Net Zero Building Enclosure Retrofits for Houses: An Analysis of Retrofit Strategies

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ABSTRACT

Efforts are underway across North America to improve the energy performance of new building stock whether through building code or energy efficient building programs; however, it is also important to find ways to address energy performance in existing buildings. A research study was completed to identify and evaluate building enclosure retrofit strategies to use in near net zero retrofits for houses across all Canadian climate zones (ASHRAE/DOE Zones 4 through 8). This paper will present the key findings of this research study.

General thermal performance targets for net zero house enclosures in heating dominated climates were developed through energy simulations of four existing archetype houses constructed between the 1950s and 1980s. Retrofit strategies to achieve these targets were then identified and analyzed.

Retrofit measures are grouped into five categories: the attic or roof, above grade walls, windows and doors, below grade walls, and slab. Each retrofit was evaluated in terms of its thermal and hygrothermal performance. As improving the thermal performance of an assembly affects its hygrothermal performance, findings and retrofit design strategies for the control of air, vapour, and moisture in highly insulated enclosure assemblies were developed and are presented.

A cost analysis was completed for each retrofit strategy to determine the financial feasibility of near net zero enclosure retrofits. It was found that such retrofits are difficult to justify based on energy savings alone in most areas of North America; however, if retrofits are being completed for other reasons, such as to upgrade aesthetics or to repair water penetration issues, the incremental cost to complete a near net zero retrofit can have good financial return.

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 building stock, 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, topping up attic insulation, purchasing EnergyStar® or other high efficiency appliances. However, less information is available on deep or very high energy savings retrofits or methods to approach net zero energy consumption in existing houses. A research study was performed for Canada Mortgage and Housing Corporation (CMHC) focusing on building enclosure energy efficiency retrofit measures that will enable near net zero energy consumption for existing houses and this paper provides a summary of the key findings (RDH 2012). The study evaluates various building enclosure retrofit alternatives using criteria that include thermal performance, hygrothermal performance and durability, cost, constructability, and environmental considerations for near net zero housing retrofits in the order of 90% space conditioning savings.

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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, with the balance over the course of the year being zero or net supply. Net zero is typically achieved by reducing the heating, cooling, and other electrical loads as much as possible through high performance enclosures, efficient mechanical and electrical systems, and generating the balance of energy required to be considered net zero through on-site 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. Net zero carbon would be a scenario where carbon offsets would be purchased to balance consumption, but is not discussed here.

The building enclosure is one component of a near net zero house. A highly insulated and airtight enclosure with appropriately selected glazing is needed to minimize heating and cooling loads and maximize solar heat gain during the winter. Without a high performance building enclosure, reaching near net zero energy consumption is very difficult. 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) and also the solar heat gain benefits, shading, ventilation, etc. The building enclosure defines the heating and cooling loads on a building. The building enclosure design should reduce the loads to a level that is as low as practically possible and should make sense from a cost and functionality standpoint.

The research presented in this paper is limited to retrofits to the building enclosure to achieve near net zero energy use. Analysis of mechanical, electrical, and renewable energy generation systems were beyond the scope of this project.

Methodology

A literature review was completed to identify a comprehensive list of potential Energy Efficiency Measures (EEMs) for roofs, above grade walls, windows, below grade walls and slab-on-grade floors. Many, but not all, of the EEMs have been implemented by builders and renovators across North America. These EEMs were then evaluated for each of four existing Canadian housing archetypes (one and a half storey post-war era house, two storey raised bungalow with attached garage, two storey house with basement and garage, two storey row house/duplex end unit with basement and garage). Each house was evaluated in 14 major Canadian cities (shown in Figure 1) relative to construction feasibility, energy savings potential, cost to implement, and cost effectiveness. EEM strategies that were considered feasible and included in more detailed evaluation are summarized in Table 1.

Energy usage characteristics were evaluated using the energy modeling program HOT2000 Version 10.51 (NRCan 2008). Building enclosure EEM packages (groups of EEMs suitable for a particular housing archetype) that provided an EnerGuide for Houses (EGH) rating of 83 were used as a benchmark of a high-performance and a near net zero building enclosure. The Canadian EnerGuide

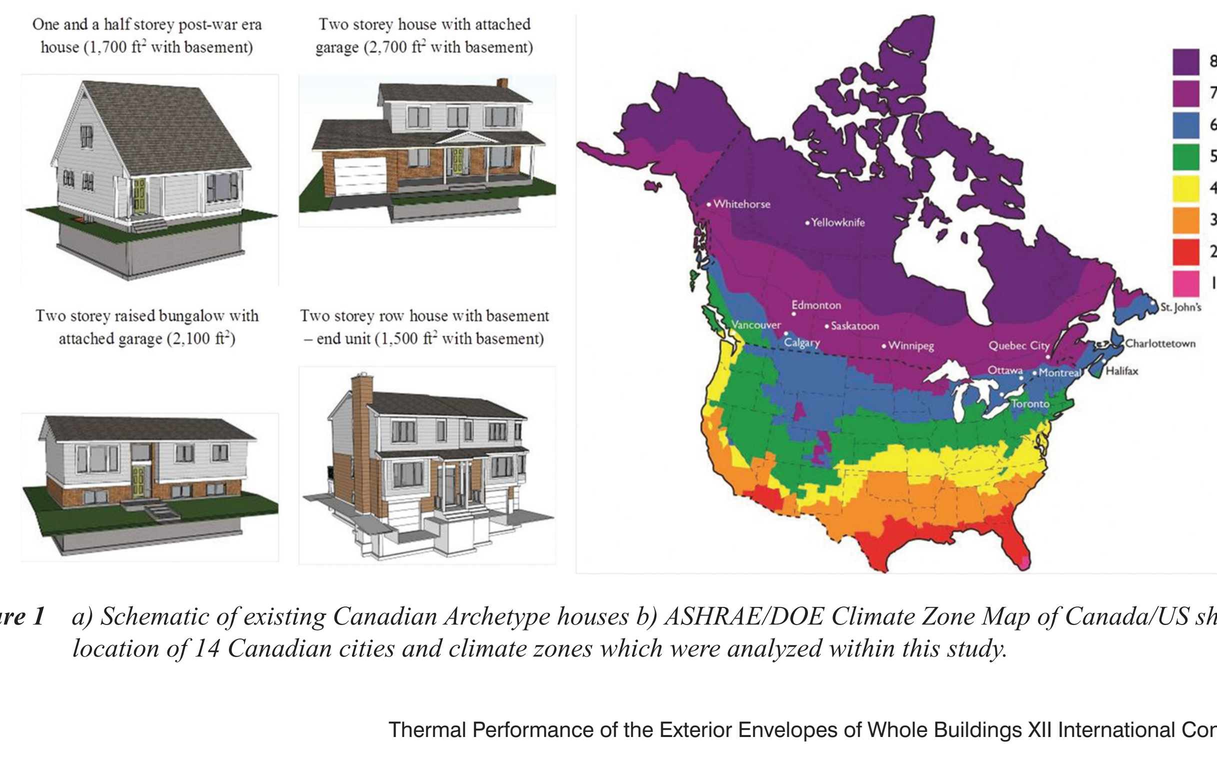

Figure 1 *a) Schematic of existing Canadian Archetype houses b) ASHRAE/DOE Climate Zone Map of Canada/US showing location of 14 Canadian cities and climate zones which were analyzed within this study.*

