C3 - Energy. Ideas. Change.

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Edmonton's Energy Transition Plan (ETP)

CASE FOR GOING BEYOND BUILDING CODE

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INTRODUCTION

CONTEXT

The energy efficiency of new buildings influences energy consumption in the residential and ICI sector far longer than other end-use components determine energy consumption in other sectors. Buildings are typically constructed for use over many decades—in some cases—for 50 to 100 years. In other areas of energy end use, the capital lifetime of energy efficiency improvements will be, at most, a few decades. Hence, influencing decisions taken during a building's design and initial construction is crucial to reducing long-term energy use in the residential and ICI sector. Moreover, energy savings obtained when construction takes place are relatively cost-effective. Some measures to improve a building's energy use can only be obtained at construction or through extensive, often expensive refurbishment at a later stage—after several decades.

The policy instrument most frequently used to influence a building's lifetime energy use at the project stage is building code—specifically minimum energy performance (MEP) requirements in the code. MEP requirements in the building code helps complete the market transformation process by mandating that all new buildings incorporate construction techniques and equipment that meet minimum energy performance levels. They purposefully target the low-efficiency segment of the market seeking to eliminate sales of obsolete or energy inefficient technology. In doing so, building codes "push" the market towards greater levels of energy efficiency by forcing builders, developers, designers, equipment manufacturers, etc. to eliminate the production of less efficient buildings previously sold.[1] Moreover, it is much more cost-effective to improve the energy efficiency of the sector's worst performers through minimum standards (applicable across all end-users) than through measures targeted at individual end-users.

At the same time as energy requirements in building code improve the energy performance of the sector's worst performers, the high-efficiency and state-of-the-art segments of the market would continue to improve. Indeed, new MEP requirements establish higher baselines for the sector's top-performers to "go beyond code", often with the support of financial and non-financial incentives. These newly established top performers serve to "pull" the market forward over time. In addition, MEP requirements in building code often serve as the benchmark for refurbishment and energy efficiency improvements in existing buildings. Higher performance requirements in code thus increase the level of energy efficiency targeted by upgrades to existing buildings. Overall, MEP requirements in building code serve to directly "push" and indirectly "pull" the average energy performance of the building sector to higher and higher levels.

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[1] Energy labels serve a complementary function in the marketplace; they "pull" the market towards greater levels of energy efficiency by helping buyers make better-informed decisions and demand more efficient buildings. This in turn encourages market actors (builders, developers, designers) to provide buildings with higher levels of energy efficiency. In the absence of the information provided by energy labels, buyers (leasers) are often ill-informed about the true life-cycle cost of a building, and suppliers lack the incentive to improve energy efficiency as there is no mechanism for the market to recognize and value this attribute. Building codes and labels work together to transform the level of energy efficiency offered in the new building market.

Across both the residential and ICI buildings sectors, recommendations for more stringent MEP requirements in the building code under the Reduced Carbon Case and Low Carbon Case in Edmonton's ETP are estimated to generate cumulative energy savings of about 390 TJ and 2,390 TJ, respectively, over the period 2014-2044.

OBJECTIVE

The overarching objective of this assignment is to develop an evidence base for residential buildings in support of more stringent MEP requirements in Alberta's building code. The evidence base comprises two elements:

1. The incremental costs, energy savings, cost of conserved energy (CCE), and simple payback time associated with different scenarios for "above code" homes in Edmonton; and
2. The incremental life-cycle energy savings, GHG savings, undiscounted social and home-owner benefits, undiscounted home-owner costs, and various metrics of economic performance (e.g., NPV, ROI, SPB, and marginal GHG abatement cost) for an illustrative incentive program to drive the supply of, and demand for, "above code" new homes in Edmonton as part of the ETP; and

A qualitative argument for going beyond building code in the context of transforming the market for residential buildings is presented in Assignment 1.6.

ELEMENT 1 – COSTS AND SAVINGS OF "ABOVE CODE" NEW HOMES

METHODOLOGY

- Develop two residential new construction building archetypes, one single family detached (SFD) home and one single family attached (SFA), as follows:
  - Calculate the median size SFD and SFA (including row and duplexes) homes built over the period 2007 to 2012 from the EnerGuide for Houses (EGH) database. These home sizes correlate well to those used by Natural Resources Canada's Comprehensive Energy Use Database (CEUD) and in Edmonton's Energy Transition Strategy (approximately 150 m^2 for SFD and 131 m^2 for SFA). The number of windows and doors from the median SFD house in the EGH database is 12 windows and 2 doors. For consistency, we use the same number of windows and doors for the SFA home.
  - Assume SFD and SFA archetypes are two floors with a full basement (representative of the majority of Edmonton homes in the EGH database).
  - Generate the archetypes using the HOT 2000 "house wizard", allowing the program to choose the house shape, window and door sizes and location, and ceiling and attic type.

