UNIVERSITY OF TORONTO | Building Energy and Indoor Environment (BEIE) Lab

Achieving a Low Carbon Housing Stock

AN ANALYSIS OF LOW-RISE RESIDENTIAL CARBON REDUCTION MEASURES FOR NEW CONSTRUCTION IN ONTARIO

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EXECUTIVE SUMMARY

INTRODUCTION

In an international effort to mitigate climate change, countries worldwide are targeting carbon and other GHG reductions in the building sector. This study examined the effectiveness of several low-carbon technologies to assess their applicability for high performance single-family housing construction. The analysis uses a combination of energy modelling, carbon calculation, and cost estimation to determine the most effective strategies to achieve net-zero carbon homes. The central objective of this analysis was to determine the most efficient strategies for transforming the new low-rise residential building stock to **net-zero carbon in terms of cost per kilogram of carbon mitigated**. This methodology can easily be adopted by other jurisdictions seeking to allocate funding and direct policy to create net-zero or near-zero carbon housing.

ENERGY MODELLING

To understand how best to reduce energy consumption, it is important to first understand how energy is currently being used in the average home. To do this, a HOT2000 energy model was prepared representing a typical two-storey single-detached house in Ontario. The model was designed to a prescriptive package from the 2017 edition of the Supplementary Standard SB-12 Energy Efficiency for Housing (SB-12)[1]. For verification, the model results were compared to the measured performance of detached houses built in Ontario between 2000 and 2011, provided by the 2011 Survey of Household Energy Use (SHEU) presented by Natural Resources Canada (NRCan).

Two major categories were considered for energy conservation: building envelope, and mechanical system. Several conservation measures were identified for both systems and were incrementally improved to measure the impact on overall energy consumption, and by extension, carbon emissions. These measures are detailed and illustrated in Appendix A. From this modelling analysis, the following conclusions can be made:

- → Among the envelope parameters, the most effective improvements include **increasing the building airtightness and adding additional exterior insulation**.
- → Among mechanical parameters, the greatest carbon reduction comes from installing an **air source heat pump**, which changes the heating fuel type from natural gas to electricity.
- → Installing a high efficiency HRV may also offer significant benefits, if comparing to a home with no HRV, or a low efficiency HRV.

Overall, the energy and carbon results demonstrate that, to achieve net-zero carbon standards, it is necessary to combine several energy efficiency measures. **The most effective strategy for reaching net-zero carbon combines complementary envelope and mechanical measures.**

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[1] The 2017 model was designed to Package A3 from Table 3.1.1.2.A

COST OF CARBON MITIGATION

When considering the incremental cost of implementing each conservation measure, strategies can be evaluated in terms of dollars per carbon mitigated ($\$/kgCO_2e$). These results are illustrated in Figure 3 in Appendix B. From these values, Figure 4 shows that by employing upgrades under $\$0.50/kgCO_2e$, a sizeable carbon reduction can be made, while **including those under $\$1.00/kgCO_2e$ can bring an average home into net-zero carbon levels**. In a new build scenario, each energy efficiency package is only a 3% and 10% premium respectively above the baseline capital cost. While this high level estimate is impacted by many factors, particularly location, it demonstrates how relatively inexpensive it can be to achieve new low carbon homes in contrast to retrofitting conventional housing.

POLICY IMPLICATIONS

As the first net-zero carbon buildings are built in Ontario, a monitoring program should also be implemented to measure their actual energy performance. Given the unique challenges to measuring and reporting household energy use, small-scale studies of strategically selected homes may be more appropriate to widescale monitoring or code mandated annual reporting. This program would provide feedback as building practices evolve toward net-zero carbon housing and verify the success of policy and technology decisions.

CONCLUDING REMARKS

This study demonstrates there are several key parameters that can be optimized to create net-zero carbon homes in Ontario. In general, reduction strategies should consider the following:

- → Combining improvements to both envelope and mechanical systems will prove most impactful; and
- → The carbon emission reduction of each efficiency measure should also be understood in terms of its relative cost per kilogram of carbon mitigated. The most cost-efficient measures should be prioritized, while the others can be implemented as the cost of carbon increases.

Within these recommendations, **net-zero carbon houses can be achieved using existing technology.** To meet this target within the timeline set out by the Ontario government, the following policy decisions should be considered:

- → Changes to the building code to prioritize the most effective reduction measures, especially those not easily changed in retrofits such as envelope upgrades;
- → Incentive and rebate programs for the most cost-effective retrofit-friendly parameters; and
- → Implementation of a monitoring program, such as a small-scale study of new net-zero carbon homes, to ensure carbon targets are being met and policies are being developed appropriately.