Table 1. Summary of Building Enclosure Retrofit Energy Efficiency Measures (EEMs) Evaluated

Attic and Roof Assemblies	Above Grade Wall Assemblies	Below Grade Wall and Slab Assemblies	Windows and Doors
• Top up existing attic insulation • Spray foam flash and fill attic insulation • Roof with exterior insulation • Improve airtightness	• Double stud (interior retrofit) • Larsen truss (exterior retrofit) • Exterior rigid or semi-rigid mineral fiber insulation (exterior retrofit) • Exterior rigid foam insulation (exterior retrofit) • Interior vacuum insulation panels (interior retrofit) • Exterior vacuum insulation panels (exterior retrofit) • Improve airtightness	• Interior slab XPS insulation • Interior slab vacuum insulation panels • Interior wall XPS or SPF insulation or in combination with fiberglass batt • Interior wall vacuum insulation panels • Exterior wall insulation (rigid XPS, SPF or mineral fiber) • Improve airtightness	• Thermally efficient frames and glazing • Insulated doors • Improve airtightness

rating system was developed by NRCan as a standard measure to measure a home's energy performance with a scale from 0 to 100 with a rating of 100 being a net zero house (NRCan 2011). A rating of EGH-83 was used since it approximates the highest energy performance level that can be achieved with a building enclosure retrofit using mid-efficiency mechanical and electrical systems (i.e., without major mechanical or electrical retrofits or renewable energy) (CMHC 2011). All simulations therefore used mid-level efficiency mechanical equipment (80% efficient furnace) and standard EnerGuide assumptions so that the only variables were the building enclosure retrofit measures. Note that while the building enclosure is important, there are many other factors that contribute to achieving net zero or near net zero energy in housing, and it takes a whole-house approach to achieve this goal. The retrofit strategies identified in this paper will therefore improve the energy efficiency of a house but will not achieve 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 including hygrothermal behaviour and relative risk as it is critical that the implementation of EEMs does not compromise other aspects of the performance of the building enclosure.

Conceptual retrofit details for EEM packages were developed for each of the four housing archetypes and are contained within the full report. An overview of the retrofit strategies and details are provided within this paper.

FINDINGS

Retrofit Strategies

As previously discussed, retrofit strategies are grouped into five areas: roof or attics, above grade walls, windows and doors, below grade walls, and slab. For each area there are a number of alternative retrofit strategies that are feasible for a near net zero enclosure 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 comparisons are made based on the parameters and assumptions of this study.

One of the biggest considerations for a building enclosure retrofit, primarily for the exterior walls, is whether to perform the work from the interior side or the exterior side of the house. This decision is something that needs to be considered carefully by the homeowner and has significant impacts on the feasibility, cost, house size constraints, aesthetics, lifestyle disruption, and long term durability. Regardless of the approach, the research finds that the best opportunity in terms of cost and disruption is to perform an enclosure retrofit when other major work is already necessary or planned. Exterior building enclosure retrofits are very common when replacing cladding, installing new windows, or repairing moisture damaged buildings and can be expanded easily to address other building enclosure issues and improve thermal performance. Occupants can continue to live within buildings undergoing an exterior retrofit which is a significant advantage in terms of convenience and cost. When performing interior retrofits, significant disruption of space is required, access to exterior walls is necessary, the work is generally dusty (and may be hazardous if exposing lead paint or asbestos), electrical work is required, and the decision may result in a loss of interior floor space.

From a building enclosure durability standpoint, exterior retrofits which replace the cladding are preferred so that water shedding details and interface details can be improved along with overall airtightness. Interior retrofits may, however, be necessary or preferred due to a heritage cladding, house aesthetic, or a building lot set-back restraint.

Figure 2 shows the typical interior and exterior building enclosure retrofit measures which were studied and are applicable to most of the housing archetypes. The two storey raised bungalow is shown in this paper and encompasses many of the common details for each archetype. The discussion in the following paragraphs covers each of the five major components from the roof to the below grade floor.

Attic or roof retrofit measures improve the attic or roof insulation and wall interface airtightness. The top-up attic insulation retrofit approach provides a high level of thermal performance at a low cost. The airtightness must be improved by sealing all ceiling penetrations to the existing polyethylene (where present) including partition walls, lights, bathroom fans, ducts, etc. to create a continuous ceiling air barrier. Alternative roof and attic retrofit strategies include a flash and fill insulation application in which a few inches of spray foam are directly applied to the existing ceiling drywall/plaster (important if there is no existing ceiling air barrier) topped with lower cost cellulose or fiberglass fill to meet the R-value needed or an exterior insulation approach (may be cost effective if the roof requires replacement and is well suited for the one and a half storey post world war two “victory house”). Figure 3 shows conceptual sketches for interior and exterior insulated roof and attic retrofits.

Above grade walls may be retrofitted from the exterior or the interior. If an exterior retrofit is chosen, exterior rigid or semi-rigid mineral wool insulation provides good thermal and hygrothermal performance with the lowest cost of the exterior insulation retrofit options. This strategy involves the removal of the existing cladding down to the sheathing. A continuous air barrier and water resistant barrier (WRB) membrane is installed over the sheathing with proper detailing at all joints/interfaces to improve the airtightness and water penetration control. Mineral wool insulation is then installed and new cladding is attached with screws through vertical wood strapping.

Where an interior retrofit is chosen, the double stud wall retrofit is the most cost effective. With this strategy the existing drywall is removed, a second row of non-load bearing 2×4 wood framing is installed and filled with dense pack fiberglass/cellulose or spray foam insulation, and new drywall is installed to finish. A continuous air barrier system is detailed utilizing either an airtight drywall, sealed polyethylene or spray foam approach with proper detailing at all joints and interfaces. This also involves removal of some ceiling drywall to insulate and air seal the floor joist cavities. Alternative above grade wall retrofit strategies include exterior foam insulation, an exterior Larsen truss filled with fiberglass or spray foam insulation, or vacuum insulated panels at the interior (Mattock 2012). Figure 4 shows conceptual level sketches for four exterior and interior insulated retrofit wall assemblies.