        - The heel height of the attic was increased (0.69 meters) to allow for up to 100 R-value of blown cellulose insulation.
        - Full details of each archetype is presented in Appendix A.

- Establish baseline energy efficiency parameters (e.g., insulation levels, mechanical system efficiency, and window efficiency) based on what is expected to be in the next iteration of updated national model construction codes (see Appendix B for details). It is assumed that Municipal Affairs follows through with its stated intention to adopt the MEP requirements in Part 9 (Housing and Small Buildings) of the National Energy Code for Buildings as written. Lower levels of insulation were considered for homes with a heat recovery ventilator. Our baseline home included a heat recovery ventilator, so these were the levels of insulation chosen. Given Alberta currently requires a minimum of 90 AFUE natural gas furnace for new construction, we choose this level of efficiency over 92 AFUE chosen by the Canadian Codes Centre study (Proskiw, 2011).
- Three levels of above code energy efficiency were applied to the baseline building archetypes. Decisions around what energy efficiency measures to include in each efficiency level was based on:
    - Energy efficiency measure cost-effective test results from previous program appraisals and evaluations performed by C3;
    - The lowest incremental capital cost net zero home in Edmonton in Canmet ENERGY's study (CanmetENERGY, 2012); and
    - Fuel choice for space and water heating.
- The three above code new SFA and SFD homes are best characterized as:
    - Moderately insulated - moderate levels of insulation and air sealing (as compared to baseline) with baseline efficiency for mechanical systems;
    - Highly efficient mechanical systems - moderate levels of insulation, better air sealing, with the higher level of efficiency for mechanical systems; and
    - Near net zero - high levels of insulation, a high level of air sealing, and the highest level of efficiency for mechanical systems possible (considering appropriate sizing and fuel type).
- Each of the SFD and SFA baseline archetype homes and the three above code levels of energy efficiency for each archetype home are modeled in HOT2000 to obtain an estimate of expected annual energy consumption per home.

RESULTS

HOT2000 ENERGY OUTPUTS

The modeled outputs for the SFD baseline and above code homes and the SFA baseline and above code homes are shown in Table 1 and Table 2, respectively.

Table 1 Energy use and EnerGuide Rating System (ERS) score for baseline archetype and four types of above code SFD homes (all energy values in MJ per year)

	ERS rating	Space heating	Water heating	Lights and appliances	HRV & fans	Energy savings	Energy savings
Baseline	79	55,814	26,874	31,536	1,829		
Moderately insulated	82	43,565	26,891	31,536	1,915	12,145	-10
High efficient mechanical systems	85	34,166	17,490	31,536	2,208	30,653	-26
Near net zero (natural gas heating)	87	19,880	17,490	31,536	1,960	45,187	-39
Near net zero (electric heating)	88	18,983	8,482	31,536	2,099	54,951	-47

Note: energy savings are relative to baseline archetype

Table 2 Energy use and EnerGuide Rating System (ERS) score for baseline archetype and four types of above code SFA homes (all energy values in MJ per year)

	ERS rating	Space heating	Water heating	Lights & appliances	HRV & fans	Energy savings	Energy savings
Baseline	81	31,264	26,744	31,536	1,157		
Moderately insulated	83	23,353	26,756	31,536	1,267	7,789	-9%
High efficient mechanical systems	85	17,533	17,489	31,536	1,409	22,732	-25%
Near net zero (natural gas heating)	87	10,068	17,380	31,536	1,454	30,263	-33%
Near net zero (electric heating)	88	9,778	8,482	31,536	1,454	39,451	-43%

Note: energy savings are relative to baseline archetype

Based on analysis of GHG emissions, the near net zero home that uses electricity for space and water heating does not reduce GHG emissions in Alberta in the near future. Our analysis shows a net increase in the Present Tonne Equivalent (PTE) emissions (i.e., the present value of GHG emission savings over a 25-year period, discounted at a social discount rate of 2.5 per cent) for the electrically heated near net zero energy home under all three scenarios in Edmonton's ETP (Reference Case, Reduced Carbon Case, and Low Carbon Case). If we do not discount GHG savings over time, lifetime GHG emissions are reduced slightly under the Low Carbon Case, but still show a net increase under the Reference Case and Reduced

Carbon Case. Of course, if the homeowner purchases or generates their own renewable electricity to displace the grid electricity used to heat their net zero energy home, lifetime GHG emissions are reduced under all three ETP scenarios.

