Path to Net-Zero Energy Homes: Cost Optimization Study of Progressively Improving Energy Efficiency of Homes in Canada

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ABSTRACT

This regional cost-optimization study involved a detailed analysis of the incremental cost of attaining tiered energy targets and, ultimately, reaching net-zero.

The study focused on developing regionally sensitive recommendations for significant energy efficiency improvements. All aspects of house construction and operation needs were analyzed, including local fuel availability, building practices and renewable energy access (solar thermal and solar electric). In each case, the initial analysis was presented to local builders, developers, and their service providers (consultants, trades and contractors) to verify the construction methods and availability, and mitigate local construction barriers and regulatory issues that could impact energy efficiency upgrades. Based on the feedback from the builders and the 'ground crew,' appropriate sets of construction specifications and option packages were developed for a number of localities.

This paper documents the uniform framework applicable to many cold climates employed for developing the specifications in different regions, with specific emphasis on methods used for the energy analysis, housing archetypes, HVAC systems and incremental cost impacts. Energy efficiency targets included 25%, 50%, 75% and net zero (100%) better than current code requirements. This paper also discusses specific case studies in achieving benchmark levels of energy efficiency in new homes.

With no change to construction practises, current trade skills or commercially available products or systems, a builder can achieve 25% energy efficiency with a marginal cost increase of about 3% (about $10K), and up to 50% energy efficiency with a marginal cost increase of about 6% (about $18K). To achieve energy efficiency levels of 75%, a renewable energy contribution is required (10 to 15 GJ/year). For a 75% target, the marginal cost is 14% (about $35K). To achieve net-zero energy performance, integration of energy efficiency and renewable energy sources becomes critical (about $110K).

***Who should read this paper**: Demand Side Management Program Managers, Residential Builders, Energy Efficiency Consultants, Building Code Developers, Building Officials, Mortgage Lenders, Planners, Architects, Home Designers, Builders, Developers, Material Manufacturers and Suppliers, Product Manufacturers and Suppliers.*

***Bfreehomes Design Ltd conducted the research studies under contract from Natural Resources Canada**[1] The intellectual property for this research resides with Natural Resources Canada. For more information contact Anil.Parekh@NRCan-RNCan.gc.ca, shawna@bfreehomes.com, hal@bfreehomes.com.*

[1] The Eastern and Central/North Ontario study was co-funded by the Ontario Power Authority and Natural Resources Canada (NRCan); and was co-administered with the Ministry of Municipal Affairs and Housing and the Ontario Ministry of Energy and Infrastructure.

1. INTRODUCTION

1.1 Background

Recently, Natural Resource Canada (NRCan) initiated a four-year research undertaking to develop regionally-sensitive recommendations for achieving significant improvements in energy efficiency and, ultimately, Net Zero Energy (NZE) housing. The focus of the four studies discussed in this paper was to develop and fine-tune a framework and methodology to analyze the cost of achieving whole house energy reduction targets. This was done via researching conventional building practices in various markets and consulting active builders in those markets. Consultations covered the use of various assemblies, high performance mechanicals, and renewables, with respect to feasibility, constructability, barriers and market acceptance. As well, the builders were consulted on real and associated costs of various upgrades. This emphasis on builder consultations helped to ensure that the recommendations on progressions to NZE could be implemented in real world settings.

The four studies were conducted from 2009 to 2011. They covered seven distinct markets: Vancouver, British Columbia; Kamloops, British Columbia; Greater Toronto Area (GTA)/Southern Ontario; Eastern Ontario; Central/Northern Ontario[2]; Halifax/Central Nova Scotia; and Annapolis Valley/rural Nova Scotia. The design and analysis process is applicable in all regions of Canada and can accommodate the full spectrum of builders, from custom to large production.

Figure 1 Locations of Focus Groups

[2] The Eastern and Central/North Ontario study was co-funded by the Ontario Power Authority and Natural Resources Canada (NRCan); and was co-administered with the Ministry of Municipal Affairs and Housing and the Ontario Ministry of Energy and Infrastructure.

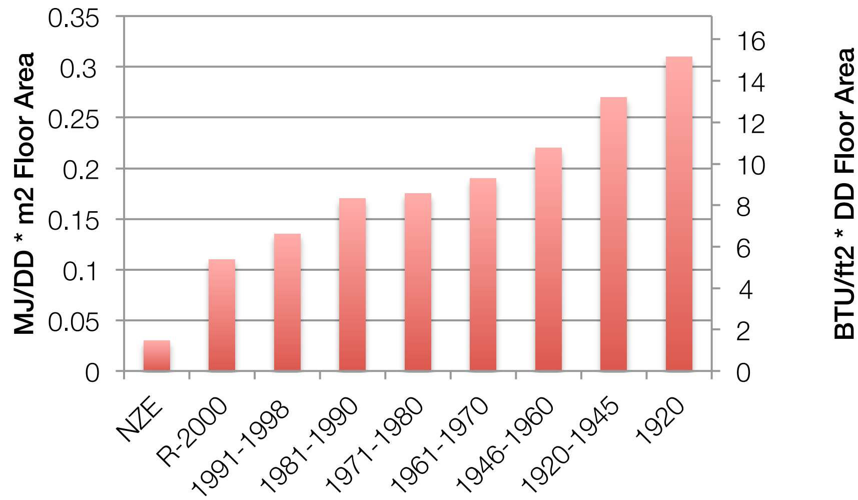

Figure 2 Progression of energy efficiency in Canadian housing vintages, from 1920 to 1991-2008, plus R-2000 and NZE.

Net Zero Energy (NZE) housing. To put NZE Housing into perspective, there are approximately 13.2 million dwellings in Canada. Roughly 63 percent are single detached. There are about 190,000 new homes built annually. Newer homes (less than 15 years old) represent 15 percent of the overall housing stock. Housing accounts for 16 percent of energy use in Canada, the third largest energy use sector after industry and transportation. It also represents the third largest source of GHG emissions.

Figure 2 shows the progression of energy efficiency in Canadian housing. Between the pre-1945 period and present day, consumption was more than cut in half, and current construction is approaching R-2000 performance. To get from R-2000 to NZE, energy consumption needs to be reduced by another two-thirds.

Although energy consumption per unit floor area has been going down, there is no concurrent drop in the amount of energy consumed by a new house, as the average heated area of new houses has increased over the past twenty years. In fact, the average annual energy consumption per household is about 127 GJ (1200 Therms) – the highest in the world. Granted, Canada has one of the most compelling reasons to require energy in our homes – a cold climate – but that also gives Canadians a compelling reason to transition to NZE housing.

Regulatory and clean energy requirements. Newly legislated and upcoming building codes that include performance based and prescribed energy efficiency measures at the regional and national levels are levelling the playing field for builders who have been working to the R-2000* standard, the ENERGY STAR® for New Homes* (ESNH) program and other regionally promoted standards that have energy reduction targets. These programs have brought up the energy efficiency standard of housing overall in Canada. It is estimated that 90% of the industry can meet the existing R-2000 standard.

The EnerGuide Rating System (ERS) from Natural Resources Canada is the current rating system for residential dwellings in Canada. A home's energy efficiency level is rated on a scale of 0 to 100. ERS80 is the current standard

* R-2000 is an official mark of Natural Resources Canada.
* The ENERGY STAR® mark is administered and promoted in Canada by Natural Resources Canada.

for most building codes in Canada, though it will be replaced by a GJ/m[2] (1 GJ/m2 = 0.88 therm/ft[2]) rating system in 2014. By the end of 2012, energy efficiency measures will be in place in six regional building codes: Nova Scotia (as of 2010 – in use at time of study), Ontario, British Columbia, Manitoba, New Brunswick and Quebec. These energy efficiency standards all include a performance path requirement equating ERS80 (on the current ERS system of 0 – 100). This equates to the current R-2000 standard and is the base equivalency for the ESNH program.