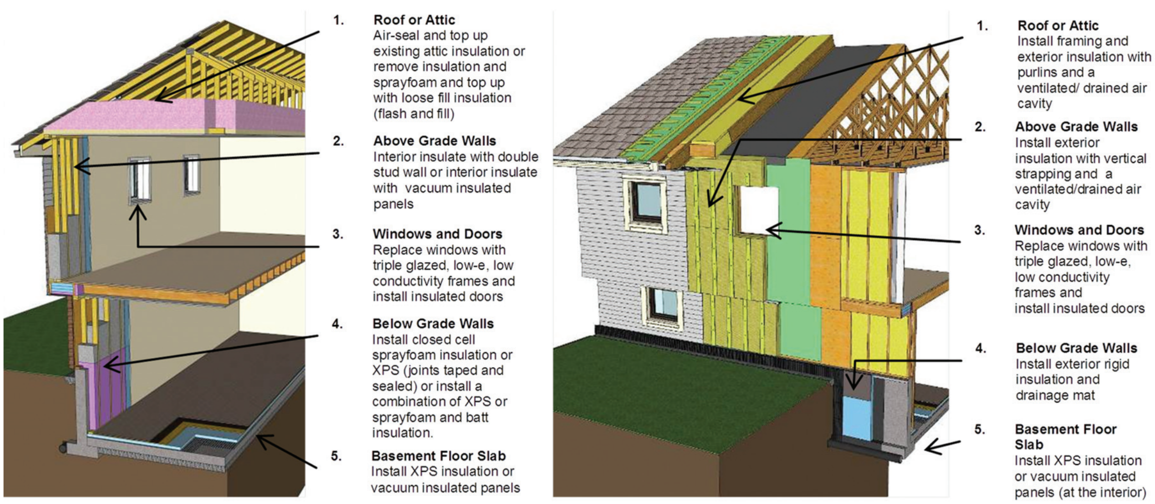

Figure 2 *(Left) Section through a house showing a full building enclosure interior retrofit and (right) exterior retrofit for the two storey raised bungalow archetype.*

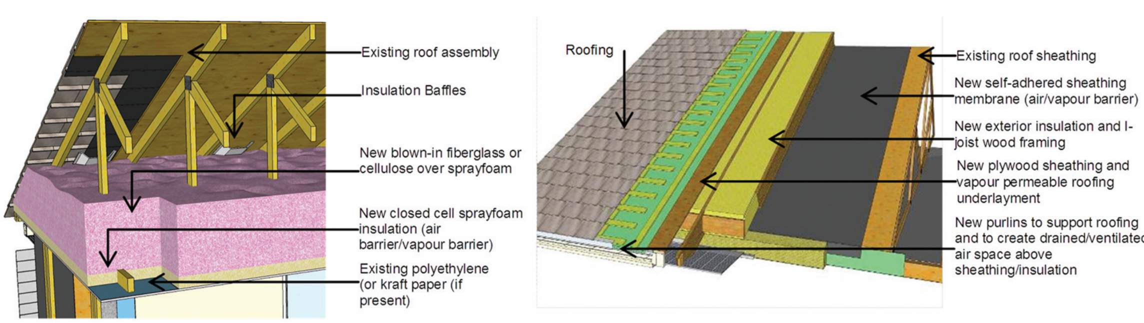

Figure 3 *(Left) Example of interior flash and fill ceiling insulation and (right) exterior roof insulation retrofit strategies.*

Window retrofits will improve the existing window thermal performance and the interface and component airtightness. Triple glazed windows with two low-e coatings, argon gas fill, low conductivity edge spacers, and low conductivity frames (vinyl, wood, or insulated fiberglass) with overall performance in the R-6 (U-0.17) range 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 (SHGC) of the glazing should be selected based on project specific conditions (generally in the moderate to high range, SHGC 0.4 to 0.5), and operable or fixed 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 still have significant energy savings. Entry doors with an insulated core can provide additional energy savings.

The near net zero retrofit will result in a thicker wall assembly. This means the window can be installed in one of three positions: in line with the exterior surface, in line with the interior surface, or in the middle of the rough opening. Any of these positions can work; however, aligned with the insulation gives a higher R-value and installing the window aligned with the interior surface will help to minimize the potential for condensation. Conceptual details for a window installed into an exterior insulated wall and interior double stud insulated wall assembly are shown in Figure 5.

Below grade wall retrofits should improve the wall insulation as well as the airtightness at the below grade to above grade wall interface. Like above grade walls, below grade walls can be retrofitted to add insulation either from the interior or the exterior. Interior retrofits are typically less expensive since exterior retrofits require excavating the foundation; however, interior retrofits typically result in a loss of floor space. With below grade wall retrofits it is important to follow

