AIR INFILTRATION: COST OF AIR-SEALING MEASURES

A REPORT PREPARED FOR
Sustainable Buildings and Communities
CanmetENERGY
NATURAL RESOURCES CANADA

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June 30, 2015

SUMMARY

Over the last 30 to 40 years, hundreds of thousands of Canadian homes have been retrofitted to reduce energy consumption. These retrofits have included measures to reduce air leakage, increase the thermal resistance of the building envelope and replace or upgrade mechanical systems. Natural Resources Canada (NRCan) has been a central player in this field and has worked closely with provincial and territorial governments as well as various energy utilities to establish programs capable of assisting those who wish to retrofit their home. As part of these initiatives, approximately 950,000 houses have received pre-retrofit airtightness tests. Out of these, close to 780,000 have also had post-retrofit tests performed.

Using NRCan's EE (energy efficiency) data base on pre-and-post airtightness, the project described in this report was carried out with two objectives: a) to identify the impact of various energy conservation retrofits on the airtightness of existing houses and b) to obtain information on the cost of air leakage sealing for existing home retrofits and new home construction.

Many of the study's findings confirm long-held, qualitative beliefs about air leakage in Canadian houses: prairie houses tend to be tighter than those in more temperate regions, partial storey (1½ and 2½) houses are generally leakier than full (1 or 2) storey houses, and older houses experience more air leakage than newer houses. While these observations are not surprising, the results of this study - since they are based on such large sample sizes (2813 to 44,230 houses) - help to quantify these differences with greater confidence than had previously been possible. Some of the key observations from the analysis include:

All of the Retrofits Reduced Air Leakage - The study confirmed that all of the energy conservation retrofits affected the airtightness of a house, whether through deliberate attempts to seal potential leakage sites or inadvertently as the result of other actions such as blowing loose fill insulation into empty exterior wall cavities.

The Retrofits Reduced Air Leakage By 7% to 15% - As shown on the next page, all of the retrofit measures produced appreciable reductions in the measured air leakage rate even though most were designed primarily to reduce conductive heat losses or improve the efficiency of the mechanical system.

The Study Results Quantified the Impact of the Various Retrofit Measures - The results of this study provide very useful, quantitative information on the air leakage benefits of various types of residential energy conservation measures. They can be used to produce more accurate estimates of actual energy savings when performing energy analyses of proposed conservation upgrades. For example, the benefits of a wall insulation upgrades are normally calculated assuming there is no change in the house's air infiltration rate - even though it is widely acknowledged that such a reduction can, and in fact usually does, occur. This study's findings provide quantitative data on the magnitude of these benefits.

Retrofit	Sample Size	Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Reduction (absolute)	Reduction (percent)
Air Leakage Sealing (w/o incentives)	43,360	5.09	4.59	0.50	7%
Air Leakage Sealing (with incentives)	2813	7.88	6.51	1.38	14%
Attic	36,136	6.37	5.33	1.04	13%
Walls	9989	7.92	6.39	1.53	15%
Foundations	23,214	6.37	5.70	1.17	14%
Windows	44,230	6.18	5.19	0.99	13%
HVAC	19,431	5.67	5.05	0.62	9%

Results for Individual Houses Varied Wildly - Every retrofit measure studied produced, on average, a tangible reduction in the measured air leakage rate of the house. However, results for individual houses varied widely. In some cases, the retrofit produced significant increases in the measured air leakage rate. Without detailed knowledge of each house and each retrofit, it is difficult to offer any definitive explanation for these outliers. However, the wide variation in results is a cause for concern since it means that while the study results provide excellent information on the average impact of these measures on a population of houses, it is very difficult to use the results to make firm predictions on the behaviour of a specific house.

Secondary Benefits of Retrofits Which Reduce Air Leakage May Outweigh the Energy Savings - The secondary benefits of conservation retrofits need to be acknowledged, particularly for exterior wall and attic retrofits. While many retrofits are mainly concerned with increasing thermal resistance, the air leakage benefits (whether intentionally or unintentionally achieved) will, in many cases, far outweigh the benefits attributable to the reduced heat loss caused by the additional insulation. For example, problems with air exfiltration and moisture deposition within the attic space are fairly common and can lead to extensive damage to the structure. The benefits of reducing these events, both in terms of frequency and magnitude, will generally far exceed the energy savings produced by the extra insulation.

Cost of Air Leakage Sealing Retrofits - The cost of air sealing an existing home can vary significantly depending on the work which has to be performed to achieve an acceptable level of airtightness. However, based on industry input from ALS contractors, the following cost data was developed.

Supplemental Attic Air Leakage Sealing

- Description of work: Accessing the attic; brushing aside the existing insulation; sealing mechanical and electrical penetrations, holes in attic perimeter (if accessible), holes in tops of partition walls and any obvious holes, and weatherstripping the attic hatch.
- Typical costs: $300 to $400.

Attic Insulation Removal and Supplemental Air Leakage Sealing

- Description of work: Accessing the attic; complete removal of all existing insulation; spray foam attic with thin layer of foam, add new insulation.
- Typical costs: $3000 to $4000, plus the cost of the new attic insulation.

Basement Air Leakage Sealing

- Description of work: Sealing of basement headers using spray foam or rigid insulation.
- Typical costs: $800 to $1000.

Whole House Air Leakage Sealing

- Description of work: Pre-retrofit airtightness test to both determine how leaky the house is and where the major leaks are located; sometimes supplemented with an infra-red examination of the house (weather conditions permitting); supplemental attic ALS; sealing of major holes; some weatherstripping; post-retrofit airtightness test.
- Typical costs: $1000 to $1500, assuming other work (such as insulation upgrades) is being performed on the house.

Exterior Wall Insulation/Air Leakage Sealing

- Description of work: blowing in dense-pack cellulose insulation into exterior wall cavities.
- Typical costs: $30/m^2 ($3/ft^2) of gross wall area.

Cost of Airtightness In New Construction - Assuming the builder is experienced with airtight construction techniques, the estimated, retail costs to air seal a new home using current techniques, products and methods are as shown below. In most cases, this should achieve a final airtightness of about 1.5 ac/hr$_{50}$.

Bungalows

Total cost: $2300 to $3000 (without airtightness test)
$2550 to $3250 (with one airtightness test)

Two-Storey Houses

Total cost: $3300 to $4200 (without airtightness test)
$3550 to $4450 (with one airtightness test)

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Section 1
Introduction

1.1 Background

It has long been acknowledged that air leakage in houses is a major energy liability and a long-term threat to a building's durability. For existing houses, many of which experience very high levels of air infiltration, a menu of air leakage sealing (ALS) techniques and strategies has been developed and successfully employed on thousands of Canadian homes. Yet these dedicated ALS retrofits represent only a small fraction of the existing housing stock which has been retrofitted to save energy. The bulk of conservation retrofits on existing houses have been performed to increase insulation levels or improve the efficiency of the home's mechanical system (space heating, domestic hot water heating, ventilating and air-conditioning). However, insulation and mechanical system measures can also impact airtightness. For example, insulating an uninsulated exterior wall or replacing existing windows or performing any of a number of different conservation retrofits should, in theory, also have a beneficial effect on airtightness. While this has been *qualitatively* understood for some time, there has been very little *quantitative* data to either confirm this belief or define its magnitude. Further, in the case of pure dedicated ALS retrofits, there has been little information available on the cost of retrofitting an existing house to reduce its air leakage.

For new construction, a slightly different situation exists. A wide assortment of design and construction details has been developed over the years which permit new homes to be built with very low levels of air leakage. However, unlike existing houses, the impact of these measures has been relatively well studied and understood such that it is now possible to design a house with an explicit airtightness target which most trained and experienced homebuilders can achieve on a fairly consistent basis. For example, experienced builders attempting to attain an airtightness target of (say) 1.5 ac/hr_{50} can usually reach that goal on the first attempt. The biggest uncertainty is the cost. How much does it cost to take an existing house design and upgrade it to some higher airtightness standard? To some extent this is an open-ended question since different builders have different "starting points" from which to begin. Nonetheless, cost data is scarce.

1.2 Objectives

The primary objectives of this project were to:

- Use existing information and published studies to identify the impact of various energy conservation retrofits on the airtightness of existing houses and
- Obtain information on the cost of air leakage sealing retrofits for existing houses and the cost of air leakage sealing for new houses.

1.3 Overview

Over the last 30 to 40 years, hundreds of thousands of Canadian homes have been retrofitted to save energy. While some of these retrofits have been designed and carried out by homeowners themselves without any outside involvement, most were assisted (financially and/or technically) by various government or utility programs. Natural Resources Canada (NRCan) has been a central player in this field for several decades and has developed a number of programs and initiatives to assist Canadians. NRCan has also worked closely with provincial and territorial governments as well as various energy utilities to put in place programs capable of assisting those who wish to retrofit their home. In most cases, NRCan's focus has been on the provision of sound technical information so that homeowners could make informed decisions on what was best for their home and their situation. One key element of this has been the development of energy advisor capabilities across the country. These are individuals who have been trained to examine a house, conduct an airtightness test, prepare a HOT2000 input file (for performing computerized energy modelling) and develop recommendations on the most cost-effective energy conservation retrofits appropriate for that house. Since 1998, an estimated 2600 energy advisors have been trained in Canada. Most of this work has occurred with NRCan's participation and support as part of various Canada-wide housing energy efficiency initiatives.

As part of these existing housing retrofit programs, approximately 950,000 houses have received pre-retrofit airtightness tests. Out of these, close to 780,000 homes have also had post-retrofit tests performed.

Further, as part of various new housing initiatives, such as ENERGY STAR, R-2000 and EnerGuide for New Houses (EGNH), close to 35,000 have been tested.

As mentioned, one key component of any residential energy assessment is an airtightness test, sometimes referred to as a blower door test. Conducted according to CGSB 149.10 "Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method", an airtightness test serves two functions: it permits the airtightness of a building to be quantitatively measured and it facilitates identification of significant air leakage locations around the house. If airtightness tests are performed before and after an energy conservation retrofit, then the impact of the retrofit (on airtightness) can be determined.

To assess the impact of various energy conservation retrofits on the airtightness of existing buildings, Natural Resources Canada's EE (Energy Efficiency) data base was accessed for this project. This data base was developed and is maintained by NRCan as a means of tracking the performance of houses which have been. It contains information on 984,938 existing and 107,129 new houses, including a HOT2000 input file and the results of before and after airtightness tests for each house.

To study the impact of specific retrofit measures on airtightness for this project, NRCan accessed and filtered the EE data base to identify and select those houses which had received only one type of retrofit (walls, attics, basements, etc.). The individual house data was then stripped of any identifying information and downloaded into an EXCEL spreadsheet and forwarded to Proskiw Engineering Ltd. (PEL) for analysis. The individual spreadsheets created for each retrofit were then processed and analyzed to determine the measure’s impact on airtightness. Thus, the discussion on “walls” in Section 5 of this report deals only with houses which had their exterior walls thermally upgraded. This process was repeated for seven types of retrofit measures:

- Air leakage sealing (without incentives)
- Air leakage sealing (with incentives)
- Walls
- Attics
- Foundations
- Windows
- Mechanical systems

The remainder of this report discusses the results of the analysis.

1.4 Format of Results

Each of the seven types of energy conservation retrofits studied is discussed separately in this report using the following format:

Description: This provides an overview of the retrofit measure and the types of air leakage sealing measures which might have been included. However, since there was limited information on the exact scope of work for each house, there is no way of knowing exactly what work was performed, for example: how much ALS was performed as part of an attic upgrade?

Sample Size: This defines the number of houses in the sample used to evaluate the impact of the retrofit measure on airtightness. Sample sizes ranged from 2813 to 44,230 houses.

Discussion: This summarizes the key observations and findings, including the effectiveness of the retrofit measure based on geographic location, house age and house type

Overview Statistics: This sub-section summarizes the pre-and-post, measured airtightness; the absolute change in airtightness and the percentage change in airtightness due to the retrofit. The metric used to express airtightness results is the number of air changes per hour at a pressure differential of 50 Pascals (ac/hr_{50})...

$$ac/hr_{50} = (\text{volumetric flow rate at 50 Pa}) / (\text{building volume}) \qquad (1)$$

For each of these results, the following data is provided: mean, minimum, maximum, standard deviation and the coefficient of variation.

The standard deviation and the coefficient of variation (C of V) are included because they describe the variation in the measured results. While the former is relatively well understood, the latter is included because it quantifies the variation in the results as a function of the mean. The C of V is defined as the standard deviation divided by the arithmetic mean of a sample, thereby expressing the variation in the data in relation to the mean. The larger the C of V, the greater the variation in the data; for example, a C of V equal to 1 would indicate that the standard deviation of the data was equal to its mean value.

By Province (table): For each type of retrofit, this table summarizes the airtightness results based on the province or territory in which the houses were located. Variations in results between houses in different regions of the country reflect differences in historical and current construction practices, industry skill and capability, fuel types, etc. Also, since most of the retrofits discussed in this report where conducted under the auspices of some provincially delivered, government or utility conservation program, the provincial and territorial data may reflect (to some extent) the quality control procedures of the host program.

By Decade (table): This reviews the airtightness results based on house age, specifically the decade in which the house was constructed (commencing in 1890). Over the last one-and-a-quarter centuries, there have been a number of significant changes to how Canadian houses are designed and constructed. While some of these changes actually targeted air leakage control, most were implemented for other reasons but nonetheless still have the potential to affect the building's airtightness. Perhaps the most obvious example of this was the introduction of explicit air leakage control measures (such as sealed polyethylene air barriers) into both building codes and on-site construction practices.

By House Type (table): This summarizes the results based on house type (1, 1½, 2, 2½, and 3 storey, split entry/raised bungalow and split level) since this can have a marked impact on the house's airtightness due to differences in how various construction details are handled. Perhaps the most obvious example is the difference between partial and full storey houses, such as 1 and 2 storey houses versus 1½ and 2½ houses. With partial storey houses, the floor system of the upper storey has to extend from inside the heated portion of the building into the unheated attic space behind the kneewalls. This can be a major air leakage pathway if explicit details are not included to seal the otherwise open floor joist cavities. However, such a practice was almost never used in this style of construction - although many thousands of partial storey houses have subsequently been retrofitted.

Section 2
Air Leakage Sealing Retrofits (without incentives)

2.1 Description: Air leakage sealing (ALS) retrofits are carried out for the sole purpose of reducing the house's natural infiltration rate; insulation upgrades or modifications to the mechanical system are not included. They can be relatively modest in scope or quite comprehensive. Some contractors use blower doors to identify major leakage locations, provide quality control and generally assess the effectiveness of their work. Others choose not to use blower doors and simply follow standardized sealing protocols. Typical areas in a house which ALS retrofits target may include:

- upgrading door and window weatherstripping
- upgrading attic hatch weatherstripping
- sealing electrical and plumbing penetrations into the attic
- sealing the tops of partition walls from the attic
- adding gaskets to electrical outlets/switches on exterior (and sometimes interior) walls
- sealing basement floor headers
- sealing service penetrations in the basement or crawl space
- sealing various penetrations and cracks into exterior walls or attic spaces
- sealing open cavities (such as floor joists) which extend into unheated spaces

No financial incentives were received by the homeowners for these retrofits.

2.2 Sample Size: 46,360 houses

2.3 Discussion:

- The mean, pre-retrofit airtightness of the 46,360 houses in the sample was 5.09 ac/hr_{50}, while the average post-retrofit value was 4.59 ac/hr_{50}.

- The air leakage sealing retrofits produced a mean reduction in their measured airtightness of 0.50 ac/hr_{50} or 7%. As to be expected with such a large sample, individual results varied wildly. For example, the minimum and maximum reductions varied from an *increase* of 11.75 ac/hr_{50} (i.e. the retrofit caused the house to become significantly more leaky) to a decrease of 33.37 ac/hr_{50}!

- House location had a significant impact on both the pre-and-post retrofit results. For example, the average pre-retrofit airtightness ranged from 3.75 ac/hr_{50} in Manitoba, to 7.53 ac/hr_{50} in Newfoundland (ignoring the Yukon results, which were based on a sample size of only 4 houses). This is a variation of 2:1. In general terms, houses which were initially fairly loose experienced the greatest reductions in their ac/hr_{50} values.

- Provincial differences observed in the pre-retrofit airtightness results are believed to be largely the result of some subtle differences in construction practices across the country. For example, many/most existing Manitoba houses use cast-in-place floor systems in which the headers and ends of the floor joists are cast into the concrete, as opposed to using a sill plate which is placed on top of the cured, concrete wall. Given that the main floor header area is often the largest single source of air leakage in a house, casting these members into the basement wall eliminates, or significantly reduces, air leakage at this location. Further, the most common exterior finish in Manitoba is stucco, which is a fairly effective air barrier. Other commonly used materials, such as vinyl, wood, brick or metal are all ventilated to control moisture intrusion through the cladding. While effective at achieving this goal, it also means they provide little, if any, restriction to air flow.

- House age had a significant impact on both the initial airtightness of the house and the improvement which the retrofit was able to achieve. Older houses were leakier than new houses and retrofitting older houses to reduce air leakage was more effective than it was on newer structures. Houses constructed between 1890 and 1940 were able to achieve double-digit reductions in their ac/hr_{50} (11% to 13%) whereas for post-1940 homes, the average reduction dropped from 8% (1950) to only 2% (2010).

- The type of house being retrofitted also had a big impact on the results. The leakiest houses were 1½, 2½ and 3 storey homes. Not surprisingly, these also experienced the largest reductions in air leakage once they were retrofitted. The first two types, 1½ and 2½ storey houses are particularly vulnerable to leakage which occurs through the floor system between the first and second levels since the floor joists cross from the heated space into the unheated attic space behind the kneewalls.

- There was significant scatter in all categories of the airtightness data. For example, consider the pre-retrofit airtightness; the mean value was 5.09 ac/hr_{50} while the standard deviation was 3.44 ac/hr_{50}, resulting in a coefficient of variation of 0.68. Likewise, the mean change in airtightness was 0.50 ac/hr_{50}, while the standard deviation was 1.41 ac/hr_{50}, producing a C of V of 2.82.

Overview Statistics:

Type of Retrofit Measure: Air Leakage Sealing (without incentives)			**Number of retrofits:** 46,360	
	Measured Airtightness (ac/hr$_{50}$)			
	Pre-Retrofit	Post-Retrofit	Change	Percent Change
Mean	5.09	4.59	0.50	7%
Min	0.37	0.37	-11.75	-543%
Max	50.00	47.60	33.37	95%
Std. Dev.	3.44	2.82	1.41	16%
C of V	0.68	0.61	2.82	2.51

By Province:

Province or Territory	Number Of Retrofits	**Measured Airtightness (ac/hr$_{50}$)**			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
B.C.	9015	6.06	5.54	0.52	6%
Alberta	351	5.03	4.28	0.75	9%
Saskatchewan	807	4.04	3.56	0.48	8%
Manitoba	556	3.75	3.37	0.38	6%
Ontario	11,316	5.12	4.53	0.59	8%
Quebec	13,978	4.31	3.97	0.34	5%
New Brunswick	6445	4.42	4.06	0.36	5%
Nova Scotia	3350	7.03	6.06	0.97	9%
PEI	86	6.18	5.42	0.77	8%
Newfoundland	438	7.53	6.62	0.91	9%
NWT	14	5.76	5.59	0.17	4%
Yukon	4	2.91	2.40	0.51	18%
Sample Weighted Avg.	46,360	5.09	4.59	0.50	7%

By Decade of Construction:

Decade of Construction	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1890	990	9.57	8.30	1.27	11%
1900	634	9.29	7.81	1.47	13%
1910	495	9.83	8.34	1.49	11%
1920	546	9.49	8.07	1.42	12%
1930	531	8.95	7.72	1.22	11%
1940	1122	8.26	7.15	1.10	11%
1950	2845	6.93	6.16	0.77	8%
1960	4357	5.97	5.37	0.59	7%
1970	8545	5.63	5.06	0.57	7%
1980	10942	4.63	4.24	0.39	6%
1990	8633	3.78	3.49	0.29	5%
2000	6115	2.95	2.80	0.15	3%
2010	605	2.18	2.06	0.12	2%
Sample Weighted Avg.	46,360	5.09	4.59	0.50	6.5%

By House Type:

House Type	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1 Storey	25,498	4.80	4.36	0.44	6%
1½ Storey	1247	7.01	6.09	0.92	8%
2 Storey	17,714	5.36	4.80	0.55	7%
2½ Storey	165	7.28	6.20	1.08	11%
3 Storey	505	7.24	6.30	0.94	10%
SE/RB	672	3.63	3.47	0.17	2%
Split Level	559	4.55	4.20	0.35	5%
Sample Weighted Avg.	46,360	5.09	4.59	0.50	7%

Fig. 2.1

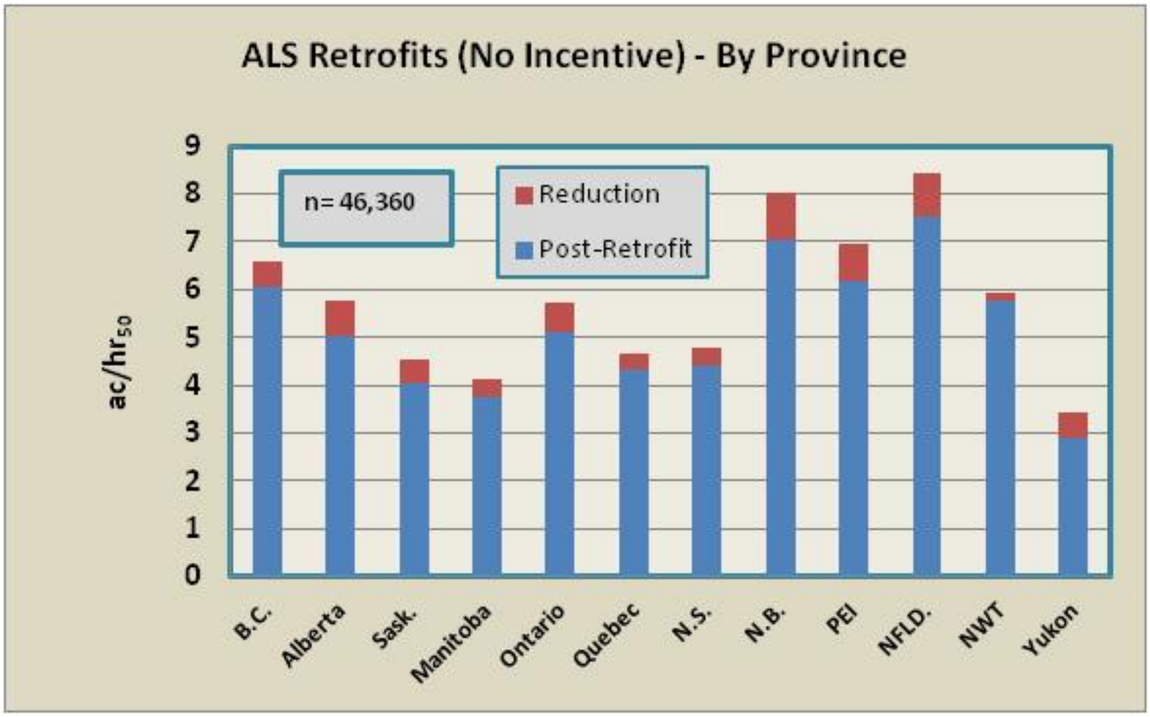

ALS Retrofits (No Incentive) - By Province
n= 46,360
Reduction
Post-Retrofit
ac/hr50
9
8
7
6
5
4
3
2
1
0
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon

Fig. 2.2

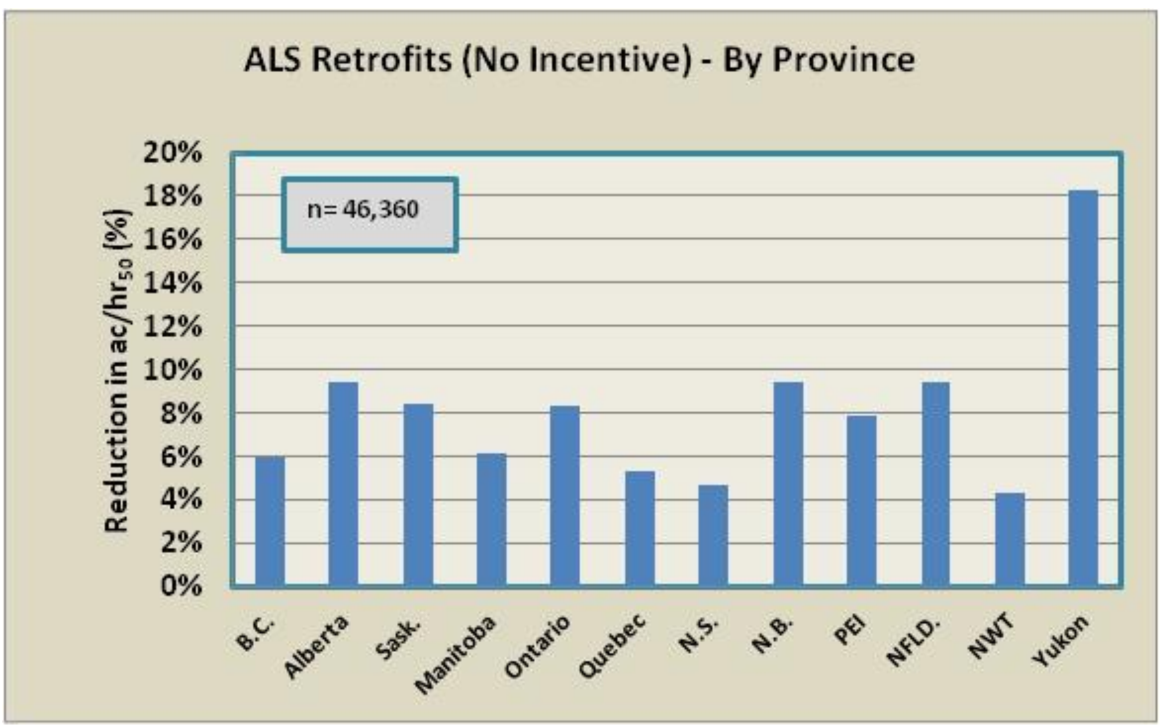

ALS Retrofits (No Incentive) - By Province
n= 46,360
Reduction in ac/hr50 (%)
20%
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon

Fig. 2.3

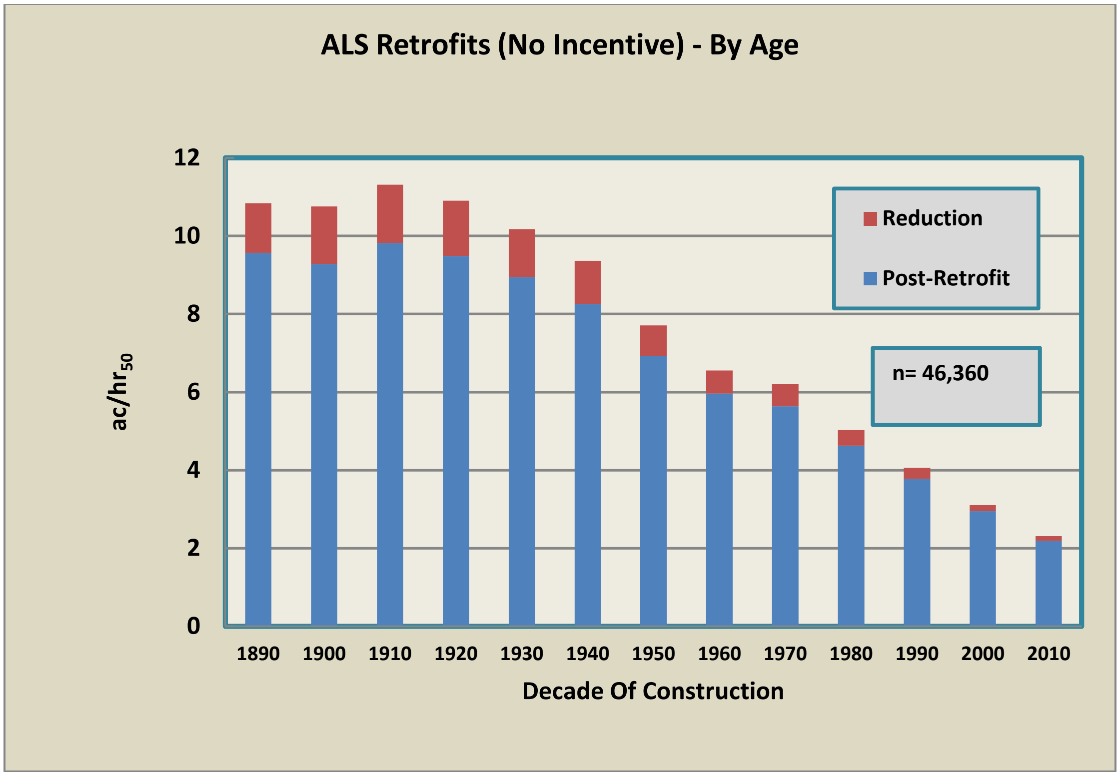

ALS Retrofits (No Incentive) - By Age
ac/hr50
12
10
8
6
4
2
0
Reduction
Post-Retrofit
n= 46,360
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Decade Of Construction

Fig. 2.4

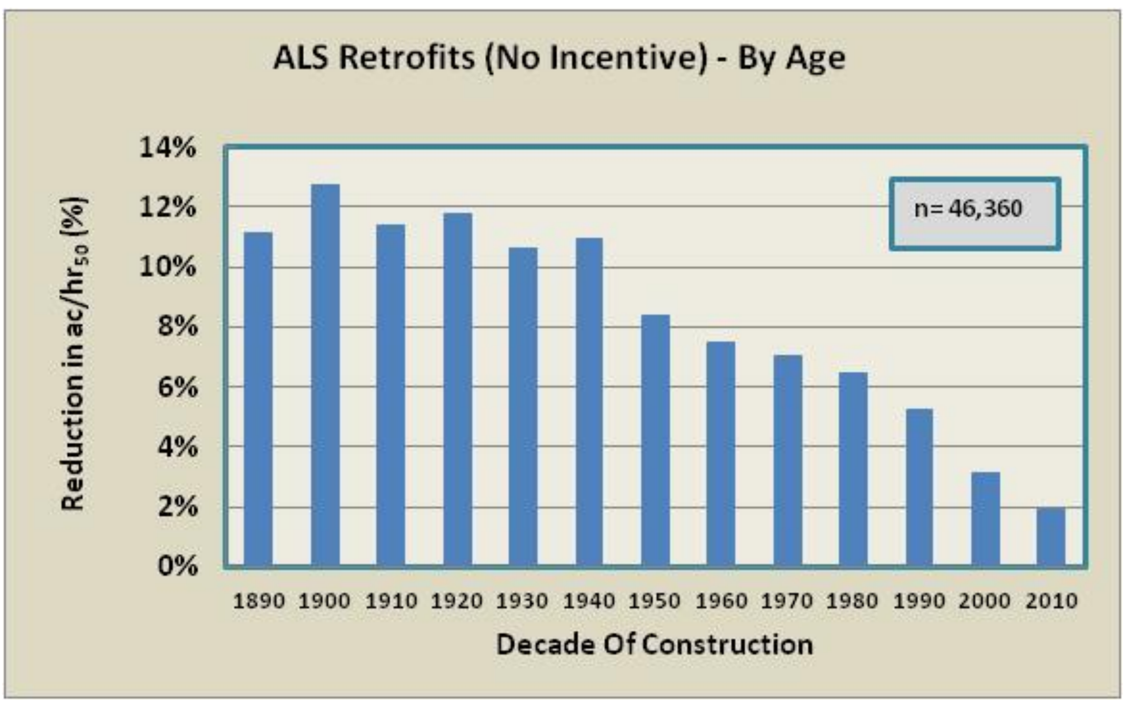

ALS Retrofits (No Incentive) - By Age
Reduction in ac/hr50 (%)
14%
12%
10%
8%
6%
4%
2%
0%
n= 46,360
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Decade Of Construction

Fig. 2.5

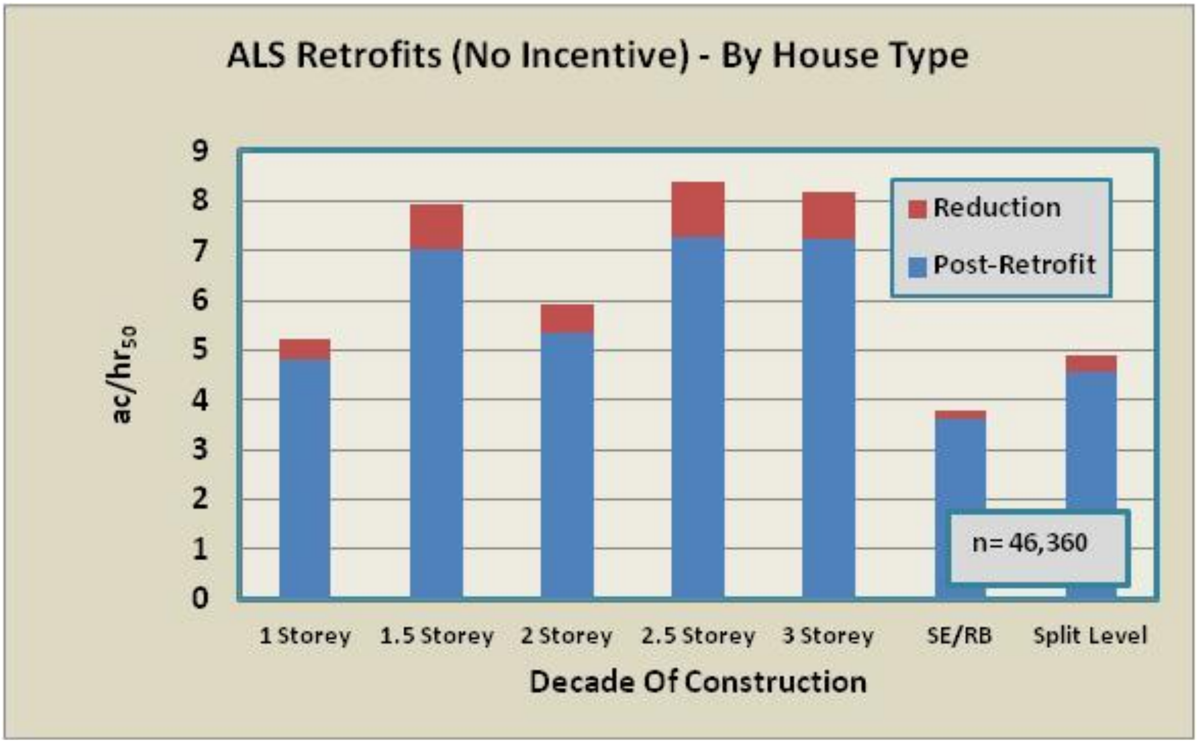

ALS Retrofits (No Incentive) - By House Type
ac/hr50
9
8
7
6
5
4
3
2
1
0
Reduction
Post-Retrofit
n= 46,360
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level
Decade Of Construction

Fig. 2.6

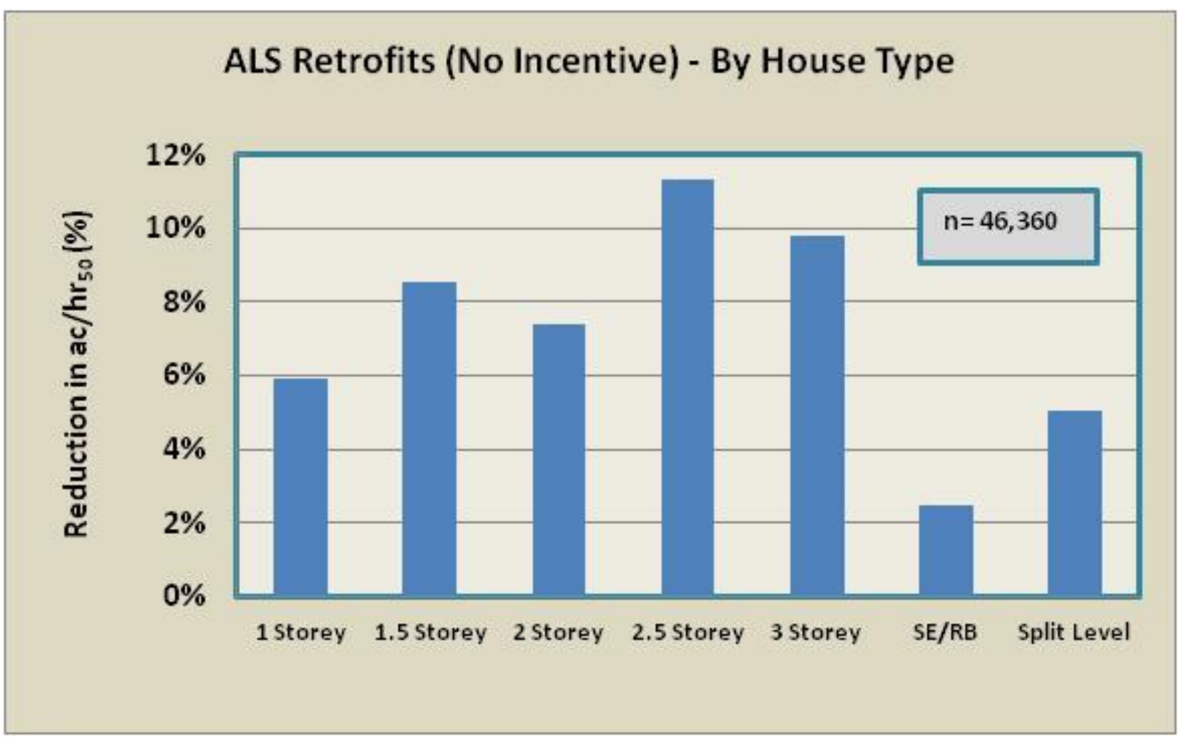
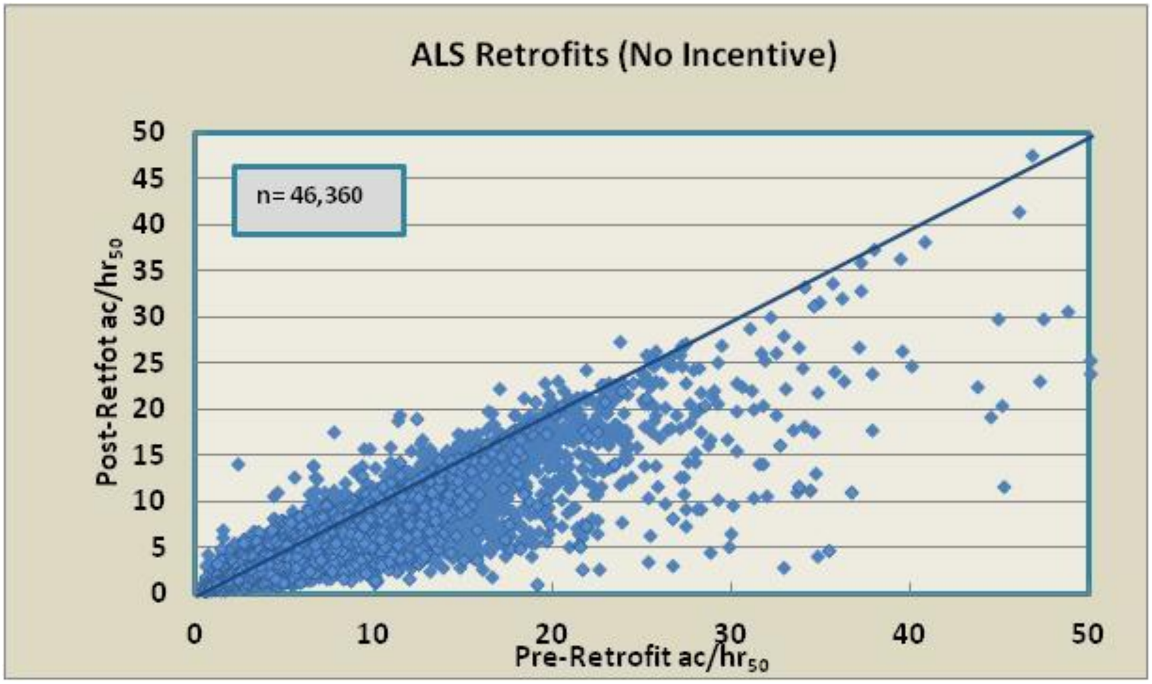

ALS Retrofits (No Incentive) - By House Type
Reduction in ac/hr50 (%)
12%
10%
8%
6%
4%
2%
0%
n= 46,360
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 2.7


ALS Retrofits (No Incentive)
n= 46,360
Post-Retfot ac/hr50
Pre-Retrofit ac/hr50
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50

Section 3
Air Leakage Sealing Retrofits (with incentives)

3.1 Description: The scope of work for these air leakage sealing retrofits was the same as the ALS retrofits (without incentives). The only difference between houses in this category and the previous was that the homeowners in this group received financial incentives to perform the work. It was also a much smaller sample – only 2813 houses (versus 46,360). Further, the sample was concentrated in Ontario, Nova Scotia and Quebec.

3.2 Sample Size: 2813 houses

3.3 Discussion:

- Interestingly, the ALS retrofits, with incentives produced greater reductions in air leakage than the ALS retrofits, without incentives. The mean reduction in the measured ac/hr_{50} was 14%, which was twice that of the incentive-free ALS category (7%). Further, the absolute reduction was considerably larger, 1.38 ac/hr_{50} versus 0.50 ac/hr_{50}. However, it is worth noting that the average pre-retrofit airtightness of houses in this category was more than 50% greater than the ALS without incentives category (7.88 vs. 5.09 ac/hr_{50}).

- The province of origin had an impact on airtightness, although the effect was less pronounced than it was for ALS retrofits, without incentives. For example, the Nova Scotia houses had initial airtightness rates (mean value 11.26 ac/hr_{50}) which were 50% to 100% higher than those of other provinces

- Once again, house age had a significant impact on both the initial airtightness and the improvement which the retrofit was able to achieve. Older houses were leakier than new houses and retrofitting older houses to reduce air leakage was more effective than it was on newer structures. The oldest houses, those constructed in the 1890's, experienced an average reduction of 21% in their measured ac/hr_{50} results. The reduction decreased with newer houses ultimately dropping to a 7% saving for houses constructed since 2010.

- Partial storey (1½ and 2½ storey) and 3 storey houses were (again) the leakiest types of buildings tested and the ones which experienced the most impressive reductions in their air leakage. Both the 1½ and 2½ storey houses had their leakage rates reduced by an average of 26%, twice that of 1 and 2 storey homes.

Overview Statistics:

Type of Retrofit Measure: Air Leakage Sealing Retrofits (with incentives)		**Number of retrofits:** 2813		
	Measured Airtightness (ac/hr$_{50}$)			
	Pre-Retrofit	Post-Retrofit	Change	Percent Change
Mean	7.88	6.51	1.38	14%
Min	0.83	0.63	-5.30	-254%
Max	50.00	33.00	32.69	94%
Std. Dev.	5.09	3.65	2.37	15%
C of V	0.68	0.61	2.83	2.51

By Province:

Province or Territory	Number Of Retrofits	**Measured Airtightness (ac/hr$_{50}$)**			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
B.C.	69	8.48	6.81	1.67	14%
Alberta	25	4.57	4.34	0.23	5%
Saskatchewan	59	4.94	4.32	0.62	9%
Manitoba	16	7.60	6.50	1.11	12%
Ontario	1469	6.98	5.96	1.01	13%
Quebec	414	6.47	5.09	1.38	15%
New Brunswick	664	11.26	8.98	2.28	15%
Nova Scotia	50	5.72	4.32	1.41	10%
PEI	2	13.54	9.87	3.67	25%
Newfoundland	38	8.47	7.27	1.19	11%
NWT	6	3.76	3.12	0.64	18%
Yukon	1	1.57	1.80	-0.23	-15%
Sample Weighted Avg.	2813	7.88	6.51	1.38	14%

By Decade of Construction:

Decade of Construction	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1890	78	13.17	9.97	3.20	21%
1900	57	11.46	8.93	2.53	20%
1910	52	12.54	9.36	3.18	21%
1920	59	10.80	8.94	1.86	17%
1930	59	10.80	8.74	2.06	16%
1940	110	10.02	8.10	1.92	17%
1950	220	8.73	7.03	1.70	15%
1960	247	8.05	6.54	1.51	14%
1970	462	9.96	7.99	1.96	16%
1980	880	6.61	5.68	0.93	12%
1990	455	5.90	5.14	0.76	12%
2000	126	3.52	3.05	0.47	9%
2010	8	1.62	1.44	0.18	7%
Sample Weighted Avg.	2813	7.88	6.51	1.38	14%

By House Type:

House Type	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1 Storey	951	8.83	7.17	1.66	14%
1½ Storey	66	9.74	6.27	3.47	26%
2 Storey	1754	7.31	6.17	1.14	13%
2½ Storey	5	11.91	7.68	4.22	26%
3 Storey	22	8.32	6.49	1.83	20%
SE/RB	7	5.40	4.11	1.29	17%
Split Level	8	4.88	4.62	0.26	5%
Sample Weighted Avg.	2813	7.88	6.51	1.38	14%

Fig. 3.1

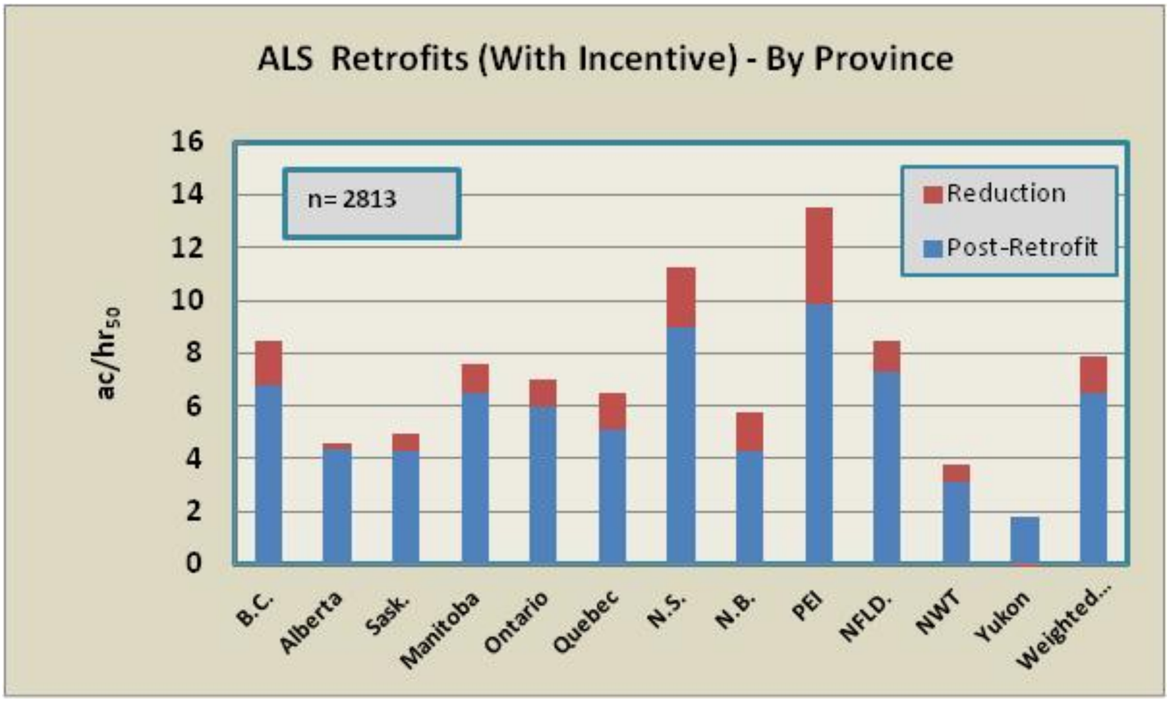

ALS Retrofits (With Incentive) - By Province
ac/hr50
16
14
12
10
8
6
4
2
0
n= 2813
Reduction
Post-Retrofit
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon
Weighted...

Fig. 3.2

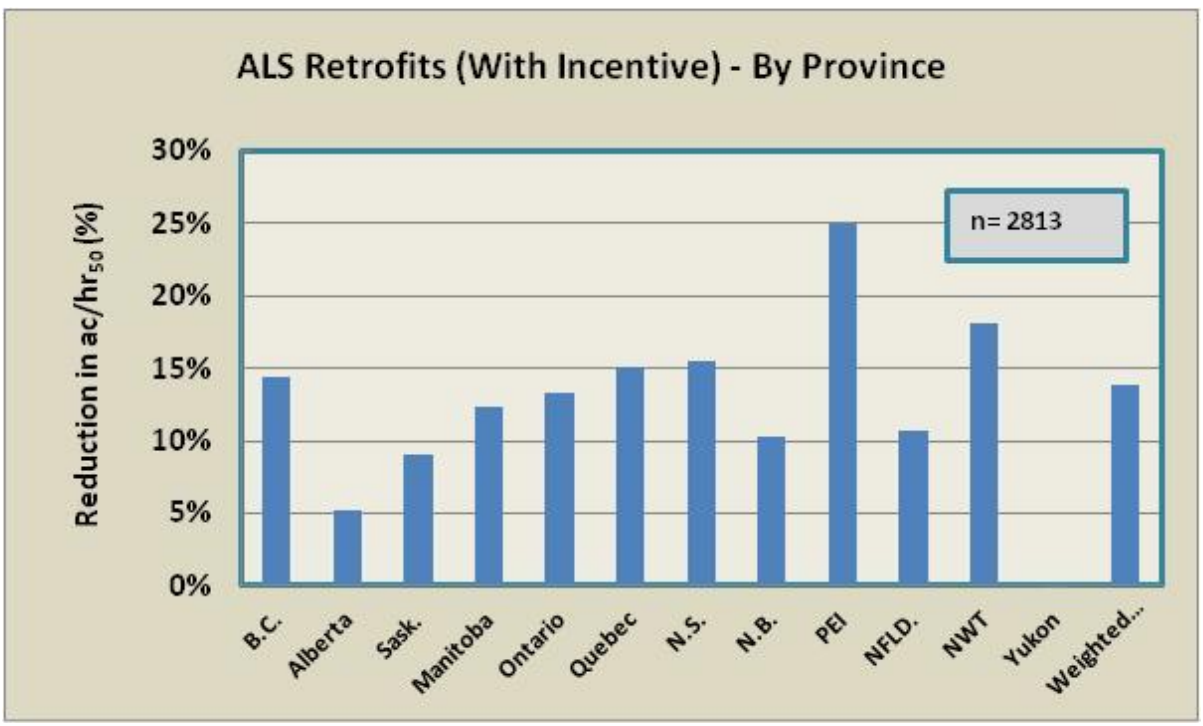

ALS Retrofits (With Incentive) - By Province
Reduction in ac/hr50 (%)
30%
25%
20%
15%
10%
5%
0%
n= 2813
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon
Weighted...

