RESEARCH HIGHLIGHT

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Highly Energy Efficient Building Envelope Retrofits for Houses

INTRODUCTION

In Canada approximately 30% of all energy is consumed in buildings, with about 16% used in residential buildings and 14% in other buildings (NRCan 2005). Efforts are underway to improve the energy performance of new buildings, however it is also important to find ways to address energy performance in existing buildings.

A large amount of information is available to the public on simple ways to save energy at home; for example turning off the lights, basic air sealing, purchasing ENERGY STAR or other high efficiency appliances, and so on. However, less information is available on high energy saving measures, or methods to approach net zero energy consumption in existing houses. This research study focuses on building envelope energy efficiency retrofit measures that can be undertaken as a part of an overall approach to achieving near net zero energy consumption for existing houses.

This research evaluates various retrofit alternatives relative to criteria that include energy and cost savings, retrofit costs, thermal performance, hygrothermal performance, and environmental considerations.

BACKGROUND

A net zero energy house is a house that produces as much energy as it consumes on an annual basis. Net zero buildings are often grid-tied, meaning they draw energy from the grid as needed and supply energy back to the grid as it is produced, the balance over the course of the year being zero. Net zero is typically achieved by reducing the heating, cooling and other electrical loads as much as possible through high performance envelopes and highly energy efficient mechanical and electrical systems, and generating the balance of energy required to be considered net zero through onsite renewable means such as solar photovoltaics.

Other terms that are often associated with net zero are near net zero and net zero ready. Near net zero simply means a house that produces “almost” as much energy as it consumes annually, though there is no quantified measure for how close to net zero the house should be. Net zero ready means a house that has minimized heating, cooling and other loads, the balance of which could be generated by on-site renewable energy installed at a later time.

A well-insulated and sealed building envelope with appropriately selected glazing is needed to minimize heating and cooling loads and maximize solar heat gain during the winter. Near net zero energy consumption would be more difficult to achieve without a high performance building envelope. The location and orientation of the house also affects near net zero design by affecting the amount of renewable energy that can be generated at the site (for example available solar energy). While the building envelope retrofit design should reduce heating and cooling loads to a minimum, it must also be practical to build and make sense from a cost and functional standpoint.

This research identified and assessed highly energy efficient building envelope retrofits that could form part of a broader, whole house retrofit project directed at attaining near net zero energy use. Analysis of mechanical, electrical and renewable energy systems that would also be needed to attain near net zero energy use is beyond the scope of this research.

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METHODOLOGY

A literature review was performed to prepare a comprehensive list of potential Energy Efficiency Measures (EEMs) for roofs, above grade walls, windows, below grade walls and slab-on-grade construction. These EEMs were then evaluated for each of four housing archetypes in 14 Canadian municipalities relative to construction feasibility, energy savings potential, cost to implement, and cost effectiveness. Some of the more feasible EEM strategies considered for each part of a building enclosure included:

For attic and roof assemblies

- Top up existing attic insulation (add insulation over existing)
- Flash and fill attic insulation (remove existing insulation, apply spray applied foam insulation (SPF), covering with additional insulation)
- Roof with exterior insulation

For above grade wall assemblies

- Double stud
- Larsen truss
- Exterior extruded polystyrene (XPS) insulation
- Exterior mineral wool insulation

For windows and doors

- Thermally efficient frames, panels and glazing

For below grade assemblies

- Interior wall 24 mm (1 in.) SPF plus 38x89 mm (2x4 in.) framing and fibreglass batt insulation
- Exterior wall XPS or SPF insulation
- Interior slab XPS insulation
- Interior wall XPS insulation
- Interior wall SPF insulation

Natural Resources Canada's HOT2000 Version 10.51 residential energy performance simulation software was used to evaluate the annual energy consumption of the selected house archetypes before and after the EEM packages were applied. Building envelope EEM packages (groups of EEMs suitable for a particular house archetype) that provided an EnerGuide for Houses (EGH) rating of 83 were used as a benchmark of a highly energy efficient building envelope that would be part of a whole house near net zero energy retrofit. EGH-83 was chosen as the target, because it approximates a relatively high energy performance level that can be achieved by building envelope retrofits in houses equipped with mid-efficiency mechanical and electrical systems (i.e. without mechanical or electrical retrofits, or renewable energy). All simulations therefore used mid-level efficiency mechanical equipment and standard EnerGuide assumptions so that the only variables evaluated were the building envelope retrofit measures. Note that while the building envelope is important, there are many other technologies and practices that must be applied to achieve net zero or near net zero energy performance. The building envelope retrofit strategies identified in this report can improve the energy efficiency of a house but will not result in the house achieving net zero energy performance on their own.

