing both pre- and post-retrofit evaluations were selected —681,587 house files. This sample size represents an overall weighted average of about 4.8 per cent of low-rise housing stock. This is a large database covering all climate zones of Canada, including specific regions and different vintages, and it represents Canada's existing housing stock, specifically built prior to 2010.

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.

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.

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.

THERMAL AND AIR LEAKAGE CHARACTERISTICS PROFILES OF BUILDING ENVELOPE CHARACTERISTICS

The data analysis contained significant information for each vintage, province, and territory. It is beyond the scope of this article to include all details for all regions. Therefore, we selected representative analytic results to show the overall "thermal" picture of dwellings in different vintages.

Data sets for each province and territory were categorized by vintage and housing type. All evaluations were combined 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.

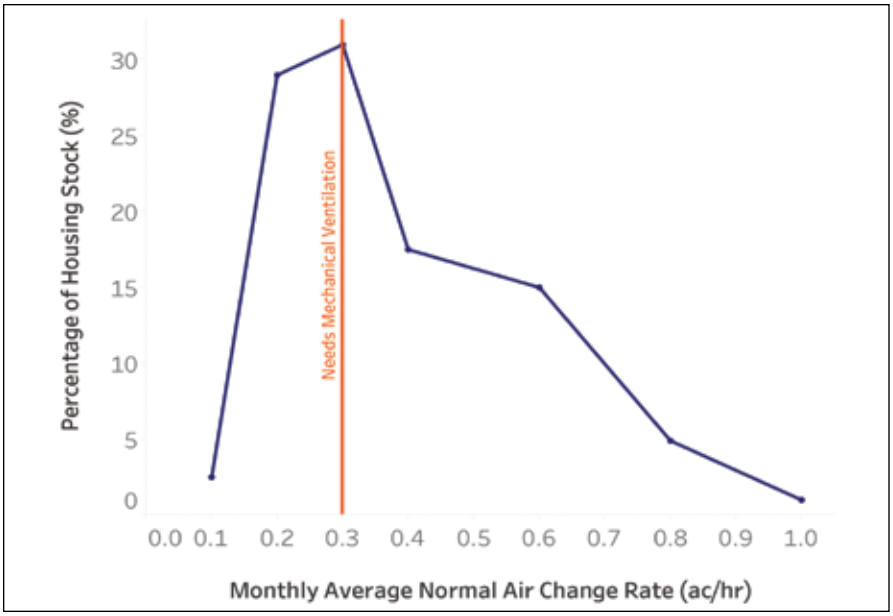

Figure 3. More than 62 per cent of stock is below the recommended normal air change rate of 0.3 and needs mechanical ventilation.[6]

Figure 2 on the previous page shows the profile of envelope insulation levels (effective thermal insulation value in m^2K/W) and average air-tightness levels for dwellings. Each bar represents a range of values for the 25th and 75th percentiles with a median value (dot). Over the years, the overall insulation levels have significantly improved; code changes since 2000 have raised the minimum insulation levels.

Over the years, houses have also become more airtight. The normal

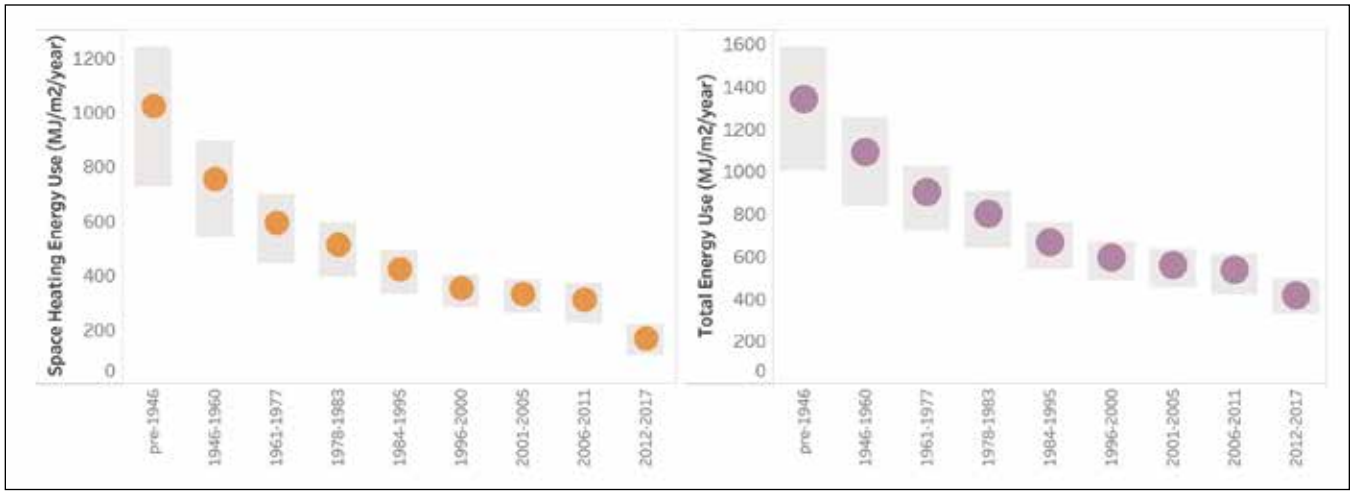

Figure 4. The profile of annual space heating and total energy use for dwellings.

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 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 3 (on page 35), more than 62 per cent of the stock fails to meet the minimum requirements for ventilation and requires mechanical ventilation system retrofits.

Figure 4, above, 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/m^2/year compared to 335 MJ/m^2/year for houses built about 15 years ago, during 1995 to 2000. The combined effects of significant improvements in insulation levels, more airtight construction practices, and improved efficiencies in mechanical equipment have led to better overall energy efficiency.

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 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 from upgrading under-insulated homes to contemporary standard.

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*.

CONCLUSIONS AND RECOMMENDATIONS

The *EnerGuide for Houses* (EGH) database is a collection of comprehensive information for close to 4.8 per cent of Canadian housing stock and is available for research purposes. Such a large

database provides 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 energy efficiency retrofits for existing houses and for incorporating necessary changes to the codes and standards for the construction of new housing.

Over the years, there has been a 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. ■

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Julia Purdy has been studying energy use in Canadian homes since she joined Natural Resources Canada in 1999. She leads NRCan's efforts to identify low-energy pathways for Northern and remote housing. In her work, Purdy develops optimization tools that can compare thousands of different combinations of energy technologies in home design and renovation. In partnership with housing corporations, she is using these findings to develop new guidelines for resilient, affordable, and low-energy construction in Canada's North. Prior to joining NRCan, Purdy completed undergraduate and graduate degrees (B.Sc. and M.Sc.E.) in mechanical engineering at Queen's University.