Estimating Preconstruction Airtightness in Ontario: Is it Possible?

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A practical method for estimating building airtightness in residential homes has steadily become an increasingly important issue for designers and builders for several reasons. Occupant thermal comfort, indoor air quality, and enclosure and structural durability are all directly affected by the air leakage through the building envelope. Furthermore, airtightness estimates are especially crucial in right-sizing heating, cooling, and air conditioning systems and determining overall building performance in today's increasingly energy-efficient homes. The following explores a methodology that could be implemented as a design tool to estimate preconstruction, light-framed, low-rise, detached residential homes within Ontario, specifically, and throughout Canada, more generally.

INTRODUCTION

Airtightness has long been understood as an important factor to have control over since the discovery of thermal bypass in the late 1970s. Investigators of this time period were introducing insulation into townhouses, but their total energy use was over 35 per cent more than expected. Air leakage through the basement to the attic was found to be one of the major culprits in reducing the effectiveness of thermal insulation.[1]

Within Canada, federal, provincial, and municipal jurisdictions have implemented a mix of airtightness design targets. The *Ontario Building Code* has a voluntary target airtightness standard of 2.5 air changes per hour at 50 pascals (ACH50). Mandatory airtightness measurements, currently in stakeholder consultation, may be become a reality in Ontario by 2020. Even with mandatory airtightness measurements, meeting these targets will not likely take force until the Ontario building industry, as a whole, has the capability to reliably achieve a 2.5 ACH50 mandate. Similarly, Alberta only requires a blower door test if a particular house energy consumption compliance path is taken, which assumes an air leakage rate lower than 2.5ACH50. The long standing R2000 Standard, which aims to improve both building performance and environmental stewardship without jeopardizing indoor and outdoor environments, has a national voluntary standard with a mandatory airtightness limit of 1.5 ACH50. Perhaps the most aggressive targets in Canada lie to the west. British Columbia's building performance-based *Energy Step Code* ranges from 3.0ACH50 to the most stringent requirement of 1.0 ACH50 for Net-Zero Ready homes, while the City of Vancouver's building code allows certain zoning relaxations for homes adhering to the German-based *Passive House Standard*, which mandates a maximum air leakage rate of 0.6ACH50 during a blower door test.

KEY BUILDING SYSTEMS RESPONSIBLE FOR AIR LEAKAGE

A collection of concise and detailed airtightness studies from the early-1980s to the late-1990s by ASHAE shows that approximately 68 per cent of air leakage in residential homes could be attributed to the details, junctions, and transition in the building enclosure,[2] while less than one per cent of air leakage could be attributed to air diffusion through the field of the wall. Thus, the ability to account for 50 per cent of air leakage in residential homes may represent a significant and practical design capability.

	ACH50			
Province	A. Mean	G. Mean	Std. Dev.	No. Homes
Alberta	5.6	4.8	3.6	100,000
British Columbia	7.9	7.0	4.2	111,000
Manitoba	5.2	4.3	3.6	26,000
New Brunswick	6.3	5.2	4.4	45,000
Nova Scotia	8.5	7.1	5.5	51,000
North West Territories	6.3	5.3	4.1	950
Nunavut	3.9	3.4	2.3	70
Ontario	6.8	5.9	4.2	460,000
Prince Edward Island	6.4	6.4	4.2	4,000
Quebec	5.9	5.0	3.9	114,000
Saskatchewan	5.1	4.4	3.4	55,000

Table 1. National airtightness distribution by jurisdiction.

OBJECTIVES

The following is a brief summary of two airtightness research studies, which aimed to create an air leakage estimation framework that could be accessible to designers, medium-volume builders, and tract builders. The studies started by examining the existing building stock of single-family homes within Canada to set an airtightness benchmark. The next step in the investigation included evaluating the possibility of using building geometry to create a robust, future-oriented airtightness estimation model.

TRENDS AND ANALYZING A NATIONAL SAMPLE OF 900,000 HOMES

Canadian National airtightness data was taken from a residential energy efficiency program provided by the federal government. The collection of data was completed under the Natural Resources Canada ecoEnergy Retrofit programs.[3] Following voluntary participation in the program, homeowners were required to have their dwellings undergo a pre-retrofit energy evaluation. All air-leakage data was collected using the fan (de)pressurization method in general accordance with governing testing standards such as the CAN/CGSB 149 and R-2000. The data set used in this study comprised over 900,000 blower door tests performed on single-family homes constructed between the late-1700s through to 2016. The NRCan data analyzed represented nearly 12 per cent of the national housing stock, and, hence, a sizable contribution to Canada's housing profile.