In addition to the energy analysis and assessment of cost effectiveness, the evaluation of EEMs considered other building science performance issues, in particular hygrothermal performance. It is critical that the implementation of EEMs does not compromise the durability of the building envelope.

Conceptual retrofit details for EEM packages were developed for each of the four housing archetypes selected for the study.

FINDINGS

Retrofit Strategies

The retrofit strategies developed were grouped into five areas: roofs or attics, above grade walls, windows and doors, below grade walls, and foundation floor slab. For each area there are a number of alternative building envelope retrofit strategies that are feasible as a part of an overall near net zero retrofit, provided that appropriate control of air, water and vapour are addressed. The most appropriate retrofit strategies will vary based on specific project variables, however general conclusions can be made based on the parameters and assumptions for this study. Figures 1 and 2 show four retrofit strategies that were studied, each involving more than one measure (i.e., airsealing and insulation).

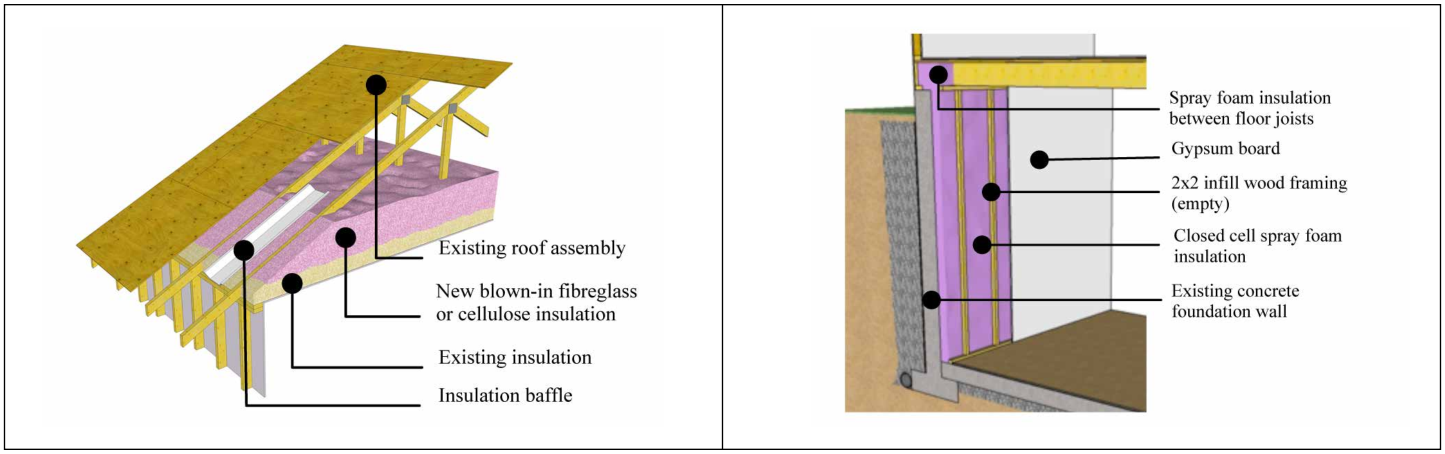

Figure 1 Example retrofit strategies: attic insulation (left) and below grade wall insulation (right).

In general, attic or roof retrofit measures should improve the attic or roof insulation and improve airtightness. The "top-up" attic insulation retrofit provides a high level of thermal performance at a relatively modest cost. The airtightness of the house-attic interface should first be improved by sealing all ceiling penetrations through the existing polyethylene air barrier including the attic hatch, electrical boxes, bathroom fans, ducts, plumbing vents, wiring etc. Alternative roof and attic retrofit measures include "flash and fill" which involves removing the existing insulation, spraying in closed-cell foam insulation to a depth of 40 - 50 mm (1.5 – 2 in.) and then blowing in additional insulation. This technique provides an air barrier at the ceiling if one did not previously exist. Alternatively, exterior insulation can be applied immediately below the roof sheathing and may be cost effective if the roof requires replacement. It is also applicable for 1.5 storey houses with knee walls.