The City of Edmonton (COE) requested that the most energy efficient home modeled attempt to meet a passive house standard. The criteria for achieving a passive house standard is:

- Space Heat Demand: maximum 15 kWh per m^2 r maximum heating load of 10 W per m^2 annually;
- Pressurization Test Result: maximum 0.6 ACH @ 50 Pa (pressurizing and depressurizing); and
- Total Primary Energy Demand: maximum 120 kWh per m^2 annually.

Some energy efficient builders believe that the passive house standard is too stringent as it pushes building envelope requirements to a point of diminishing returns. We followed Canmet's measure choices with the lowest incremental cost to achieve net zero in Edmonton, as these provided some guidance on cost optimization for a high performing building in Edmonton (even if we did not have to achieve net zero). Based on these measure choices, we did not manage to fully achieve the passive house standard for both SFA and SFD homes. The SFA near net zero homes (both electricity and natural gas based space and water heating) met all passive house criteria. In contrast, the SFD near net zero homes (both electric and natural gas space and water heating) did not meet the passive house standard for space heating (achieving 21 kWh per m^2 for space heating demand). The SFD homes did meet the passive house standard fully when modeled without basements. The insulation levels in the basement were lower than a passive house standard given Canmet's cost optimization, but the other efficiency features of the building envelope could pass the passive house standard.

INCREMENTAL COSTS OF GOING BEYOND CODE

A range of incremental cost estimates for achieving the four levels of above code SFD homes in Edmonton are shown in Table 3; estimates for SFA homes are shown in Table 4. Details of the cost estimates are provided in Appendix C.

Table 3 Total incremental costs for four types of above code SFD homes

	Higher-cost	Mid-cost	Lower-cost
Moderately insulated	$6,424	$5,050	$3,676
High efficient mechanical systems	$12,604	$9,696	$6,789
Near net zero (natural gas heating)	$38,780	$30,423	$21,862
Near net zero (electric heating)	$27,056	$23,968	$20,880

Table 4 Total incremental costs for four types of above code SFA homes

	Higher-cost	Mid-cost	Lower-cost
Moderately insulated	$4,464	$3,485	$2,506
High efficient mechanical systems	$11,630	$8,138	$6,319
Near net zero (natural gas heating)	$36,361	$28,379	$20,397
Near net zero (electric heating)	$25,850	$23,074	$20,299

COST EFFECTIVENESS OF GOING BEYOND CODE

To assess the cost-effectiveness of the different "above code" SFD and SFA homes in saving energy, we calculate the cost of conserved energy (CCE) for each new home. The CCE is analogous to the often used levelized cost of energy or electricity (LCOE), which is commonly used by utilities to minimize the present value of investments needed to provide energy to consumers. For our purpose here, we use a simplified specification of the CCE ($ per GJ):

$$CCE = \frac{IC}{\left[\frac{1-(1+r)^{-n}}{r}\right]} x \frac{1}{E} \qquad \text{Equation 0-1}$$

Where:

- *r* is the discount rate or cost of capital used to value future costs and benefits in present day dollars. We use a nominal annual rate of 3.7% representative of 5-year fixed rate mortgages currently offered by major lenders in Canada (equivalent to an annual real rate of about 1.7%);

- *IC* is the total incremental investment costs of each home relative to baseline expenditures ($ per home);
- *E* is estimated annual energy savings (in GJ per home per year); and
- *n* is the lifetime of the investment (in years). We assume an investment lifetime of 25 years, typical of many mortgages in which the incremental costs would be embedded.