Fig. 3.3

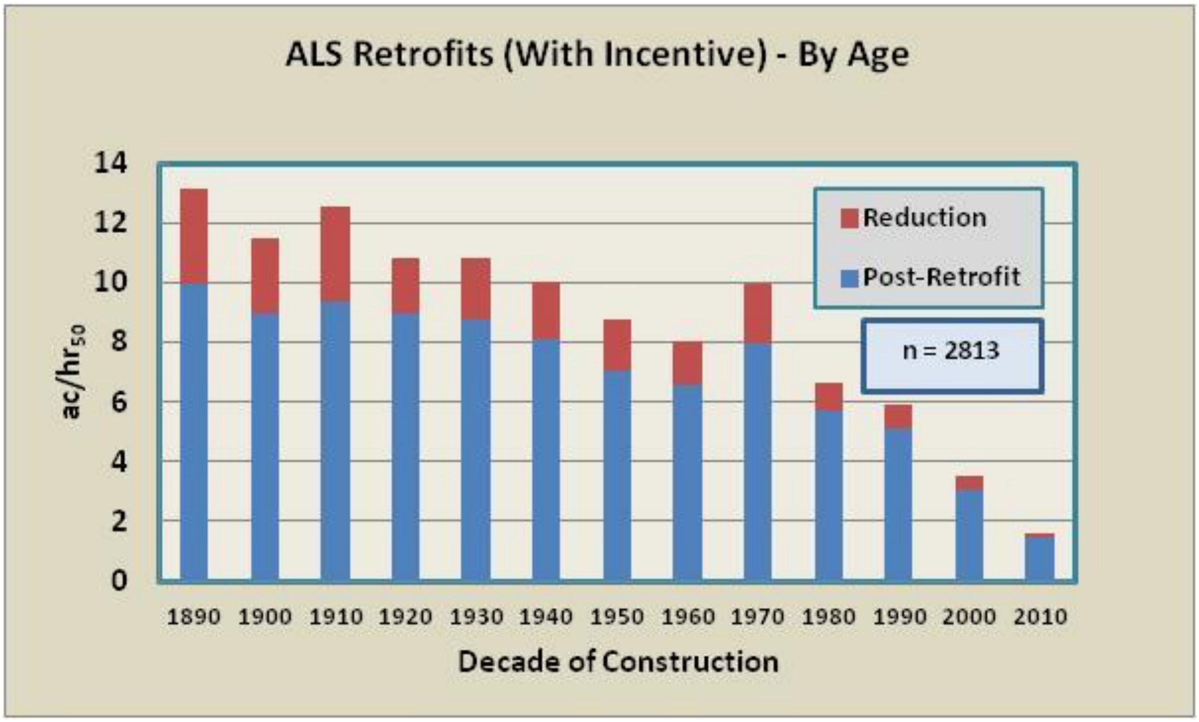

ALS Retrofits (With Incentive) - By Age
Reduction
Post-Retrofit
n = 2813
ac/hr50
0
2
4
6
8
10
12
14
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Decade of Construction

Fig. 3.4

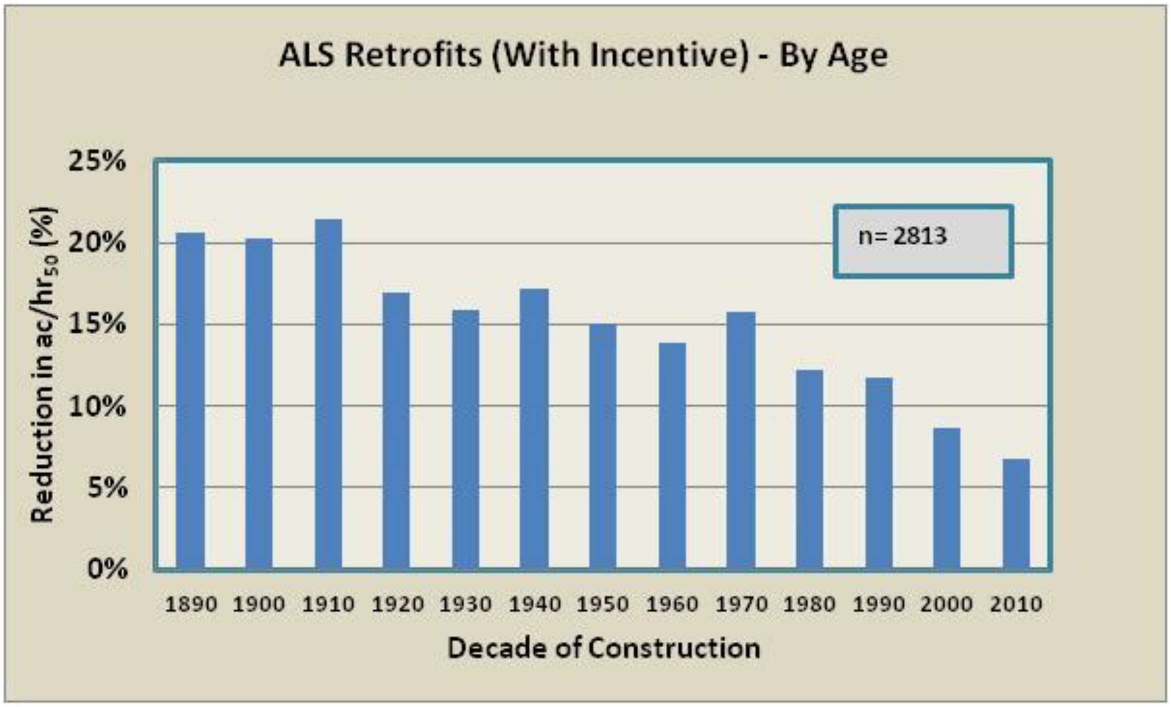

ALS Retrofits (With Incentive) - By Age
n= 2813
Reduction in ac/hr50 (%)
0%
5%
10%
15%
20%
25%
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Decade of Construction

Fig. 3.5

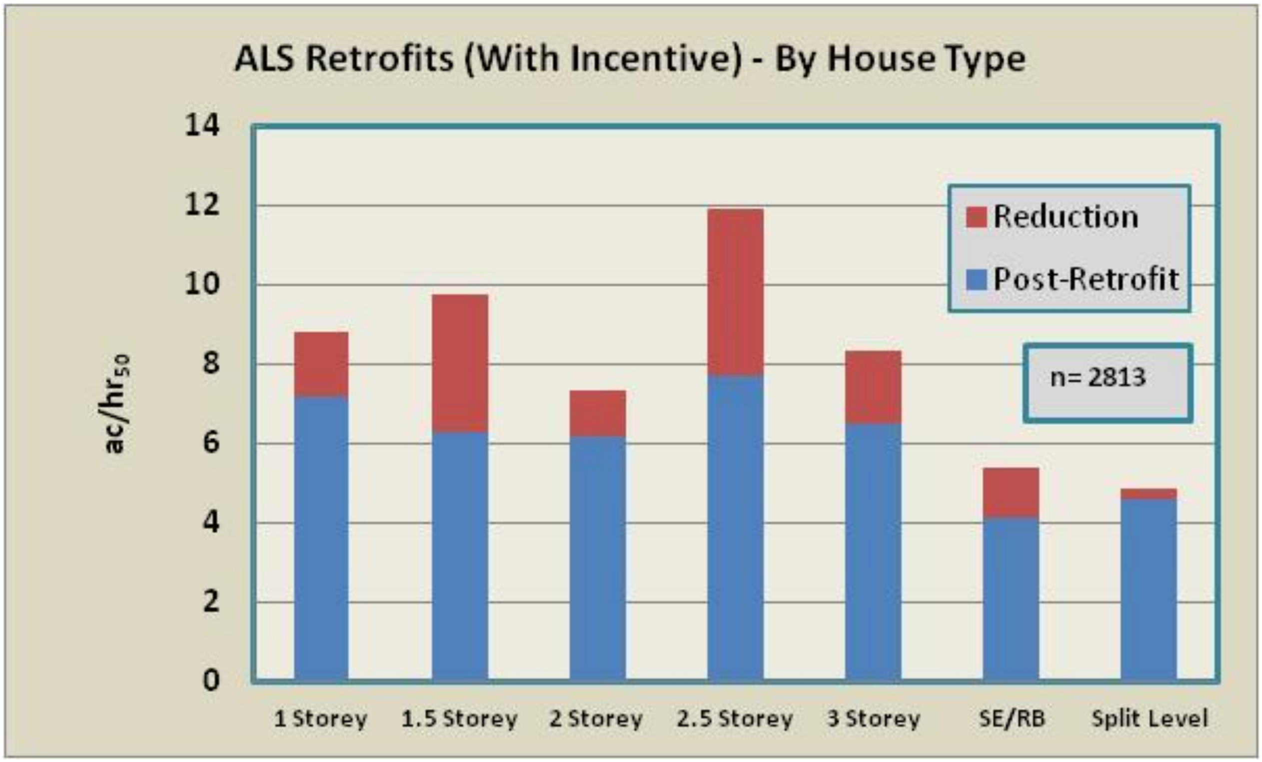

ALS Retrofits (With Incentive) - By House Type
ac/hr50
14
12
10
8
6
4
2
0
Reduction
Post-Retrofit
n= 2813
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 3.6

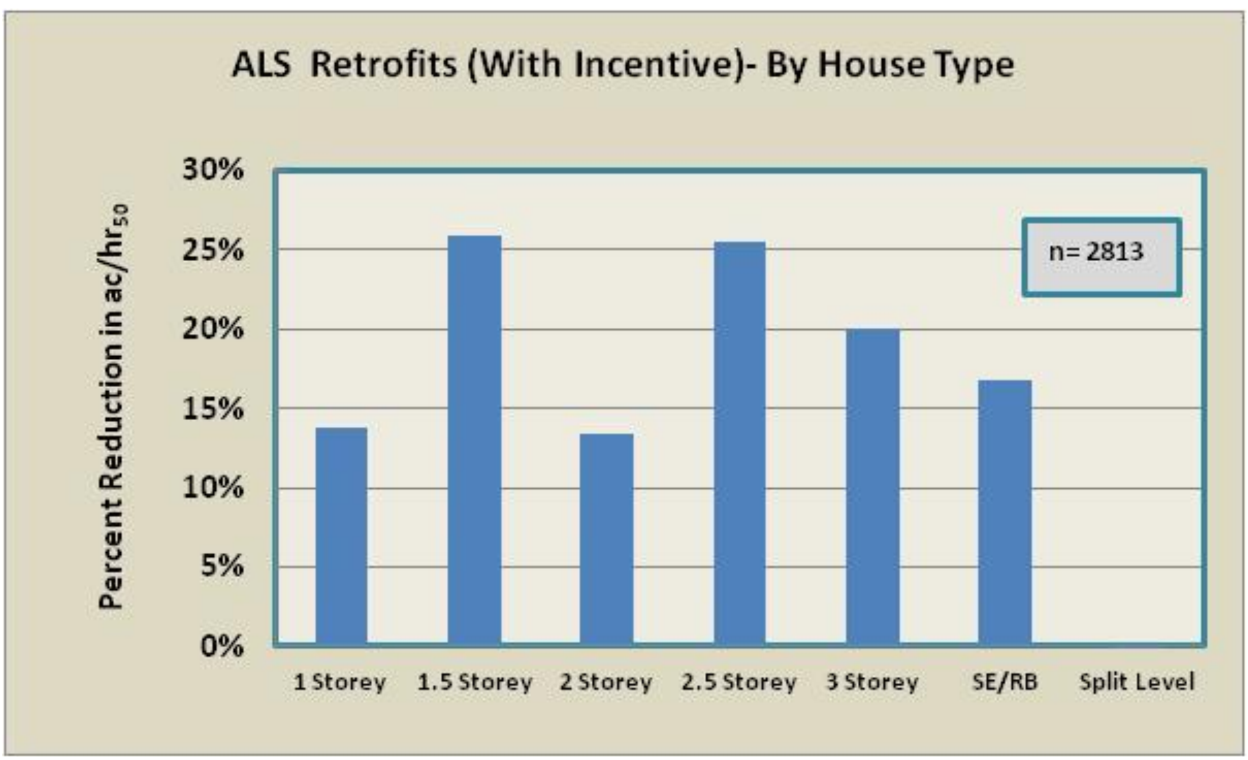
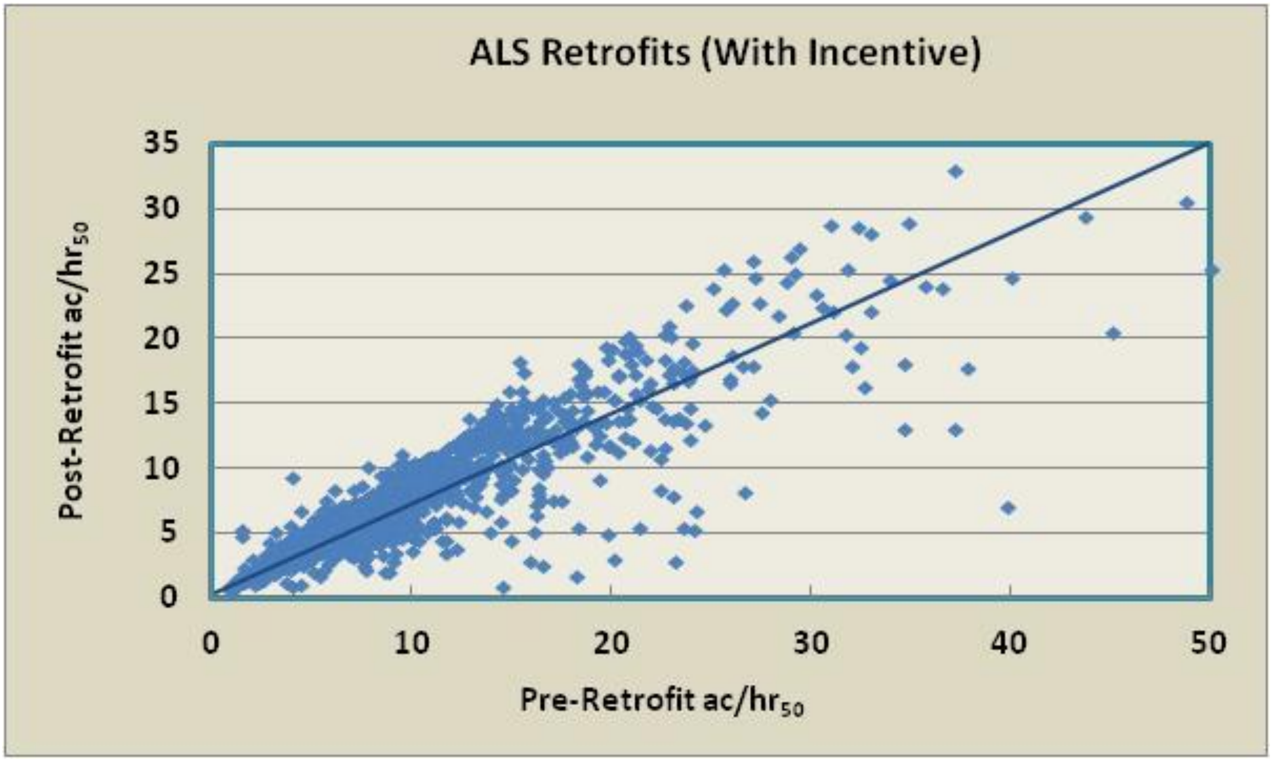

ALS Retrofits (With Incentive)- By House Type
Percent Reduction in ac/hr50
30%
25%
20%
15%
10%
5%
0%
n= 2813
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 3.7



ALS Retrofits (With Incentive)
35
30
25
20
15
10
5
0
0
10
20
30
40
50
Post-Retrofit ac/hr$_{50}$
Pre-Retrofit ac/hr$_{50}$

Section 4
Attic Retrofits

4.1 Description: Attic retrofits generally consist of upgrading the attic insulation levels, plus some air leakage sealing of the attic area. This may range from as basic as merely adding a small amount of extra insulation to as comprehensive as complete removal of all existing insulation, air leakage sealing of the entire attic area followed by application of new insulation to higher-than-original levels. Ideally, the air leakage sealing should be carried out with the assistance of a blower door to identify the major leakage locations.

In all cases however, the extent of ALS which took place with the survey houses is unknown.

Sealing of the attic area is critical for two reasons. First, since the ceiling below an attic is at the top of the house, the air exfiltration forces (due to stack effect) will be at their maximum thereby enhancing air leakage into the attic. Second, air leakage from the house into an unheated attic space can easily lead to condensation problems. From a moisture perspective, attics are particularly vulnerable since most ceilings are horizontal thereby precluding drainage to the outdoors.

Typical attic areas which ALS might address include:

- Attic hatches
- Pot lights
- Ceiling-mounted electrical fixtures
- Chimney or heating vent penetrations
- Tops of partition walls
- Plumbing penetrations (primarily the drain/waste/vet stack)
- Floor joist penetrations into the attic space on 1½, 2½ and other partial storey houses

4.2 Sample Size: 36,136 houses

4.3 Discussion:

- The 36,136 houses which underwent attic retrofits experienced an average reduction in the measured ac/hr_{50} of 13%, while the absolute reduction was 1.04 ac/hr_{50}.

- Provincially, the measured reduction in ac/hr_{50} values varied from a low of 9% in Manitoba and Alberta (ignoring the small sample of 3 houses from NT) to a high of 20% in British Columbia. As a rough generalization, provinces which had the leakiest houses also experienced the greatest reduction in their mean ac/hr_{50} values, although this was not always the case. For example, the leakiest houses were located in Newfoundland and New Brunswick, yet their reductions in air leakage were moderate.

- Once again, house age had a pronounced impact on both the initial airtightness and the improvement which the retrofit was able to achieve. Older houses were leakier than new houses and retrofitting older houses to reduce air leakage was more effective than it was on newer structures. The oldest houses, those constructed in the 1890's, were the leakiest in the sample (10.66 ac/hr_{50}) while houses built post-2010 achieved reductions of only 3%.

- Partial storey (1½ and 2½ storey) and 3 storey houses were the leakiest house types tested and the ones which experienced the most impressive reductions in their air leakage. The 1½ and 2½ storey houses had their leakage rates reduced by 16% and 22% respectively, while the 3 storey houses also demonstrated a 16% reduction. The smallest reductions were achieved in the split entry/raised bungalow and the split level house categories.

Overview Statistics:

Type of Retrofit Measure: Attic Retrofits			Number of retrofits: 36,136	
	Measured Airtightness (ac/hr$_{50}$)			
	Pre-Retrofit	Post-Retrofit	Change	Percent Change
Mean	6.37	5.33	1.04	13%
Min	0.46	0.45	-13.35	-636%
Max	52.85	41.49	39.59	93%
Std. Dev.	3.89	2.93	1.84	17%
C of V	0.61	0.55	1.77	1.36

By Province:

Province or Territory	Number Of Retrofits	Measured Airtightness (ac/hr$_{50}$)			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
B.C.	5180	7.78	6.02	1.76	20%
Alberta	1760	5.04	4.41	0.63	9%
Saskatchewan	823	5.36	4.53	0.83	12%
Manitoba	1554	4.52	4.03	0.49	9%
Ontario	14,889	6.45	5.50	0.95	12%
Quebec	4807	5.21	4.35	0.86	13%
New Brunswick	3223	5.03	4.35	0.68	10%
Nova Scotia	2852	8.27	6.77	1.50	14%
PEI	147	5.85	5.08	0.77	11%
Newfoundland	893	8.62	7.45	1.17	12%
NWT	3	7.89	7.10	0.78	6%
Yukon	5	4.99	4.12	0.86	18%
Sample Weighted Avg.	36,136	6.37	5.33	1.04	13%

By Decade of Construction:

Decade of Construction	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1890	713	10.66	8.56	2.10	17%
1900	602	11.05	9.02	2.02	15%
1910	558	10.26	8.51	1.75	14%
1920	768	9.71	7.88	1.83	16%
1930	684	9.65	8.01	1.63	14%
1940	1506	9.01	7.43	1.59	15%
1950	4496	7.41	6.19	1.22	14%
1960	5990	6.47	5.43	1.04	13%
1970	9880	5.81	4.91	0.90	12%
1980	6025	5.45	4.57	0.88	13%
1990	3475	4.41	3.68	0.73	13%
2000	1418	3.37	2.97	0.40	8%
2010	21	2.01	1.92	0.08	3%
Sample Weighted Avg.	36,136	6.37	5.33	1.04	13%

By House Type:

House Type	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1 Storey	20,765	6.16	5.17	0.98	12%
1½ Storey	627	8.67	6.89	1.78	16%
2 Storey	13,643	6.62	5.51	1.11	14%
2½ Storey	60	9.39	7.06	2.33	22%
3 Storey	254	7.92	6.35	1.57	16%
SE/RB	433	4.59	4.13	0.45	8%
Split Level	354	5.63	4.97	0.66	9%
Sample Weighted Avg.	36,136	6.37	5.33	1.04	13%

Fig. 4.1

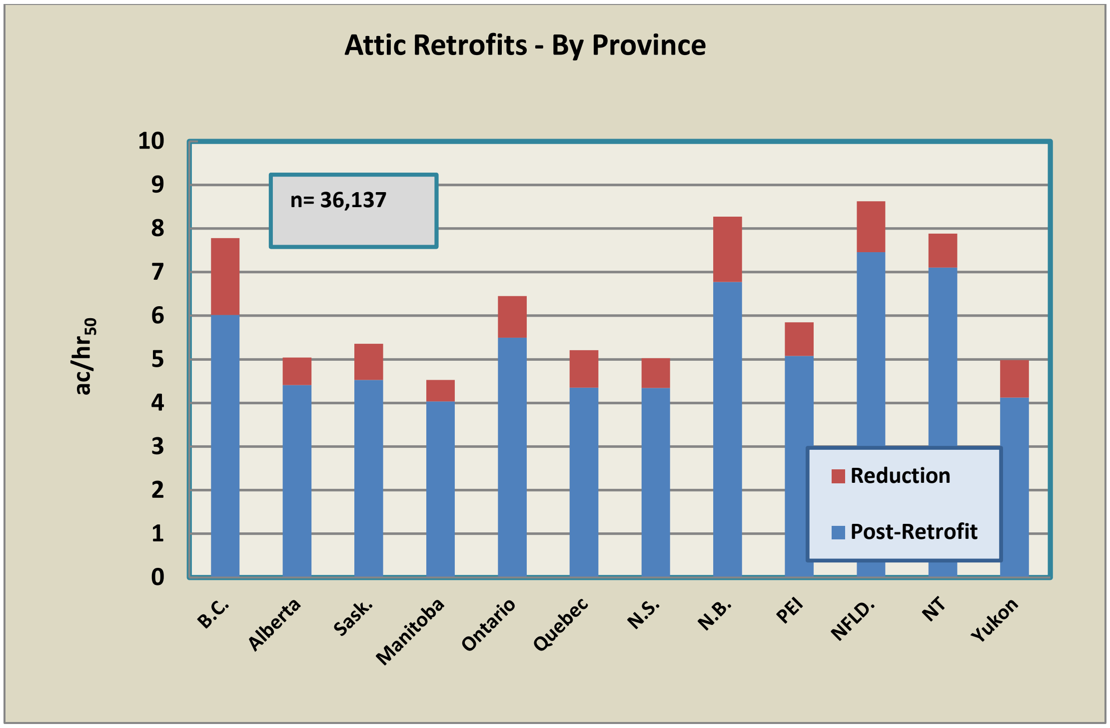

Attic Retrofits - By Province
ac/hr50
10
9
8
7
6
5
4
3
2
1
0
n= 36,137
Reduction
Post-Retrofit
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NT
Yukon

Fig. 4.2

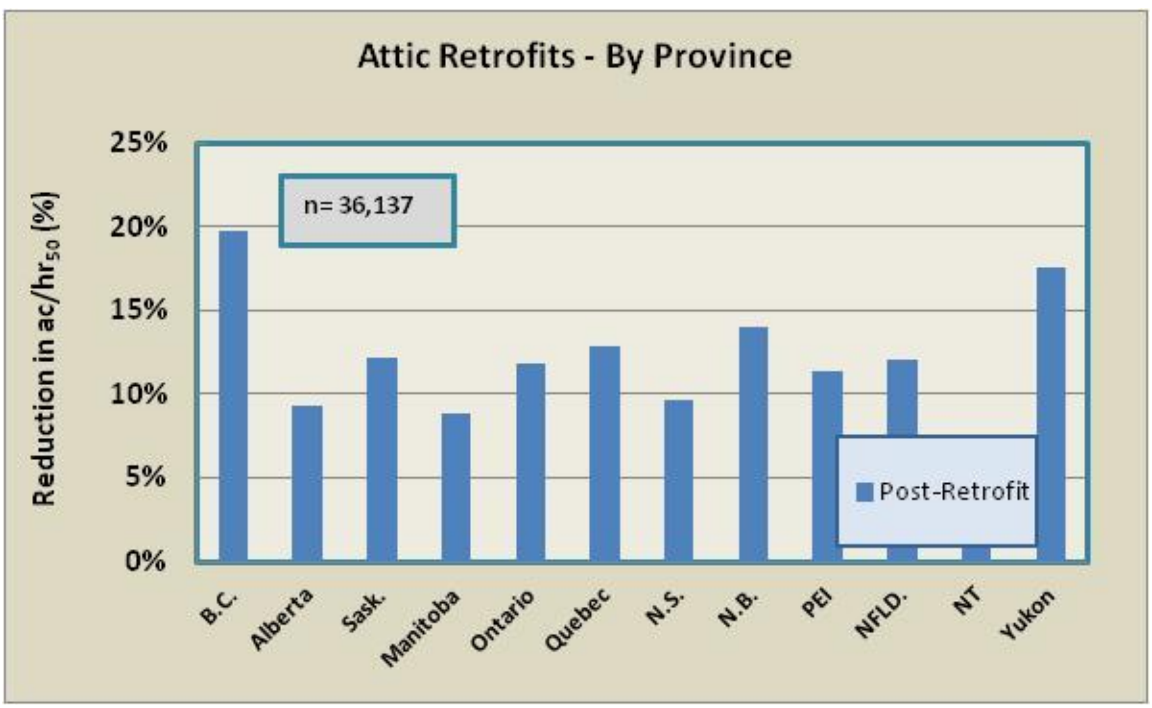
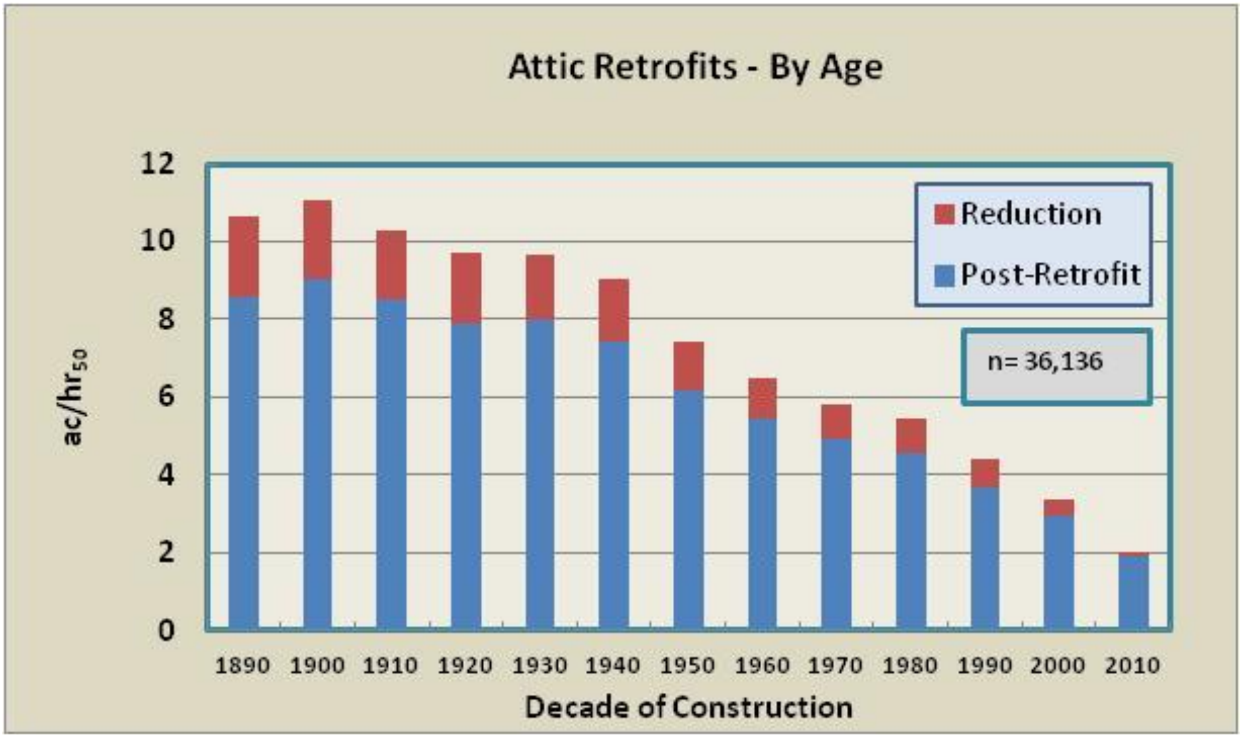
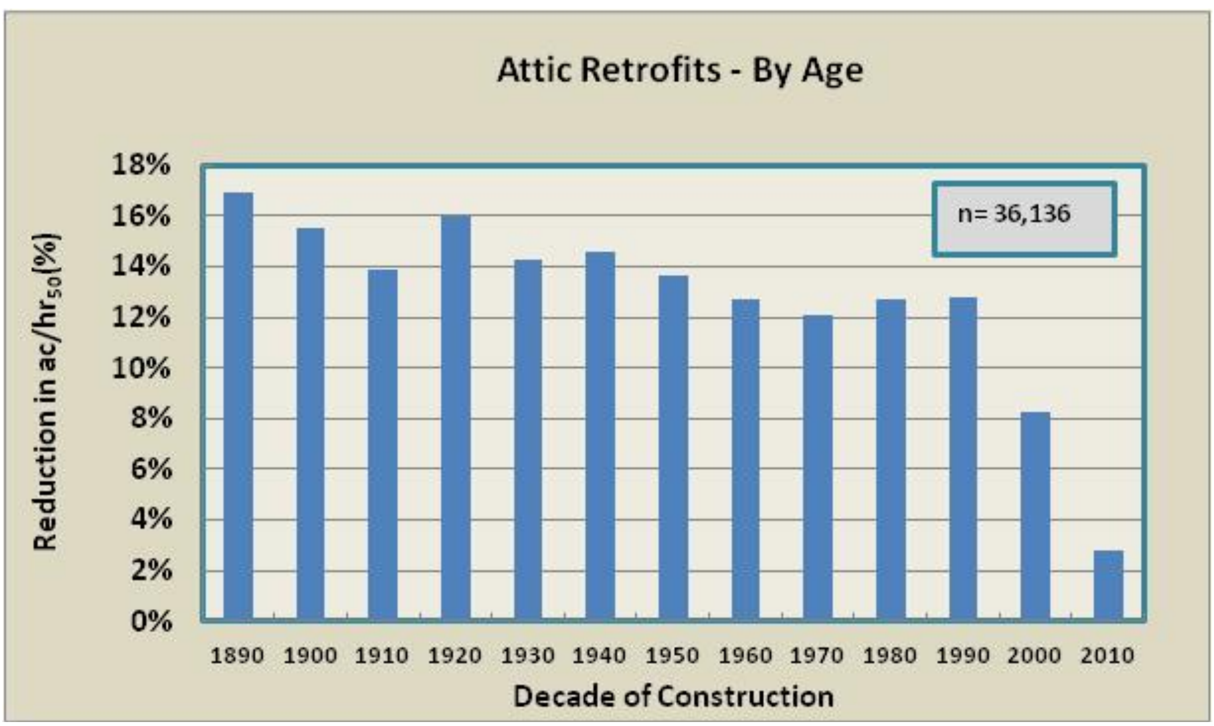