Path to net-zero concepts. A Net Zero Energy House is defined as one that produces as much energy annually as it consumes. As it is always cheaper to save a watt than make a watt, the primary focus of NZE strategies is to reduce the amount of energy the building requires to maintain comfort levels. This is achieved through improved air sealing and insulation levels as well as high-performance windows and doors. Improving the thermal envelope results in smaller heating system capacity and reduced energy use, both of which impact the manner in which renewable energy systems can be optimized.

In new housing, builders have strongly established patterns of construction and scheduling of trades, but flexibility can be found through careful planning before the construction phase. There is a bigger challenge in existing housing, where variations in house type, construction vintage and previous renovations and additions require a nearly custom approach to each house.

It is generally accepted that the best way to move to NZE is through envelope improvements initially, then through resizing/rethinking mechanical systems based on reduced loads and required capacity, and then by adding renewable energy sources. As shown in Figure 3, optimized envelope improvements can bring a house to ERS86.

As the envelope is improved past ERS86, space heating needs drop dramatically and hot water requirements become a higher priority. The challenge then becomes meeting this low load. The focus switches from prioritizing/optimizing the space heating system to optimizing domestic hot water (DHW) delivery and determining ways that DHW can augment/provide space heating load. After that point, renewable energy supply can be optimized for space and water heating. Only when all predictable energy uses (i.e., space and water heating) have been minimized should site-production of energy be considered.

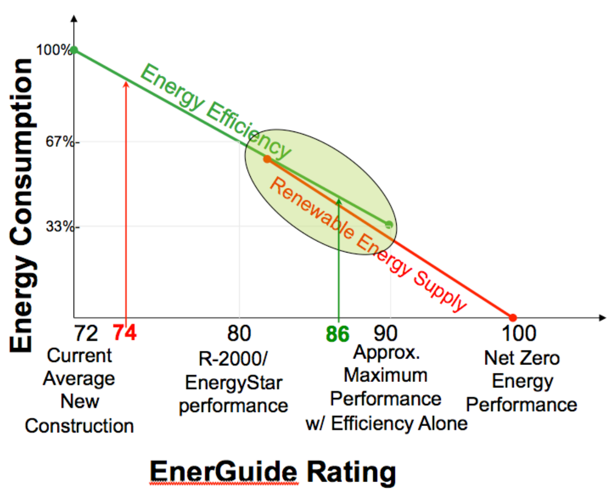

Figure 3 Progression of Upgrades to Net Zero

2. METHODS

Over the course of the four studies, a stepwise method for conducting applied research in NZE was developed. This generalized approach is applicable in all regions in Canada and can accommodate a wide range of builders, from custom to large production volumes.

2.1 Select Archetypes

Natural Resources Canada (NRCan) provided eleven archetype house plans, including Hot2000 files. For each market, the four most popular house types were chosen.

Table 1. Archetypes, by Region

	Vancouver	Kamloops	Toronto	Sudbury	Ottawa	Halifax	Wolfville
1-storey w/full basement, 177 m^2 (1900 s.f.)			√			√	√
1-storey, raised basement (split entry), 177 m^2 (1900 s.f.)				√	√		
2-storey slab-on grade, 195 m^2 (2100 s.f.)	√		√	√	√	√	√
2-storey w/walkout basement, 325 m^2 (3500 s.f.)						√	√
2-storey w/full basement, >15% window area, 325 m^2 (3500 s.f.)			√	√	√		
Row house, end unit w/full basement, 139 m^2 (1500 s.f.)	√	√	√	√	√	√	√

Table 2. Archetype, Envelope Information

		1 storey, full basement, raised basement	2 storey, full basement, walkout	2 storey, slab-on-grade	Row end, full basement
Ceiling	Area, m^2 (s.f.)	175 (1878)	210 (2260)	130 (1387)	113 (1216)
Walls	Perimeter, m (ft)	50 (165)	53 (175)	63 (209)	40 (132)
Windows	Area, m^2 (s.f.)	14 (149)	39 (424)	28 (300)	20 (216)
Foundation walls	Perimeter, m (ft)	48 (160)	51 (170)	61 (204)	38 (127)
Slab	Area, m^2 (s.f.)	165 (1776)	135 (1451)	108 (1161)	76 (818)

2.2 Conduct Background Research

Background research was conducted through online searches of trusted data sources, including energy efficiency organizations, local codes, key product suppliers and the previous research of the consultants. The following categories of information were included:

General

- Range of prominent builder types
- Most common house types
- Local code requirements
- Upcoming code changes
- Energy prices
- Energy options

Envelope

- Standard construction practices (to code) & air change rate
- Standard EE construction practices & air change rate
- Standard 'Green' construction practices & air change rate

Mechanicals

- Standard space heating & common upgrades
- Standard water heating & common upgrades
- Standard ventilation & common upgrades

2.3 Conduct Initial Energy Performance Modelling

Using the base Hot2000 files, the archetypes were subjected to increases in insulation levels to determine not only the cost-effectiveness of the measure, but also the most cost-effective combination of energy conservation and renewable energy to reach these specified energy targets:

- Baseline (code-built varied by region, roughly ERS80)
- 25% belter than the code-built (ERS84: proposed Energy Star target ERS80↓25%))
- 50% better than the code-built (ERS86: proposed R-2000 target (ERS80↓50%)
- 75% reduction from code-built (from ERS80 ERS80↓75%)
- Net Zero Energy (NZE) Scenarios (1 – 3 Scenarios, depending on the study)

Table 3. Upgrades to NZE (HP = heat pump, DHW = direct hot water)

	NZE 1	NZE 2	NZE 3
Ottawa	Air-to-water HP + gas water heating	Air-to-water HP + electric back up	Solar thermal + gas water heating
Nova Scotia	Air-to-air HP (solar DHW + electric backup)	Air-to-water HP + electric water heating	Solar thermal + electric water heating
Vancouver	Air-to-water HP (combo space and DHW)	Solar thermal (combo space and DHW)	
Kamloops	Air-to-water HP (combo space and DHW)	Solar thermal (combo space and DHW)	
GTA	Air-to-air HP (same as ERS80↓75%)		

2.4 Conduct Builder Survey, Interviews and Focus Groups

The premise of all of the studies was to engage builders in various markets in discussions about making cost-effective changes towards NZE in their building programs. The participants advised on current regional practices and helped to identify regionally appropriate energy technology options that fit into trades capacities and overall project scheduling.

The consultations included a mix of production and custom builders. Most of the custom builders were already ahead of market and could better relate to the issues being addressed.

Meetings were held with builders active in each of the markets to:

- discuss the progressive reduction scenarios;
- discuss the feasibility, constructability, barriers and market acceptance (including labour issues) for component assemblies, high performance mechanicals and renewables within the scenarios;
- discuss the point at which low heating loads prove to be a challenge;
- discuss the point at which the scale tips in favour of renewable energy systems; and
- determine, from local consultants' experiences and leading-edge regional builders' offerings, which renewable or alternate energy systems are already in the market or are poised to break into market due to provincial/regional initiatives, rebate programs, availability from local manufacturers, etc.

Phone and on-line surveys were conducted in advance of the meetings to develop a database of baseline regional building practices in order to refine and focus the meeting agenda, as well as regional costs for assemblies, mechanicals and labour. A presentation and workbook was composed for each meeting, which included the study objectives, detailed background information on NZE, and a sample progression scenario using one archetype, with a proposed set of progressions to NZE and a spreadsheet showing the modelled reductions in energy use using appropriate weather and building data. During the meeting, builders were asked to discuss and recommend ways in which the target reductions could be met cost-effectively and with minimal impact on scheduling and learning curves for trades and contractors.

As a follow-up, a recap of the meeting was sent out to the builders, and a phone interview was carried out with selected builders who agreed to review the recap memo. In some cases, the builders chose to respond to the memo via email.

The scenarios for progressions to NZE were modified based on builder feedback. For example, production builders in the large populated centre of Toronto (GTA) felt they could not meet the stated air changes per hour (ACH) targets due to labour and market constraints, so the progressions were modified to place greater emphasis on high performance mechanicals and renewables.