APPENDIX A: ENERGY EFFICIENCY PARAMETERS

Table 1 - Envelope based efficiency parameters

Envelope Parameter	Baseline and Incremental Efficiency Measures
Airtightness	*Baseline: 2.5 ACH_{50}* ⇒ Improvements: 2.0, 1.5, 1.0, or 0.6 ACH_{50}
Windows	*Baseline: USI-1.4 W/m²K vinyl frame [U-0.25 Btu/ ft²·°F·hr]* ⇒ Improvements: USI-0.99, vinyl frame; USI-0.97, fiberglass frame
Ceiling & Attic Insulation	*Baseline: Effective RSI-8.67 m²K/W [nominal R-50 ft²·°F·hr/Btu]* ⇒ Improvements: RSI-10.43 or RSI-12.16 (nominal R-60 and R-70)
Wall Insulation	*Baseline: Effective RSI-3.28 [nominal R-24.6] - Combination of RSI-3.35 (R-19) batt insulation and RSI-1.19 (R-2.5) exterior insulation* ⇒ Improvements: RSI-0.88, 1.76, 2.64, 3.52, or 4.40 exterior insulation
Basement Insulation	*Baseline: Effective RSI-3.72 interior insulation only [nominal R-20]* ⇒ Improvements (2 configuration cases): 1. Additional exterior insulation to 0.6 m depth below grade: ⇒ RSI-0.88 or RSI-1.76 exterior insulation (2 iterations) 2. Exterior insulation extended to full depth: ⇒ RSI-0.88 or RSI-1.76 exterior insulation (2 iterations)
Basement & Foundation Insulation	*Baseline: Effective RSI-3.72 interior insulation only [nominal R-20]* Improvements: Additional RSI-0.88 or RSI-1.76 full depth exterior and slab insulation

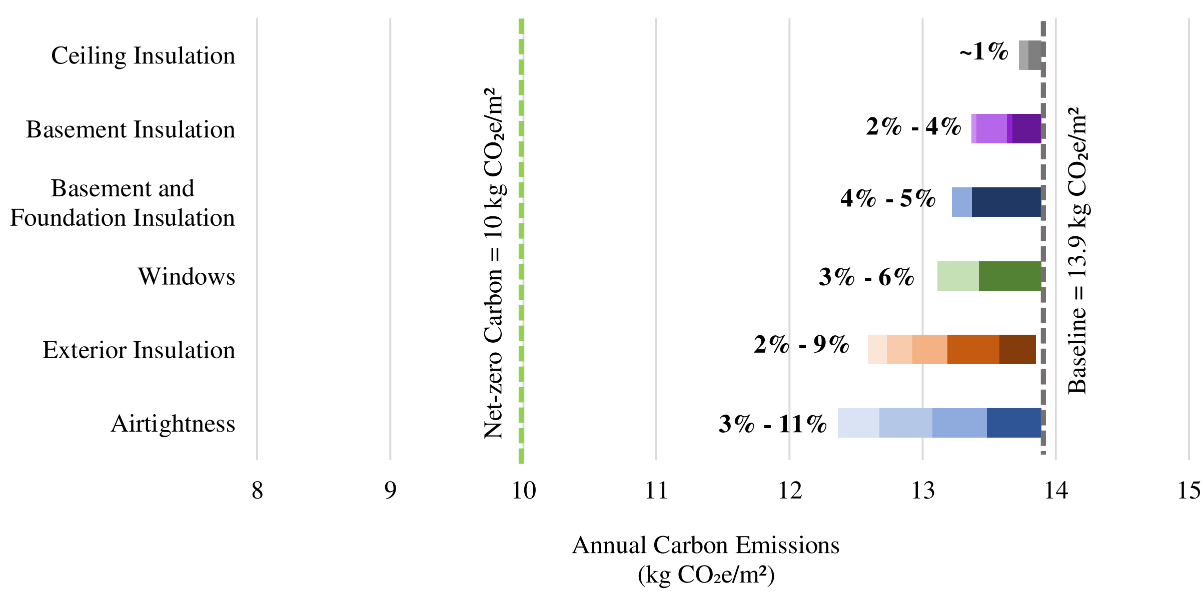


Figure 1 - Carbon reduction from envelope parameters

Table 2 – Mechanical based efficiency parameters

Mechanical Parameter	Baseline and Incremental Efficiency Measures
Furnace	*Baseline: 94% AFUE Condensing* ⇒ Improvement: 98% AFUE Condensing
Air Conditioning	*Baseline: 13 SEER Central split-system* ⇒ Improvements: 15, 17, or 21 SEER
HRV	*Baseline: 81% SRE* ⇒ Improvements: 84, 92, or 95% SRE
Air Source Heat Pump (ASHP)	*Baseline: None* ⇒ Improvement: High-efficiency split system heat pump (heating up to 10 HSPF, cooling 20 SEER)