Attic Retrofits - By Province
Reduction in ac/hr50 (%)
25%
20%
15%
10%
5%
0%
n= 36,137
Post-Retrofit
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NT
Yukon

Fig. 4.3



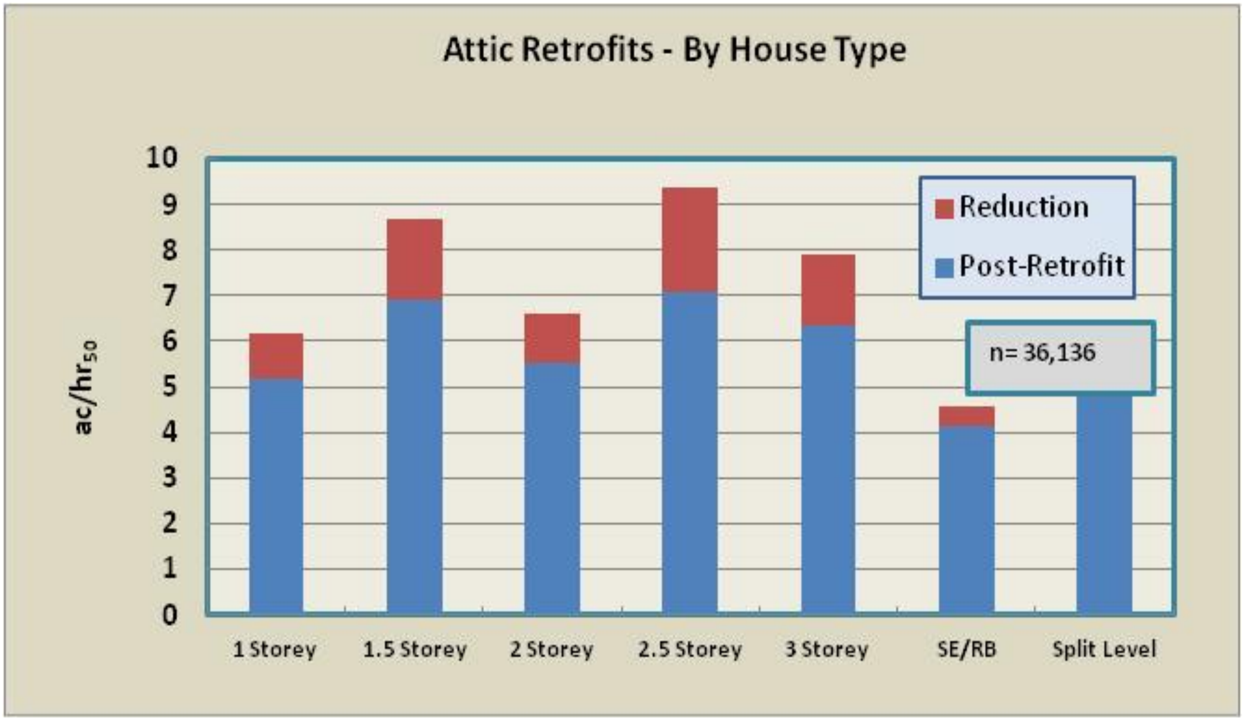
Attic Retrofits - By Age
12
10
8
6
4
2
0
ac/hr50
Reduction
Post-Retrofit
n= 36,136
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Decade of Construction

Fig. 4.4



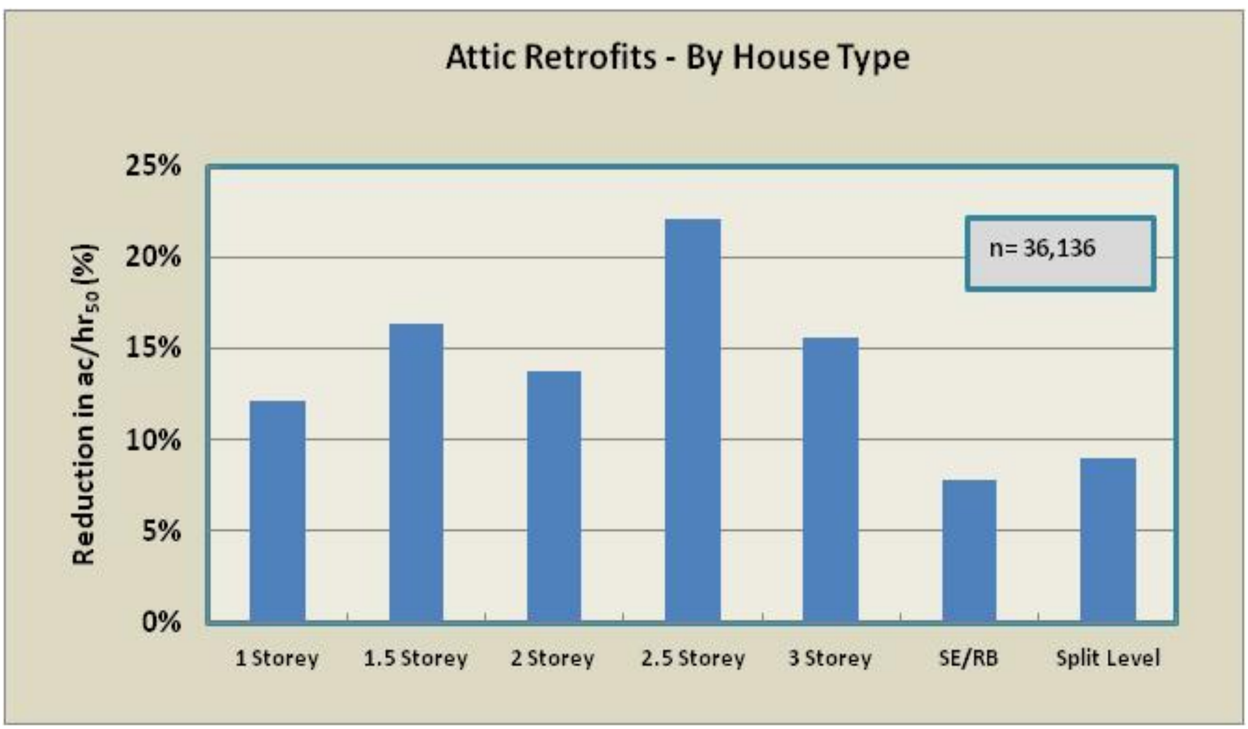
Attic Retrofits - By Age
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
Reduction in ac/hr50(%)
n= 36,136
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Decade of Construction

Fig. 4.5



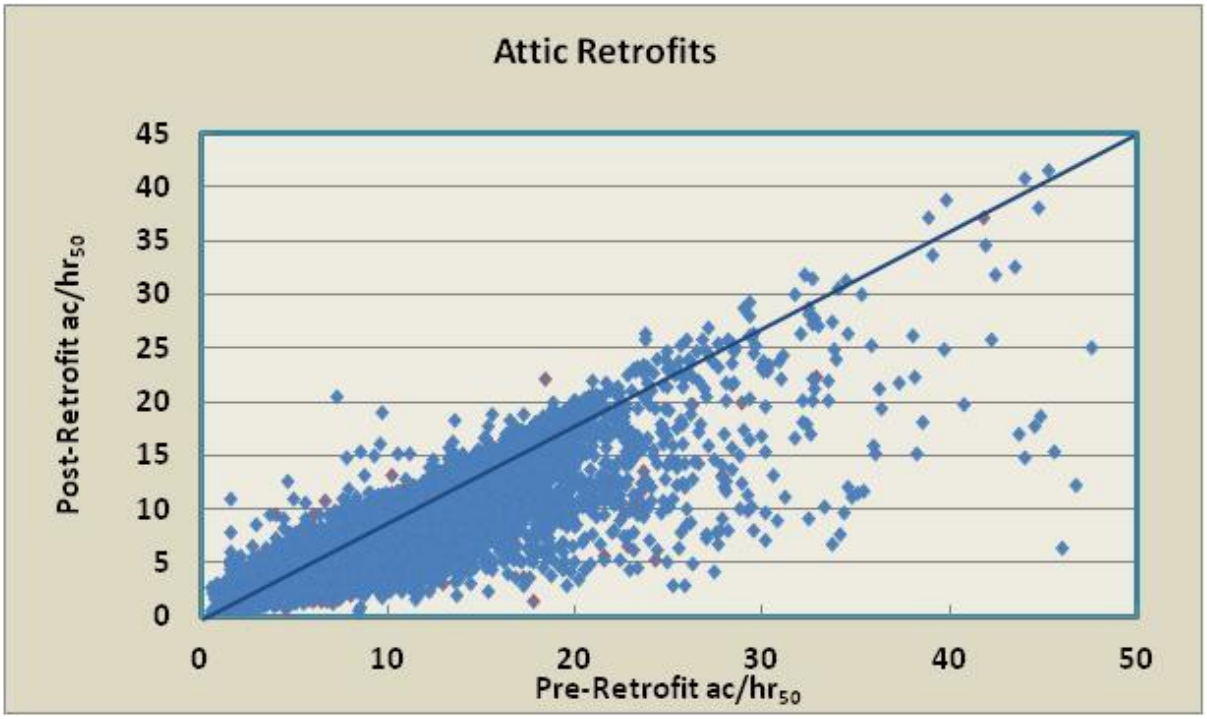
Attic Retrofits - By House Type
Reduction
Post-Retrofit
n= 36,136
ac/hr50
10
9
8
7
6
5
4
3
2
1
0
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 4.6



Attic Retrofits - By House Type
n= 36,136
Reduction in ac/hr50 (%)
25%
20%
15%
10%
5%
0%
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 4.7



Attic Retrofits
Post-Retrofit ac/hr50
Pre-Retrofit ac/hr50
0
5
10
15
20
25
30
35
40
45
0
10
20
30
40
50

Section 5
Main Wall Retrofits

5.1 Description: Main wall retrofits basically consist of increasing the amount of insulation in the wall cavities, usually by blowing it in through the exterior cladding or adding a layer of rigid or semi-rigid insulation to the exterior. Many of the project houses would have had uninsulated wall cavities or cavities only partially insulated (e.g. R-8 batts in 2x4 cavities).

In addition to the extra insulation, and depending on the contractor and/or homeowner, the work might also include some basic ALS measures. However, even in the absence of dedicated air leakage sealing measures, adding extra insulation to wall cavities almost always reduces the amount of main wall leakage, particularly if blown-in insulations are used since they have a higher density than (say) batt insulation. In some cases, the wall retrofits would have consisted of application of an additional layer of insulation to the house exterior. This would also reduce air leakage, particularly if sheet insulation was used and the joints sealed between individual pieces.

Typical ALS measures which might be applied during a main wall retrofit include:

- Installing gaskets on exterior wall electrical outlets
- Sealing baseboards and wall/floor junctions
- Sealing door and window trim
- Sealing electrical penetrations into the walls
- Taping or sealing of board insulation added to the exterior of the main walls

5.2 Sample Size: 9989 houses

5.3 Discussion:

- The 9989 houses which underwent retrofits to their main walls experienced an average reduction in the measured ac/hr_{50} of 15%, while the absolute reduction was 1.53 ac/hr_{50}.

- Provincially, the measured reduction in ac/hr_{50} values varied from a low of 9% in Manitoba and Alberta (ignoring the small sample sizes from NWT and the Yukon) to a high of 18% in British Columbia. Generally, provinces which had the leakiest houses also experienced the greatest reduction in their mean ac/hr_{50} values.

- Once again, house age had a pronounced impact on both the initial airtightness and the improvement which the retrofit was able to achieve. Older houses were leakier than new houses and retrofitting older houses to reduce air leakage was more effective than it was on newer structures. The oldest houses, those constructed in the 1890's, were the leakiest in the sample (11.88 ac/hr_{50}) while those constructed post-2000 had a pre-retrofit airtightness of 3.16 ac/hr_{50}.

- Partial (1½, 2½), 2 and 3 storey houses displayed the highest, pre-retrofit ac/hr_{50} values. However, house type had less influence on the measured reductions in air leakage than was observed for ALS or attic retrofits. Given the target of the retrofits (walls), this was not surprising.

Overview Statistics:

Type of Retrofit Measure: Main Wall Retrofits			**Number of retrofits:** 9989	
	Measured Airtightness (ac/hr$_{50}$)			
	Pre-Retrofit	Post-Retrofit	Change	Percent Change
Mean	7.92	6.39	1.53	15%
Min	0.73	0.62	-6.52	-184%
Max	49.26	43.33	43.19	91%
Std. Dev.	4.98	3.67	2.58	18%
C of V	0.63	0.57	1.68	1.18

By Province:

Province or Territory	Number Of Retrofits	**Measured Airtightness (ac/hr$_{50}$)**			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
B.C.	516	10.09	7.89	2.20	18%
Alberta	337	5.61	4.73	0.89	9%
Saskatchewan	791	5.57	4.81	0.76	9%
Manitoba	327	6.85	5.67	1.18	13%
Ontario	3926	8.52	6.85	1.67	16%
Quebec	1739	6.55	5.16	1.39	16%
New Brunswick	690	6.72	5.59	1.12	12%
Nova Scotia	1359	9.40	7.56	1.85	16%
PEI	51	9.18	7.46	1.72	15%
Newfoundland	234	10.90	8.77	2.14	18%
NWT	15	6.85	6.62	0.23	5%
Yukon	4	4.14	3.12	1.02	26%
Sample Weighted Avg.	9989	7.92	6.39	1.53	15%

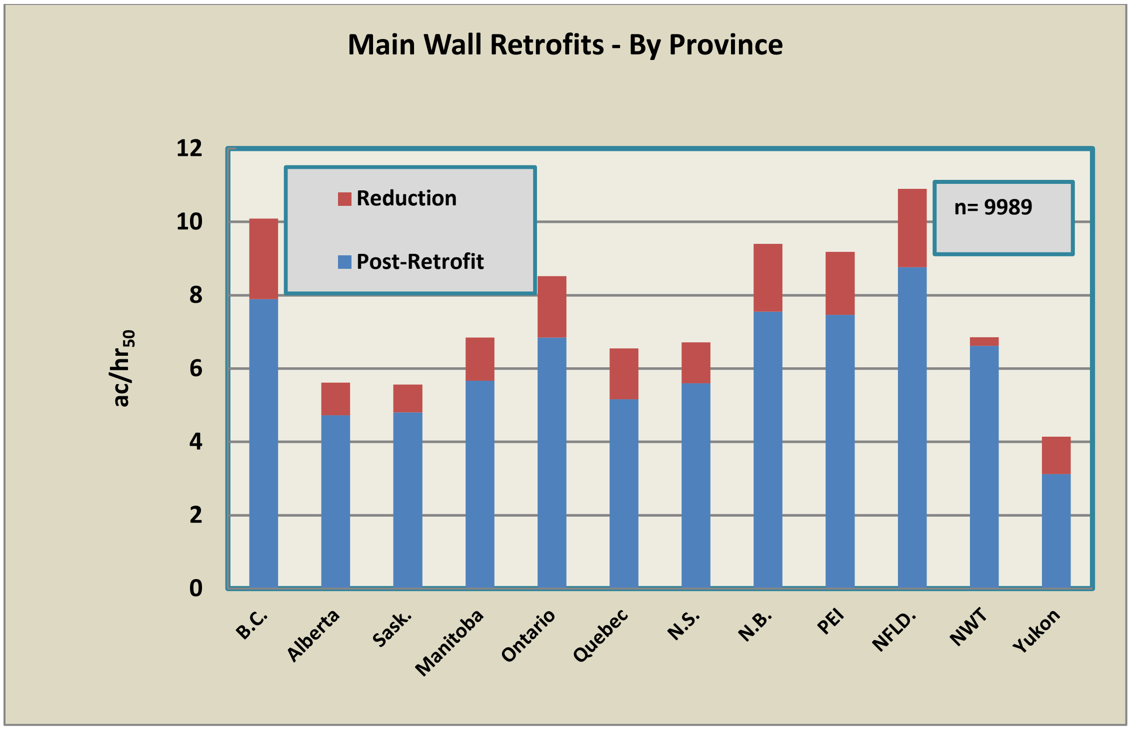
By Decade of Construction:

Decade of Construction	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1890	518	11.88	9.21	2.67	20%
1900	534	11.29	8.76	2.53	19%
1910	515	10.97	8.57	2.40	20%
1920	638	10.18	8.10	2.08	18%
1930	515	10.41	8.08	2.33	20%
1940	1046	9.28	7.43	1.85	17%
1950	1978	7.80	6.42	1.38	15%
1960	1255	6.36	5.22	1.13	13%
1970	1960	5.60	4.69	0.91	12%
1980	761	5.42	4.45	0.97	14%
1990	215	4.99	4.21	0.77	10%
2000	54	3.16	2.78	0.39	9%
2010	0				
Sample Weighted Avg.	9989	7.92	6.39	1.53	15%

By House Type:

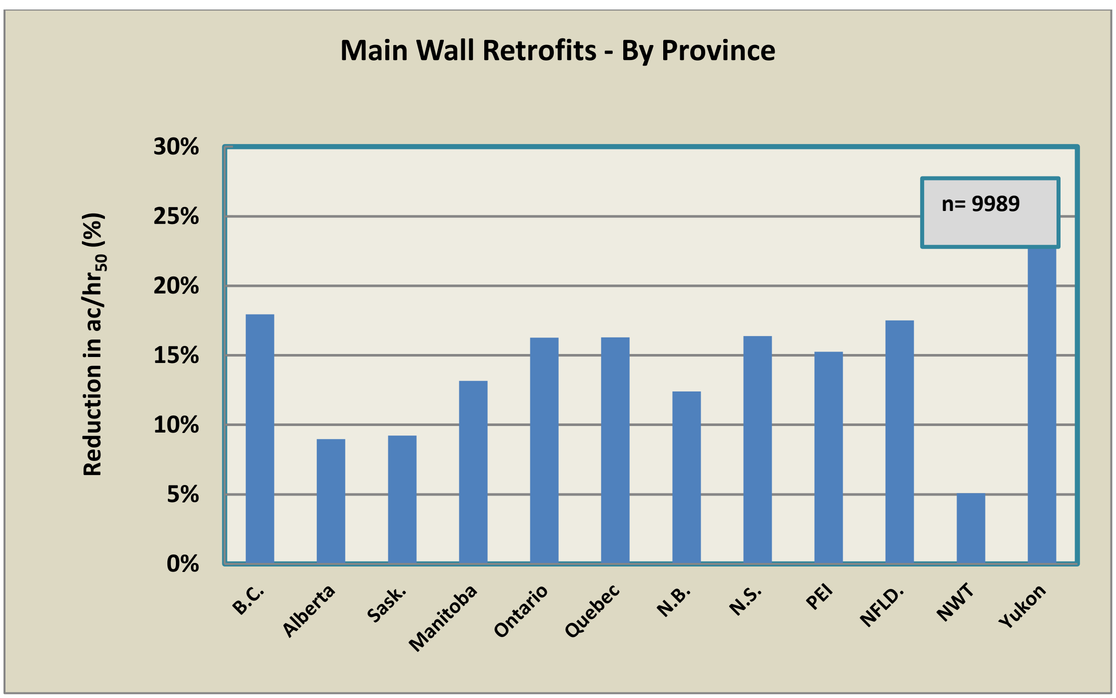
House Type	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change %)
1 Storey	4943	6.65	7.84	2.04	18%
1½ Storey	642	9.80	8.17	2.11	16%
2 Storey	3856	9.10	5.89	1.33	15%
2½ Storey	89	9.24	7.31	3.04	29%
3 Storey	374	9.62	7.43	2.04	21%
SE/RB	37	5.59	7.34	1.01	12%
Split Level	48	5.41	7.94	0.76	9%
Sample Weighted Avg.	9989	7.92	7.09	1.77	17%

Fig. 5.1



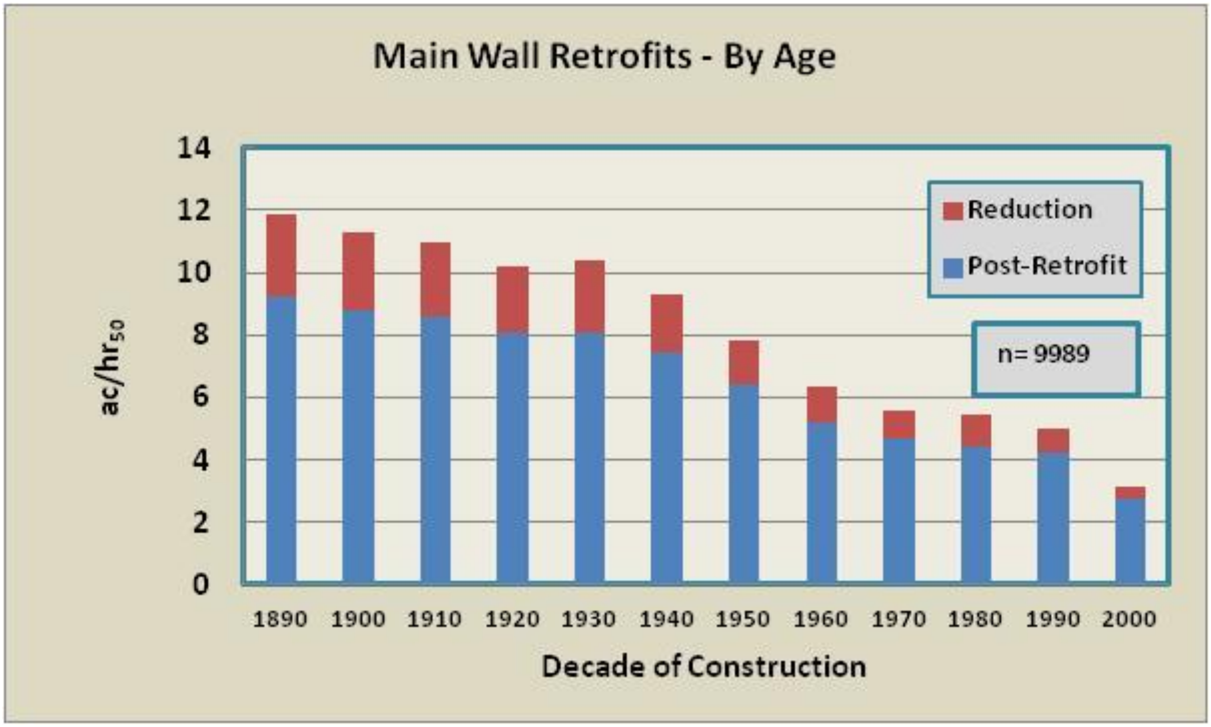
Main Wall Retrofits - By Province
Reduction
Post-Retrofit
n= 9989
ac/hr50
12
10
8
6
4
2
0
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon

Fig. 5.2



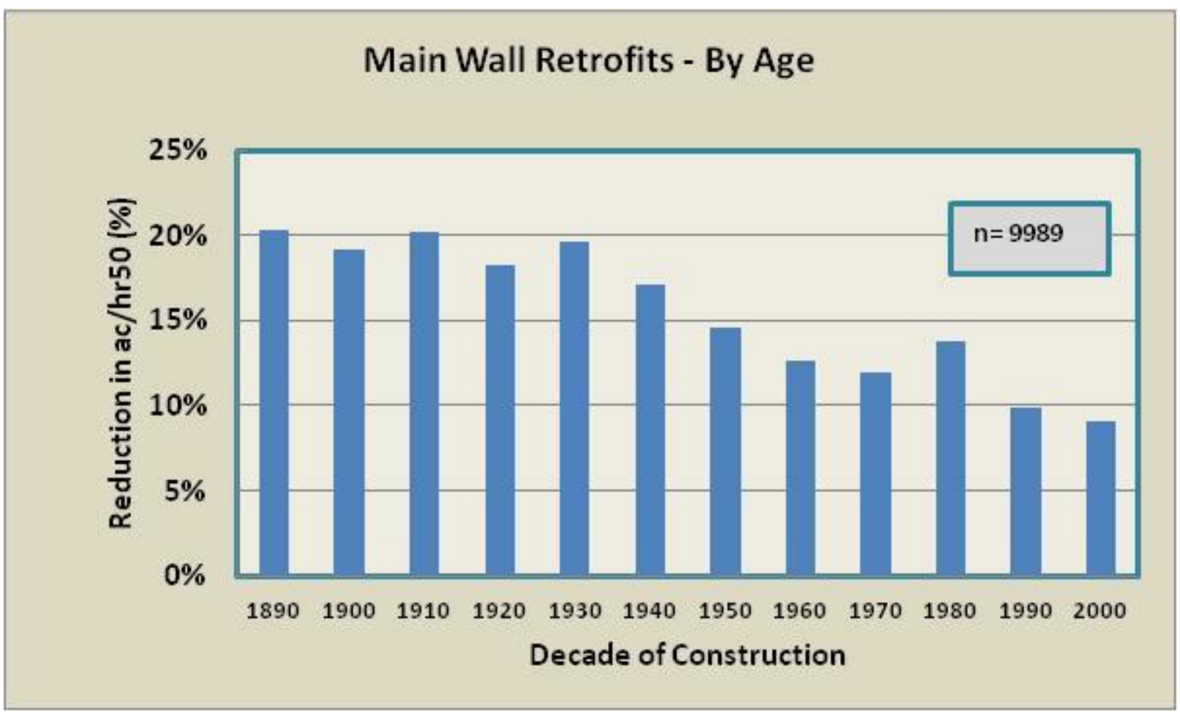
Main Wall Retrofits - By Province
n= 9989
Reduction in ac/hr50 (%)
30%
25%
20%
15%
10%
5%
0%
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.B.
N.S.
PEI
NFLD.
NWT
Yukon