2.5 Obtain Costs

The following costs were obtained from local suppliers and consultant's network:

- Per lineal foot for walls and per square foot cost for windows, ceiling insulation and slab insulation
- Equipment costs for code through 100% upgrades

Current costs associated with various wall assemblies, insulation types and levels and mechanical systems were compiled from RS-Means, current price information and previous current research results.

Installation costs for building assemblies were included in the cost estimates, derived from RS-Means. Installation costs associated with mechanical systems were not included, nor were the costs of the distribution system, controls, buffer tanks, etc.

2.6 Conduct Energy Analysis

The data collected above was used in the energy analysis. The energy analysis used the following methodology:

- Select target reductions from baseline (code prescriptive path or ERS80).
- Model the baseline and reductions from baseline for 25%, 50%, 75%, and 100%, to determine the best fit for component insulation levels and targeted blower door results.
- Estimate space and water heating loads, and determine plug loads.

- Select regionally appropriate building assembly products.
- Identify high performance mechanicals and renewable technologies.
- Provide contributions to purchased fuel (e.g. solar thermal) and offsets to purchased fuel (such as drainwater heat recovery [DWHR]).
- Identify regional costs for components and mechanicals, including product costs, labour and related installation costs for building assemblies and renewables.
- Identify regional fuel costs.
- Develop a separate spreadsheet for each progression that contains:
    - Costing for all assemblies, high performance mechanicals, renewable technologies and heat recovery such as DWHR.
    - Space and water heating loads with their fuel equivalents.
    - Energy contributions from renewable technologies for each scenario that offset costs of purchased fuel (modelled).
- Review the energy analysis and revise the worksheets as needed to arrive at cost effective targets.

2.7 Conduct Financial Analysis

Simple payback is the most common method for analysing the return from an energy/housing investment. In business and economics, payback period refers to the time required for the return on an investment to repay the sum of the original investment. The simple payback has a serious drawback in that it instils a mindset of “the quicker the better” rather than a mindset of what is the best long-term investment.

Relative financial returns associated with energy saving investment options can be ranked according to their Internal Rate of Return (IRR) and then compared to the next best investment alternative. For example, an IRR of 10% over 10 years for a NZE house can be compared to interest on the increased mortgage principal needed for the premium to be paid over and above a baseline house (ERS80 in this case).

IRR, an annualised estimate, is calculated based on the net benefits across each year of the planning horizon (10 or 20 years, depending on the study). The net benefits are the additive results of:

- Incremental capital costs of the energy-saving measures compared to the baseline (-).
- Reductions in purchased fuel [oil, electricity] for space, water heating and ventilation compared to the baseline (+).
- Contributions from solar thermal for DHW and space heating to offset purchased fuel; and PV (to offset plug loads in kWh-e) (+).
- Offsets to purchased fuel for DHW from DWHR (+).

A planning horizon of 20 years was chosen for Vancouver/Kamloops, GTA and Halifax/Wolfville since this is the most realistic way of framing investment decisions for getting to Net Zero Energy. This planning horizon forces one to look at the housing stock across multiple owners with the view of enabling existing homeowners to claim additional value in the re-sale of their dwelling based on the IRR to year 20 and beyond. However, the volatile world of fuel prices led us to experiment with a planning horizon of 10 years in the Ottawa/Sudbury study.

In all studies except Ottawa/Sudbury, incremental capital costs over baseline were taken in year 1. In Ottawa/Sudbury the capital costs were amortized over each year of the 10-year planning horizon using a notional 20-year mortgage.

In the GTA NZE study (the first study) a survey of average current fuel rates was conducted to generate the data for projections of fuel rates over the planning horizon. These rates were used to estimate fuel costs for years 1-5. For years 6-20 these rates were multiplied by 150%. These were illustrative planning assumptions, not estimates.

The other NZE studies (Vancouver/Kamloops, Ottawa/Sudbury, Halifax/Wolfville) used more conventional methods for fuel estimation. An economist was brought in to establish and implement the following methodology:

- All dollar values are stated in current year dollars. The Canadian Consumer Price Index was used to estimate the value of prices for the planning horizon. Variations above or below those rates were assumed to reflect real price changes.
- Energy prices are taken before indirect consumption taxes.
- Current rates for consumption taxes were applied to projected real prices to arrive at ”retail” prices.
- Price projections were based on 6- to 10-year histories for energy sources. “Best fits” were estimated.
- The vertical positions of the regression curves were adjusted up or down depending on the residual value associated with the most recent historical data point. The process maintained the shape of the projected price curve and eliminated the statistical disconnect between the latest historical data point and the first projected data point.
- The mean and standard deviation of regression residuals, combined with a normal distribution function, were used to estimate the variance around the projected trend line for each energy price.

The Ottawa/Sudbury study used stochastic modelling to estimate fuel prices. A stochastic model estimates probability distributions of potential outcomes allowing for random variation in one or more inputs over time. IRR was therefore represented as probability distributions in this study.

Figures 4 through 6 on the following page indicate the modelled increase for each fuel type in the various regional studies.

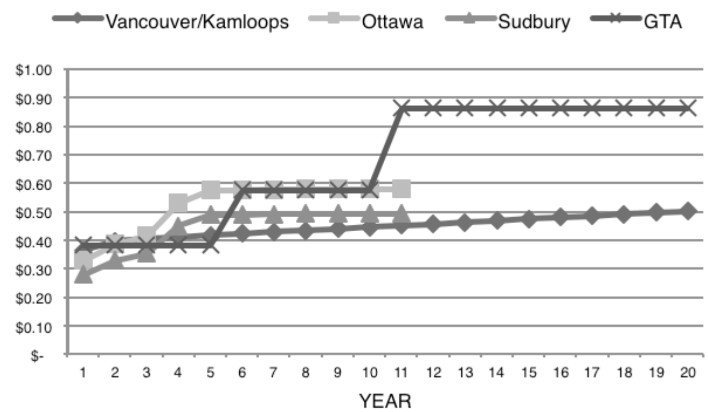

Figure 4 *Modelled Electricity Price Increases ($/kWh)*

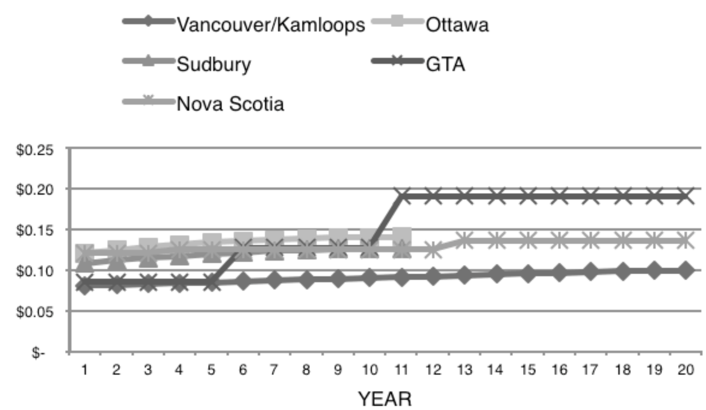

Figure 5 *Modelled Natural Gas Price Increases ($/m^3)*

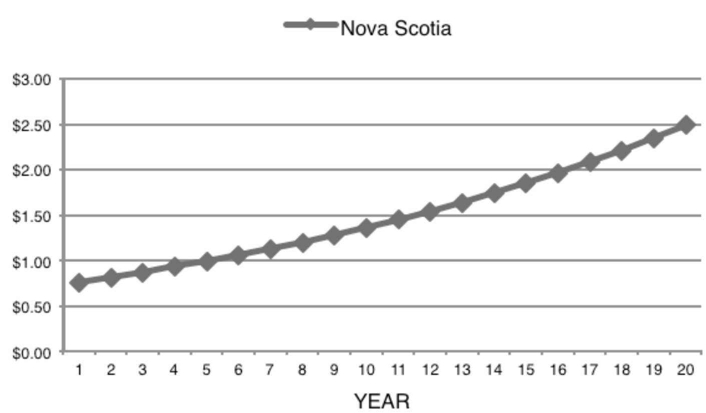

Figure 6 *Modelled Fuel Oil Price Increases ($/litre)*

3. RESULTS

3.1 Cost Estimates

The cost estimates for each region varied widely, due to local building conventions (i.e., all-brick cladding in GTA required either high-cost 2 lb. foam in the wall cavity or exterior rigid board with high-cost specialty fasteners and thicker foundation/brick ledge details), and the baseline used in each study. The GTA baseline was Ontario Building Code (OBC) 2006, while the Ottawa and Sudbury baselines were one of the prescriptive paths proposed for OBC 2012. Both of these baselines were below ERS80, so there was an addition cost incurred to bring the house up to ERS80. Vancouver, Kamloops and Nova Scotia all started from ERS80.