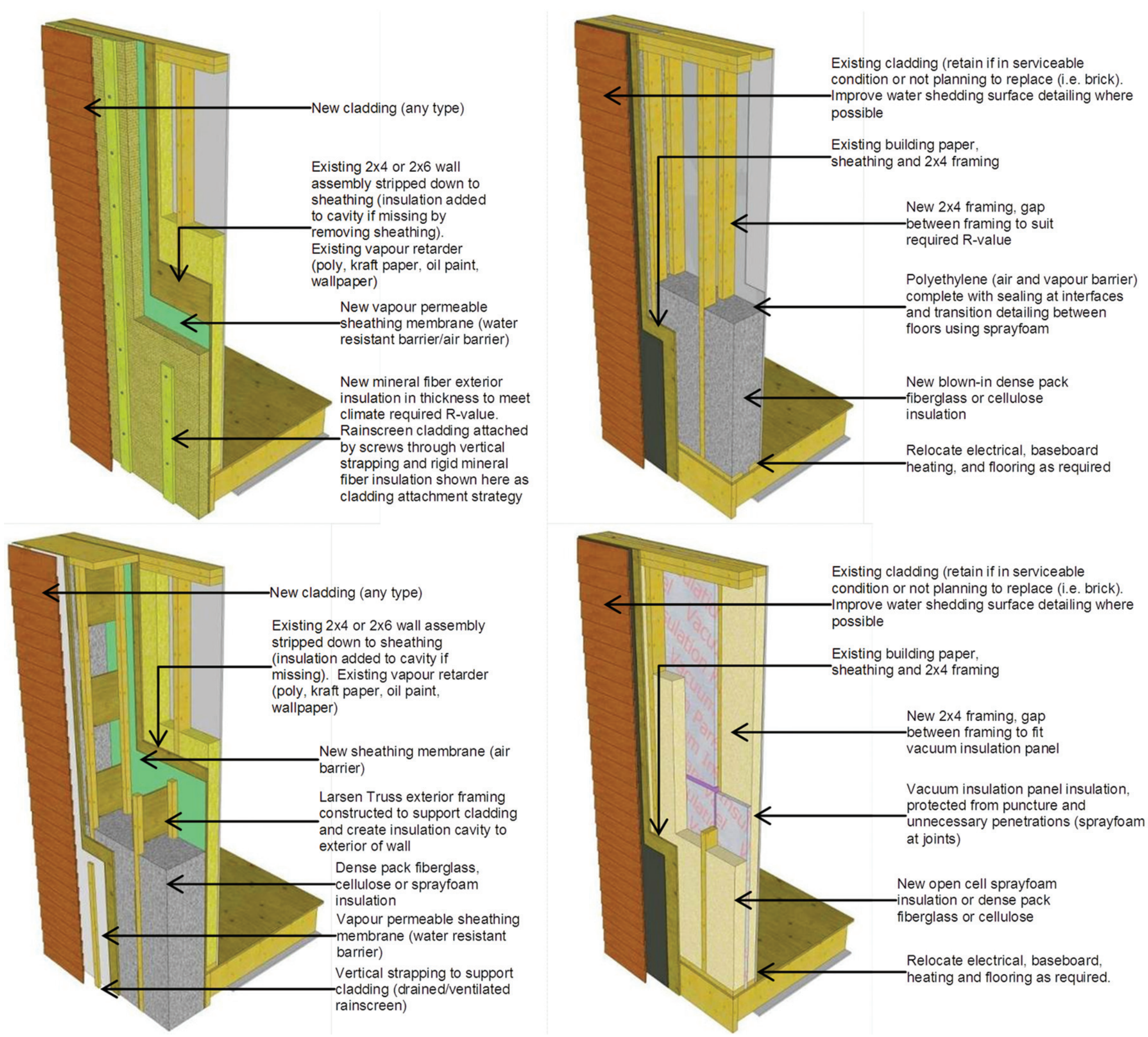

Figure 4 *Conceptual wall retrofit assemblies: (top left) exterior mineral wool insulation, (top right) interior double stud wall, (bottom left) exterior Larsen truss, and (bottom right) interior vacuum insulation panel.*

best practice guidelines for the control of air and water vapour in order to prevent moisture problems. The interior closed cell spray foam insulation retrofit provides the best hygrothermal performance of the interior retrofits based on the study results (exterior insulation is the best but is often cost prohibitive). Other retrofits have comparable cost but require more attention to installation and details to provide good hygrothermal performance. Alternative below grade wall retrofit strategies include installing XPS insulation with sealed and taped joints, installing only 1 to 2 in.of closed cell spray foam insulation followed by 2×4 framing with batt insulation to reduce the cost, installing vacuum insulation panels, or excavating the foundation and installing XPS insulation at the exterior. Figure 6 presents conceptual sketches for an exterior and interior insulated below grade retrofit.

Floor slab retrofits should improve the insulation and be airtight to prevent moisture problems. Insulating the slab at the exterior is generally not practical in retrofits unless the basement is being deepened for other purposes, and therefore the slab must be insulated at the interior. This limits the thickness of insulation that can be used since added interior slab insulation results in loss of floor to ceiling height in the interior space. The slab can be insulated by installing XPS insulation with taped joints below the flooring. An alternative but more expensive slab retrofit is to use vacuum insulated panels and may be desirable in basements with lower ceiling clearances.

Insulating the slab at the interior can create colder conditions at the bottom plate of partition walls. To protect the wood at these locations, consider the following precautions:

- Structural partition walls: replace the bottom plate with pressure treated wood.
- Non-structural partition walls: raise the bottom plate to sit on top of the floor sheathing. If VIPs are used, strips of XPS must be installed beneath the bottom plate to allow for fastening to the concrete slab.

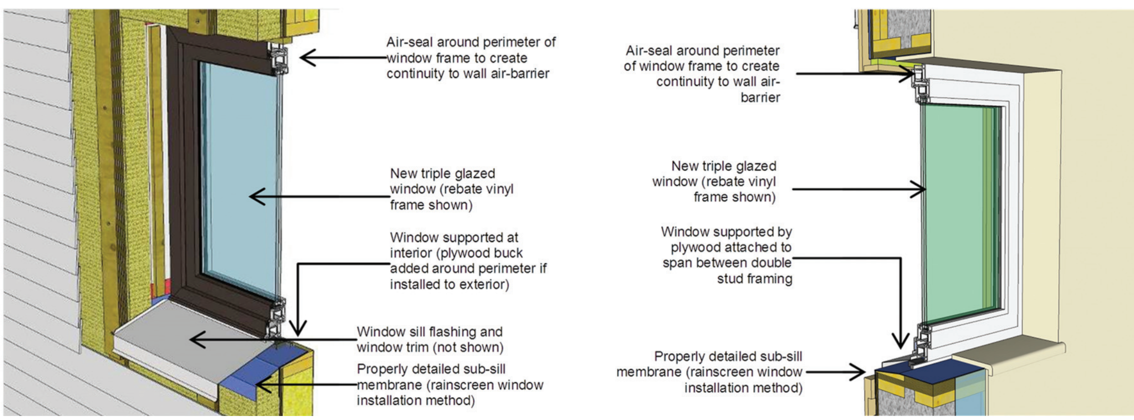

Figure 5 *Conceptual detailing for (left) windows installed into exterior insulated wall and (right) interior double stud insulated wall assembly.*

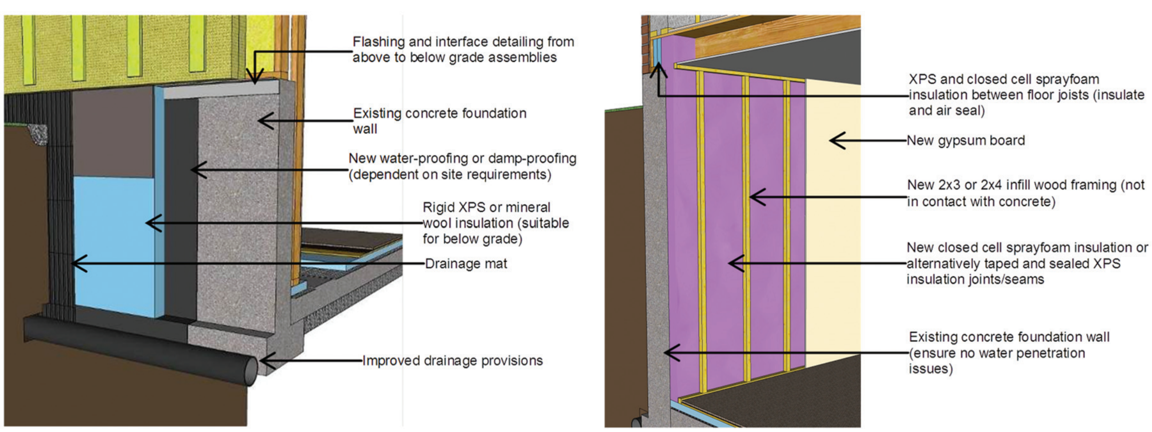

Figure 6 *Conceptual below grade wall assemblies: (left) exterior insulated for half height basement in split level bungalow and (right) interior insulated for other archetypes.*

Figure 7 presents a conceptual sketch for a basement slab and partition wall details. Adding insulation in this configuration over a drainage/ventilation matt also decouples slab moisture issues, particularly in slabs that do not have an existing vapour retarder or capillary break.