Figure 1 and Figure 2, respectively, present the calculated CCEs for each of the four above code SFD and SFA new homes in Edmonton. The calculated CCEs represent the lifetime cost of providing the same energy services that would otherwise be provided by less efficient homes. By expressing costs as an equivalent energy price, the calculated CCEs can be compared to actual or assumed energy prices to assess the cost effectiveness of the above code investments in providing energy services. In both Figure 1 and Figure 2 the solid red line indicates the (weighted average) levelized price of energy (natural gas and electricity) calculated from the base case energy price projections in the ETP Discussion Paper—approximately $19 per GJ. Estimates of the CCEs below the solid red line are cost-effective—in that the cost of supplying a unit of energy forgone exceeds the cost of avoiding that unit of energy; values above the line are not cost-effective. Looking at Figure 1, for example, a new SFD home achieving an ERS=85 is cost-effective under the medium and low incremental cost estimates, and marginally not cost-effective under the high incremental cost estimate. A new gas-heated SFD home achieving an ERS=87 is not cost-effective even under the incremental cost estimate. The conclusions are practically the same for SFD and SFA new homes.

Of course, the cost effectiveness of the above code homes in saving energy is improved if (a) the projected levelized price of energy increases, (b) the incremental costs of achieving the above code ERSs decreases, or (c) a combination of (a) and (b). To provide some insights into how much incremental construction costs need to decrease in order to make the above code new homes attractive to buyers we calculate the simple payback time for each of the SFD and SFA homes under four scenarios: (1) 0% reduction in incremental costs; (2) 40% reduction in incremental costs; (3) 55% reduction in incremental costs; and (4) 70% reduction in incremental costs. The results for SFD and SFA new homes are shown in Figure 3 and Figure 4, respectively. The assumed target simple payback time is about 10 years (indicated by the solid red line in the figures); we assume a new home buyer will want to recover their investment in improved energy efficiency within 10 years before they move home.[2]

[2] The average age of a first time homebuyer in Canada is 33 years. The average life expectancy of a person at 33 years old is about 81 years. A person will own, on average, five homes during their lifetime. Hence, person will stay in each home for, on average, about 10 years [(81-33)/5 = 9.6 years, or 10 years].