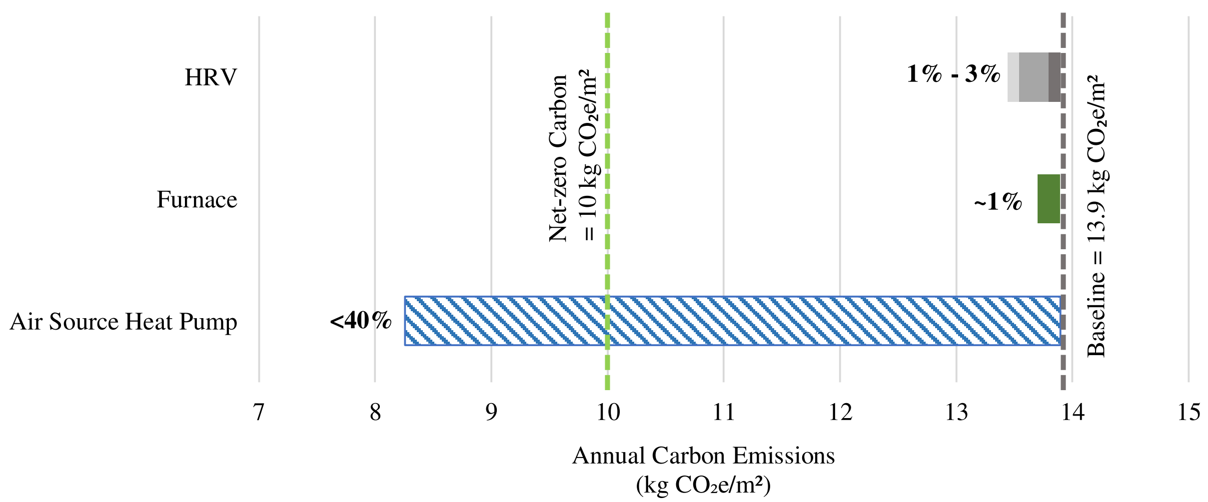
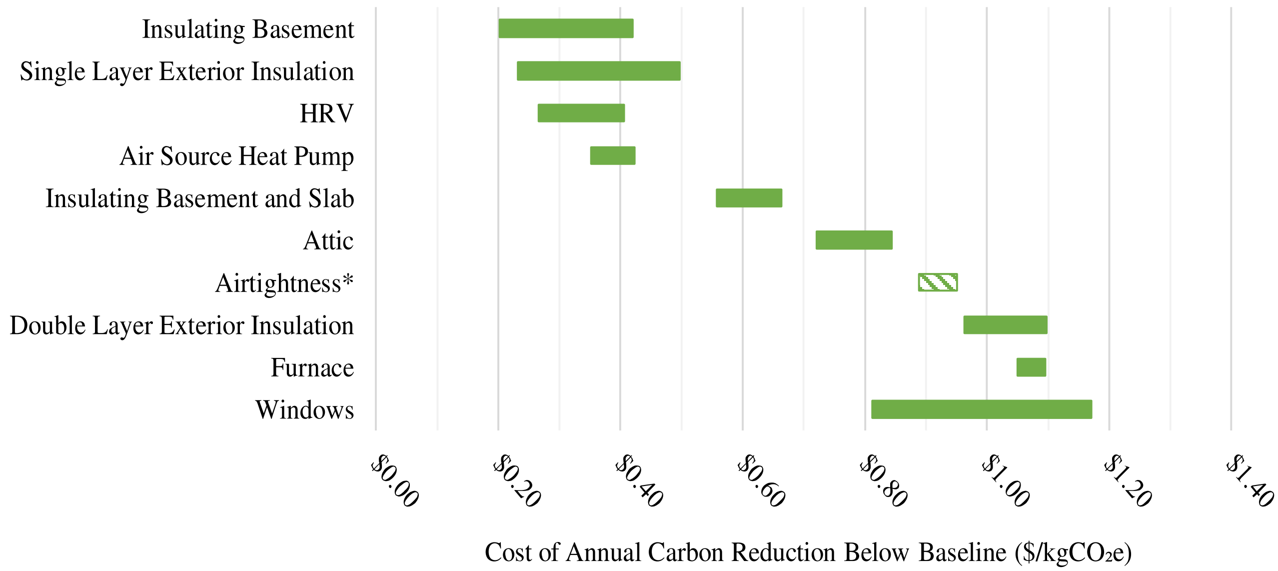