Fig. 5.3



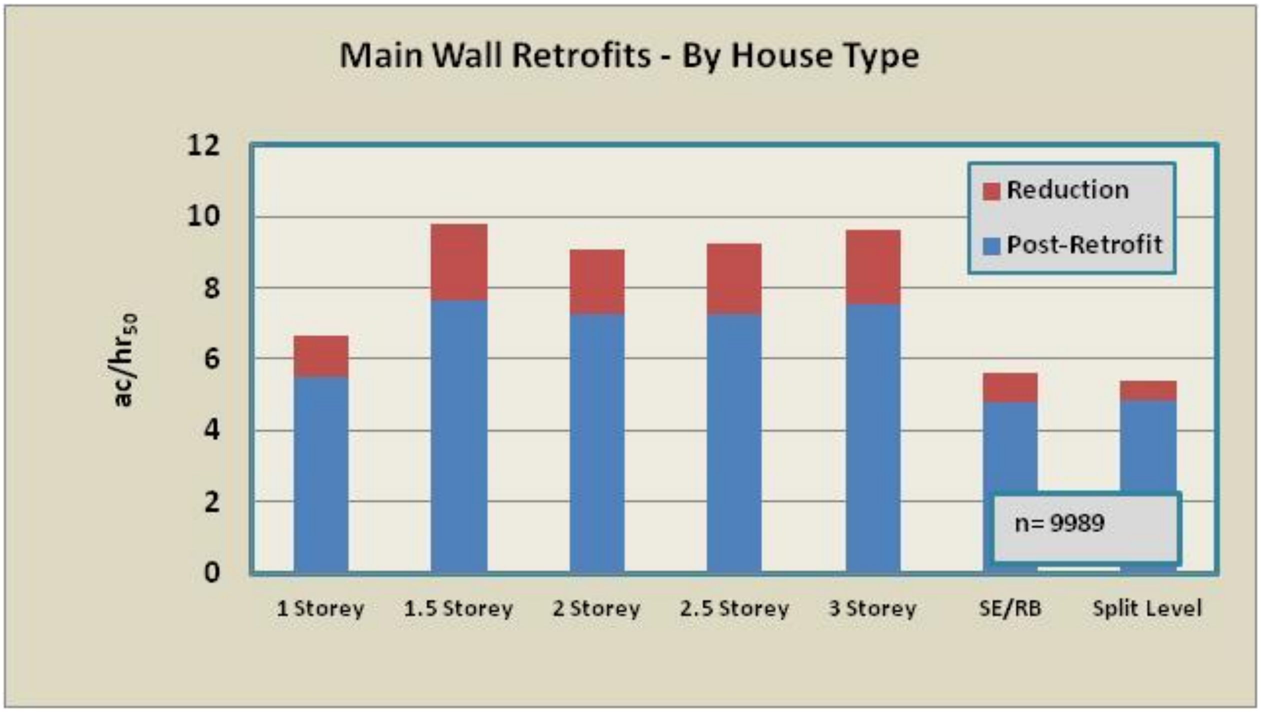
Main Wall Retrofits - By Age
14
12
10
8
6
4
2
0
ac/hr50
Reduction
Post-Retrofit
n= 9989
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
Decade of Construction

Fig. 5.4



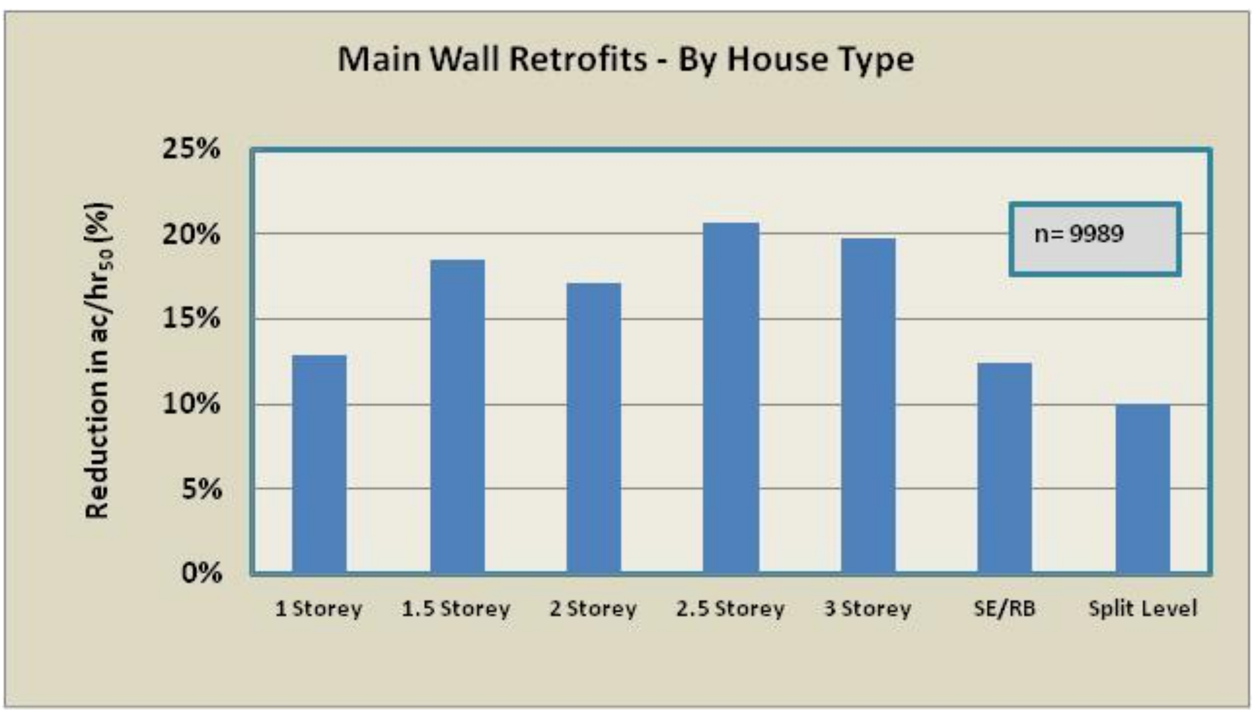
Main Wall Retrofits - By Age
25%
20%
15%
10%
5%
0%
Reduction in ac/hr50 (%)
n= 9989
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000
Decade of Construction

Fig. 5.5



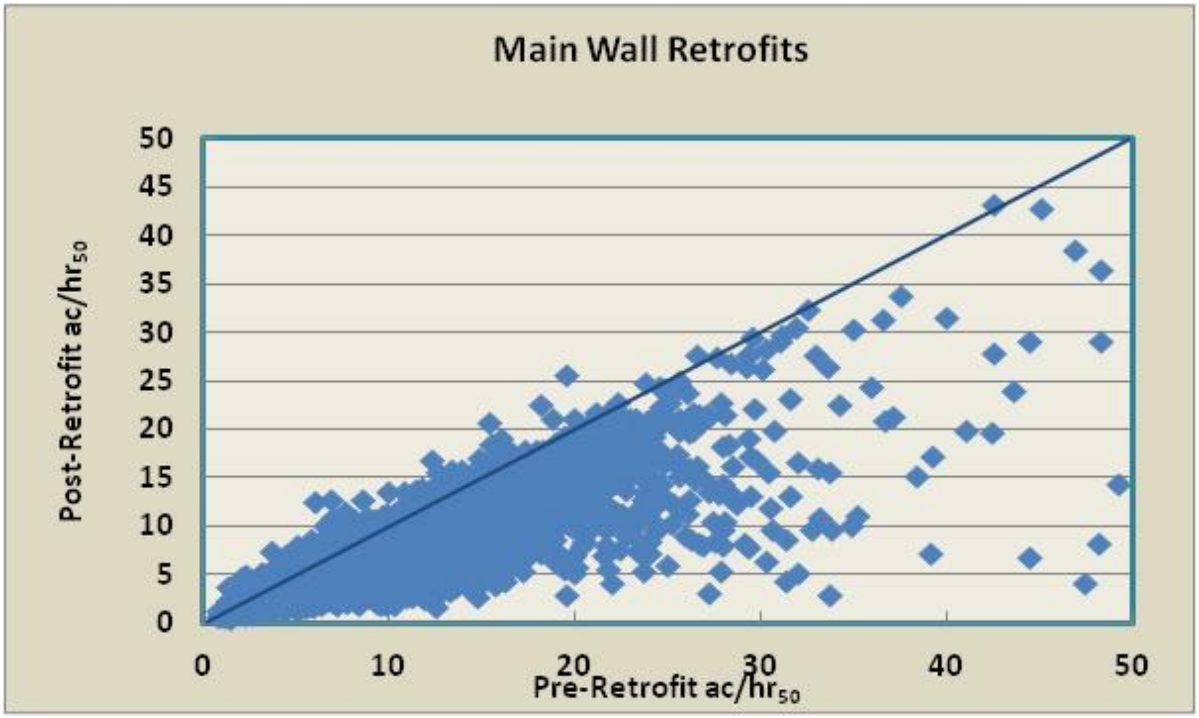
Main Wall Retrofits - By House Type
12
10
8
6
4
2
0
ac/hr50
Reduction
Post-Retrofit
n= 9989
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 5.6



Main Wall Retrofits - By House Type
25%
20%
15%
10%
5%
0%
Reduction in ac/hr50 (%)
n= 9989
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 5.7


Main Wall Retrofits
Post-Retrofit ac/hr50
Pre-Retrofit ac/hr50
0
5
10
15
20
25
30
35
40
45
50
0
10
20
30
40
50

Section 6
Foundation Retrofits

6.1 Description: The most common types of residential foundations in Canada are basements and crawl spaces. The main objective of foundation retrofits is to increase the thermal resistance of the foundation walls. However, some degree of air leakage sealing is usually included since the foundation, being at the bottom of the house, is subject to the strongest air infiltration forces - which create cold drafts. In many cases, the intersection between the foundation wall, floor system and the main wall of the house (i.e. the header area) is the largest single source of air leakage in a house, particularly if a sill plate foundation is used since it constitutes an intersection between three major house components (foundation wall, floor system and main wall). Likewise, foundation retrofits will likely have the largest impact on houses with air permeable cladding systems. Impermeable claddings, such as stucco, often seal any air leakage in this area.

Typical areas which might be sealed as part of a foundation retrofit include:

- Header area
- Electrical, plumbing and natural gas penetrations
- Floor drain or sump pit
- Floor perimeter as well as penetrations through the floor for teleposts, services, etc.

6.2 Sample Size: 23,214 houses

6.3 Discussion:

- The 23,214 houses which underwent foundation retrofits experienced an average reduction in the measured ac/hr_{50} of 14%, while the absolute reduction was 1.17 ac/hr_{50}. Overall, this category of retrofits displayed some of the most uniform percentage reductions in the entire study.

- Overall, the measured reductions in ac/hr_{50} values were fairly consistent between provinces. Ignoring the 3 house sample from the Yukon, all of the measured reductions were in the range of 10% to 15%. This is somewhat surprising given that one of the largest sources of air leakage in a wood frame house occurs at the foundation/floor system/wall intersection. Coupled with the different treatment which this area receives (i.e. cast-in-place vs. sill plate foundations) in different parts of the country, the uniformity of these results was unexpected.

- Once again, house age had a pronounced impact on both the initial airtightness and the improvement which the retrofit was able to achieve. Older houses were leakier than new houses and retrofitting older houses to reduce air leakage was more effective than it was on newer structures. The oldest houses, those constructed in the 1890's, were the leakiest in the sample (10.52 ac/hr_{50}) while those constructed in 2010 or later had a pre-retrofit airtightness of 2.12 ac/hr_{50}. One surprising result was that even for the newest houses, foundation retrofits produced a 10% to 12% reduction in leakage.

- While partial (1½, 2½), 2 and 3 storey houses displayed the highest, pre-retrofit ac/hr_{50} values, house type had less influence on the measured reductions in air leakage than was observed for most other types of retrofits.

- While foundation retrofits will save energy, they will generally have little impact on comfort levels in the house since the basement is usually not occupied on a regular basis such that reduced foundation air leakage may not be noticed by the homeowners.

Overview Statistics:

Type of Retrofit Measure: Foundation Retrofits			**Number:** 23,214	
	Measured Airtightness (ac/hr$_{50}$)			
	Pre-Retrofit	Post-Retrofit	Change	Percent Change
Mean	6.37	5.20	1.17	14%
Min	0.58	0.45	-9.22	-363%
Max	50.09	39.46	37.15	92%
Std. Dev.	4.22	3.16	1.98	18%
C of V	0.66	0.61	1.70	1.24

By Province:

Province or Territory	Number Of Retrofits	**Measured Airtightness (ac/hr$_{50}$)**			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
B.C.	1610	7.55	6.08	1.47	15%
Alberta	381	5.30	4.52	0.78	11%
Saskatchewan	1589	3.52	3.01	0.50	11%
Manitoba	794	5.46	4.71	0.75	11%
Ontario	8103	7.03	5.69	1.33	15%
Quebec	4171	6.20	5.02	1.18	15%
New Brunswick	2612	6.95	5.66	1.29	14%
Nova Scotia	3062	5.70	4.70	1.00	13%
PEI	179	5.16	4.38	0.78	10%
Newfoundland	698	6.34	5.28	1.06	14%
NWT	12	4.94	4.38	0.56	10%
Yukon	3	7.52	3.47	4.06	39%
Sample Weighted Avg.	23,214	6.37	5.20	1.17	14%

By Decade of Construction:

Decade of Construction	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1890	979	10.52	8.12	2.40	20%
1900	864	10.15	8.02	2.14	18%
1910	657	9.66	7.79	1.87	17%
1920	744	9.49	7.60	1.88	17%
1930	718	9.70	7.54	2.16	18%
1940	1483	8.82	7.03	1.80	17%
1950	3183	7.46	6.12	1.33	15%
1960	3213	6.15	5.10	1.05	14%
1970	3845	5.87	4.84	1.03	14%
1980	2799	5.10	4.25	0.85	13%
1990	1845	3.97	3.33	0.64	12%
2000	2703	2.74	2.40	0.34	10%
2010	181	2.12	1.76	0.36	11%
Sample Weighted Avg.	23,214	6.37	5.20	1.17	14%

By House Type:

House Type	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1 Storey	11,689	5.73	4.69	1.04	14%
1½ Storey	1228	8.85	7.00	1.85	17%
2 Storey	9255	6.76	5.54	1.22	14%
2½ Storey	126	9.40	7.38	2.02	18%
3 Storey	463	8.55	6.81	1.75	18%
SE/RB	116	4.05	3.59	0.46	10%
Split Level	157	5.18	4.28	0.90	13%
Sample Weighted Avg.	23,214	6.37	5.20	1.17	14%

Fig. 6.1

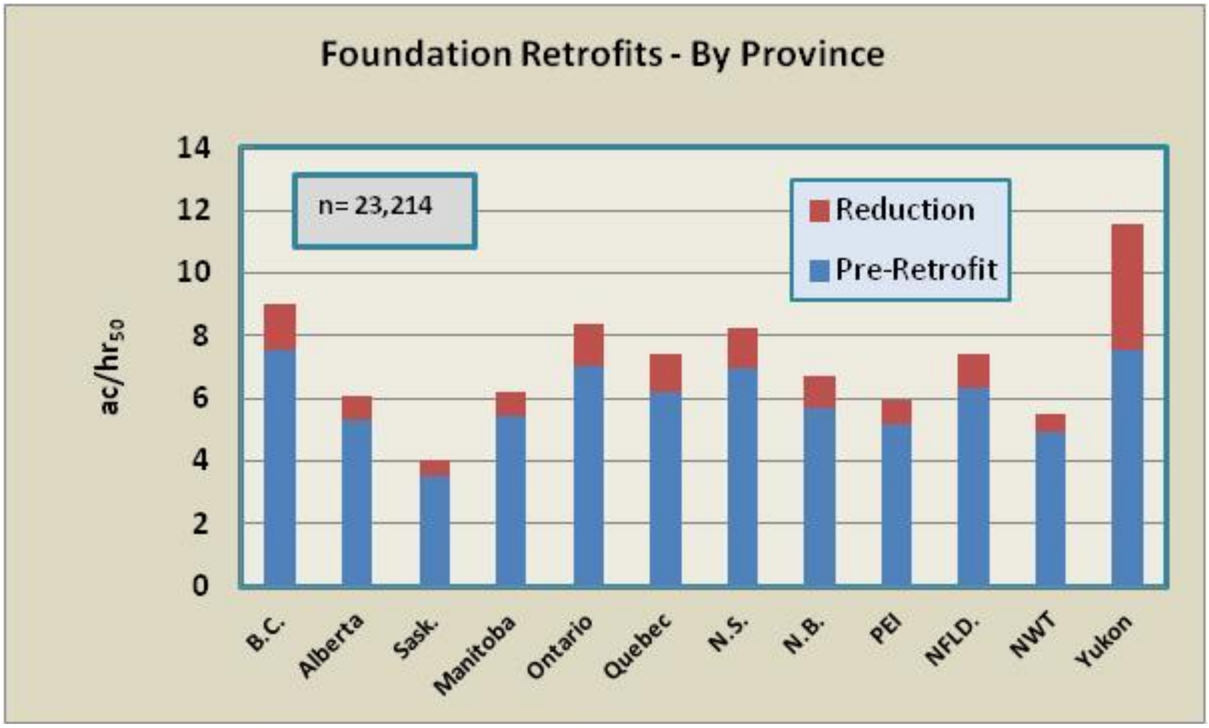

Foundation Retrofits - By Province
n= 23,214
Reduction
Pre-Retrofit
ac/hr50
14
12
10
8
6
4
2
0
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon

Fig. 6.2

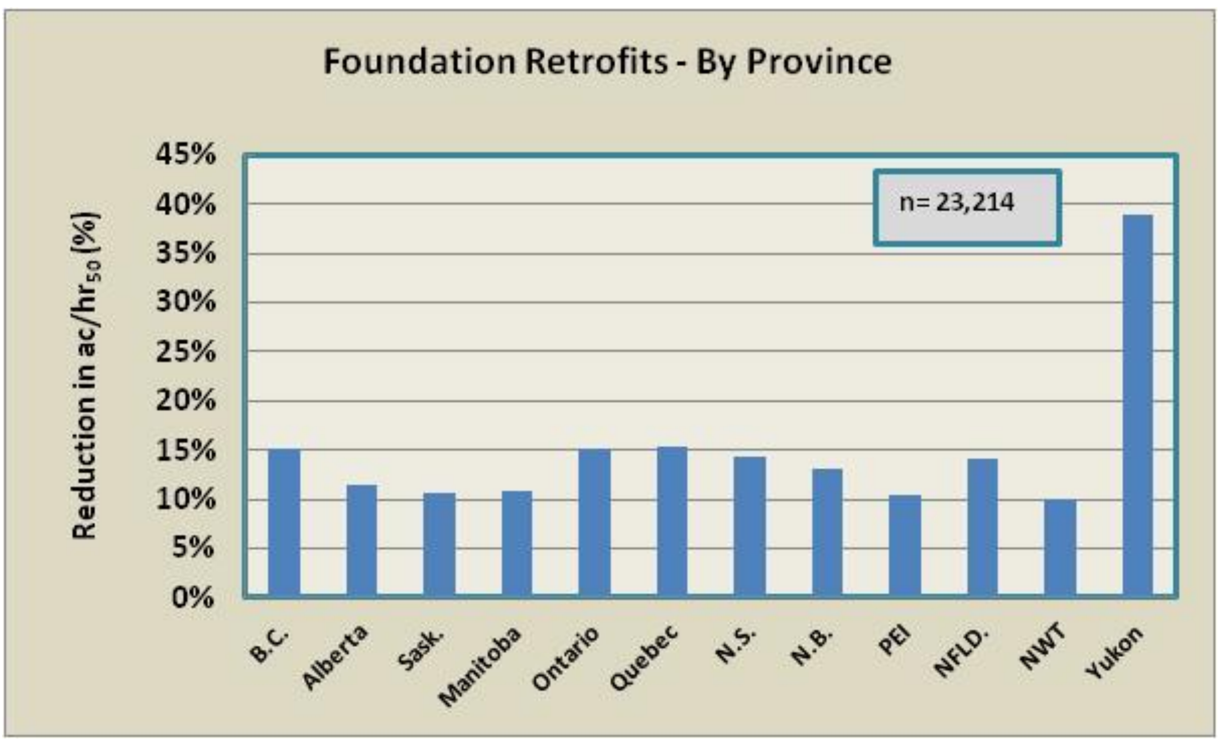

Foundation Retrofits - By Province
n= 23,214
Reduction in ac/hr50 (%)
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon

Fig. 6.3

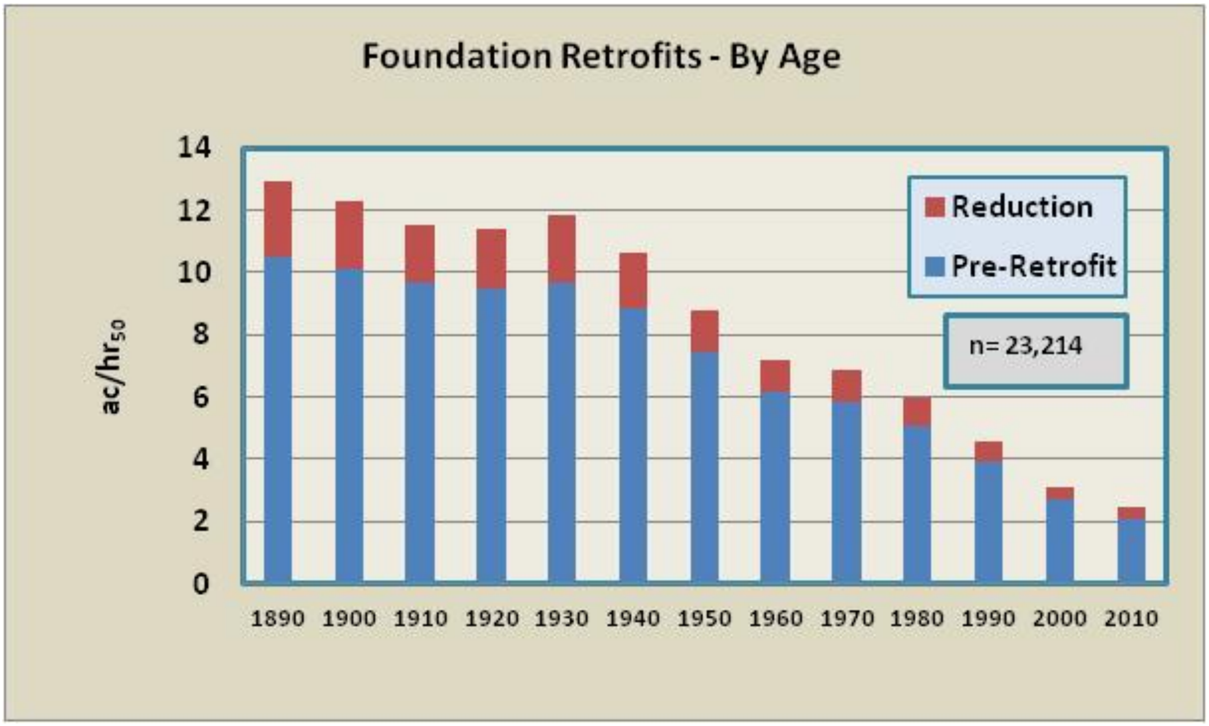

Foundation Retrofits - By Age
ac/hr50
14
12
10
8
6
4
2
0
Reduction
Pre-Retrofit
n= 23,214
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

Fig. 6.4

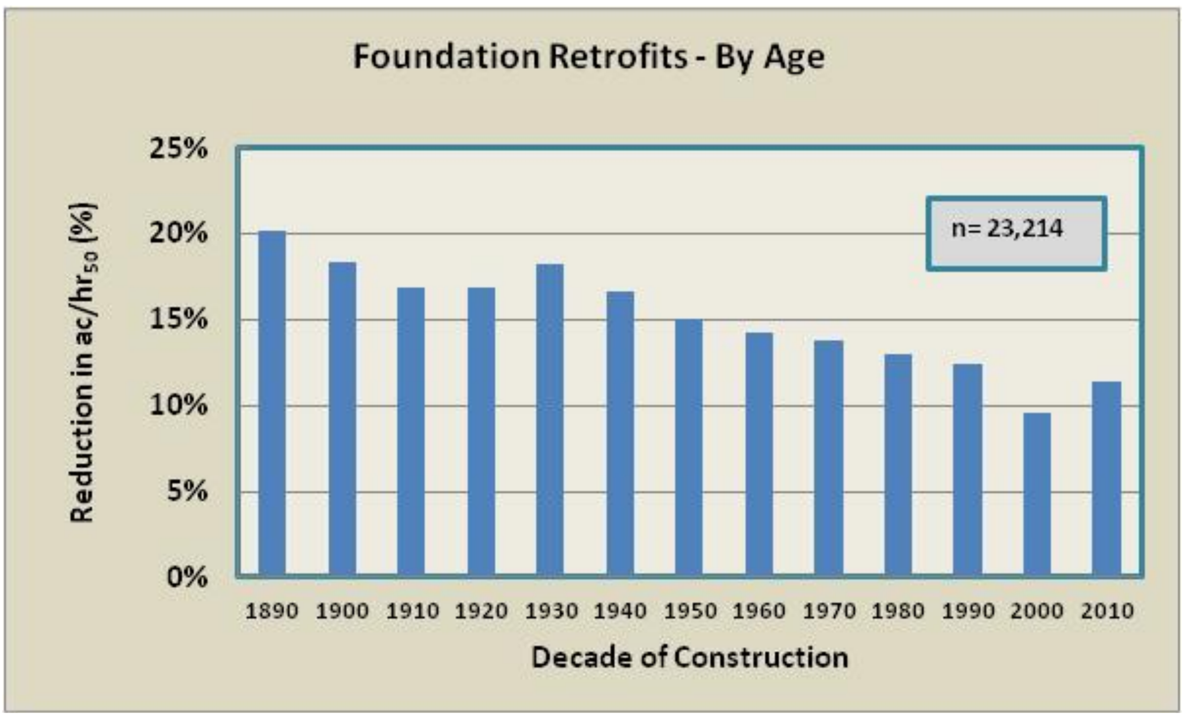

Foundation Retrofits - By Age
Reduction in ac/hr50 (%)
25%
20%
15%
10%
5%
0%
n= 23,214
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Decade of Construction