Above grade walls may be retrofitted from the exterior or the interior. If an exterior retrofit is undertaken, exterior mineral wool insulation was found to provide good thermal and hygrothermal performance for the lowest cost of the exterior insulation retrofits studied. This strategy involves removing the existing cladding, installing an air barrier system, placing mineral wool insulation and a protective weather barrier, attaching vertical strapping and then installing new cladding. A continuous air barrier should be installed with proper detailing at all joints to improve airtightness. If an interior retrofit is undertaken, the research suggests that a double stud wall retrofit could be cost effective. With this strategy the existing gypsum board and vapour barrier are removed, a second row of 38x89 mm (2x4 in.) wood framing is installed and filled with insulation, and a new vapour barrier and gypsum board are installed. In addition, a continuous air barrier should be installed using an airtight drywall approach with

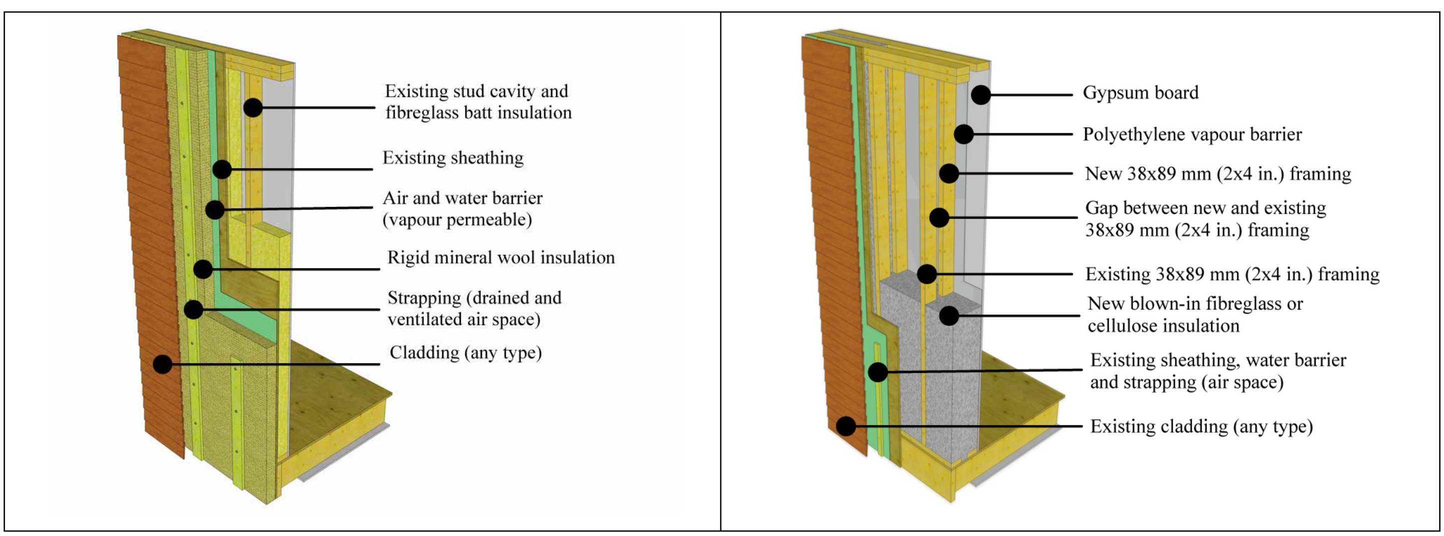

Figure 2 Wall retrofit strategies: exterior mineral wool insulation (left) and double stud wall (right).

proper detailing at all joints. Alternative above grade wall retrofit strategies include exterior extruded polystyrene (XPS) or expanded polystyrene (EPS) insulation, an exterior Larsen Truss filled with fibreglass, and, cellulose or spray foam insulation.

Window retrofits should improve the thermal performance and airtightness of the building enclosure system as well. Triple glazed windows with two low-e coatings, argon gas fill, low conductivity spacers and low conductivity frames (vinyl, wood or fibreglass) provide significant energy savings. Proper detailing is important at the window to wall interface to provide a continuous air barrier and effective water penetration control. The solar heat gain coefficient of the glazing should be selected based on project specific conditions, and exterior shading devices should be used to optimize seasonal solar heat gain. If triple glazed windows are cost prohibitive, installing new double glazed windows can also offer energy savings. Doors with an insulated core can provide additional energy savings.