3.2 Cost Estimate Ranges

While there is a wide range of increased costs between archetypes and high variation between regions, there is a distinct pattern. The increased cost for the first 25% reduction from ERS80 is relatively small: well under $10,000 in all markets but Ottawa/Sudbury (median cost per region shown in Figure 7). The median cost of achieving ERS80↓25% across all studies was $6,850.

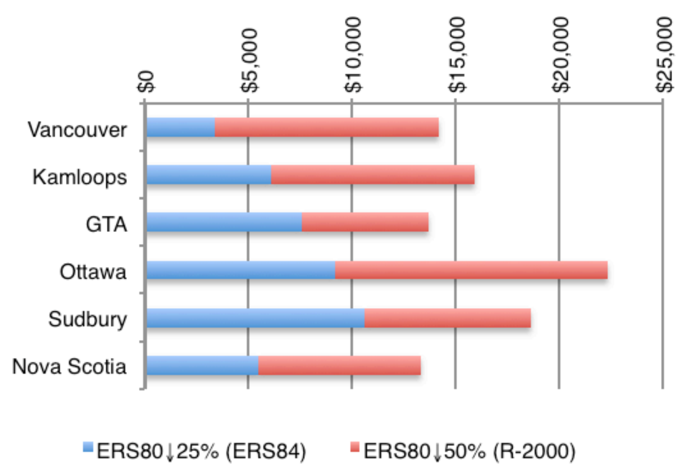

Figure 7 *Cumulative Median Cost Increase for ERS80↓25 and ERS80↓50*

The next reduction, to 50% of ERS80, was more costly, with a median increase across all studies of $8,900, but ranging up to $13,100 in Ottawa. This is in keeping with the fact that it becomes more difficult, complex and expensive to reduce heat loss as the building envelope improves. For example, in all but the Vancouver study, achieving ERS80↓50% meant upgrading the windows in the archetypes from double-pane, low-e, argon filled units to triple pane with suspended film, two low-e coatings and argon fill as well as increasing the insulation levels in the ceiling, above grade walls and foundation.

Cumulative median costs for achieving ERS80↓50% ranged from $13,300 to $22,300, with a median increase of $15,750 across all regions and all archetypes.

The third progression (ERS80↓75%), with a focus on upgraded space and water heating equipment, varied widely, but was less costly than the cumulative cost of reaching the first two progression targets, as it was primarily an upgrade to an existing delivery system.

Getting to NZE requires the largest single amount of any of the progressions, due to the cost of PV and solar thermal. In almost all cases, the cost of the NZE progression outweighed the cost of the previous three progressions combined. For example, the median cost increase for Vancouver from ERS80 to ERS80↓75% was $17,400, but the cost to go from ERS80↓75% to NZE was between $41,200 and $57,900, depending on the system chosen and the size of the corresponding PV system required to offset the energy consumption of the house. Likewise, in jurisdictions where the overall costs were much higher, such as Ottawa, achieving ERS80↓75% cost $26,700, and attaining NZE required an additional $46,800 to $64,500.

Figure 7 shows the median cumulative increases in cost for all progressions in the various jurisdictions. The multiple bars in the histogram reflect the different modeled scenarios for achieving NZE (e.g. solar thermal combination space and water heating systems; air-to-air heat pumps; air-to-water heat pumps).

Reducing overall energy use by 75% had a median cost increase range of $17,400 to $26,700. Achieving NZE had a median cost increase range of $58,600 to $95,000.

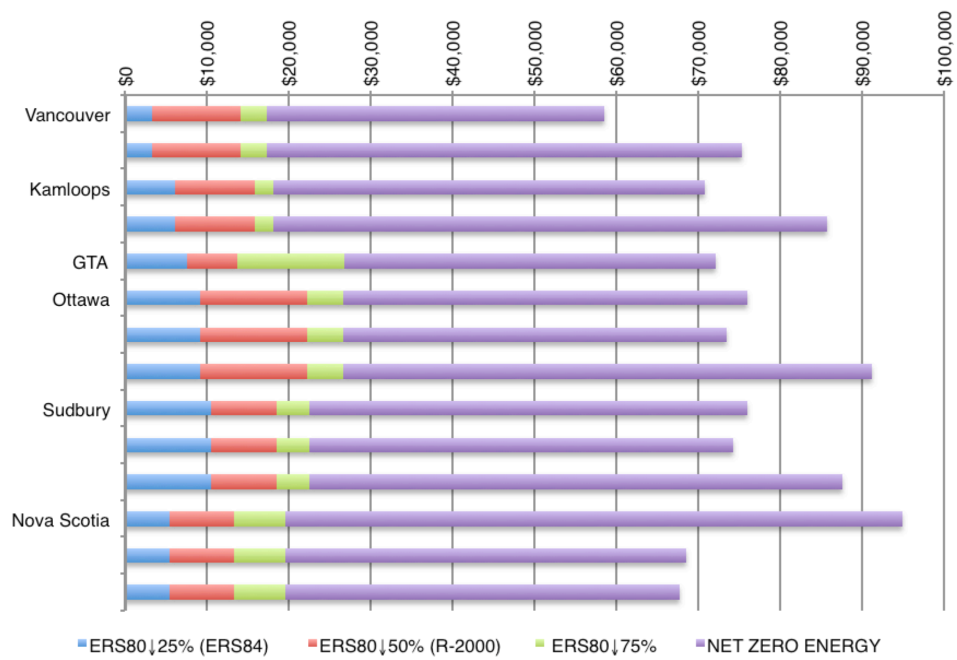

Figure 8 Median Cumulative Cost Increases

3.3 Cost Impacts of House Type

In general, the 2-storey slab-on-grade and the row house archetypes were brought to ERS80↓25% and ERS80↓50% most cost-effectively, while the 2-storey walk-out basement and the 2-storey full basement archetypes were the most costly. Reasons for this include the fact that the 2-storey basement archetypes are larger units, requiring more materials and associated labour. In the case of the walkout basement unit, there is more exposed wall, requiring higher insulation levels and air sealing work to compensate for the higher heating loss. While the slab-on-grade unit suffers from a high surface-to-volume ratio in reaching the energy reduction targets, the smaller volume translates into lower costs to improve the whole envelope.

ERS80↓75% deals primarily with mechanical systems, and so didn't show much favour to any archetype, other than smaller capacities for space heating systems. The variation in increase cost arises from the type of space heating system modelled in each study, which was determined through the builder focus groups in each city.

Table 4.1.b: Estimated Additional Costs Associated with Each Progression*

	ERS80↓25% (ERS84)	ERS80↓50% (R-2000)	ERS80↓75%	NET ZERO ENERGY
Vancouver	$1,400 to $5,000	$7,600 to $17,300	$2,000 to $3,800	$37,200 to $60,300
Kamloops	$3,500 to $7,200	$7,935 to $11,500	$1,400 to $5,000	$43,700 to $73,000
GTA	$6,700 to $10,400	$2,300 to $9,400	$11,800 to $13,800	$41,600 to $52,900
Ottawa	$8,100 to $12,600	$2,900 to $17,600	$3,500 to $4,400	$48,500 to $74,700
Sudbury	$6,200 to $14,500	$6,100 to $10,300	$6,000 to $12,000	$54,700 to $77,600
Nova Scotia	$4,500 to $6,700	$4,600 to $9,300	$6,100 to $11,700	$41,700 to $84,800

*Figures in this table represent the delta between the baseline cost of the structure and envelope for each progression.