Fig. 6.5

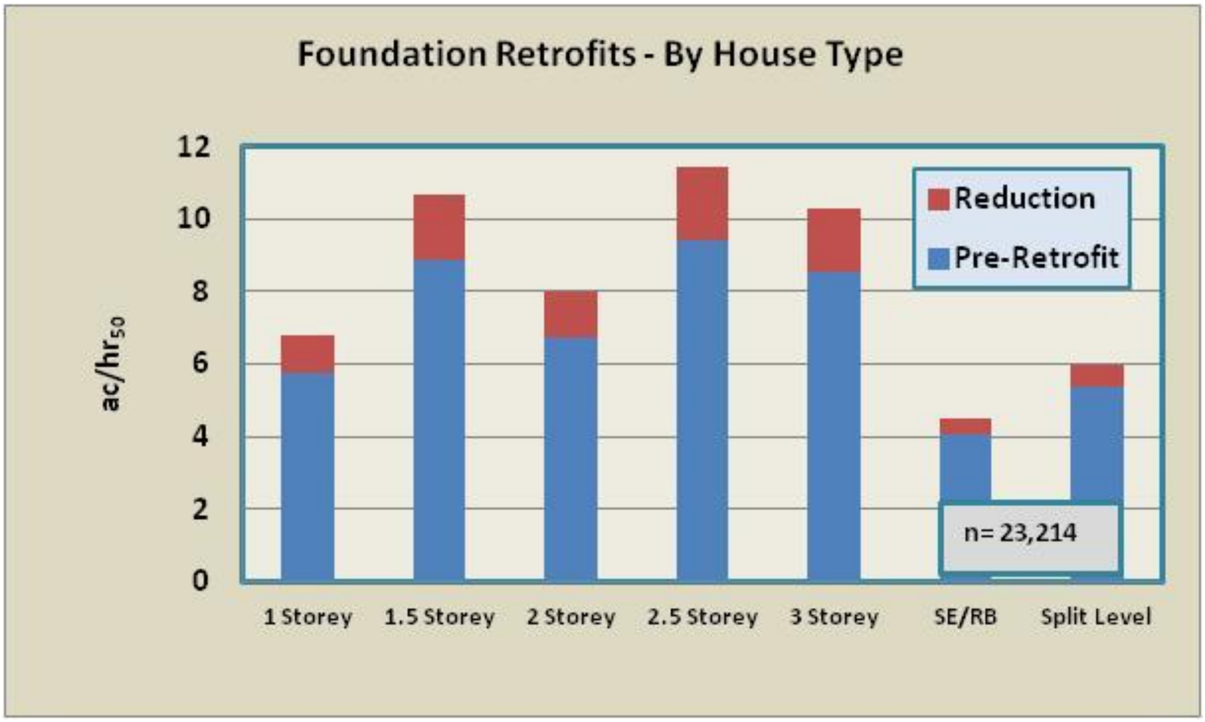

Foundation Retrofits - By House Type
ac/hr50
12
10
8
6
4
2
0
Reduction
Pre-Retrofit
n= 23,214
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 6.6

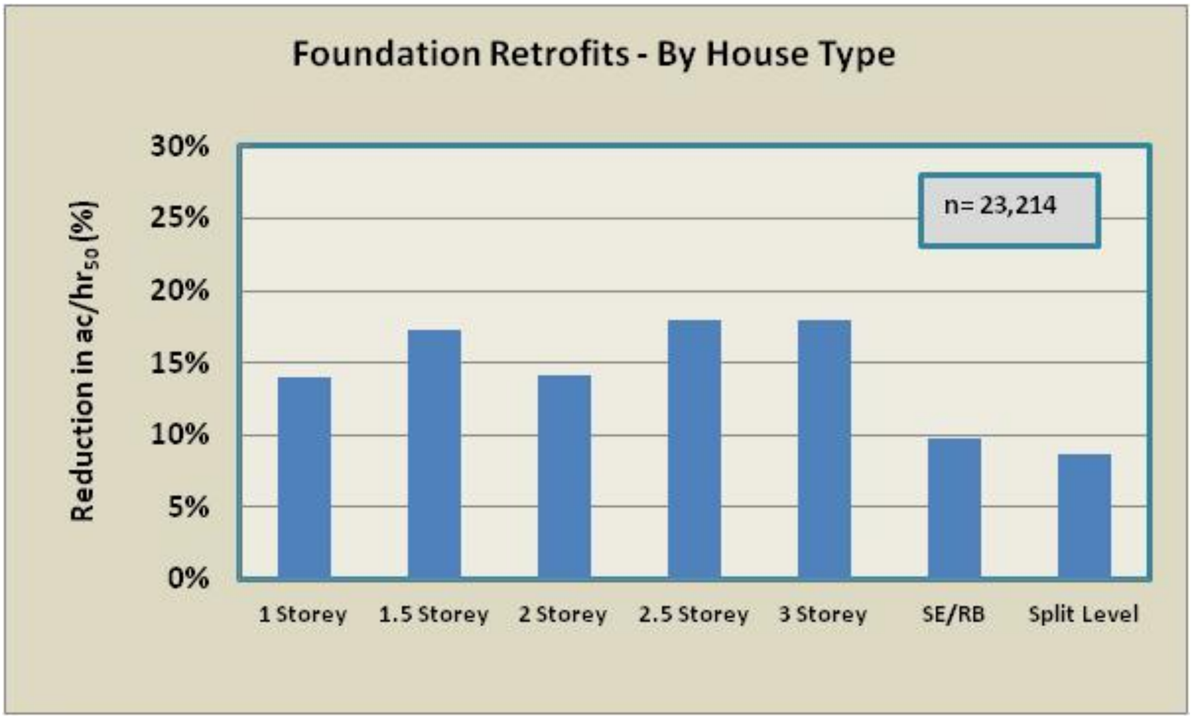
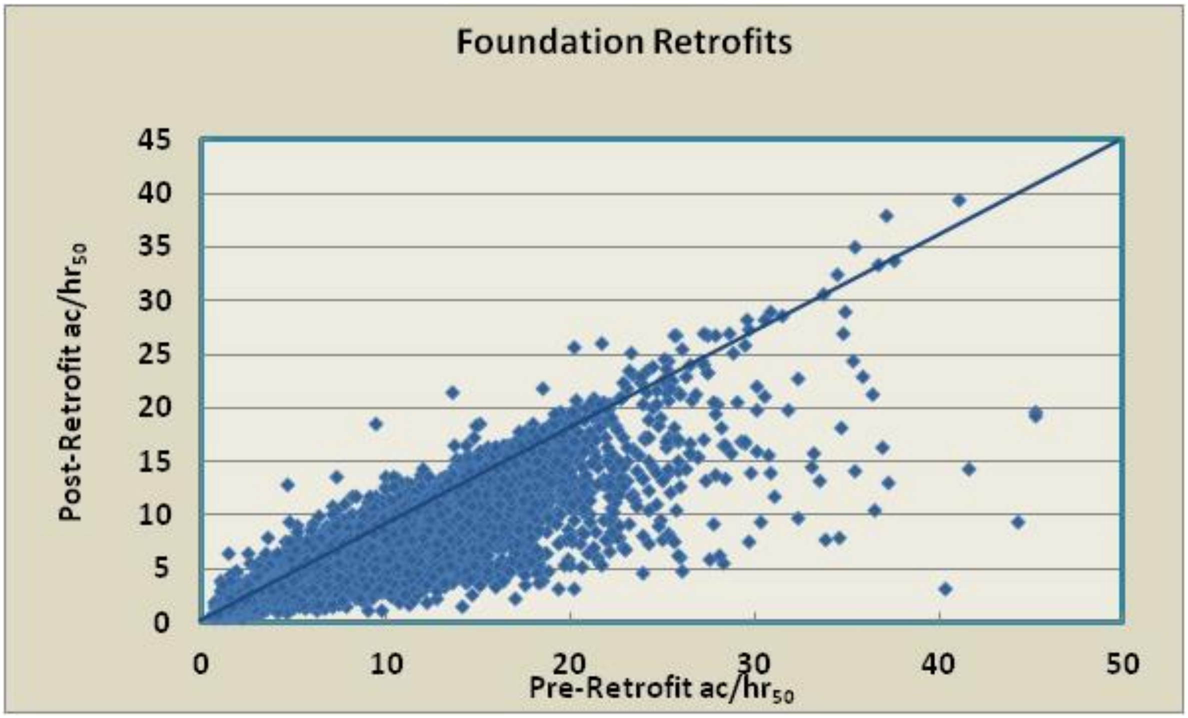

Foundation Retrofits - By House Type
Reduction in ac/hr50 (%)
30%
25%
20%
15%
10%
5%
0%
n= 23,214
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 6.7


Foundation Retrofits
Post-Retrofit ac/hr50
Pre-Retrofit ac/hr50
0
5
10
15
20
25
30
35
40
45
50

Section 7
Window Retrofits

7.1 Description: Since most windows have a relatively limited life expectancy (for example, the seals used on modern Insulated Glazed Units last about 20 to 25 years), they have to be replaced several times over the life of the house. This provides regular opportunities to improve the performance of the glazing system.

Historically, most windows were poorly sealed, single or double-glazed units with questionable weatherstripping and only basic "sealing" of the rough-opening (R/O) between the window unit and the wall framing (rolled-up newspaper was popular for sealing the gap). In contrast, newer window units usually display significantly less leakage than older models and much greater care is taken to seal the R/O gap - for example, one-component polyurethane foam is now very common with window replacements.

7.2 Sample Size: 44,230 houses

7.3 Discussion:

- The 44,230 houses which underwent window retrofits experienced an average reduction in their measured ac/hr_{50} of 13%, while the absolute reduction was 0.99 ac/hr_{50}. Overall, this category of retrofits displayed some of the most uniform percentage reductions in the entire study.

- Overall, the measured reductions in ac/hr_{50} values were fairly consistent between provinces. Ignoring the 4 house sample from the Yukon and the medium-sized sample of 89 PEI houses, all of the measured reductions were in the range of 10% to 16%.

- Once again, house age had an impact on both the initial airtightness and the improvement which the retrofit was able to achieve. Older houses were leakier than new houses and retrofitting older houses to reduce air leakage was more effective than on newer structures. One surprising result was that even for newer houses (built between 1990 and 2009), window replacements generated a reduction in air leakage of 10%.

- The reduction in air leakage produced by window retrofits was relatively independent of the type of house. All house types experienced reductions in air leakage between 11% and 17%.

- Reduced air leakage through windows will not only save energy but can significantly increase comfort levels in the house. This will likely occur to a greater extent than with other types of retrofits since windows are natural "magnets" for occupants. Air leakage which is noticed by homeowners when they are close to the windows will often result in increased thermostat settings leading to higher house temperatures and increased energy use.

Overview Statistics:

Type of Retrofit Measure: Window Retrofits			**Number:** 44,230	
	Measured Airtightness (ac/hr_{50})			
	Pre-Retrofit	Post-Retrofit	Change	Percent Change
Mean	6.18	5.19	0.99	13%
Min	0.45	0.41	-14.73	-298%
Max	49.72	42.81	34.71	93%
Std. Dev.	3.56	2.75	1.66	16%
C of V	0.58	0.53	1.67	1.19

By Province:

Province or Territory	Number Of Retrofits	**Measured Airtightness (ac/hr_{50})**			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
B.C.	11,950	8.11	6.67	1.44	16%
Alberta	883	4.63	3.99	0.64	11%
Saskatchewan	1755	4.06	3.50	0.56	11%
Manitoba	356	4.83	4.16	0.68	11%
Ontario	18,701	5.58	4.73	0.84	12%
Quebec	4679	4.98	4.20	0.78	13%
New Brunswick	2612	6.61	5.63	0.98	12%
Nova Scotia	2703	5.46	4.61	0.85	12%
PEI	89	5.59	5.12	0.47	5%
Newfoundland	483	6.85	5.94	0.91	13%
NWT	15	4.52	3.63	0.89	11%
Yukon	4	1.76	1.66	0.10	-16%
Sample Weighted Avg.	44,230	6.18	5.19	0.99	13%

By Decade of Construction:

Decade of Construction	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1890	591	10.53	8.61	1.92	16%
1900	635	10.88	8.58	2.30	18%
1910	527	10.34	8.49	1.85	16%
1920	752	10.35	8.37	1.98	17%
1930	655	9.68	7.88	1.80	16%
1940	1480	9.18	7.43	1.75	16%
1950	3187	7.71	6.45	1.27	14%
1960	4758	7.00	5.83	1.17	14%
1970	9906	6.57	5.50	1.07	14%
1980	15,290	5.10	4.35	0.75	12%
1990	6199	4.08	3.56	0.52	10%
2000	248	3.72	3.22	0.50	10%
2010	2	2.11	2.11	0.00	1%
Sample Weighted Avg.	44,230	6.18	5.19	0.99	13%

By House Type:

House Type	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1 Storey	19,068	6.23	5.19	1.04	14%
1½ Storey	847	8.12	6.61	1.51	16%
2 Storey	22,643	6.03	5.11	0.92	13%
2½ Storey	122	9.55	7.93	1.62	15%
3 Storey	616	8.60	6.86	1.74	17%
SE/RB	439	4.69	4.10	0.59	11%
Split Level	495	5.06	4.43	0.63	11%
Sample Weighted Avg.	44,230	6.18	5.19	0.99	13%

Fig. 7.1

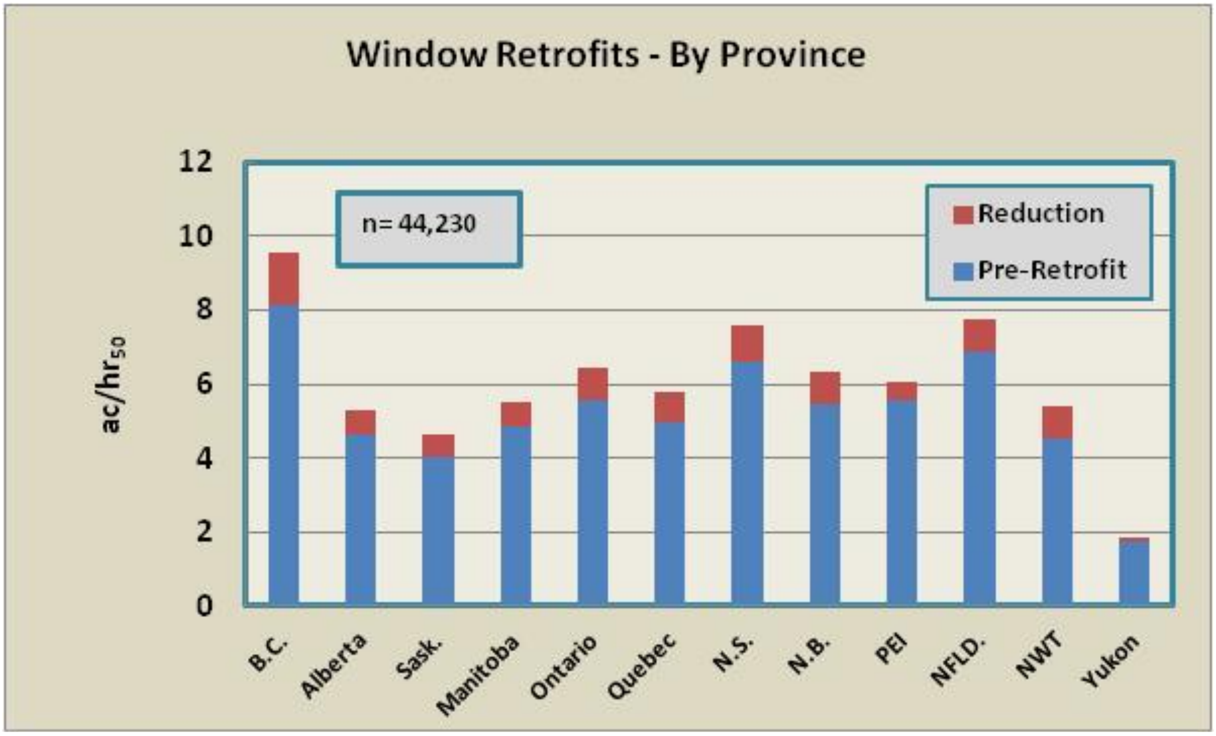

Window Retrofits - By Province
12
10
8
6
4
2
0
ac/hr50
n= 44,230
Reduction
Pre-Retrofit
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon

Fig. 7.2

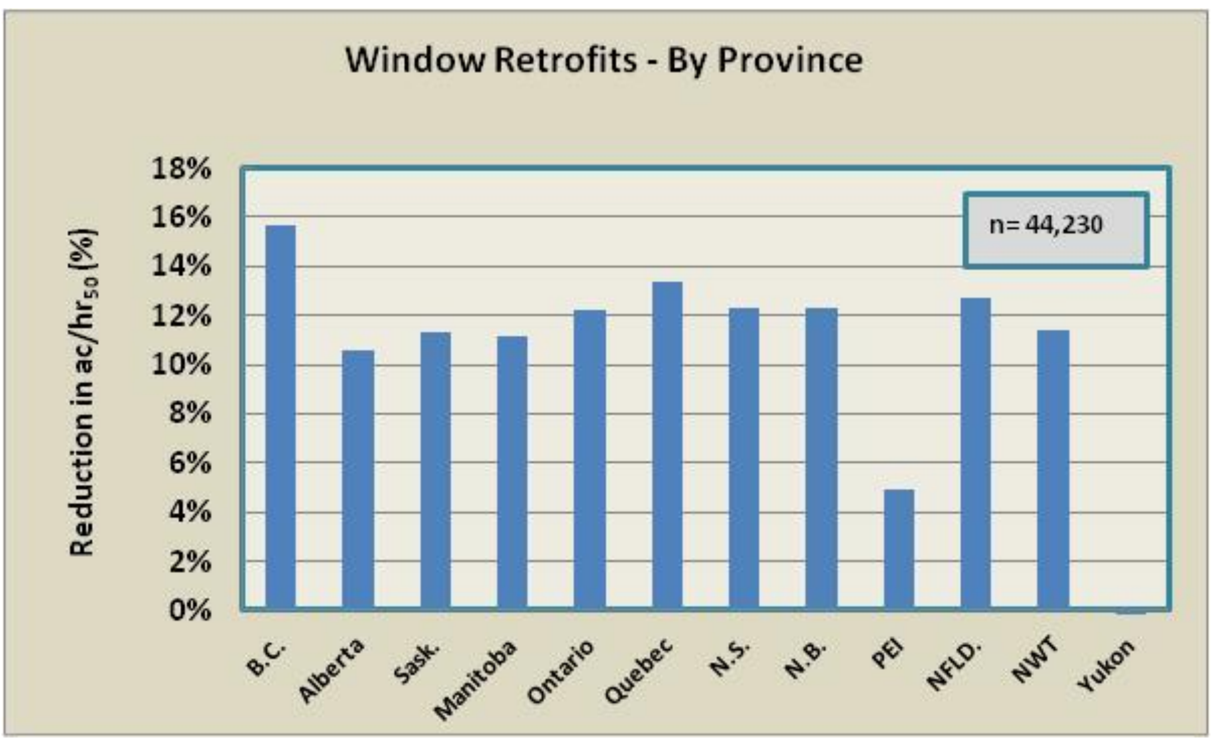

Window Retrofits - By Province
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
Reduction in ac/hr50 (%)
n= 44,230
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon

Fig. 7.3

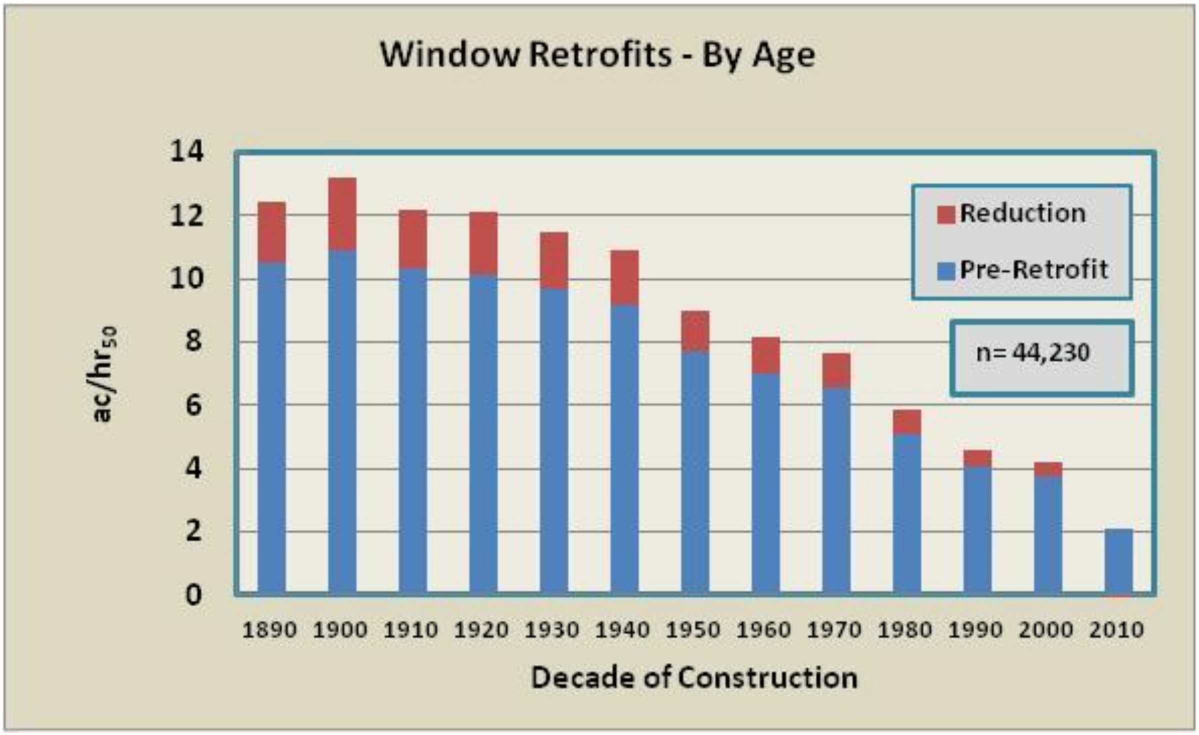

Window Retrofits - By Age
Reduction
Pre-Retrofit
n= 44,230
ac/hr50
14
12
10
8
6
4
2
0
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Decade of Construction

Fig. 7.4

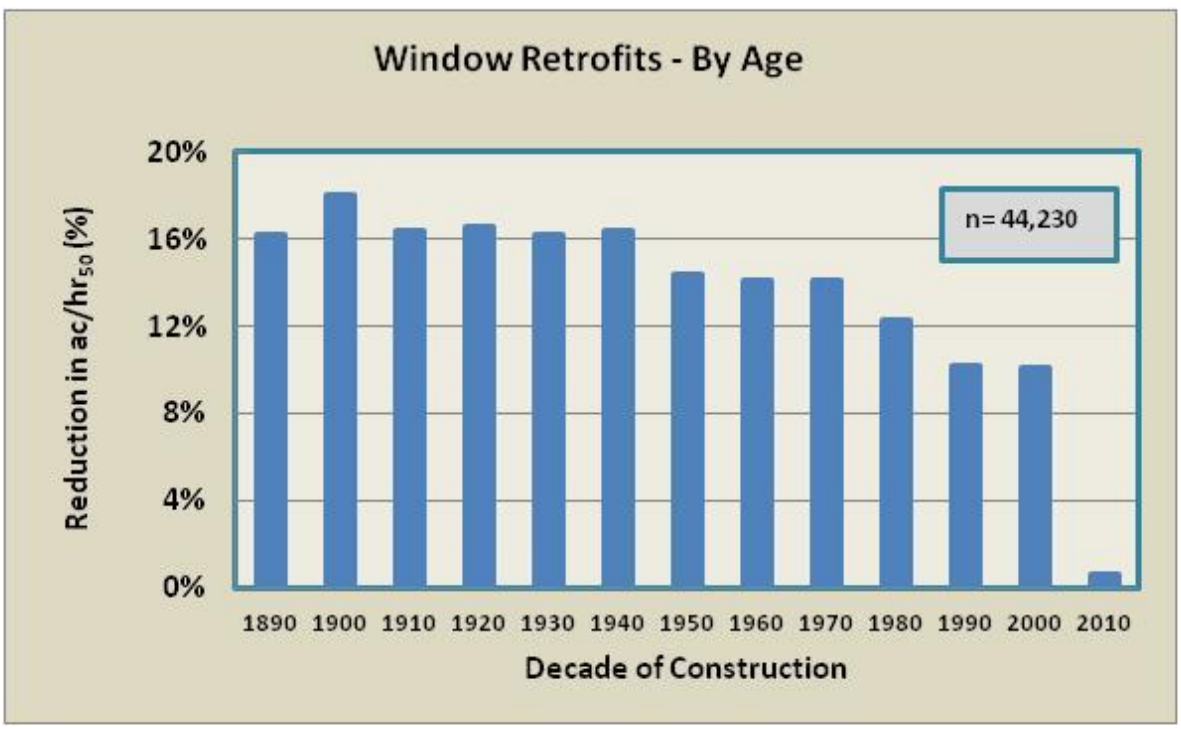
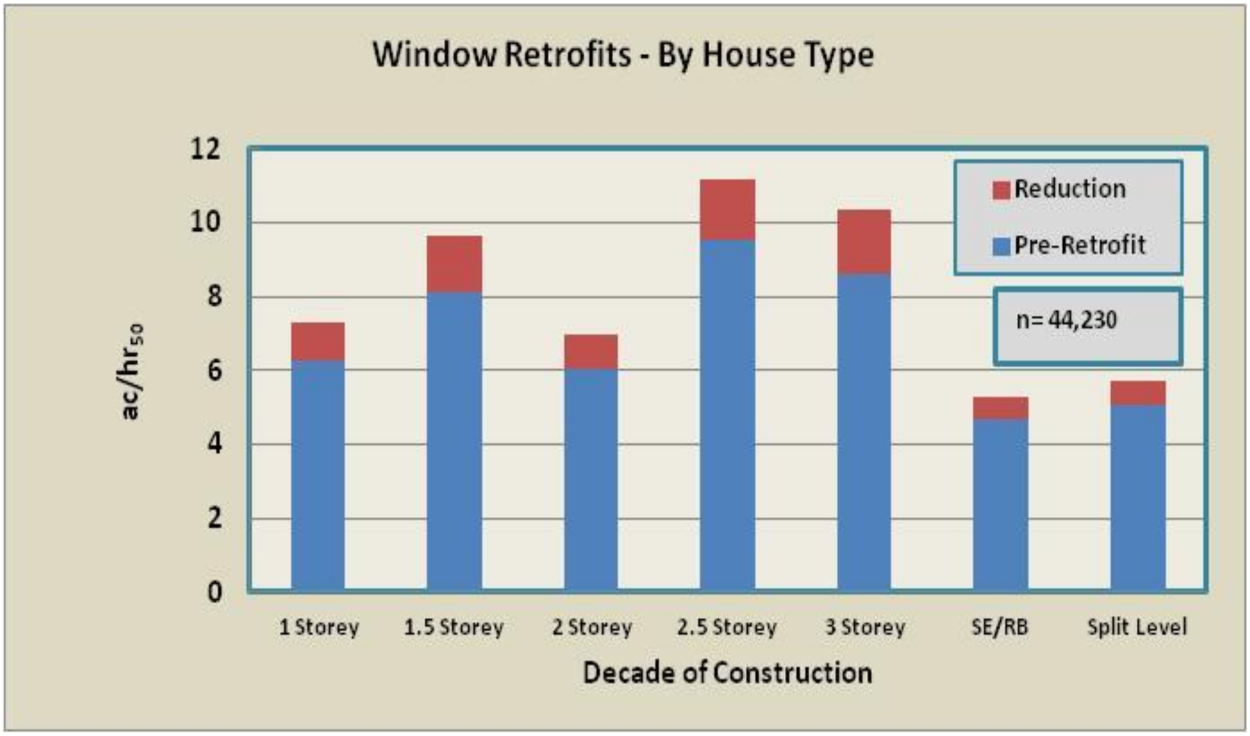
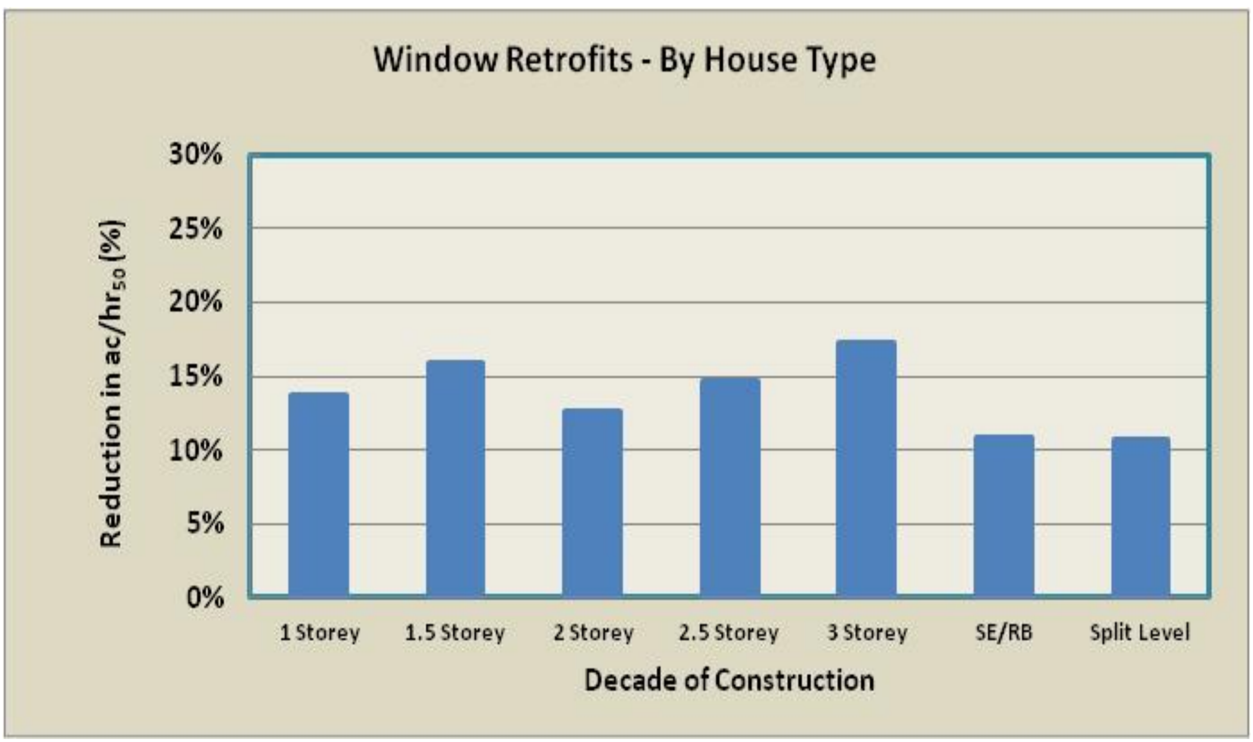