Thermal Performance of Near Net Zero Enclosures

To achieve near net zero energy consumption, regardless of geographic location, more insulation always reduces the heating and cooling load. However, increasing insulation has diminishing returns on energy savings. Each retrofit project should be evaluated for how much insulation is required and makes sense on a case-by-case basis considering the location, mechanical and electrical systems, economics of the owners, renewable energy, and overall energy goals for the project.

The following general guidelines for effective R-values (i.e., including the impact of thermal bridging) and whole house airtightness for near net zero houses were identified through this research, and this finding is fairly consistent with other research findings in the literature review (i.e., Passivhaus Standard and CMHC EQuilibrium™ Project Profiles):

- Ceiling or roof: R-60 $h \cdot ft^2 \cdot °F/Btu$ (R_{SI}-10.6 $m^2 \cdot K/W$)
- Above grade walls: R-40 $h \cdot ft^2 \cdot °F/Btu$ (R_{SI}-7.0 $m^2 \cdot K/W$)
- Windows: R-6 $h \cdot ft^2 \cdot °F/Btu$ (R_{SI}-0.9 $m^2 \cdot K/W$)
- Doors: R-6.5 $h \cdot ft^2 \cdot °F/Btu$ (R_{SI}-1.1 $m^2 \cdot K/W$)
- Below grade walls: R-20 $h \cdot ft^2 \cdot °F/Btu$ (R_{SI}-3.5 $m^2 \cdot K/W$)
- Foundation slab: R-10 $h \cdot ft^2 \cdot °F/Btu$ (R_{SI}-1.8 $m^2 \cdot K/W$)
- Airtightness: 1 ach @ 50 Pa

Specific building enclosure R-value requirements for each of the different housing archetypes in each city and climate zone are provided within the full report (RDH 2012). For example in Vancouver, BC (Climate Zone 4) it is possible to avoid insulating the basement slab, and lower wall R-values may be feasible for some archetypes which can allow for flexibility in the retrofit.

Hygrothermal Considerations

Near net zero energy building enclosure retrofits for houses require significantly higher enclosure R-values than is typical for new or retrofit construction. The net result on construction is thicker insulated walls and roofs, split insulated walls, and the use of alternate insulation materials which all reduce heat flow through the building enclosure. The reduction in heat flow through these highly insulated enclosure assemblies is beneficial to whole building energy consumption but does introduce additional considerations with respect to heat, air, and moisture control.

Analysis was undertaken to evaluate the heat, air, and moisture control functions for each of the proposed retrofit strategies to assess how the retrofit may change the moisture performance of the wall assembly. Thermal performance was assessed by determining the overall effective R-value of the assemblies using the three-dimensional heat transfer simulation program HEAT3. Hygrothermal analysis was performed qualitatively for each assembly using industry accepted best practices, and for more complex assemblies, hourly hygrothermal simulations were performed using the WUFI 5.1 Pro (WUFI) computer model. WUFI was used to simulate the performance of the wall assemblies under climatic loads for representative Canadian cities including Vancouver, Calgary, Edmonton, Winnipeg, Toronto, Ottawa, Montreal, Quebec, and St. John's. Exterior boundary conditions were assessed to model different orientations and a range of exposure and driving rainfall conditions. The interior climate was modeled in WUFI based on the exterior climatic conditions with typical interior moisture generation rates and house air-exchange rates. A range of interior moisture generation rates were simulated to assess the impact of varying low to high indoor relative humidity levels on the performance of the enclosure assemblies here. As expected, higher indoor RH levels put some of the assemblies at greater risk for condensation and wetting, and decreased the drying potential.

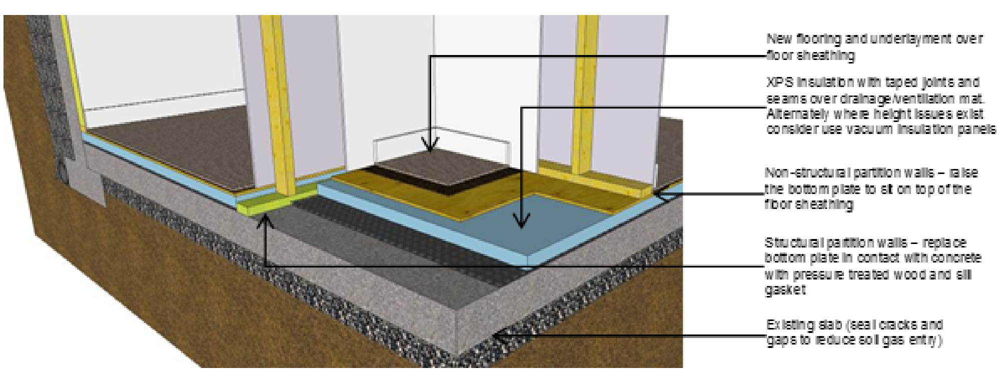

Figure 7 *Conceptual level floor slab insulation retrofit and partition wall considerations.*

The hygrothermal performance of each of the proposed highly insulated enclosure assemblies was compared to a calibrated baseline wall or roof assembly that is known to provide satisfactory performance. Assemblies are calibrated to field testing and experience in the assessment of performance of standard 2×4 or 2×6 insulated wood-frame assemblies. The performance of these baseline assemblies under normal Canadian climate conditions is well understood and modeling using WUFI has found good agreement with field measurements and historical performance data for these baseline assemblies. Supplemental data from field monitoring studies of highly insulated assemblies was also used where available to calibrate the results.