The first two progressions are of most interest to builders, as these represent the coming upgrades to the ESNH Program (25% reduction from current R-2000/ERS80, equivalent to ERS84) and the R-2000 program (50% reduction from current R-2000/ERS80). It should be noted that several builders in the following markets indicated that they are already offering an ERS84 rating on some or all of their houses: Vancouver, Kamloops, Ottawa, Halifax and Kentville.

3.4 The Estimated Cost of the Progression ERS80 to ERS80↓25%

Across the board, reducing energy consumption for space and water heating by 25% is estimated to have a median cost of $6,850.

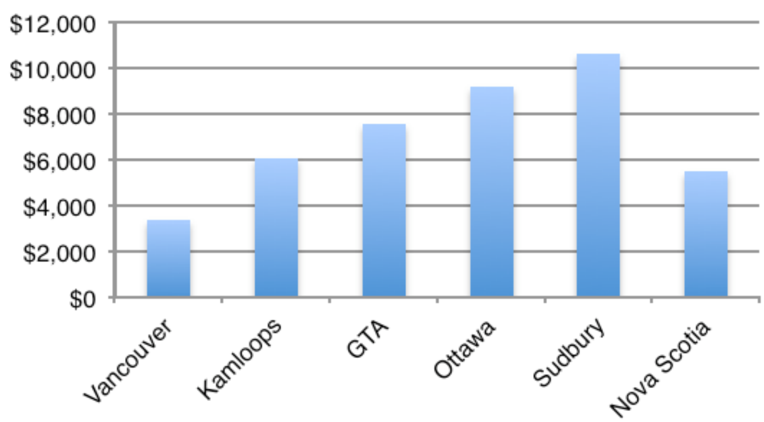

Figure 9 *Estimated Median Cost Increase of Progression for ERS80↓25% (ESNH)*

3.5 Ways to reduce costs for the progression ERS80 to ERS80↓25%

Work on the envelope first:

1. Push air sealing to the maximum.
2. Improve the wall insulation in a cost-effective way.
3. Integrate these two aspects through material and assembly choices to minimize labour costs/optimize scheduling.

Case in point: GTA builders were hesitant to look at a deeper reduction in air leakage and at thicker rigid insulation to the exterior, in part, because of labour issues. Going with a higher-priced insulation material, such as high-density spray foam, that also functions as an air barrier[3], was one solution that met the issues raised by the builders.

Going with a low-cost material in the cavity (RSI 3.9/R22 batt), and using 50 to 75mm (2" to 3") of rigid board as an air barrier has proven successful in Nova Scotia as an approach to meeting the current R-2000 air tightness target (≤1.5 ACH50) as well as hitting the thermal envelope requirement. The extra costs involved in building out brick ledges and the treatment of window and door openings in the walls have been minimized and absorbed into the overall cost of construction. Brickmolds are a standard feature of windows and can accommodate thicker exterior insulation where brick is not the cladding material of choice.

In markets where heat recovery ventilators (HRVs) are 'standard' equipment, such as Nova Scotia, an upgrade from a mid-efficiency to a high-efficiency unit is a minor premium. In markets where HRVs are not considered to be part of a conventional package, the inclusion of a unit is a considerable cost upgrade[4]. Likewise, where standard construction already includes rigid board insulation on the exterior, an increase in board thickness is a small premium compared to the addition of labour and material costs associated with rigid board as an addition to a conventional package.

3.6 The estimated cost of the progression ERS80 to ERS80↓50%

Across the board, reducing energy consumption for space and water heating by 50% had a median cost of $15,750, with a range of $13,300 to $18,600. This is relevant to builders who are currently reaching the current R-2000 standard and are planning to continue with the new standard. For R-2000 builders who are already reaching ERS84, the median cost increase between ERS80↓25% (ERS84/new ESNH) and ERS80↓50% (ERS86) is about $8,900, roughly 30 percent higher than the median cost increase between ERS80 and ERS80↓25%.

[3] Meets permeability requirements when applied in a layer of 50mm (2").
[4] This will change with the adoption of new building codes, such as OBC 2012, as several prescriptive paths include HRVs as required equipment.

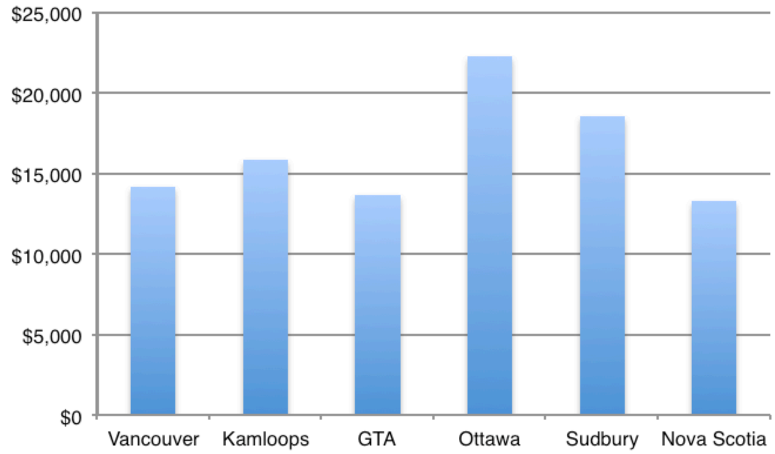

Figure 10 *Estimated Median Cost Increase of Progression for ERS80↓50% (New R-2000)*

The exercise in the four studies was to optimize the building envelope before moving to significant improvements or changes in the mechanical systems. As a result, most of the house archetypes in the four studies (except Vancouver) required an improvement to the windows in this progression. Double-pane, low-e, argon-filled glazing with insulating spacers were replaced with suspended film triple-glazed units with low-e, argon and insulating spacers ('Heat Mirror 88' or equivalent). The thermal envelope is built out significantly and costs associated with thicker walls, such as built-out window bucks and thickened brick ledges at the foundation, are allowed for in the estimates.

However, the cost of optimizing the building envelope may be too great for the builder to pass along to the homebuyer in any competitive market. In this case, using the thermal envelope levels of the 25% reduction coupled with a high-performance air-to-air heat pump (mini split or fully-ducted system) could offset the costs associated with the upgraded R-2000 standard presented here.

3.7 Ways to Reduce the Cost of the Progression ERS80 to ERS80↓50%

To optimize labour and materials, continue to look for improvements in air sealing and insulation per unit of thickness. There could be a drop in the prices of windows – one of the major costs for this progression - as triple glazing with low-e coatings and argon fill become code-regulated by climatic zone.

Cost-saving measures not covered here include: simplifying the building shell (not probable in highly competitive markets); maximizing the passive solar gain (only doable in the design phase and not applicable to every site); all available combinations of wall assembly/insulation packages for improving the thermal envelope.

3.8 The Estimated Cost of the Progression from ERS80 to ERS80↓75%

Across the board, reducing energy consumption for space and water heating by 75% from ERS80 is estimated to have a cumulative median cost increase of $21,000, with a range of $17,400 to $26,900. For builders who are reaching ERS84 and striving for deeper cuts, the median cost increase from ERS80↓50% to ERS80↓75% is $4,200 (range: $2,200 to $6,300, up to $13,200 if a window upgrade is included in this step). In markets where gas-fired forced air systems are the conventional choice, moving from a high-efficiency furnace to a small-capacity, high-efficiency air-to-air heat pump with a secondary compressor and variable fan speeds is a cost-effective way to meet the space heating reduction target.