Window Retrofits - By Age
n= 44,230
Reduction in ac/hr50 (%)
20%
16%
12%
8%
4%
0%
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010
Decade of Construction

Fig. 7.5



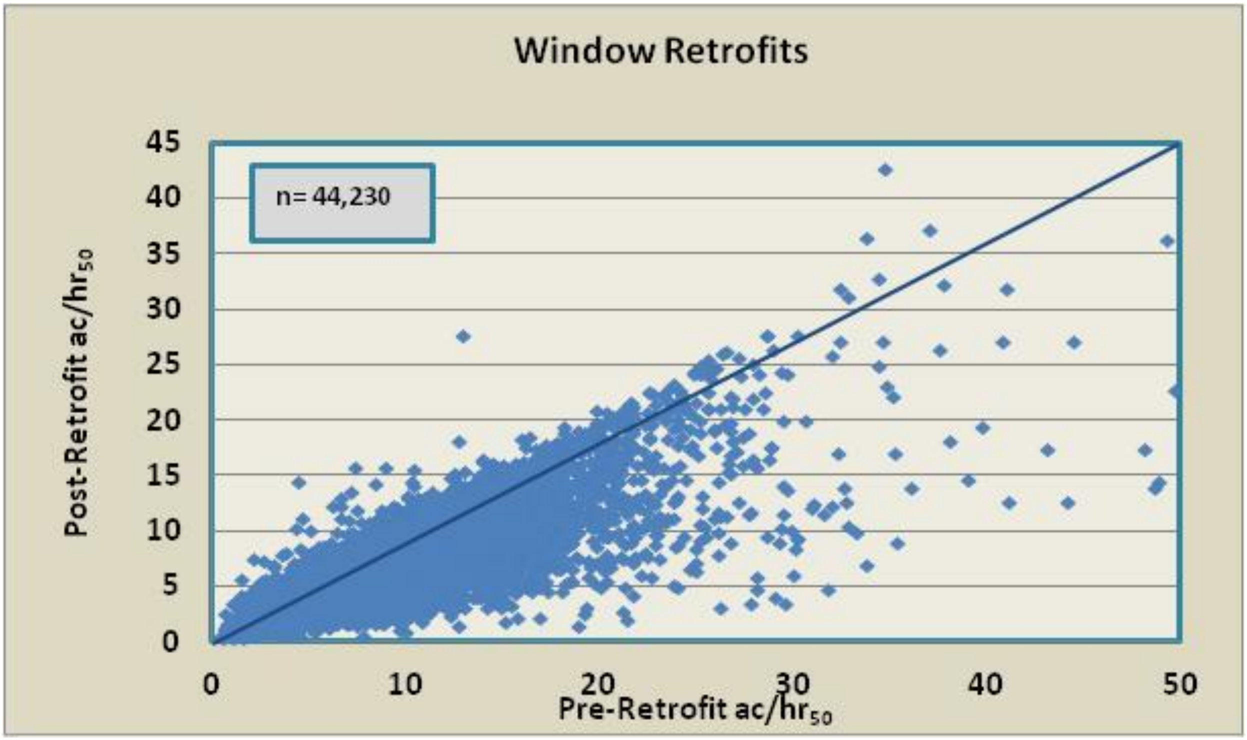
Window Retrofits - By House Type
12
10
8
6
4
2
0
ac/hr50
Reduction
Pre-Retrofit
n= 44,230
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level
Decade of Construction

Fig. 7.6



Window Retrofits - By House Type
30%
25%
20%
15%
10%
5%
0%
Reduction in ac/hr50 (%)
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level
Decade of Construction

Fig. 7.7



Window Retrofits
n= 44,230
Post-Retrofit ac/hr50
Pre-Retrofit ac/hr50
0
5
10
15
20
25
30
35
40
45
0
10
20
30
40
50

Section 8
Mechanical System Retrofits

8.1 Description: Most residential heating appliances have a relatively short-to-medium life span and thus have to be replaced on a regular schedule. Furnaces last 20 to 25 years, while hot water tanks last between 5 and 10 years.

The most common types of mechanical system retrofits are basic furnace and hot water tank replacements. For the houses discussed in this study, furnace "replacements" often involved upgrading to a new unit with significantly better performance. In contrast, combustion hot water tank replacements usually result in a new tank with basically similar performance. DHW tank upgrades are much less common than for furnaces.

The impact on airtightness created by these retrofits is largely due to changes in the appliance's venting system. For example, many thousands (millions?) of older, naturally aspirated furnaces have been replaced by either induced draft or direct vent devices whose venting systems exhaust much less air out of the house, both when the appliance is firing and when it is not. In some instances, this can create problems with "orphaned vents". These are venting systems originally designed for an older, oversized furnace and a hot water tank, but which now serve only the hot water tank since the original naturally aspirated furnace has been replaced by a direct vent unit which exhausts the products of combustion through the side of the house. Under these circumstances the vent should be downsized (i.e. a liner installed inside the original vent to reduce its cross-sectional free area). However, this does not always occur. In some houses, the original furnace has been replaced by a direct vent unit and the gas DHW by an electric tank. In such instances, the vent can be completely sealed, thereby eliminating what may have been the largest hole in the house.

This category would also include ventilation system retrofits, however these would be a minority within the sample size. When improvements are made to ventilation systems in older houses, the work usually consists of fairly simple measures such as adding a bathroom fan.

8.2 Sample Size: 19,431 houses

8.3 Discussion:

- The 19,431 houses which underwent some form of retrofit to their mechanical systems experienced an average reduction in the measured ac/hr_{50} of 9%, while the absolute reduction was 0.62 ac/hr_{50}.

- Excluding those regions with small sample sizes (Newfoundland, NWT and the Yukon), mechanical system retrofits produced reductions in air leakage which varied from 4% to 12%. The largest reductions occurred on the prairies while the smallest took place in the Maritimes and Ontario. This may be connected to the fact that natural gas has been the dominant heating fuel on the prairies for the last 50 years while oil was the primary heating fuel in the Maritimes. Replacing older, naturally aspirated gas furnaces with modern units which use smaller vents would have produced reductions in air leakage larger than those which would have occurred with oil furnace replacements.

- House age had less of an impact on the percentage reductions in air leakage than it did on other types of retrofits. However, the absolute reductions in measured airtightness were most pronounced on older house and then decreased with as the house age. For example, the mean absolute reduction in airtightness was 1.28 ac/hr_{50} for houses constructed in the period 1890 to 1899 but decreased to 0.31 ac/hr_{50} for houses constructed post-2000 (ignoring the 3 houses in the 2010 category).

- The type of house in which the HVAC system retrofit occurred had little impact on the percentage reduction in air leakage, although the absolute reductions showed a stronger dependence on house type. For example, 1½ storey houses experienced an average reduction of 1.17 ac/hr_{50}, whereas retrofits to split level houses produced a mean reduction of 0.43 ac/hr_{50}, while the corresponding percentage reductions were 11% and 10% respectively.

- The reduction in air leakage due to mechanical system retrofits is likely the result of reduced venting requirements resulting from the replacement of naturally aspirated, or induced draft, furnaces and hot water tanks with direct vent or electric appliances

Overview Statistics:

Type of Retrofit Measure: Mechanical System Retrofits			**Number:** 19,431	
	Measured Airtightness (ac/hr$_{50}$)			
	Pre-Retrofit	Post-Retrofit	Change	Percent Change
Mean	5.67	5.05	0.62	9%
Min	0.62	0.42	-12.43	-1199%
Max	45.51	34.86	32.22	93%
Std. Dev.	3.26	2.81	1.32	17%
C of V	0.58	0.56	2.14	1.86

By Province:

Province or Territory	Number Of Retrofits	**Measured Airtightness (ac/hr$_{50}$)**			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
B.C.	2189	7.31	6.51	0.80	9%
Alberta	1295	4.50	3.86	0.64	12%
Saskatchewan	2601	4.31	3.77	0.54	12%
Manitoba	555	3.81	3.36	0.45	11%
Ontario	12,093	5.85	5.24	0.61	8%
Quebec	276	5.89	5.15	0.74	10%
New Brunswick	234	6.47	5.92	0.54	7%
Nova Scotia	99	6.73	6.05	0.68	7%
PEI	73	4.72	4.47	0.26	4%
Newfoundland	0				
NWT	13	5.79	5.03	0.76	14%
Yukon	3	4.29	3.65	0.64	15%
Sample Weighted Avg.	19,431	5.67	5.05	0.62	9%

By Decade of Construction:

Decade of Construction	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1890	292	9.96	8.68	1.28	10%
1900	324	10.45	9.07	1.39	12%
1910	402	9.56	8.45	1.12	10%
1920	575	9.21	8.18	1.03	10%
1930	422	8.90	7.88	1.02	10%
1940	797	8.33	7.31	1.02	11%
1950	2176	6.99	6.19	0.80	10%
1960	2391	5.88	5.29	0.60	9%
1970	3117	5.44	4.78	0.66	11%
1980	5128	4.61	4.15	0.46	9%
1990	3154	3.83	3.48	0.35	7%
2000	650	3.53	3.22	0.31	6%
2010	3	5.19	4.50	0.69	9%
Sample Weighted Avg.	19,431	5.67	5.05	0.62	9%

By House Type:

House Type	Number Of Retrofits	Measured Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Change	Percent Change
1 Storey	8535	5.41	4.79	0.62	10%
1½ Storey	405	8.73	7.56	1.17	11%
2 Storey	9527	5.70	5.11	0.59	8%
2½ Storey	103	8.84	7.93	0.91	9%
3 Storey	398	8.33	7.37	0.96	10%
SE/RB	166	3.94	3.27	0.67	13%
Split Level	297	4.35	3.92	0.43	10%
Sample Weighted Avg.	19,431	5.67	5.05	0.62	9%

Fig. 8.1

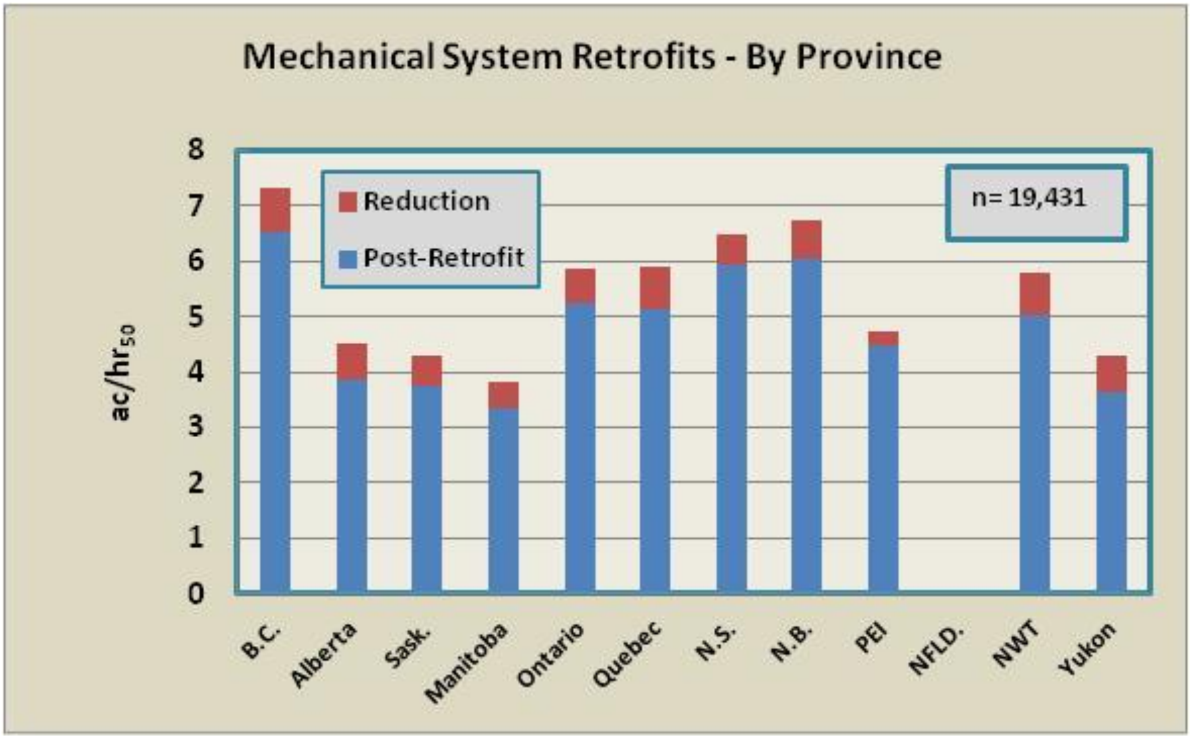

Mechanical System Retrofits - By Province
ac/hr50
8
7
6
5
4
3
2
1
0
Reduction
Post-Retrofit
n= 19,431
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon

Fig. 8.2

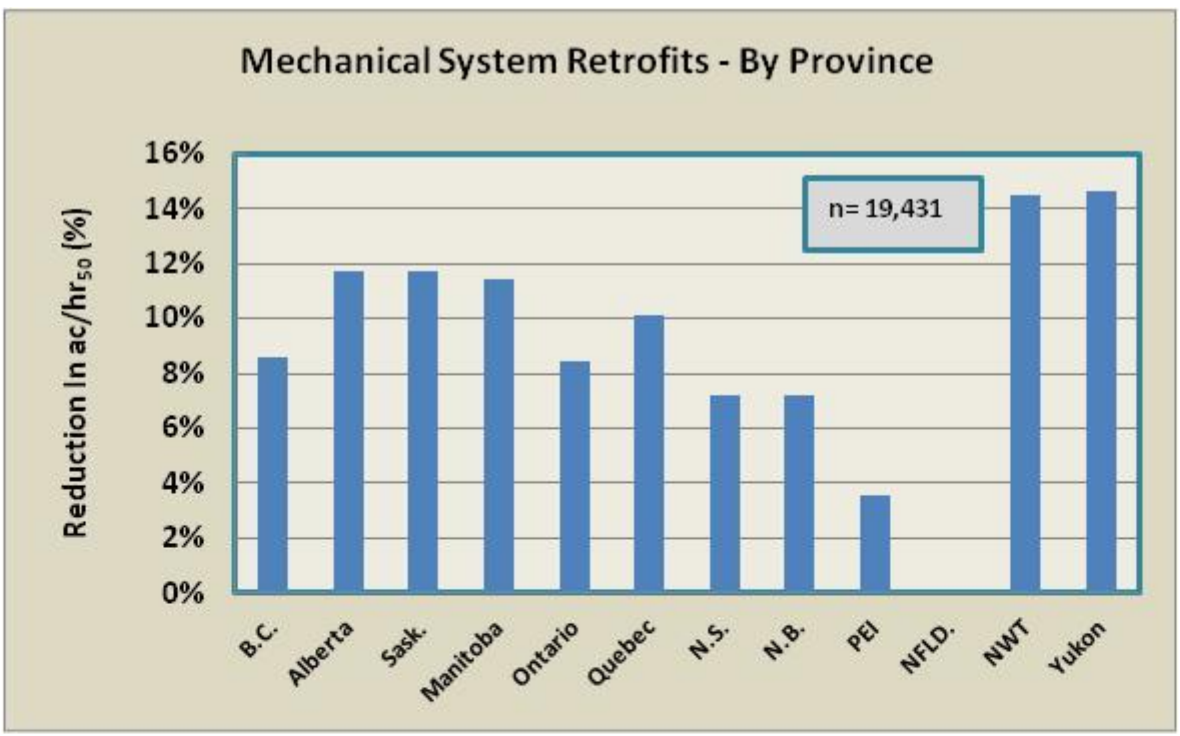
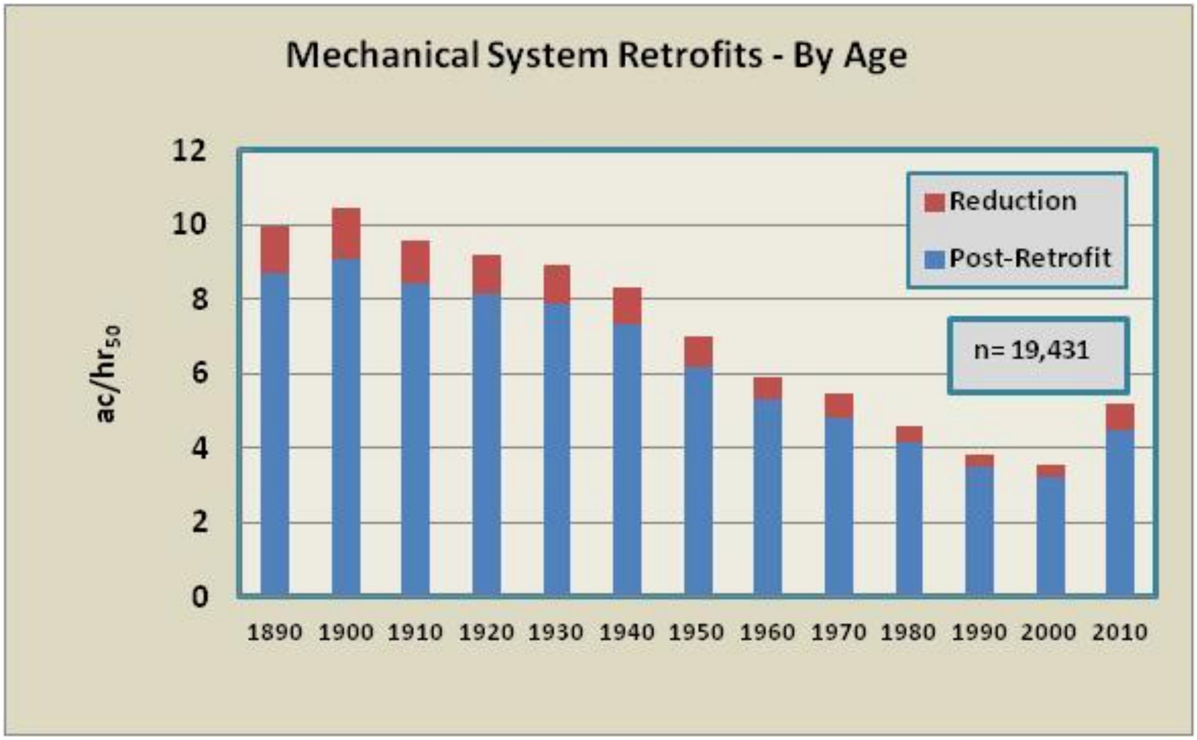
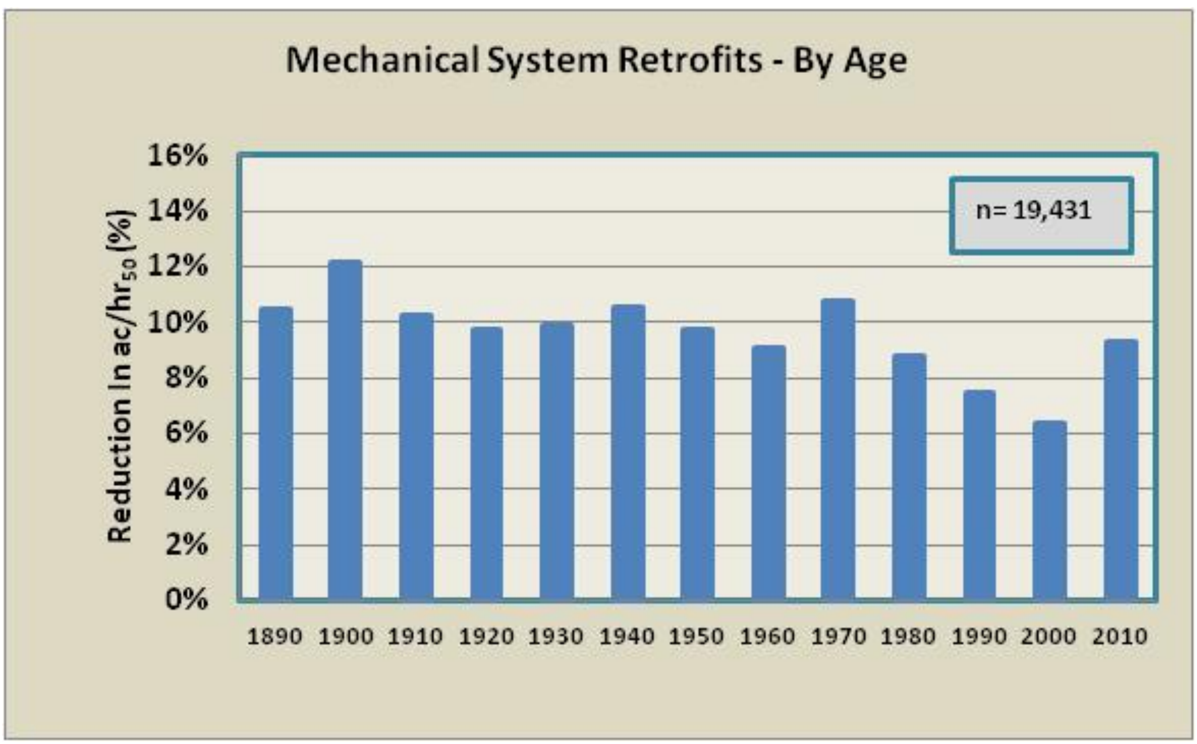

Mechanical System Retrofits - By Province
Reduction In ac/hr50 (%)
16%
14%
12%
10%
8%
6%
4%
2%
0%
n= 19,431
B.C.
Alberta
Sask.
Manitoba
Ontario
Quebec
N.S.
N.B.
PEI
NFLD.
NWT
Yukon

Fig. 8.3



Mechanical System Retrofits - By Age
ac/hr50
12
10
8
6
4
2
0
Reduction
Post-Retrofit
n= 19,431
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

Fig. 8.4



Mechanical System Retrofits - By Age
Reduction In ac/hr50 (%)
16%
14%
12%
10%
8%
6%
4%
2%
0%
n= 19,431
1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