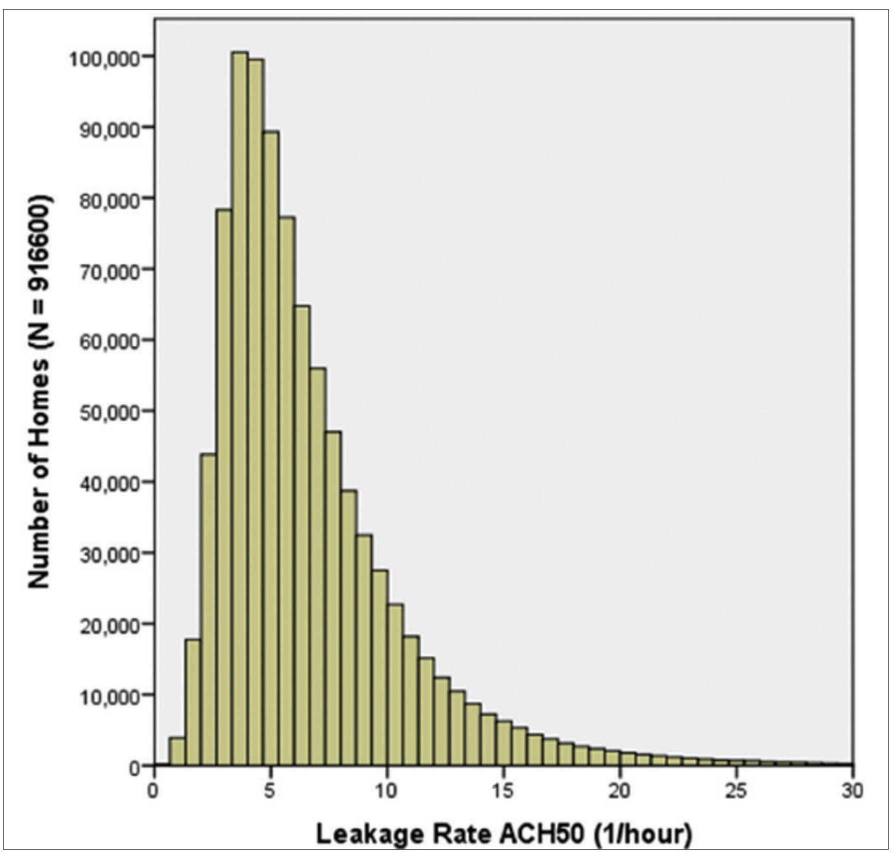

Figure 1. National airtightness distribution.

Figure 1 (on page 32) shows the frequency distribution of airtightness measurements in ACH50 for over 900,000 single family homes. The home types include solid masonry and light framed homes. The foundations walls range from block walls, rubble walls to poured concrete. The building enclosure type was not controlled for and thus likely contributed to the vast range of air leakage measures shown in Figure 1. The mean airtightness was 5.7ACH50 (arithmetic) to 6.7ACH50 (geometric). The general, but by no means exclusive trend was that newer homes were increasingly more airtight. However, this study also showed that general trends may not always hold true for every jurisdiction. For instance, Manitoba and Saskatchewan represented two regions that averaged older homes, yet these very same provinces belonged to the most airtight projects (as can be seen in Table 1 on page 32, top).

Building on previous North American and European studies, a set of predictive equations were refined and modeled. The first predictive equation used three input variables:

1. Building volume;
2. Building height; and
3. Year of construction.

The output variable shown in Equation 1 (at the top of the next page) was ACH50. The three variable equations had explained approximately 32 per cent of the air leakage in the 900,000 homes.

Equation 1

ACH = 135.304 - 0.005(Volume) + 1.048(Height) - 0.065(Year)

A subset of 330,000 homes with more detailed building enclosure information was developed. Envelope details such as insulation levels in the ceilings, walls, and foundation walls were integrated into the predictive equation. Furthermore, the location of the homes was used to estimate the climate via heating degree days (HDD). The resulting mathematical eight-input variable model shown in Equation 2 (below) was able to better predict the airtightness in these homes, with approximately 46 per cent of the air leakage accounted for by the model.[4]

Equation 2

ACH = 126.649 - 0.005(Volume) - 0.939(Height) - 0.057(Year) - 0.001(HDD) - 0.288(CeilingRSI) - 0.218(FoundationRSI) - 3.264(WindowRSI) - 0.400(WallRSI)

What is common between these two predictive equations is the reliance on building age. In fact, the building age, or year of construction, was found to be one of the most important prediction variables in both models. This observation has been consistent with airtightness predictions developed for studies done in North America and Europe. The importance of building age is likely due to its association with building practices, building materials, and housing types. More precisely, building age is likely a proxy for material quality, detail robustness, deterioration, and handicraft. Therefore, Equations 1 and Equation 2 could only predict the airtightness of buildings that have already been built. The natural question arises: How does a builder estimate airtightness of houses at the design stage?