Three hygrothermal modeling scenarios were simulated to assess the relative performance and risk of each proposed enclosure assembly. For each assembly, at least a two year simulation is performed to assess the year over year moisture content, relative humidity levels, and the potential for long-term moisture accumulation. The three scenarios include:

- Normal performance
- Assembly exposed to air-leakage
    - An exfiltration air leakage rate that results in condensation and wetting of the interior surface of the wall or roof sheathing is selected, which brings the moisture content up to 30% MC for a few weeks in the winter but dries out in the spring. This air leak, which is then known to be seasonably tolerable within the baseline wall or roof, is introduced into the models for the alternate assemblies to compare relative performance. The quantity of air leakage is not important since the analysis is intended to be a relative comparison to the baseline assembly.
- Assembly exposed to a driving rain leak
    - A driving rain leak that results in wetting of the sheathing is selected which brings the moisture content in the baseline wall or roof sheathing up to 30% MC for a few weeks in the winter but dries out in the spring. The leakage rate is selected as a percentage of the driving rain and is introduced to wet the exterior surface of the sheathing. This rain leak, which is known to be seasonably tolerable within the baseline wall or roof, is introduced into the models for the alternate assemblies to assess relative performance. The quantity of rain leakage is not important since the analysis is intended to be a relative comparison to the baseline assembly.

While all parameters and results from the hygrothermal simulation were reviewed to assess the hygrothermal performance, the moisture content of the sheathing is used as a primary indicator of performance within the above grade wall and roof assemblies. The sheathing is moisture sensitive and is typically the component most likely to be become damaged by moisture ingress from vapour diffusion, air leakage, or water leakage.

Results demonstrating the hygrothermal performance and the relative sensitivity of the interior double stud retrofit and exterior insulation retrofit (with foam or rigid mineral wool) to both air leakage and rain water penetration are shown in Figure 8 and 9 for Vancouver, BC. In addition, the total number of hours per year that the sheathing is above 20% MC in six Canadian cities is shown in Table 2 for both of the wall assemblies.

The results demonstrate that the interior double stud retrofit increases the risk of air leakage or rainwater leakage wetting and damage to the exterior sheathing as compared to the baseline wall, largely because of the colder sheathing temperatures from the high levels of interior insulation. This means that detailing of both the air barrier and water shedding surface/water resistant barrier is crucial to the long-term durability of this wall. This highlights the importance of water penetration control at the interface details and can be an issue in an interior retrofit if these details are not being improved.

The results also show that the type of insulation in an exterior retrofit is very important. Rigid foam insulation is vapour impermeable and coupled with the existing vapour impermeable interior finishes (oil paint, tiles, kraft paper, or polyethylene) in an exterior retrofit can result in a situation where moisture that gets into the assembly through a defect is unable to dry out and may lead to damage. The use of vapour permeable exterior insulation such as rigid mineral fiber allows for drying outwards (beneficial in all Canadian climate zones) regardless of the interior finish. Inward vapour drive through the mineral fiber insulation is not an issue if the cladding is ventilated (i.e., rainscreen), though it could potentially be problematic in more humid and southern climate zones (i.e., Zones 1–3) with unventilated claddings due to inward vapour drive. In these climate zones, the usual lack of interior vapour control allows for the more safe use of exterior foam insulation with direct applied claddings, which reduces the inward vapour drive.

The hygrothermal analysis indicates that most of the assemblies perform well under normal conditions when care is taken to follow best practices for the control of heat, air, and moisture. Some assemblies perform better than the baseline wall (i.e., less moisture accumulation occurs), while other assemblies see greater moisture accumulation. All of the assemblies, including the baseline assemblies, will perform adequately provided that moisture risks related to rain or air leakage control can be minimized through the use of good water managed assemblies (i.e., rainscreen walls) with appropriate detailing, interfaces, flashings, and continuous air barriers. Care must be taken to avoid a dual vapour barrier situation including the use of exterior foam insulation with interior polyethylene, kraft paper, wallpaper, oil paint, or other impermeable finishes.

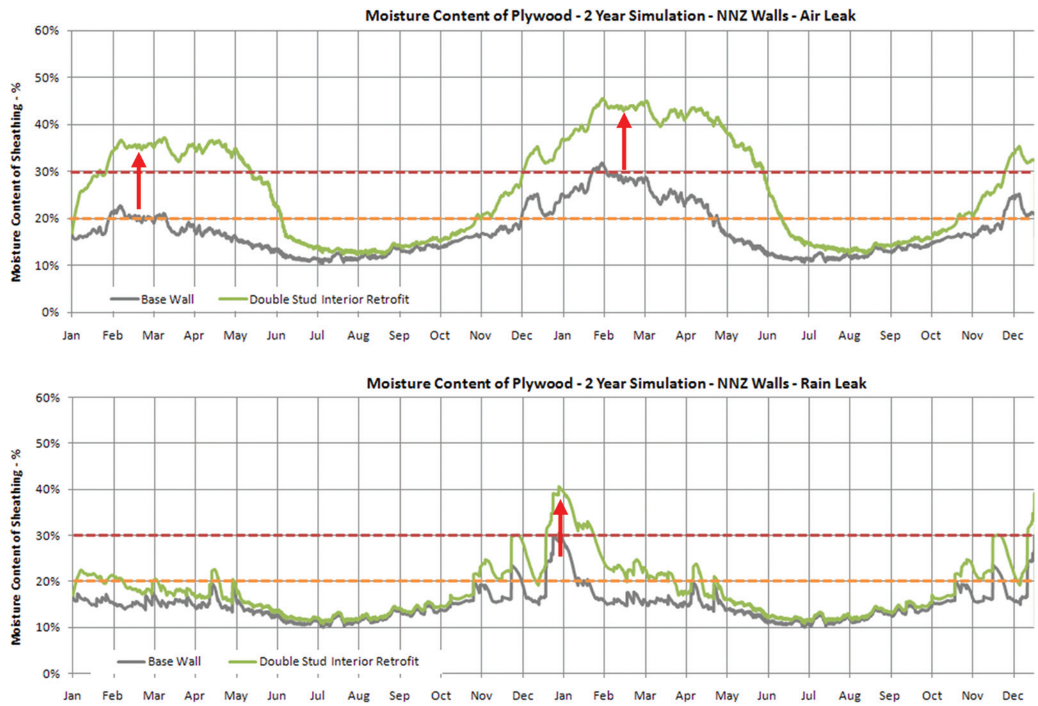

Figure 8 *Moisture content of exterior plywood sheathing (existing) in a double stud retrofit wall and baseline 2×4 insulated wall exposed to (upper) an air leak and (lower) rain water leak for Vancouver, BC.*