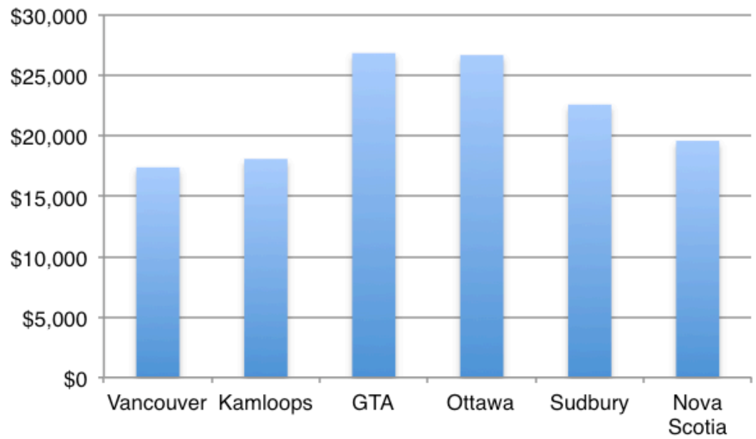

Figure 11 *Estimated Median Cost Increase of Progression for ERS80↓75%*

3.9 Ways to Reduce the Cost of the Progression ERS80 to ERS80↓75%

As this progression in the four studies was seen as the step where potential and cost-effective envelope upgrades were exhausted, improvement to the space and water heating systems were addressed. With that in mind, the ways to reduce the cost increases include all the information noted in the above sections in terms of reducing the overall heating load and resulting heating system capacity. Due to the limitations inherent in Hot2000, it was impossible to model some innovative mechanical systems or site-based passive solar options for space (and water) heating.

Reducing the load will always result in a smaller capacity furnace, boiler, heat pump or other heating source. Once the house has become very tight and well insulated, there is little demand for a full-size heating system, and, in reality, many homes at this level would be able to maintain a high comfort level with a series of space heaters in milder climates such as Vancouver and Halifax.

3.10 The Estimated Cost of the Progression from ERS80 to Net Zero Energy

Across the board, achieving NZE had an overall median cumulative cost increase of $75,700. There was a very wide range of costs for this last progression because of the variety of scenarios created for the different studies. In general, scenarios with solar thermal combination space and water heating systems required higher PV offsets than those with air-to-air or air-to-water heat pumps. However, the auxiliary fuel had an impact on the extent of the PV offset. An all-electric system (with 100% efficiency at the house) had lower energy consumption than a gas-fired boiler or water heater, requiring a lower PV offset. This analysis, in all markets but Vancouver and Kamloops, disregarded the GHG associated with fuel-fired electrical plants and on-site gas heating appliances.

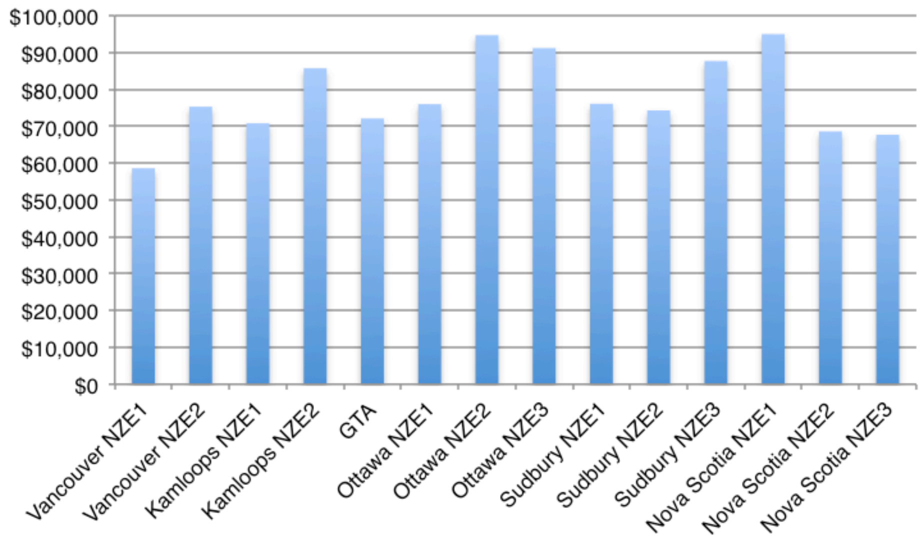

Figure 12 *Estimated Median Cost Increase of Progression for Net Zero Energy*

3.11 Ways to Reduce the Cost of the Progression ERS80 to Net Zero Energy

The progression to NZE is the most costly of all of the steps. This is the progression where all previous measures have a very clear impact: the size of the PV system is directly related to the amount of energy production required to offset the overall energy consumption of the house. The installed cost of PV was, at the time the studies were carried out, around $7/Watt. For this to be a cost-effective measure, the installed cost will have to be less than $4/Watt, assuming energy prices hover around the same mark as they have been. The balance tips in favour of PV financially when energy costs go up and a lucrative feed-in tariff is offered.

3.12 Internal Rate of Return (IRR) Results

IRR was estimated for each scenario as defined by the combinations of archetype house by progressions to NZE (e.g. Row End at 25% reductions from baseline as one scenario). The left hand column notes the number of scenarios in each jurisdiction. The centre column notes the planning horizon for the study. The right hand column notes the number of scenarios showing an IRR > 0 with the ranges for IRR.

In the GTA study (the first study) the microFIT (Feed In Tariff) was not included in this analysis as the program was not in force at the time of study.

All 12 NZE combinations in both Ottawa/Sudbury (4 archetypes x 3 NZE scenarios), where the microFIT was taken into account, show an "infinite" IRR in that there is a positive net benefit in each year of the planning horizon[5].

[5] The infinite value of the IRR occurs because the financial benefits exceed the costs at every time point in the analysis. At its most basic level, one judges if an investment makes financial sense by deciding if the rate of return is acceptable compared to rate of return of alternative investments. In the case of infinite IRR, the judgment call includes consideration of the need for the investment, risk tolerance and the working capital (including interest rates) and cash flow needed to cover short-term costs.

Table 4: IRR Results

	# of Scenarios	Planning Horizon	# of Scenarios with IRR > 0
BC: Kamloops	20	20 years	0
BC: Lower Mainland	20	20 years	2 scenarios with an IRR of 1%
GTA[6]	16	10 years	5 scenarios[7] 1 25% row end scenario with an IRR of 2% 4 NZE scenarios with IRR of 6-9%
Sudbury	28	10 years	12 scenarios[8] 12 NZE scenarios with "infinite" IRR*
Ottawa	28	10 years	15 scenarios 3 scenarios with IRR 1-3% 12 NZE scenarios with "infinite" IRR
Nova Scotia	28		23 scenarios with IRR 1-21% with an average of 8%

It was not possible to conduct a sensitivity analysis[9] in the studies (archetype, region, assemblies, mechanicals, etc.) due to the low number of data points; however, a cursory review of the data indicates that the following factors clearly influence the IRR estimates:

- the relatively low price for hydroelectricity and natural gas in a number of jurisdictions[10];
- the relatively high price for energy when heating with #2 fuel oil in Nova Scotia; and
- the microFIT (Feed-in Tariff) for the NZE scenarios in Sudbury and Ottawa.

4. RECOMMENDATIONS AND OBSERVATIONS

It is most effective to improve typical assemblies before looking at different materials or assemblies. It can be difficult to adapt the trade and supplier chain to minor modifications moving beyond prescriptive "code" requirements. Builders in all studies agreed that it would be difficult to implement wide-ranging changes quickly, while trying to stay competitive.

It is easy to analyse the cost increase of modifying a wall assembly over not, as the original cost is known and the modifications can be assessed with costing databases. The cost increase can be a huge detriment, as demand for new homes is driven by price and location first, and custom specification second. For example, Structural Insulated Panels (SIPs) were noted as being part of the custom build market in Vancouver, but they posed challenges for production builders.

Regional building authorities also play a large factor in material selection, as their interpretations of the building code can impact time lines and costs. For example, foam insulations are treated differently from region to region with respect to their properties as air barriers, and the need for vapour barriers, thermal protection, et cetera. This factor was most prominent in the discussions with the GTA builders.

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[6] Net Present Value (NPV) was used in the report for this study; however, since this concept is very difficult to grasp it was not used in the other three studies.

[7] 4 data points are NetZero scenarios

[8] Sudbury and Ottawa analysis used stochastic modelling for fuel prices. IRR values with at least a 50% probability were deemed to be material.

[9] Sensitivity Analysis, using techniques such as multivariate linear regression, orders by importance the strength and relevance of the inputs in determining the variation in the output (in this instance IRR).