Figure 2 - Carbon reductions from mechanical parameters

While Figure 2 implies that the home can achieve net-zero carbon performance with only the addition of an air source heat pump, *this is unlikely to occur in reality*. Heat pump performance varies greatly under different operating temperatures. While this variation was incorporated into the modelling calculation, it still relies upon the rated efficiencies at low temperatures. However, these rated efficiencies may overestimate actual performance, particularly at low temperatures. Considering Ontario has a heating dominated climate, this could result in a significant reduction in the heat pump's associated carbon benefit. Therefore, these values, as with the other mechanical systems, should be used with caution, and further research should be done into the discrepancy between rated and actual performance in cold climates.

APPENDIX B: COSTING ANALYSIS



**The airtightness cost is approximate. See section below.*

Figure 3 - Cost for efficiency upgrades ($/kgCO₂e)

COSTING NOTE ON AIRTIGHTNESS

Attributing a specific cost for better airtightness is more complex than the other factors. In an energy model, airtightness can be entered as a defined value, but in practice, there is no single product or procedure that can achieve a specific level of airtightness in a home. Several factors contribute to the success or challenge in achieving an airtight home, including:

- → Building geometry; it is easier to achieve better airtightness in simpler houses than those with challenging shapes and transitions.
- → Experience of the builders, which works in conjunction with the quality of the drawings provided. To achieve high performance levels, proper training must be provided for the designers and builders involved.

The 2017 edition of the SB-12 Energy Efficiency for Housing building code allows for substitutions at an airtightness level of 2.5 ACH_{50} which is already considered to be airtight for an average home. According to communications with building professionals, to achieve airtightness beyond this level in a new build would be primarily a difference in labour hours, making the incremental cost likely linear**. The cost included in Figure 3 is an estimate for high airtightness levels that are incorporated into a new house during the design and construction phases**. As airtightness testing becomes more common in the low-rise residential sector, greater data availability and experience will make this value more robust.

APPENDIX C: LOW CARBON HOUSING PACKAGES

Table 3 - Upgrades for each cost-based carbon reduction package

Baseline	Sample Package 1: Measures ≤\$0.50/kgCO_2e	Sample Package 2: Measures ≤\$1.00/kgCO_2e
RSI-1.32 (R-7.5) exterior insulation	Additional RSI-1.32 (R-7.5) exterior insulation	Additional RSI-2.20 (R-12.5) exterior insulation
No basement exterior insulation	RSI-1.76 (R-10) full depth basement exterior insulation	RSI-1.76 (R-10) full depth basement exterior and slab insulation
HRV – 81% SRE	HRV – 92% SRE	HRV – 92% SRE
RSI-8.81 (R-50) attic insulation		Additional RSI-3.52 (R-20) attic insulation
Airtightness at 2.5 ACH_{50}		Airtightness at 1.0 ACH_{50}
Double glazed, vinyl frame windows		Triple glazed, fiberglass frame windows

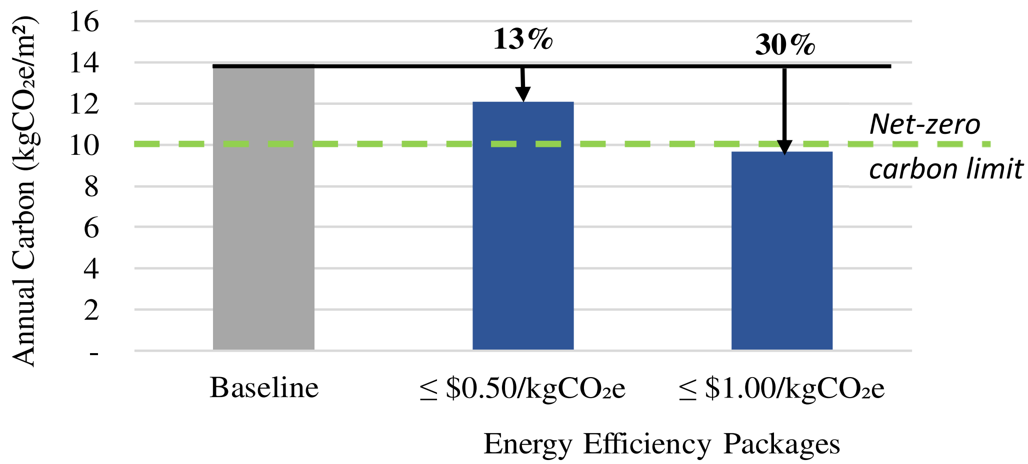


Figure 4 - Carbon reductions demonstrated by two possible cost based packages of efficiency measures