Fig. 8.5

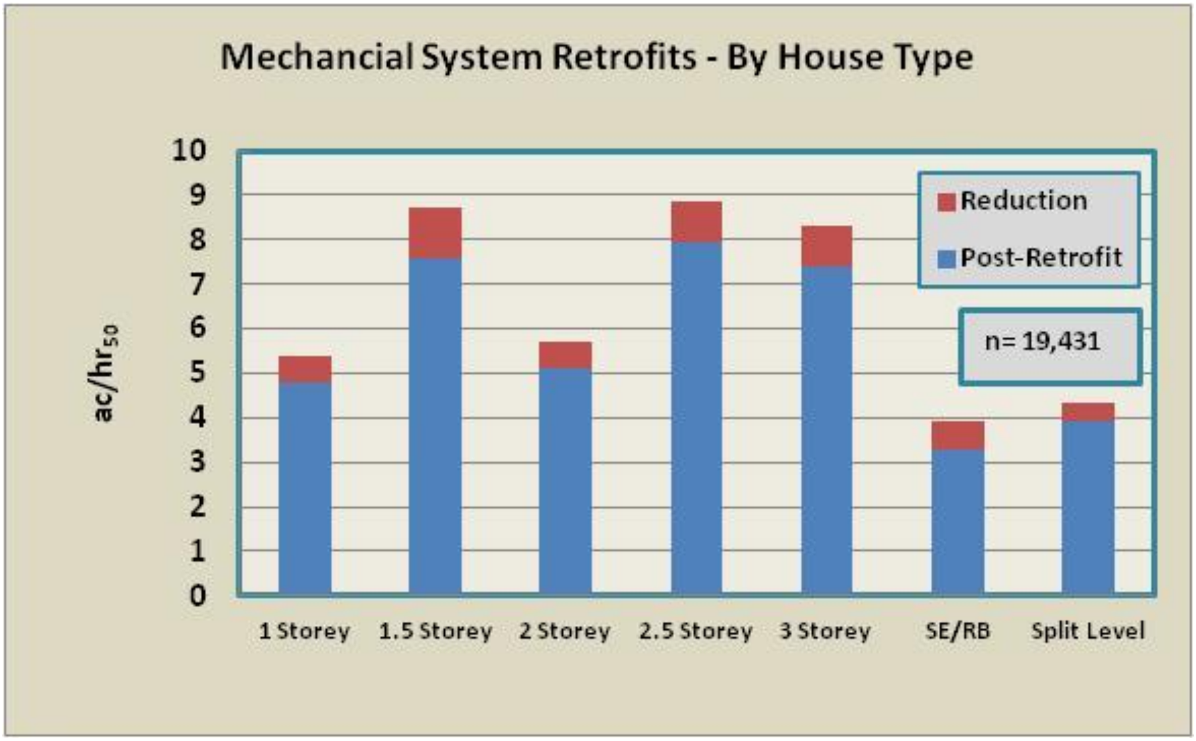

Mechancial System Retrofits - By House Type
ac/hr50
10
9
8
7
6
5
4
3
2
1
0
Reduction
Post-Retrofit
n= 19,431
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 8.6

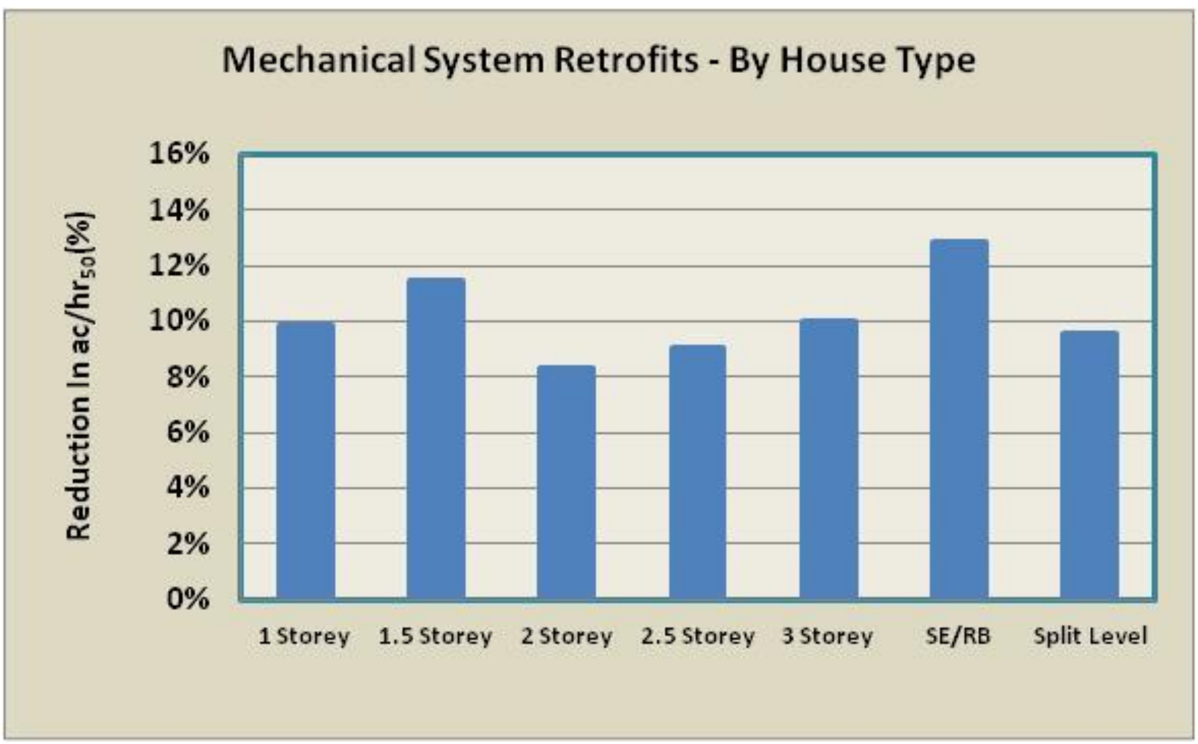
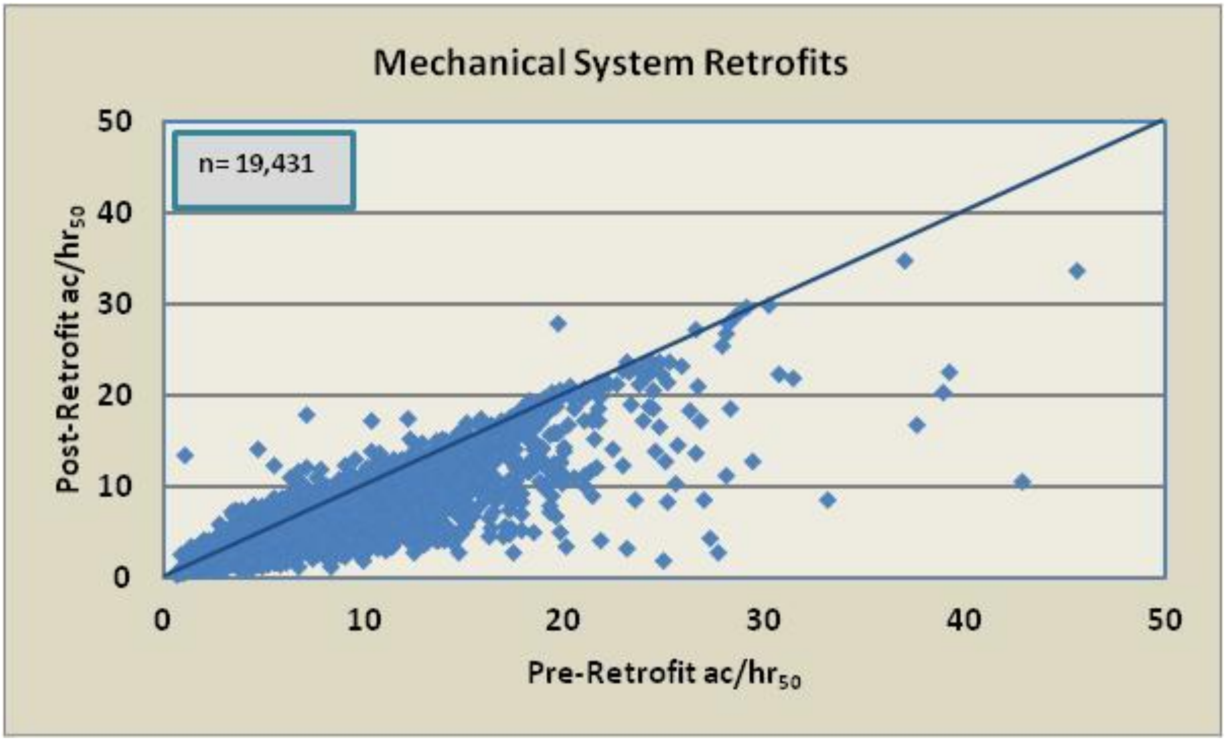

Mechanical System Retrofits - By House Type
Reduction In ac/hr50(%)
16%
14%
12%
10%
8%
6%
4%
2%
0%
1 Storey
1.5 Storey
2 Storey
2.5 Storey
3 Storey
SE/RB
Split Level

Fig. 8.7



Mechanical System Retrofits
n= 19,431
Post-Retrofit ac/hr50
Pre-Retrofit ac/hr50
0
10
20
30
40
50

Section 9
Cost Of Air Leakage Sealing

9.1 INTRODUCTION

Defining the costs of air leakage sealing, either in retrofits or new construction, is difficult at best. Different contractors and builders use different techniques and approaches, different materials are employed, they have varying levels of experience with air leakage sealing and have developed widely differing competence levels, etc.

The costs which are discussed below were based on relatively (from an architectural perspective) conventional house designs. Obviously, some custom homes with non-standard features may require additional effort, and costs, beyond that shown here. Also, it should be appreciated that the techniques, materials and procedures assumed below are not the definitive word on air sealing houses. New products, new methods and new ideas are constantly being introduced into both the retrofit and new home markets which always have to potential to affect costs.

For this project, discussions were held with a small number of Winnipeg contractors and builders to obtain input on their costs. All were very experienced and familiar with the relevant techniques.

9.2 RETROFITS

The air leakage sealing contractors who were consulted for information were very forthcoming and provided some valuable insight into the industry. They were very experienced and their firms had each performed several thousand retrofits over the last five years. Each employed several crews and had developed detailed protocols for performing the work. Although their businesses were not devoted solely to residential air leakage sealing, the vast majority of their non-ALS work was in closely related fields such as insulation upgrades and radon mitigation measures.

One challenge with attempting to define the costs of air leakage sealing retrofits is that there is no standardized definition of what constitutes "air leakage sealing". In practice, it could range from such basic measures as weatherstripping a couple of windows and sealing a few obvious holes to as comprehensive as whole house sealing of all portions of the building envelope (walls, attics, foundations, windows and doors) along with before-and-after blower door testing and an infra-red examination of the home. Also, given that governments and utilities have played a huge role in the residential ALS industry, they have often helped to define the scope of work for retrofits conducted under the auspices of their programs.

In any event, the contractors (and likely the ALS industry) have responded by developing and employing standardized ALS retrofit packages which can be selected (individually or collectively) based on the specific job requirements. These are summarized below. All of the costs shown are consumer costs and include contractor mark-up.

1. Supplemental Attic Air Leakage Sealing

- Description of work: Accessing the attic; brushing aside the existing insulation; sealing mechanical and electrical penetrations, holes in attic perimeter (if accessible), holes in tops of partition walls and any other obvious holes, and weatherstripping the attic hatch.
- Most of this work has been performed under the auspices of a utility or government energy conservation program.
- Supplemental attic ALS is performed on $90\%^+$ of all houses, although often as a part of a larger retrofit package.
- Typical costs: $300 to $400. Costs are not very dependent on house size.

2. Attic Insulation Removal and Supplemental Air Leakage Sealing

- Description of work: Accessing the attic; complete removal of all existing insulation; spray foam attic with thin layer of foam, add new insulation.
- Attic insulation removal complete with supplemental ALS is only performed on about 5% of the number of houses which receive supplemental attic ALS.
- Most of these jobs are conducted because of performance issues such as ice dam formation or comfort complaints.
- Typical costs: $3000 to $4000, plus the cost of the new attic insulation.

3. Basement Air Leakage Sealing

- Description of work: Sealing of basement headers using spray foam or rigid insulation.
- Typical costs: $800 to $1000.

4. Whole House Air Leakage Sealing

- Description of work: Pre-retrofit airtightness test to both determine how leaky the house is and where the major leaks are located; sometimes supplemented with an infra-red examination of the house (weather conditions permitting); supplemental attic ALS; sealing of major holes; some weatherstripping; post-retrofit airtightness test.
- Relatively small numbers of these types of jobs are performed.
- Typical costs: $1000 to $1500, assuming other work (such as insulation upgrades) are being performed on the house.

5. Exterior Wall Insulation/Air Leakage Sealing

- Description of work: blowing in dense-pack cellulose insulation into all exterior wall cavities.
- Although this is not a pure ALS task (since wall insulation is being added), it is often recommended as a means of reducing air leakage, as well as upgrading the thermal resistance of the walls.
- Typical costs: $\$30/m^2$ ($\$3/ft^2$) of gross wall area.

9.3 NEW CONSTRUCTION

Before discussing the cost of airtightness in new construction, it is important to distinguish between conventional houses and those designed to meet "program" requirements, i.e. houses intended for enrollment in a government or utility-run energy conservation program (such as R-2000). The latter are normally required to meet an explicit airtightness requirement which has to be verified by testing (e.g. 1.5 ac/hr_{50} in the case of R-2000 houses). However, program houses make up a relatively small percentage of all new home starts in Canada. In fact, one of their primary benefits for the homebuilding industry has been to serve as a learning vehicle for builders who can develop their skills on the program houses which can then hopefully be absorbed into their mainstream production.

Today, many (or most) builders who routinely deliver production houses with measured airtightness rates in the 1.0 ac/hr_{50} to 2.0 ac/hr_{50} range, developed their skills with program houses. For example, builders in western Canada routinely deliver production houses with these types of measured air leakage rates - which is well below that normally achieved in most other parts of the country. In almost all cases, these builders were educated about airtight construction through the training components of these energy conservation programs. The costs discussed below were primarily based on production, not program houses.

The builders who were consulted were all very experienced with airtight construction techniques and procedures and had been using them for many years (or decades). They were asked to base their costs on one of their standard-sized houses, typically a one or two-storey structure with full basement and a floor area of roughly 200 m^2 (2000 ft^2). The costs shown below are all consumer costs and include labour and materials plus a builder mark-up of 15%.

1. Sealing Polyethylene Air/Vapour Barriers

- Description of work: apply acoustical sealant and seal all joints in the polyethylene air/vapour barriers on the exterior walls, ceilings and basement walls.
- The cost of the polyethylene is ignored because that would have to be supplied and installed to meet the vapour diffusion requirements of the National Building Code.
- Normally performed by the drywaller/insulator.
- Typical costs: $300 to $600.

2. Sealing Rough-Openings Around Doors and Windows

- Description of work: apply polyurethane foam to the rough-openings of all doors and windows.
- Normally performed by the drywaller/insulator.
- Typical costs: $300 to $600.

3.Sealing the Basement and Second Floor Headers

- Description of work: apply polyurethane foam to the basement and (if applicable) main floor headers.
- Normally performed by the foam contractor or drywaller/insulator.

- Typical costs: $875 to $1200 per level (i.e. the cost for a two-storey house would be $2000 to $2400).

4. Sealing electrical and plumbing penetrations Into the Attic

- Description of work: apply polyurethane foam and appropriate gaskets to seal all penetrations into the attic.
- This is a much simpler task for new construction (compared to retrofits) since there is no existing insulation which has to be removed; also accessibility is usually better than it is for retrofits.
- Normally performed by the drywaller/insulator.
- Typical costs: $100 to $200.

5. Install and Seal Plastic Polypans for Electrical Fixtures on Exterior Walls

- Description of work: install plastic polypans behind all electrical fixtures on exterior walls.
- Normally performed by the electrician.
- Typical costs: $100 to $200.

6. Seal All Pot Lights Which Penetrate Into the Attic

- Description of work: install plastic boxes around all pot lights which penetrate into the unheated attic space.
- Normally performed by the electrician.
- Costs include supplying the plastic boxes which cover the pot lights.
- Typical costs: $100 to $200.

7. Airtightness Test

- Some of the builders surveyed routinely conducted airtightness tests on a portion of their production houses as a quality control measure.
- Normally, only a single test is conducted although in some cases additional tests may be performed if significant air leaks problems are encountered and have to be fixed.
- Typical costs: $250 to $350 per test.

8. Allowances for Warranty Work

- With tighter houses, reduced venting requirements for combustion appliances and (in some cases) problematic mechanical ventilation systems, there is a greater probability for increased interstitial moisture deposition problems - particularly in the attic since it is at the top of the house where the air exfiltration forces are the most powerful.
- Typical costs: $0 to $250. The builders acknowledged the potential for these types of problems but some did not usually include an allowance for warranty work (although most suggested that this would be a good idea).

Cost of Airtightness For New Home Construction

Using these costs, the total cost to seal a new home would be:

Bungalow

Total cost: $2300 to $3250 (without airtightness test)
$2550 to $3350 (with one airtightness test)

Two-Storey House

Total cost: $3300 to $4450 (without airtightness test)
$3550 to $4800 (with one airtightness test)

Section 10
Conclusions

10.1 INTRODUCTION

Many of the findings of this study confirm long-held, qualitative beliefs about air leakage in Canadian houses, such as: prairie houses tend to be tighter than those in more temperate regions, partial storey (1½ and 2½) houses are generally leakier than 1 or 2 storey houses, and older houses experience more air leakage than newer houses. While these observations are not surprising, the results of this study - since they are based on such large sample sizes - help to quantify these differences with greater confidence than had previously been possible.

The vast majority of the retrofits discussed in this report were commercially applied by renovation contractors. Some would have been performed by the homeowners however these are believed to be in the minority.

Table 10.1 and Fig. 10.1 provide an overview of the effectiveness of the various energy conservation retrofits in terms of their impact on the measured airtightness of the building. This leads to a number of additional observations.

10.2 CONCLUSIONS

All of the Retrofits Reduced Air Leakage - The study confirmed that all of the energy conservation retrofits affected the airtightness of a house, whether through deliberate attempts to seal potential leakage sites (such as sealing a ceiling-mounted pot light which leaks air into the attic) or inadvertently as the result of other actions which cause the air leakage to be reduced as a secondary effect (such as blowing loose fill insulation into empty exterior wall cavities).

The Retrofits Reduced Air Leakage By 7% to 15% - All of the retrofit measures produced appreciable reductions in the measured air leakage rate even though most were designed primarily to reduce conductive heat losses or improve the efficiency of the mechanical system.

Interestingly, the retrofit category which produced the smallest reduction in air leakage was the dedicated air leakage sealing retrofit, without incentives. It produced an average reduction in the ac/hr_{50} of 7% whereas all other types of retrofits produced reductions ranging from 9% to 15%. The explanation for why dedicated air leakage sealing retrofits with incentives produced twice the reduction of incentive-free ALS retrofits is unknown. It could be due to differences in the scope of work, quality control procedures or other factors.

The Study Results Quantified the Impact of the Various Retrofit Measures - The results of this study provide very useful, quantitative information on the air leakage benefits of various types of residential energy conservation measures. They can be used to produce more accurate estimates of actual energy savings when performing energy analyses of proposed conservation upgrades. For example, the benefits of a wall insulation upgrades are normally calculated assuming there is no change in the house's air infiltration rate - even though it is widely acknowledged that such a reduction can, and in fact usually does, occur. This study's findings provide quantitative data on the magnitude of these benefits, which can be easily used in energy simulations such as those employing HOT2000. Once these benefits are factored in, some previously uneconomic retrofit strategies may now become cost-effective.

Results for Individual Houses Varied Wildly - Every retrofit measure studied produced, on average, a tangible reduction in the measured air leakage rate of the house. However, results for individual houses varied widely. In some cases, the retrofit produced significant increases in the measured air leakage rate. Without detailed knowledge of each house and each retrofit, it is difficult to offer any definitive explanation for these outliers. Experimental error (such as failing to seal an intentional opening during the airtightness test or simply making a procedural blunder) is certainly a possibility. And, given the sample sizes involved, this undoubtedly occurred in at least some cases. But given the relatively limited information available on each case, it is unknown how frequently this occurred. It should also be noted that all of these airtightness tests were conducted as part of some government or utility energy conservation program. These programs normally contain quality control features designed to limit these types of problems. This suggests that some of these artifacts (in which the retrofit resulted in an increase in the measured air leakage) may - in fact - be real. If so, it means that opportunities exist to improve the effectiveness of residential energy conservation retrofits by investigating why these anomalies. By ultimately feeding this information back to the industry, more effective results can hopefully be achieved.

The wide variation in results is a cause for concern. To illustrate, Table 10.2 summarizes the Coefficients of Variation for the 7 categories of retrofit measures. Recall that the Coefficient of Variation is defined as the standard deviation divided by the sample mean; so the larger the C of V, the greater the variation in the data. Notice that both the absolute and percentage changes in the C of V were greater than 1 for all the retrofit measures. This means that while the results of this study provide excellent information on the average impact of these measures on a population of houses, it is very difficult to use the results to make firm predictions on the behaviour of an individual house.

Secondary Benefits of Retrofits Which Reduce Air Leakage May Outweigh the Energy Savings - The secondary benefits of conservation retrofits need to be acknowledged, particularly for exterior wall and attic retrofits. Remember that airtightness results only comment on how leaky a building is, not where the leakage is occurring. While wall and attic retrofits are primarily concerned with increasing the effective thermal resistance of the attic insulation, the air leakage benefits (whether intentionally or unintentionally achieved) will, in many cases, far outweigh the benefits attributable to the reduced heat loss caused by the additional insulation. For example, problems with air exfiltration and moisture deposition within the attic space are fairly common and can lead to extensive damage to the structure. This can easily result in repair bills which far exceed any benefits which may result from the reduction in energy costs. The benefits of reducing these events, both in terms of frequency and magnitude, will generally far exceed the energy savings produced by the extra insulation.

Cost of Air Leakage Sealing Retrofits - The cost of air sealing an existing home can vary significantly depending on the work which has to be performed to achieve an acceptable level of airtightness. However, based on industry input from ALS contractors, the following cost data has been developed.

1. Supplemental Attic Air Leakage Sealing

- Description of work: Accessing the attic; brushing aside the existing insulation; sealing mechanical and electrical penetrations, holes in attic perimeter (if accessible), holes in tops of partition walls and any obvious holes, and weatherstripping the attic hatch.
- Typical costs: $300 to $400.

2. Attic Insulation Removal and Supplemental Air Leakage Sealing

- Description of work: Accessing the attic; complete removal of all existing insulation; spray foam attic with thin layer of foam, add new insulation.
- Typical costs: $3000 to $4000, plus the cost of the new attic insulation.

3. Basement Air Leakage Sealing

- Description of work: Sealing of basement headers using spray foam or rigid insulation.
- Typical costs: $800 to $1000.

4. Whole House Air Leakage Sealing

- Description of work: Pre-retrofit airtightness test to both determine how leaky the house is and where the major leaks are located; sometimes supplemented with an infra-red examination of the house (weather conditions permitting); supplemental attic ALS; sealing of major holes; some weatherstripping; post-retrofit airtightness test.
- Typical costs: $1000 to $1500, assuming other work (such as insulation upgrades) is being performed on the house.

5. Exterior Wall Insulation/Air Leakage Sealing

- Description of work: blowing in dense-pack cellulose insulation into exterior wall cavities.
- Typical costs: $30/m^2 ($3/ft^2) of gross wall area.

Cost of Airtightness In New Construction

Assuming the builder is experienced with airtight construction techniques, the estimated, retail costs to air seal a new home using current techniques, products and methods would be as shown below. In most cases, this should achieve a final airtightness of about 1.5 ac/hr$_{50}$.

Bungalows

Total cost: $2300 to $3000 (without airtightness test)
$2550 to $3250 (with one airtightness test)

Two-Storey Houses

Total cost: $3300 to $4200 (without airtightness test)
$3550 to $4450 (with one airtightness test)

Fig. 10.1

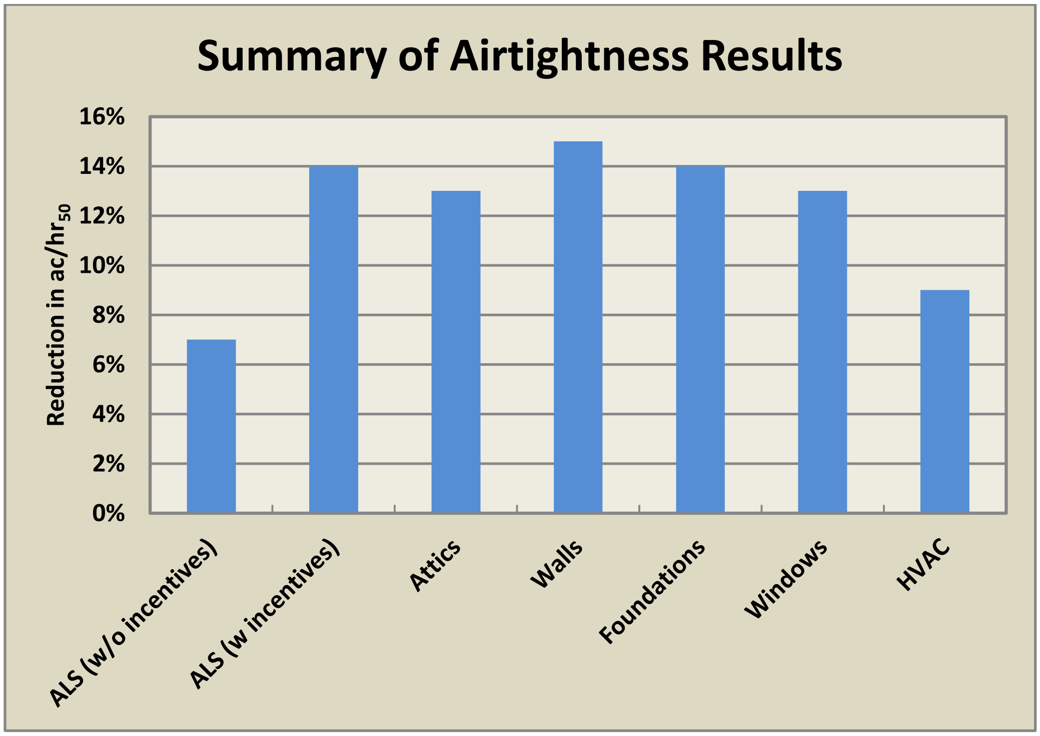


Table 10.1
Summary of Airtightness Results

Retrofit	Sample Size	Airtightness (ac/hr_{50})			
		Pre-Retrofit	Post-Retrofit	Reduction (absolute)	Reduction (percent)
Air Leakage Sealing (w/o incentives)	43,360	5.09	4.59	0.50	7%
Air Leakage Sealing (with incentives)	2813	7.88	6.51	1.38	14%
Attic	36,136	6.37	5.33	1.04	13%
Walls	9989	7.92	6.39	1.53	15%
Foundations	23,214	6.37	5.70	1.17	14%
Windows	44,230	6.18	5.19	0.99	13%
HVAC	19,431	5.67	5.05	0.62	9%

Table 10.2
Coefficient of Variation of the Various Retrofit Measures

Retrofit	Coefficient of Variation			
	Pre-Retrofit	Post-Retrofit	Change	Percent Change
ALS (without incentives)	0.65	0.56	1.72	1.11
ALS (with incentives)	0.68	0.61	2.83	2.51
Ceilings	0.61	0.55	1.77	1.36
Walls	0.63	0.57	1.68	1.18
Foundations	0.66	0.61	1.70	1.24
Windows	0.58	0.53	1.67	1.19
HVAC	0.58	0.56	2.14	1.86
Mean	0.63	0.57	1.93	1.49