Below grade walls can be retrofitted by adding insulation either on the interior or the exterior. Interior retrofits were found to be typically less expensive since exterior retrofits require excavating the foundation. However, interior retrofits may result in a small loss of floor space. With below grade wall retrofits it is important to correct any foundation moisture problems before proceeding and control air and vapour movement into the retrofitted wall assembly to prevent moisture problems. The interior spray foam insulation retrofit provides the best hygrothermal performance. Other retrofits have comparable cost but require more attention to installation and details to provide good hygrothermal performance. Alternative below grade wall retrofit measures include installing XPS insulation with sealed (taped) joints, installing only 25 to 50 mm (1 to 2 in.) of closed cell spray foam insulation followed by 38x89 mm (2x4 in.) framing with batt insulation to reduce the cost or excavating the foundation and installing XPS insulation at the exterior.

Insulating the underside of basement floor slabs is generally not practical in retrofits given the cost and disruption of removing the existing slab, installing insulation and pouring a new slab. Therefore insulation is more likely to be retrofitted on top of the slab. This limits the thickness of insulation that can be used since adding insulation and new flooring on top of the slab reduces floor to ceiling height in the interior space. The slab can be insulated by installing XPS insulation with taped joints on top of the slab and covering with new flooring.

THERMAL PERFORMANCE OF NEAR NET ZERO ENCLOSURES

Regardless of geographic location, more insulation should always reduce the heating and cooling load. However, increasing insulation has diminishing returns with respect to energy savings. Therefore, each retrofit project should be evaluated for how much insulation is required and make sense on a case-by-case basis, considering the location, mechanical and electrical systems, renewable energy opportunities and costs, and overall goals for the project. The following general guidelines illustrate the level of building envelope insulation retrofit, and air leakage performance, that would be required as a part of a whole house near net zero energy retrofit. The findings are fairly consistent with other research findings:

- Ceiling or Roof: RSI-10.6 m^2-K/W (R-60 hr ft^2 F/Btu)
- Above Grade Walls: RSI-7.0 m^2-K/W (R-40 hr ft^2 F/Btu)
- Windows: RSI-0.9 m^2-K/W (R-6 hr ft^2 F/Btu)
- Below Grade Walls: RSI-3.5 m^2-K/W (R-20 hr ft^2 F/Btu)
- Foundation Slab: RSI-1.8 m^2-K/W (R-10 hr ft^2 F/Btu)
- Airtightness: 1 ACH @ 50 Pa

BUILDING SCIENCE CONSIDERATIONS

Analysis was undertaken to evaluate the heat, air and moisture transfer performance of each of the proposed retrofit strategies. The most important consideration was how the retrofits may change the moisture performance of the retrofitted envelope assemblies. Thermal performance was assessed by determining the overall effective thermal

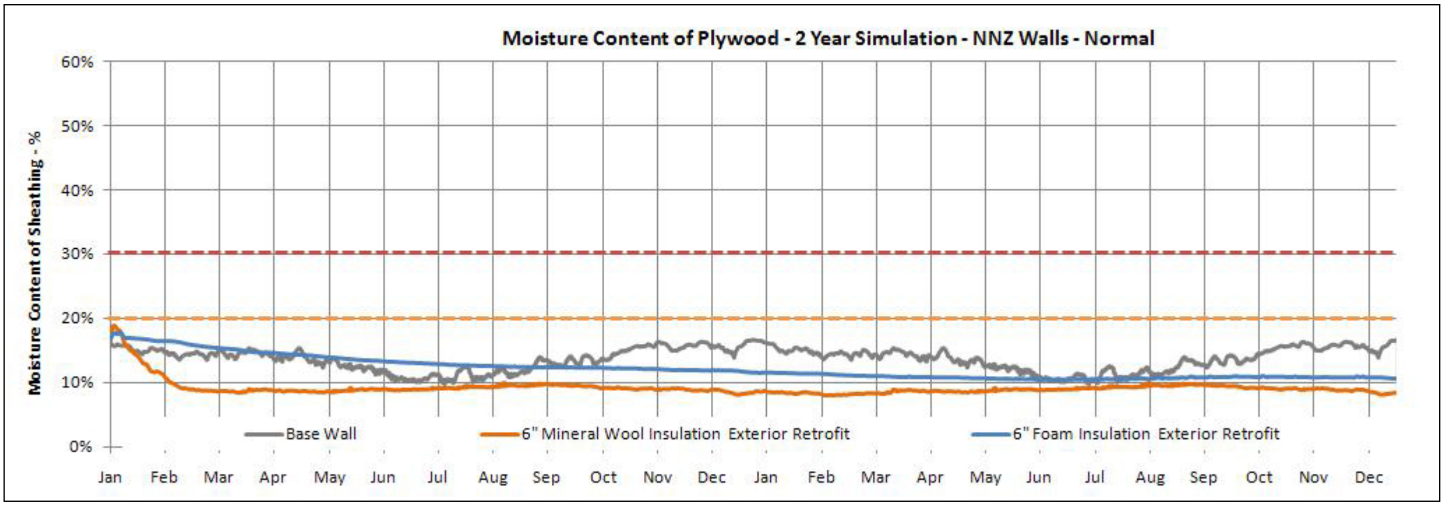

Figure 3 WUFI simulation results, moisture content of plywood in exterior insulation retrofit, Vancouver.