[10] A key factor in the overall IRR results is relatively low prices for hydro and natural gas. For example, negative cumulative net benefits result from fuel savings being offset by the current high costs of PV installation, and, in some cases, the capital costs of solar thermal.

4.1 Air Leakage

Other common issues include cost-effective ways of bringing down air leakage levels to less than 1.0 ACH50. For builders who go the prescriptive route, there is no reason to move past the existing standard. There is discussion about including blower door testing in the prescriptive path for the National Building Code, which would be a game-changer for many builders. Some techniques associated with lower air leakage levels require re-sequencing of trades, but are not insurmountable obstacles. For example, one option put forward to the builders to reach the air tightness goals is to use a minimum of 50 mm (2 inches) of closed-cell insulation to the ceiling below the attic prior to loose fill being added. This detail requires the drywall schedule to go out of sequence because the ceiling below the attic needs to be boarded prior to spraying.

- Vancouver builders who were not in the R-2000 program had numerous questions about how to reach 1.5 ACH50. Discussion during the focus group led to an agreement that it could be reached.
- Kamloops builders noted that most if not all houses they are building reach < 2.0 ACH50, with some below 1.0. As a group, they felt that 1.5 ACH50 was aggressive for the overall new housing stock. They felt it was feasible to get below 0.5 ACH50, moving towards NZE, but that it was pushing the limit.
- GTA production builders couldn't see getting any lower than 2.0 ACH50 without major changes to the building process. Custom builders in the three Ontario markets were more confident in their ability to reach 1.5 ACH50, especially those who work with the R-2000 program.
- Halifax and Wolfville builders who routinely reach ERS84 or better noted their challenges include finding cost-effective ways of bringing down air leakage levels to less than 1.0 ACH50.

4.2 Foundations

Insulating Concrete Forms (ICF) foundations could also be implemented to achieve NZE performance, but the header area may still remain a weak spot depending on the overall envelope assembly specifications along with regional building authority interpretations. Across the board in all studies, ICF remains in the "custom builder" market, and has not gained much of a presence in the production home market due to scheduling constraints and trades' concerns with mechanical rough-ins. ICF foundation is seen as do-able for a small incremental cost, whereas building ICF to the rafters was a challenge, cost-wise.

- Vancouver and Kamloops: most builders used ICF for their foundations as a standard product.
- Vancouver builders were using 'bag' strip footings as opposed to standard formed and poured footings.

4.3 Doors and Windows

Doors and windows are very easily specified and ordered by a production builder; however, the perceived consumer benefit will determine how much of an increased cost a production builder can deliver to market for any improvements. Where many builders are already offering new houses at ERS 80 and beyond, selective glazing by orientation could bring down the premium on high-performance glazing.

- Vancouver builders are installing triple glazing for marketing reasons.
- Kamloops builders noted that the 5 to 10% increase in window costs associated with triple glazing was a 'no brainer' for their clients.
- Kamloops builders noted that is significant failure rates in window vacuum seals, which are manufactured at lower altitudes, when they are transported to the higher altitudes.

4.4 Mechanicals

Mechanicals offer a variety of ever-changing options.

In BC (outside the Vancouver area) and most of Ontario, forced-air duct systems provide benefit and remain a simple choice (high comfort/knowledge level) for trades. Traditional ducted systems have the ability to easily handle both heating and cooling needs for builders. Where baseboard hydronics are standard, in Vancouver and Nova Scotia, low-temperature delivery systems such as solar thermal may act as pre-heat to some space heating needs (especially across shoulder seasons). In-floor hydronics, a common choice in Vancouver, Halifax and Wolfville, with a lower delivery temperature, are better suited to solar thermal or other low-temperature heating sources.

Where heating loads become minimal, it may be an easier adaptation for a forced air system to use a hot water air exchanger and air handler combination to integrate DHW and space heating needs. If a heat pump or other thermal resistance space heating system is used in response to minimized heating loads, time-of-use energy storage units would be one approach to reducing peak loads.

4.5 Renewables

Solar ready features (pre-plumbing, prewiring) are achievable in a cost-effective manner in new construction and also provide marketing opportunities. Current costs for renewables, such as PV, are not in line with production builder pricing at this point, but preparation for these systems makes sense as building envelope improvements are made. The Kamloops focus group noted that there is a move from fossil fuels to renewable energy systems, but it is still in its infancy. They flagged issues with limited capacity of renewable energy trades and suppliers as being one major obstacle to overcome.

The choice of mechanical system also impacts the size of the on-site generation system required to bring the house to NZE capacity. In the following chart, the two NZE options for a 2-storey slab on grade house in Vancouver are shown. The overall amount of energy required for the proposed NZE #2 (solar thermal + gas backup boiler for space and water heating) is higher than that required by NZE #1 (air-to-water heat pump for space and water heating). As a result, NZE #2 requires 300W more capacity for an on-site generation source. In other jurisdictions, the delta in energy consumption between NZE options translated into as much as 1000W of additional capacity.

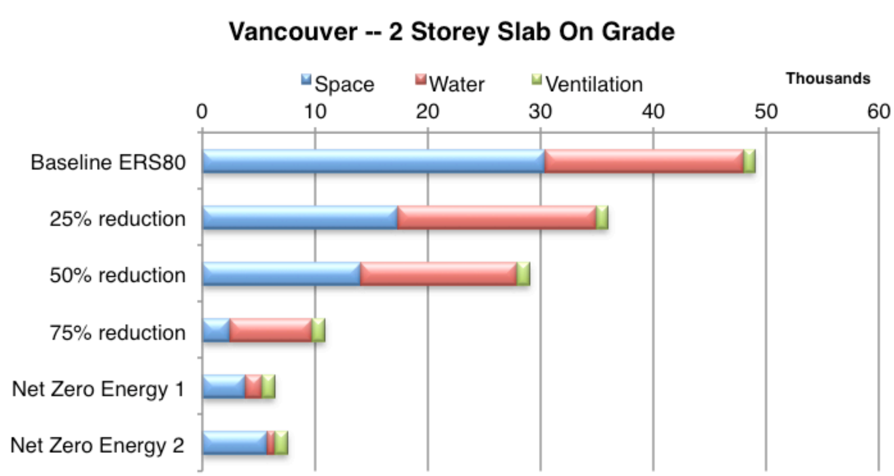

Figure 13 *Aggregate Reductions in Space Heating, Water Heating and Ventilation, MJ*

4.6 Greenhouse Gas Emissions

While not a primary driver of mechanical system choices in the studies, the GHG emissions were considered in the overall picture in the BC study.

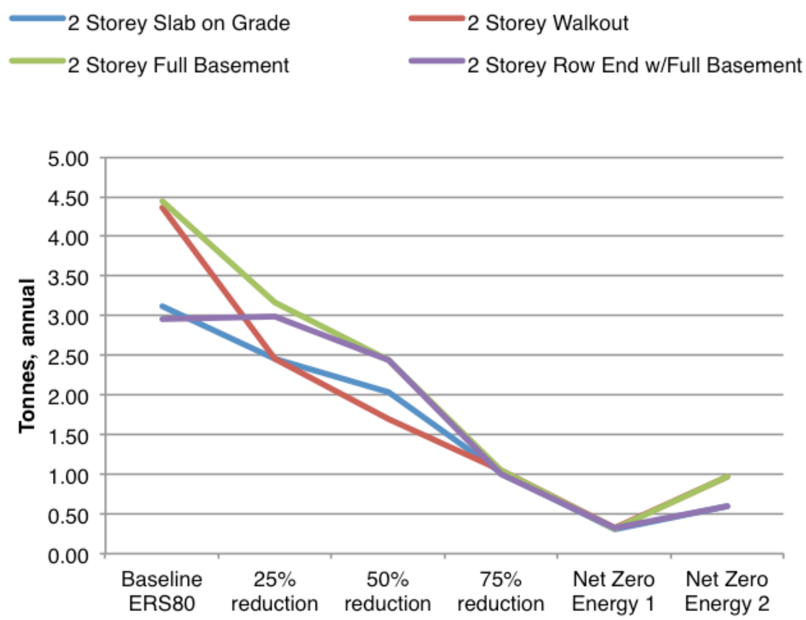

Figure 14 CO_2-e Reduction, Vancouver

Using the same example (the 2 storey slab on grade house in Vancouver), it is clear that NZE #1 has both the lowest energy consumption and the lowest CO_2-equivalent emission. This is because it is an all-electric house, but energy efficiency and CO_2-equivalent emissions do not necessarily coincide in all scenarios. GHG emissions associated with electricity production in BC (20 g/kWh[11]) are minimal compared to other areas such as Alberta (880/g/kWh)[12]. Thus, in some regions, use of a highly efficient natural gas unit such as an integrated space/water heating appliance would show a better reduction in emissions than an all-electric system[13].