Figure 1 CCEs for four types of above code SFD homes in Edmonton

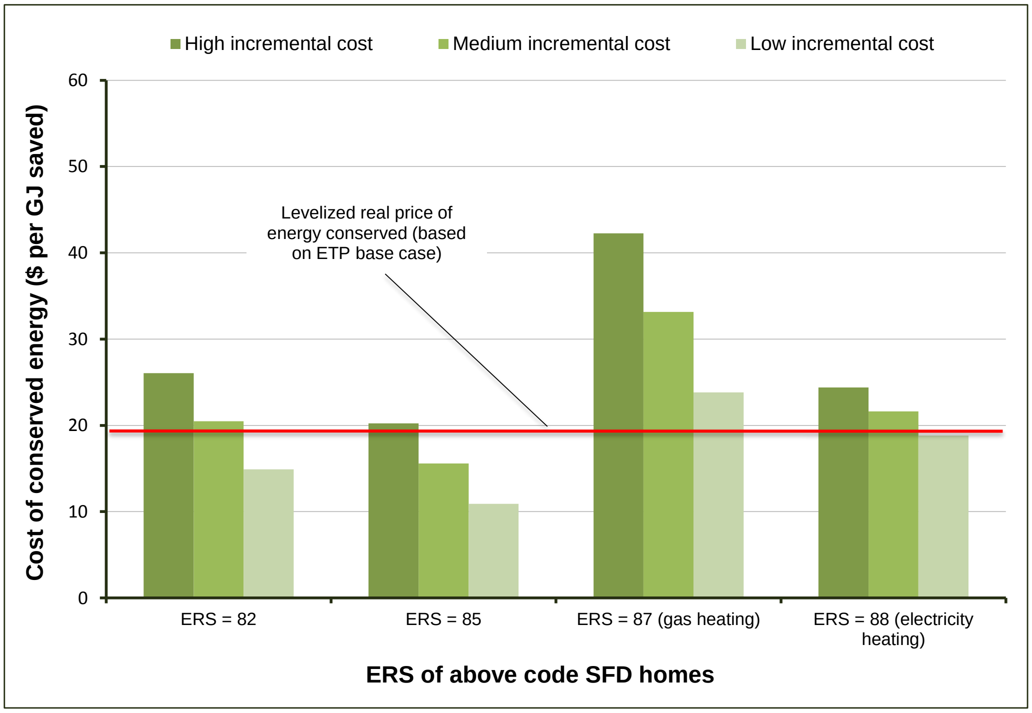


Figure 2 CCEs for four types of above code SFA homes in Edmonton

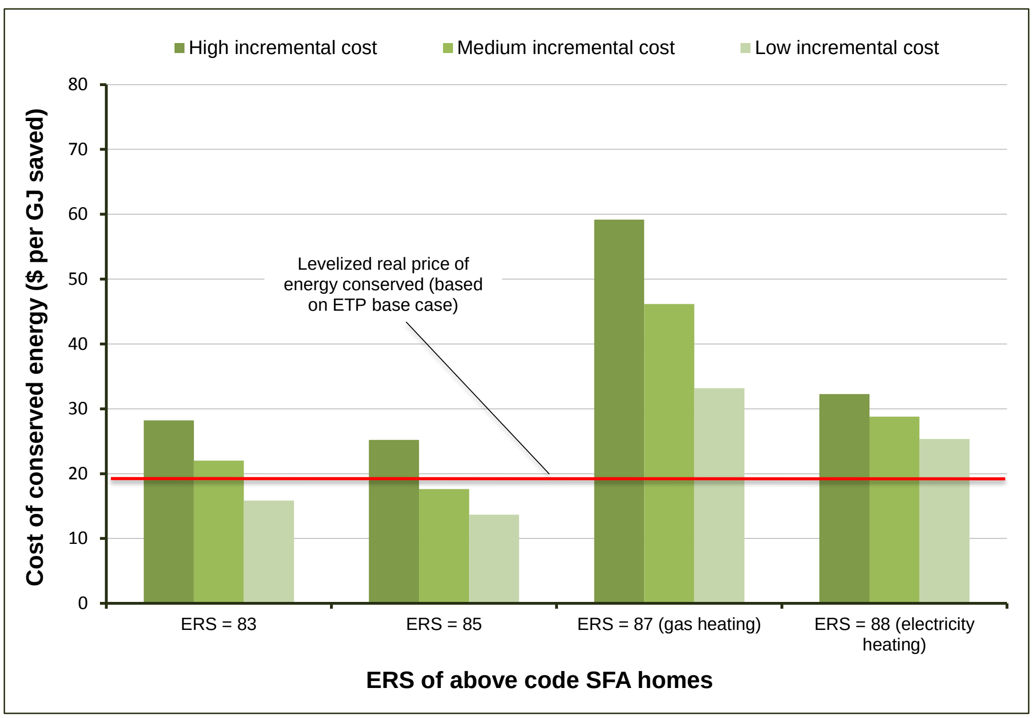


Figure 3 Impact of incremental cost reductions on the simple payback time of four types of above code SFD homes in Edmonton (based on medium incremental cost estimate)