ZEROING IN ON A REGIONAL SAMPLE OF 3,200 HOMES

As demands for building performance increase, builders and designers could benefit from having an airtightness estimation rooted in regional experience. Moreover, each builder has its own internal assembly practices and unique design approaches that satisfy the local building code. It may be possible, however, for firms with sufficient building history, a log of blower door tests, and detailed building plans to predict the airtightness of a building at the design stage.

Approximately 3,200 light-framed, single-family homes from southern Ontario, all built within the last decade, were analyzed based on their blower door test results. In contrast to the data from the national sample, these homes were tested shortly after construction was completed. In addition, the set of 3,200 homes were attempting to meet some form of energy-efficient voluntary target. Figure 2 (on this page) shows the distribution of these homes' airtightness measurements. The horizontal axis

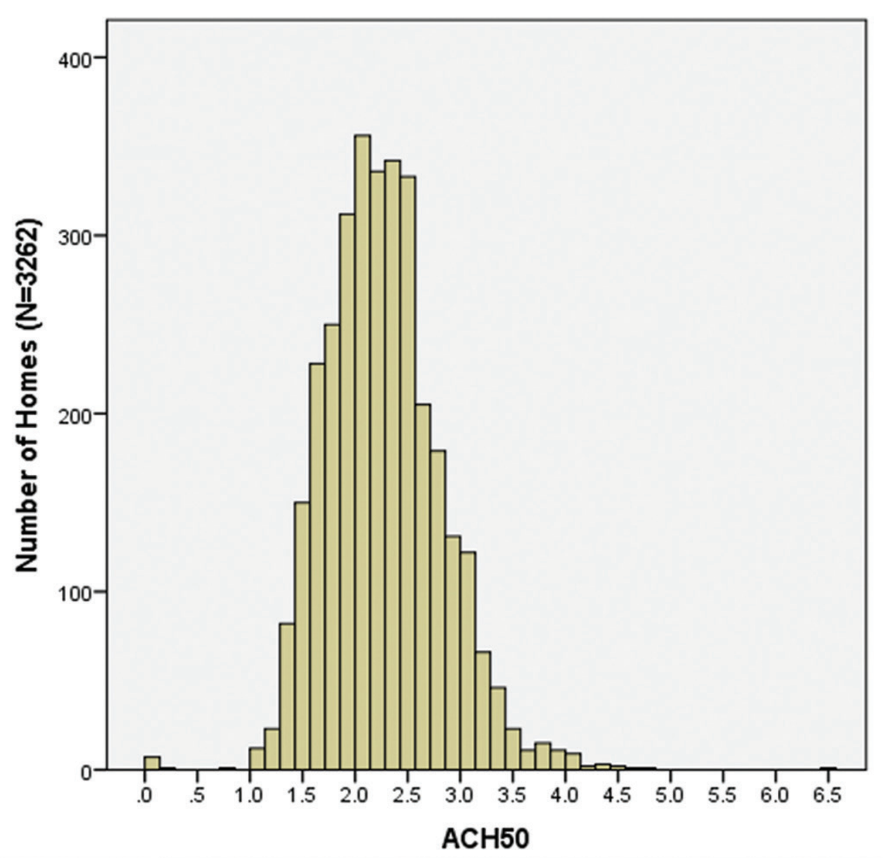

Figure 2. Regional airtightness distribution.

represents the airtightness achieved under pressurization, while the vertical axis represents the number of homes falling into this test criteria. The mean airtightness was found to be 2.3ACH50 (Std. Dev = 0.5), a value below the voluntary the *Ontario Building Code* target.

ATTENTION TO DETAIL: CUSTOMIZED MODELING USING APPROXIMATELY 200 HOMES

A subset of these homes with construction details were further analyzed. These construction details allowed the authors to experiment and construct over 20 possible variables that could influence airtightness in light-framed, single-family homes. The variables fell in four broad classes:

1. Area-based;
2. Length-based;
3. Volume-based; and
4. Handicraft-based variables.

The mean airtightness was found to be 2.4ACH50 (St.Dev = 0.5), which is still beneath the *Ontario Building Code* voluntary leakage standard. The strongest mathematical prediction models used was able to explain over 50 per cent of the airtightness data, with 13 to 14 variables; a marked improvement on the three-variable national model using over 900,000 blower door tests, and an important improvement over the eight-variable national model using nearly 330,000 homes. There are many other compelling aspects about this modeling approach.