insulation value of the assembly using either HOT2000 or, for more complex assemblies, the three-dimensional heat transfer simulation program HEAT3. Hygrothermal analysis was performed for each assembly using industry accepted best practices. For more complex assemblies, hourly hygrothermal simulations were performed using the WUFI 5.1 Pro hygrothermal modeling software. Figure 3 illustrates one example of the WUFI analysis.

The modelling was used to establish pre and post insulation retrofit moisture conditions, in the plywood sheathing of the original wall assembly. This location was chosen as it tends to represent one of the more moisture sensitive components of a wood frame wall system and is most likely to be adversely affected by interior or exterior moisture sources. Figure 3 indicates that the addition of 150 mm (6 inches) of exterior insulation tended to reduce the moisture content in the exterior plywood sheathing relative to the base case (pre-retrofitted) wall which would suggest that the retrofit strategy would not intrinsically result in moisture problems.

In general, the hygrothermal analysis indicated that most of the assemblies studied perform well under normal conditions when care is taken to control heat, air and moisture. Some assemblies were found to perform better than the pre-retrofit baseline wall (i.e. less moisture accumulation occurs), while other assemblies were found to experience greater moisture accumulation. However, all of the retrofitted assemblies were found to perform adequately provided that moisture risks related to rain or air leakage can be minimized through the use of good water management practices such as rainscreen walls with appropriate detailing, flashings, etc.

FINANCIAL ANALYSIS

The individual EEM analysis showed that many of the EEMs studied have payback periods greater than 20 years. The whole house energy consumption analysis showed that where a retrofit is undertaken for reasons other than energy savings (e.g. to repair water penetration issues or to upgrade aesthetics), the incremental cost associated with the additional insulation and air sealing can result in shorter payback periods. Further, it was found that many of the building envelope EEMs studied can be more cost effective than the installation of a photovoltaic system as the cost per unit of energy saved by the retrofit is often less than the cost per unit of energy generated by the PV system. The financial analysis showed that energy prices have a significant effect on payback periods. Higher energy costs over time will make near net zero retrofits more financially feasible.

ENVIRONMENTAL CONSIDERATIONS

The primary focus of the highly energy efficient building envelope retrofits research is to reduce energy use in single family residential buildings to near net zero. Other important considerations of a whole house near net zero energy retrofit include ensuring good post-retrofit indoor air quality, reducing resource use and environmental impact, and maximum use of recycled materials.

CONCLUSIONS

The results of this study demonstrate strategies for building envelope insulation and airtightness retrofits that can be applied as a part of whole house highly energy efficient building envelope energy retrofits in typical Canadian houses. The insulation and airtightness retrofits are technically feasible and reduce energy consumption and costs, but can have relatively long payback periods. If building envelope retrofits are required for other reasons such as to improve durability, comfort and aesthetics, the payback period based on the incremental costs associated with the insulation retrofits alone can be reduced. Further, based on the analysis conducted, the study shows that with proper detailing to control moisture, the retrofits studied would not be expected to adversely affect the moisture performance of the post-retrofit assemblies.

IMPLICATIONS FOR THE HOUSING INDUSTRY

This study has several implications for the housing industry. It demonstrates that building envelope insulation and airtightness retrofits can lead to significant reductions in energy consumption and can be cost-effective in comparison with renewable energy systems. Building envelope insulation retrofits represent an important starting point for projects seeking to reduce whole house energy consumption to near net zero levels. Another important consideration is that building envelope retrofits are not often undertaken due to cost, disruption and need. Therefore, a case can be made to include as much insulation in enclosure retrofit projects as possible as the opportunity to add more insulation in the future may not occur for many years. The results of the study also indicate that each building envelope insulation and airtightness retrofit project should be carefully assessed so that the costs and benefits are understood and that appropriate measures are taken to ensure that the long-term moisture performance of the retrofitted wall assembly is not adversely affected.

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Housing Research at CMHC

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