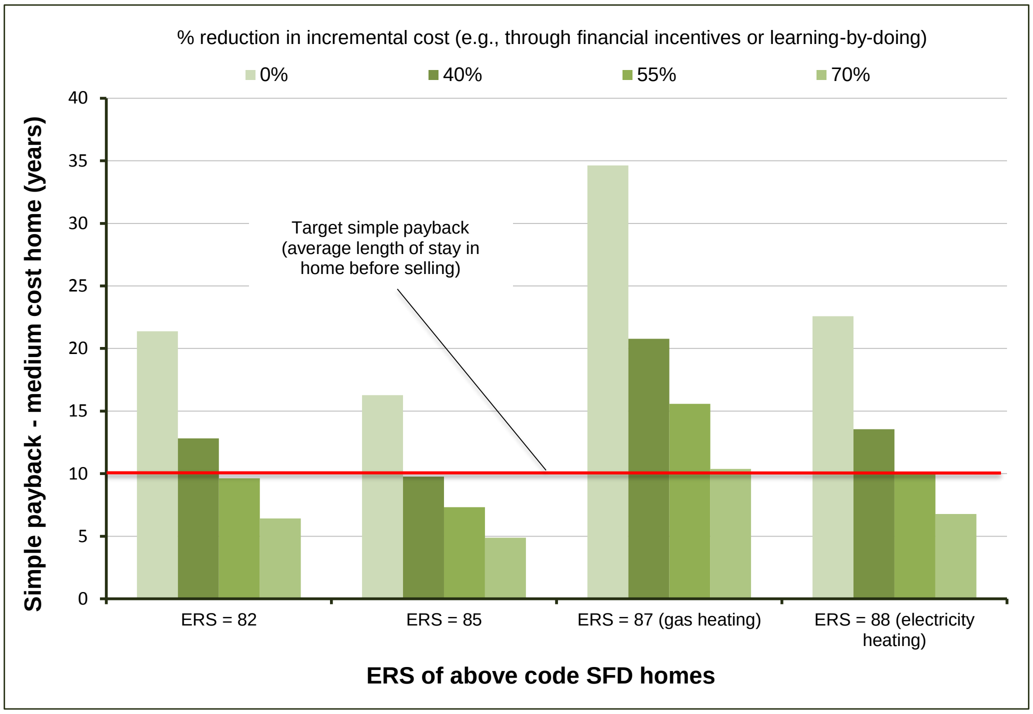
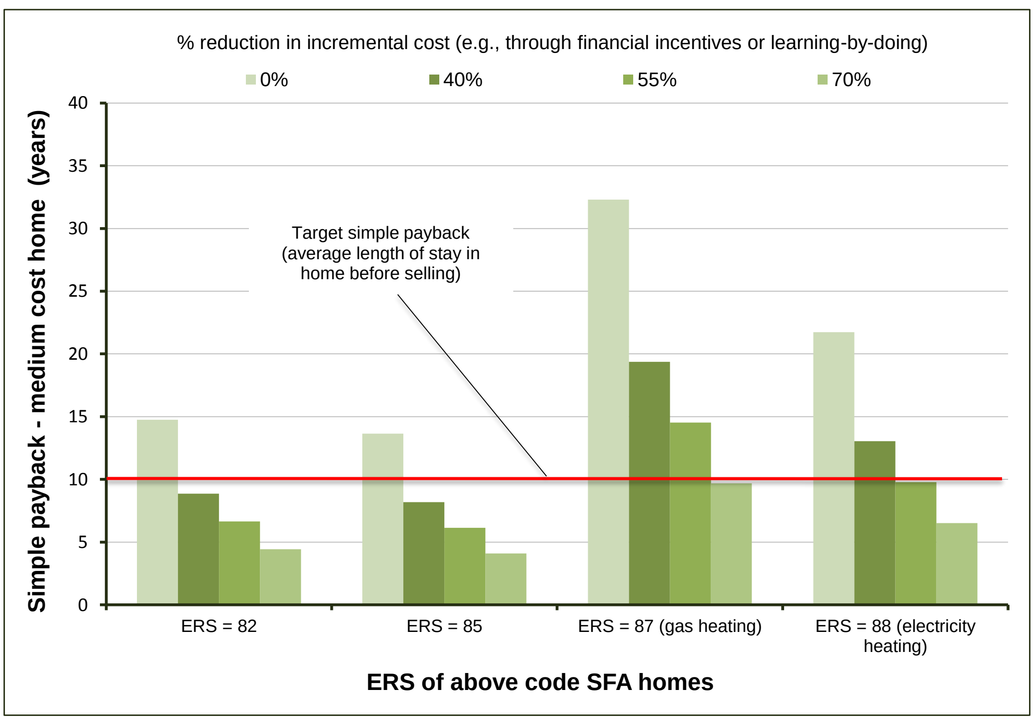


Figure 4 Impact of incremental cost reductions on the simple payback time of four types of above code SFA homes in Edmonton (based on medium incremental cost estimate)



Looking at new SFD homes in Figure 3, for example, the target simple payback time is achieved if incremental costs are reduced at most by:

- 55% for the ERS=82 new home;
- 40% for the ERS=85 new home;
- 70% for the ERS=87 (natural gas heated) new home; and
- 55% for the ETR=88 (electricity heated) new home.

For the new SFA homes in Figure 4, the target simple payback time is achieved if incremental costs are reduced at most by:

- 40% for the ERS=83 new home;
- 40% for the ERS=85 new home;
- 70% for the ERS=87 (natural gas heated) new home; and
- 55% for the ETR=88 (electricity heated) new home.

Incremental costs can be reduced through different mechanisms, including:

- Rebates, discounts or subsidized financing provided through a tiered incentive new home program;
- Experience or learning effects. These effects relate the unit costs of a technology or practice to cumulative sales through a “progress ratio” (the rate at which unit costs decline for each doubling of cumulative production). A progress ratio of 90% results in a learning rate of 10% and similar cost reductions per doubling of cumulative sales. For many energy technologies estimated progress ratios are in the range of 70-90%. Under the ETP Reference Case, the cumulative supply of new homes in Edmonton is projected to double about 3.5 times over the period 2014-2044; or
- A combination of both. A tiered incentive program will serve to accelerate market penetration of above code home and the accumulation of knowledge in market actors, in turn, reducing unit costs.