First, the regional airtightness prediction model methodology can be used by a moderate-sized firm with a building track record of a few hundred homes (minimum 250 homes) as opposed to depending on thousands of homes. With the proviso that detailed building takeoffs are known and that the builders' homes have been subject to a blower door test, a builder can have an experience-specific, predictive formula based on assembly methods that the firm is both familiar and comfortable with.

A second unique feature of this modeling approach is that it is almost wholly based on housing geometry. The 13- and 14-variable models are independent of time. This means that designers and builders could estimate the airtightness of new homes based on a portfolio of existing homes that are five to 10 years old.

A third important feature is that this airtightness methodology is for a unique wall buildout that consists of wooden, light-framed homes. This fits well with the typical construction firm that may specialize in a particular home portfolio with a particular wall buildout. Previous time-independent models required a portfolio of heterogeneous wall types, like framed, block, and prefabricated wall assemblies, to be included in their models.

A fourth aspect is that the model is climate-independent. The most comprehensive models to date have used climate as a variable. Climate zones, and, by extension, HDD, is strongly related to local building code and construction practices. Thus, a general increase in HDD and wall insulation reduced the air leakage in residential homes. This inference is supported by the regional, often climate-dependent construction practices and codes found in North America.

Lastly, the modelling approach is independent of volume. Volume dependence has been an important variable in predicting airtightness on an air change per

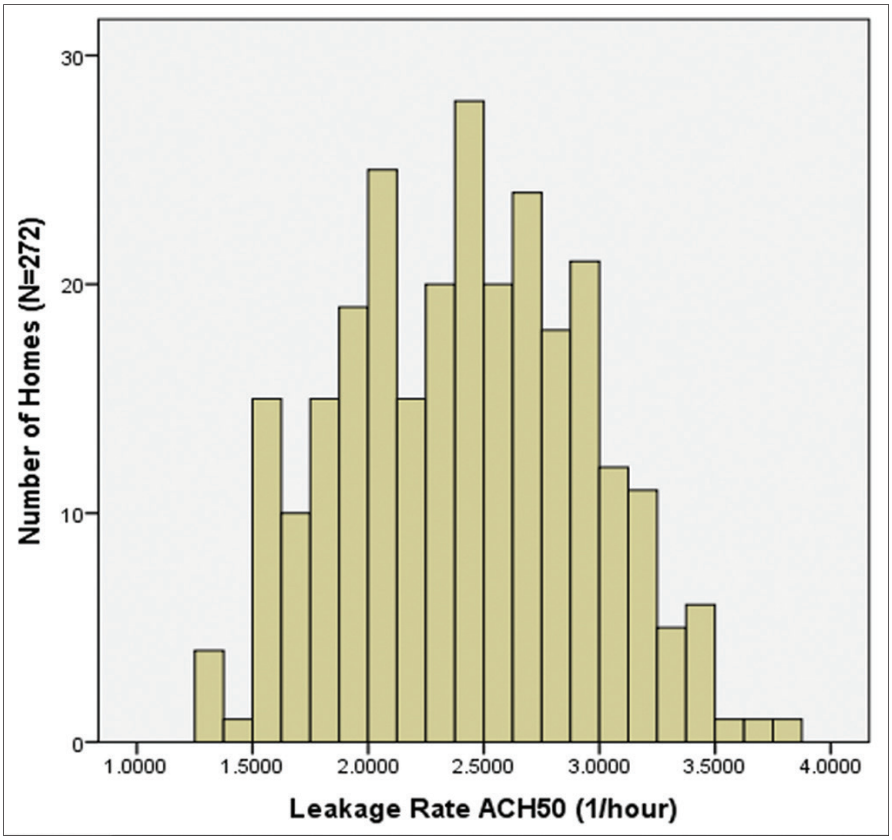

Figure 3. Distribution of airtightness subset used in modelling.

hour basis. This dependence is, of course, expected since ACH50 is a volumetric leakage rate base on total building volume. The time-independent 13- and 14-variable models factor in building size implicitly through a series of perimeter-based ratios.

CONCLUSION

A customizable, builder-centric, airtightness modeling methodology has been created with the goal of being a design tool for low-rise, light-framed residential homes. Despite the general trend of increasing airtightness throughout Canadian residential housing stock, the research has indicated there is considerable variability in the measurable air leakage rates between the provinces and territories. Therefore, designers could seek a common method which yields portfolio specific airtightness estimates that meet the unique needs of a given construction firm. ■

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