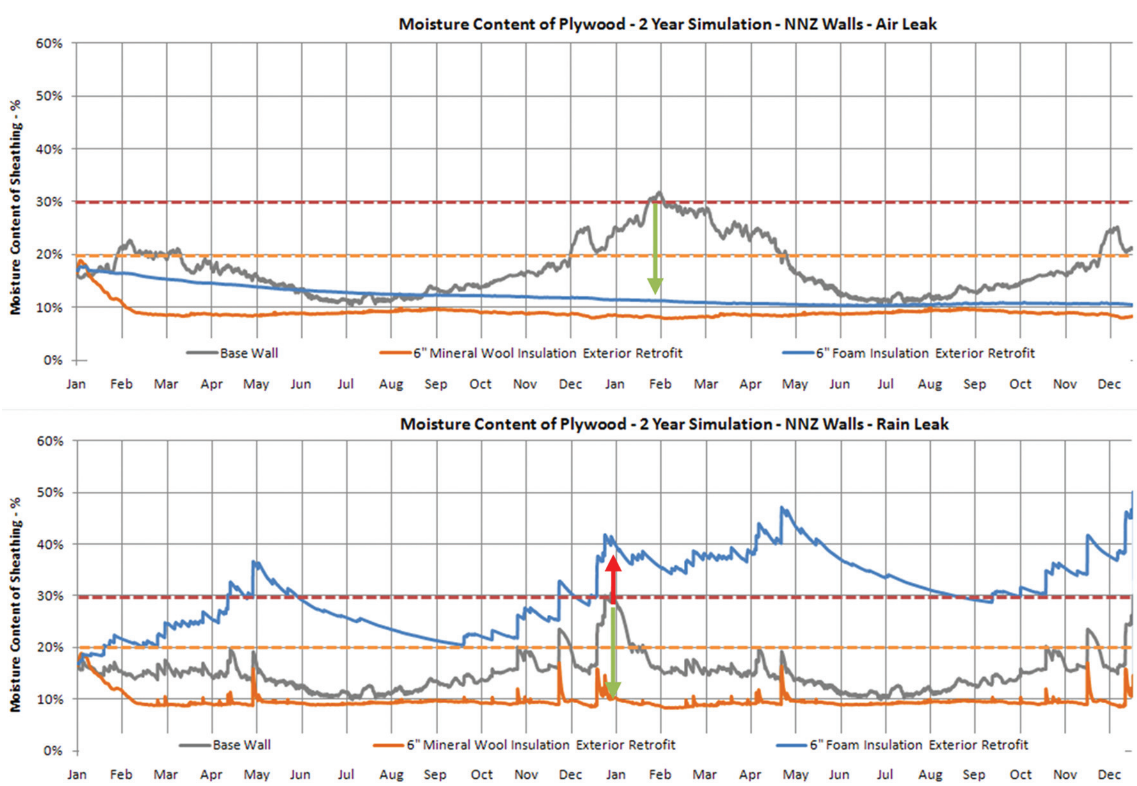

Figure 9 *Moisture content of exterior plywood sheathing (original) in a exterior insulation retrofit with either mineral fiber or foam insulation and baseline 2×4 insulated wall exposed to (upper) an air leak and (lower) rain water leak for Vancouver, BC.*

Energy Savings

A near net zero building enclosure retrofit can significantly reduce the heating energy consumption when high insulation values are used, thermal bridging is minimized, and airtightness is improved. Specific retrofit costs, energy savings, and payback periods depend on many factors, including the location, the design and construction of the existing house, and the level of retrofit performed. Every retrofit project will be different, so it is important to look at costs and savings on a case-by-case basis.

Figure 10 shows annual heating energy consumption for a typical raised bungalow house in various Canadian climates with various levels of enclosure thermal performance (all with the same mid-efficiency mechanical equipment). If a near net zero building enclosure retrofit is completed with highly insulated enclosure components, heating energy consumption could be reduced by up to 90%, depending on the existing construction and the level of enclosure retrofit performed.

Financial Analysis

A financial analysis was performed to estimate the initial construction costs for a near net zero enclosure retrofit and to estimate the annual savings in energy costs. Many home retrofit projects are undertaken for reasons other than energy consumption, for example to repair damaged assemblies, to replace assemblies at the end of their service life (such as roofs), or to improve aesthetics. If retrofits are done for reasons other than energy savings, the incremental cost of incorporating energy efficiency measures (EEMs) will always have a better financial payback than the cost of renovating for energy savings alone. Base costs were estimated for an exterior wall assembly retrofit and roof retrofit to determine the incremental payback on the additional cost of incorporating EEMs.

The four baseline archetypes were simulated using HOT2000 to determine the baseline or typical energy consumption of each of the four archetype houses. The energy consumption of the house with each individual EEM was compared to the baseline energy consumption to determine

Table 2. Summary of the Number of Hours per Year that the Exterior Sheathing Moisture Content is Above 20% when Retrofit and Baseline Walls are Exposed to Calibrated Air and Rain Water Leaks, Six Canadian Cities

City	Vancouver, BC	Edmonton, AB	Winnipeg, MB	Ottawa, ON	Quebec, QC	Saint John’s, NL
Air Leaks						
Baseline 2×4 wall	3510	2650	3463	2910	2842	3820
Interior double stud	5453	4420	4864	4205	6176	5889
Exterior mineral fiber	0	0	0	0	0	0
Exterior foam	0	0	0	0	0	0
Rainwater Leaks						
Baseline 2×4 wall	853	346	342	276	1024	436
Interior double stud	3832	425	445	1169	2058	772
Exterior mineral fiber	0	27	125	45	0	19
Exterior foam	8760	6667	8760	8760	8760	544

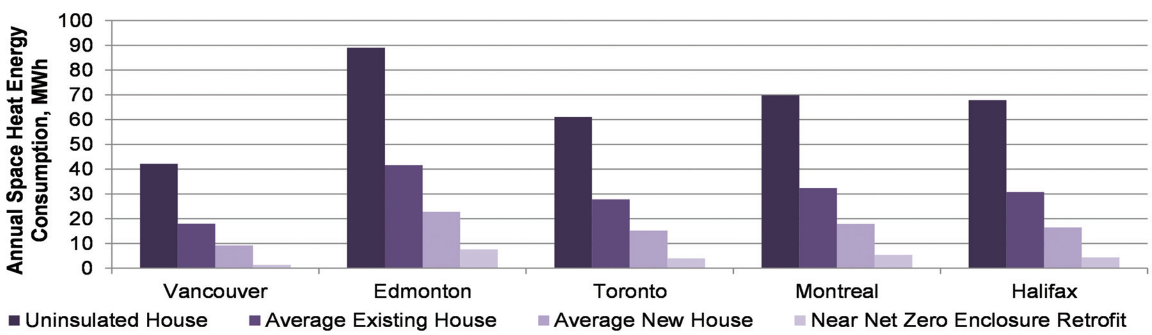

Figure 10 *Annual space heat energy consumption of houses with various insulation and airtightness levels in five different cities across Canada.*

the energy savings resulting from each EEM. For EEMs where a base retrofit was identified, the financial metrics were calculated for both the total cost of the full retrofit and the incremental cost of the EEM. To determine the energy savings of a whole house enclosure retrofit, a group of EEMs for one house were identified and simulated. The payback period and other financial metrics were calculated for the whole house near net zero retrofit. This analysis was done for locations across Canada. The construction cost of each EEM was estimated using published cost data from various sources, tempered by knowledge and experience of the retrofit market in 2011. This information is contained within the full report (RDH 2012). The energy cost savings from each EEM was based on 2011 utility rates for those cities analyzed (Hydro Quebec 2011).