Likewise, where electricity generation in Nova Scotia is roughly 60% coal/fuel oil fired, installing a heat pump may reduce the energy consumption for heating, but the overall emissions associated with fossil fuels may exceed that of a more traditional choice: the on-site oil tank feeding a high-efficiency boiler. This is partly because up to two-thirds of the energy in the fuel is lost at the power station and in transmission losses.

[11] https://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=EAF0E96A-1#section4, the figures are for 2008
[12] ibid
[13] Average carbon coefficient of natural gas is 14.47 kg carbon per mmbtu (EPA 2010). If there are 293kWh-e in 1mmBtu of natural gas and it is assumed the heating unit is 90% efficient, then:
((14.47*1000)/293)*1.1 = 54g/kWh. EPA CO_2-e figure accessed 4 Feb 2012: http://www.epa.gov/cleanenergy/energy-resources/refs.html

4.7 Comments on Financial Valuation

Reductions in material and labour costs, suchs as PV, could significantly impact IRR results in the studies.

No allowance was made for any incentive program or upcoming feed-in tariff schemes, although Ontario's microFIT program was included in the IRR calculations for Ottawa/Sudbury, as it is a long-term program[14].

Economic methods of estimating future fuel pricing rely on the past and do not take into account future volatility and availability. Future studies should conduct and update this economic analysis as a baseline and then create 10 year projections for fuel pricing that take into account expert opinions and opinions of various stakeholder groups. The intent of this type of scenario planning is not to predict the future, it is to develop plausible scenarios that can be taken into account for planning purposes.

Scenario planning is important as more and more people are concerned about energy security (price and availability in the future) as opposed to near-term simple payback. Energy security is also the key to looking at the viability of the housing stocks across Canada.

4.8 Getting to Net Zero

The premium that a customer is willing to pay is the wildcard question for every builder, but especially so for the production builder, who could have little or no interaction with the buyer of the house.

House purchasing on turnkey construction is based on a "monthly payment" mindset, and reduced monthly mortgage payments can offset additional ongoing energy costs. This is often a satisfactory trade-off for consumers, when they are unsure how long they will be holding that investment before it is re-sold.

This is less of an issue for most custom builders and in some markets (such as the Annapolis Valley in Nova Scotia), where homebuyers are often looking at a long-term investment in a home where they will raise their family or retire. Because they are able to work more closely with potential homeowners and can clarify the cost-benefit aspects of housing with reduced energy consumption (personal benefit), custom builders and smaller builders who are committed to providing sustainable housing will have a better chance of moving closer to Net Zero.

The National Building Code will up the ante in terms of energy efficiency requirements over the coming years, forcing the home building industry to follow. Some builders will just meet requirements, and others will try to position themselves slightly ahead of code to differentiate themselves (while maintaining reasonable differences when compared to their competition).

Most builder groups noted that construction (both materials and labour) costs have risen in the last 10 years for high-end houses. Additional capital cost associated with NZE measures may push the limit of new home affordability. The big issue is quality versus quantity; for example, consumers may expect larger and more costly upgrades (e.g. bathrooms) instead of, or as well as, high performance.

The Kamloops builders suggested that building green requires a simplified building process rather than higher costs. First models will have higher costs than subsequent units because of the learning curve; however, there was concern that as demand rises for high performance housing there won't be enough experienced builders to keep up.

For the new home industry, competition always lies in the resale market and if pricing of new home construction increases dramatically, due to changes in specifications, consumers may substitute resale homes into their purchasing decisions. The resale home market has not yet recognized the improved energy and construction features that some builders have implemented by creating a higher resale price for those homes versus competing

[14] The only place where the high capital costs associated with PV are not a limiting factor are in Ontario, where the microFIT program (the feed-in tariff for systems with under 10kW capacity) offers a significant income stream to the benefit of the homeowner if the amount of electricity consumed by the house at ±$0.16/kWh plus the amount of energy consumed from other sources (ie, natural gas) is offset by the amount of electricity supplied to the grid and bought at $0.64/kWh for ground mounted and $0.80/kWh for rooftop.

homes without similar features/quality.

The economics of future energy and materials costs will be critical to the marketing abilities of builders delivering improvements to the market at higher prices. When the market fully evolves to the point where an advanced built/energy efficient production home obtains a higher resale value for a consumer based on lower future costs (or conversely if an older, inefficient resale home is discounted by consumers based on higher future costs), the market for advanced homebuilding in a production environment will propagate itself.

Where new houses are required to be built to ERS80, and typical residency patterns indicate that Canadians move every 5 to 6 years on average, by 2017, new houses will have to “prove” their energy economy against existing houses with proven energy use track records. This will become more of a factor as mandatory energy labelling comes into the market. Depending on what the tipping point proves to be, it is conceivable that energy costs per square foot could overtake the selling cost per square foot as the driving factor in purchases. By 2017, new houses may well have to meet ERS85 to sell, regardless of legislation.

The other needed change is going to have to come through consumer education (media, government programs, builders’ associations, realtor associations, etc.) to appropriately assign increased value to advanced products and techniques, and to educate consumers about the importance of plug load reductions to sustain the energy savings of a Net Zero Energy house. To further the capacity of the building industry and the home buying consumer, communications objectives must be clarified and tailored for specific stakeholder groups.

Builders and renovators have different objectives than homeowners, and those differing objectives predicate the investment each group is willing to make in getting to Net Zero. Builders and renovators are looking for market niche features and options that are no/low cost. Homeowners are more likely swayed by non-quantifiable benefits than by energy savings benefits. They may buy into a Net Zero/Net Zero Ready home because it is ‘the right thing to do’, or because they want to hedge their bets with respect to fuel pricing and availability. Other stakeholders, such as investment property owners or social housing organizations are more likely to take a longer view of the investment if they can see the business case for improvements that will lead to higher rental/lease rates and long-term tenancies/shorter vacancies.

Housing can be seen as a commodity, a product designed and produced by builders in a capitalist economy, or it can be seen as social infrastructure, with costs and benefits that extend far beyond the construction industry. The cost to society of homes that use the “standard” PITE (Principal and Interest, property Taxes and Energy costs) ratios assumed by mortgage lending institutions will soon be out-dated, as the increasing costs of energy outstrip income increases due to cost of living, et cetera.

Policy decisions such as Ontario’s Green Power Act dramatically change the effectiveness of investing in such high-cost generation systems as PV. Broad reaching incentives are not in place across the country because power generation is under provincial control. Energy efficiency measures are currently funded at the federal and provincial – and sometimes municipal – levels. Because provincial and federal incentive programs are currently of a relatively short time frame, and so considered to be overly variable, they were not included in the models for payback and internal rate of return calculations, with the exception of Ontario’s feed-in tariff (FIT) program for the Ottawa/Sudbury study; however, they are part of the decision-making process for homeowners and homebuyers. Future work should focus on incentive levels and the rate of buy-in from various stakeholder groups.

The amount of energy reduction per unit of new housing shown in these studies has implications for planning for electricity generation and supply of natural gas. The corresponding reductions in greenhouse gas emissions become significant when carbon tax or cap and trade schemes come into play in Canada. These figures could be used as part of long-range projections for energy security and greenhouse gas reduction targets associated with new housing.