Previous research shows that many deep energy retrofit measures have long payback periods (though this could change as energy costs rise). Despite high initial costs it may still be desirable to perform a near net zero energy retrofit for other non-financial reasons. An important consideration when designing a near net zero energy retrofit is to consider the cost of retrofits compared to the cost of renewable energy; at some point it may be cheaper to use renewable energy than to lower the energy consumption through enclosure EEMs (e.g., photovoltaics or solar domestic hot water). A metric to compare the cost of EEMs to the cost of renewable energy is the Value Index (Proskiw and Parekh 2010), which is the initial cost (or incremental cost) of the EEM divided by the annual energy savings attributed to it.

The Value Index can be compared to the cost of renewable energy that may also be used to achieve energy efficiency targets. In urban settings a common renewable energy source used for near net zero houses is photovoltaics. Solar PV prices have significantly dropped in the past few years from about \$8/kWh per year in 2008 (Proskiw and Parekh 2010) to less than \$3.75/kWh per year in 2011 (Mattock 2011). PV costs will continue to decrease as the technology becomes more common, and this value index can be calculated on a project basis based on local PV prices. The Value Index comparison can be thought of as comparing the cost per kWh saved (i.e., building enclosure EEMs) to the cost per kWh generated (i.e., renewable energy). This metric can help determine whether it is more cost effective to achieve near net zero energy by reducing the loads with enclosure retrofits or by generating renewable energy.

The individual EEM analysis showed that many individual or packaged house EEMs have payback periods greater than 20 years. The whole house analysis showed that where a retrofit is being completed for reasons other than energy savings (e.g., to repair water penetration issues or to upgrade aesthetics), the incremental cost to complete a near net zero retrofit can have a reduced payback period, particularly in those cities with high utility rates or rural houses still utilizing fuel oil for heating. Further, if a near net zero retrofit is desired, many of the enclosure EEMs are more cost effective than the installation of a photovoltaics system in order to achieve near net zero energy consumption. The financial analysis by city showed that energy prices have a significant impact on payback periods. High energy costs can make near net zero retrofits more financially feasible. Table 3 provides a brief summary of the total and incremental retrofit costs (as well as other financial metrics) to retrofit the building enclosure of a two storey raised bungalow archetype in six Canadian cities to near net zero.

Environmental Considerations

The primary focus of the near net zero retrofits research is to reduce the energy use in single family residential buildings. Other important considerations are occupant health and safety, resource efficiency, and environmental effect. With regards to health and safety, important issues to address as part of a near net zero enclosure retrofit include hazardous materials (asbestos, vermiculite, and lead paint), carbon monoxide, ventilation, and radon gas. The need to consider the impact of improved airtightness on the potential for back-drafting of naturally aspirated gas/oil appliances is critical, and may necessitate dedicated appliance makeup air or upgraded direct-vent appliances.

A near net zero building enclosure retrofit will provide a more airtight house, which is important for reducing energy consumption; however, this will also result in less incidental ventilation that was otherwise provided by a leaky enclosure. Therefore, the retrofit should also include energy efficient mechanical ventilation. This can be accomplished by adding a heat recovery ventilator (HRV) or an energy recovery ventilator (ERV). This ventilation should prevent condensation in the house and improve occupant health and comfort.

CONCLUSIONS

The results of this study indicate that near net zero retrofits are technically feasible but cannot be justified in the short term on the basis of a simple payback analysis alone. However, most retrofit projects are initiated to address a variety of other parameters such as moisture related performance issues, updating of the appearance of the building, or thermal comfort issues. The cost associated with minimum building enclosure retrofits to address a variety of drivers is more reasonably considered the baseline for near net zero cost payback analysis. In addition, it may be cheaper to use a combination of renewable energy (photovoltaics or solar domestic hot water) together with some of the more cost effective building enclosure retrofits to meet overall energy efficiency goals. However, as energy becomes more expensive, near net zero enclosure retrofits will become increasingly financially viable. This study has several implications for the housing industry:

- Building enclosure retrofits can lead to significant reductions in energy consumption in existing homes.
- High performance building enclosure retrofits can significantly decrease the energy loads for houses in Canada to the point where, in combination with efficient mechanical systems and on-site renewable energy generation, net zero energy can be achieved.

Table 3. Financial Analysis of Incremental Cost for Full Near Net Zero Retrofit in 6 Canadian Cities, Bungalow Archetype, 2011 Construction Cost and Utility Rates

City	Total Versus Incremental Retrofit	Cost	Annual Savings	Value Index	Simple Payback (Years)	Discounted Payback (Years)	Return on Investment
Vancouver	Total	$73,900	$1,400	$1.82	55	33	1.8%
	Incremental	$37,400	$1,400	$0.92	28	20	3.6%
Edmonton	Total	$75,800	$1,300	$0.94	56	33	1.8%
	Incremental	$38,500	$1,300	$0.48	29	21	3.5%
Winnipeg	Total	$68,700	$3,700	$0.82	18	14	5.4%
	Incremental	$34,800	$3,700	$0.42	9	8	10.7%
Toronto	Total	$74,800	$1,300	$1.32	56	33	1.8%
	Incremental	$37,900	$1,300	$0.67	29	21	3.5%
Montreal	Total	$72,100	$2,100	$1.13	34	23	2.9%
	Incremental	$36,600	$2,100	$0.57	17	14	5.8%
Halifax	Total	$67,200	$6,300	$1.07	11	9	9.4%
	Incremental	$34,000	$6,300	$0.54	5	5	18.5%

- Short-term financial benefits should not be overstated. Low energy prices mean that it will take longer for energy savings to offset retrofit costs than in places with higher energy costs.
- Consider the opportunity to make incremental energy efficiency improvements if performing such renewal or rehabilitation work as re-cladding, window replacement, or repairs to address moisture damage, as these will have the greatest payback.
- Building enclosure energy efficiency retrofits can be undertaken with little risk of moisture damage, provided care is taken to control water, air, and vapour.

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