ELEMENT 2 – ILLUSTRATIVE COSTS AND BENEFITS OF TIERED INCENTIVE PROGRAM FOR GOING BEYOND CODE

This section presents the estimated economic and environmental outcomes of an **illustrative** tiered incentive program to encourage builders in Edmonton to construct new homes that exceed the minimum energy performance requirements in the new national building code. The outcomes are generated using C3’s energy-economic-emissions model of the residential housing sector in Alberta. The approach and key assumptions are presented first, followed by the results.

METHODOLOGY

OVERALL APPROACH

The net benefits of the incentive program are appraised from two perspectives:

1. Society

This perspective includes the broadest range of costs and benefits, including monetized externalities, regardless of who experiences them. It offers the most comprehensive assessment of the program's net benefit to society as a whole. Appraising the program from this perspective answers two essential questions for policy-makers: Are all of the benefits of the program greater than all of the costs, regardless of who pays the costs and who receives the benefits? Are Edmontonians collectively better off as a result of the program and by how much?

The costs include all costs incurred by any member of society: the City, the program administrator, the participants, and anyone else. The two main cost components are:

1. The premium cost of the energy-saving technology or practice (i.e., the "equipment cost"). Equipment costs are the capital, operating and maintenance and, where relevant, fuel costs incurred by builders to achieve a reduction in electricity or natural gas use in new homes. Due to the nature of the equipment purchase decision—that is, during construction as opposed to a retrofit—the equipment cost is given by the cost difference between the energy-saving equipment and the baseline equipment; and
2. The other main cost component is the "delivery cost". These are the costs related to: planning, design, analysis, measurement and verification, and evaluation of program elements; compliance and enforcement activities, where relevant (i.e., "regulatory costs"); activities designed to reach participants, bring them into programs, and deliver services such as marketing and application processing; inspections and quality control; staff recruitment, placement, compensation, development and training; data collection, reporting, record-keeping, and accounting; and overhead costs such as office space and equipment, and legal fees. In this analysis, incentive costs are included as part of delivery costs, in order to highlight the total cost of the program to the City. Incentive costs are payments made to builders to cover the cost of energy assessments and to assist builders with the incremental equipment costs. Incentive costs take the form of rebates in the analysis, but can also involve low or no interest loans, shared savings arrangements, service fees, etc. Incentive costs represent a transfer of funds between the City and participating builder, thereby reducing energy assessment and equipment costs. Hence, in order to avoid double counting and underestimating aggregate net benefits, participant (builder) costs are adjusted accordingly.

Similar to costs, the benefits of each above code new home include all of the benefits experienced by any member of society. The benefits are given by the energy supply costs and monetized externalities that are avoided as a result of the energy savings achieved by the program, or simply the "avoided costs". There are two main categories of avoided costs: energy-related costs; and capacity-related costs. The former include costs associated with avoided electricity generation and natural gas purchases, and their transmission and distribution, and other benefits associated with energy production such as reduced GHG emissions and water usage. Capacity-related avoided costs involve infrastructure investments such as power plants and transmission and distribution lines. The impact of the program on capacity-related costs is not considered, since the majority of energy savings result from reduced natural gas consumption, as opposed to reduce electricity use.

2. Participants

This perspective includes the costs and benefits experienced by the eventual homeowner directly targeted by the program. It provides an indication of the distributional effects of the program, and—while of limited use for appraising the overall economic merit of the program as a public investment—it may be used to help design programs to optimize participation (in terms of buyers' willingness to pay and demand for more efficient homes). To this end, appraising the program from this perspective reveals whether a targeted actor is better off as a result of the program and by how much? Consequently, analysis from this perspective provides insight into whether the targeted actor is likely to want to adopt a desired practice or energy-saving technology.

The costs include the incremental equipment costs, net of all applicable incentive payments (it is implicitly assumed that net increment equipment costs are passed through to homebuyers in the price of the new home). The benefits include the eventual reduction in the household's electricity and natural gas bills.

Analyzing the economic costs and benefits of the program from either perspective requires a calculation of the (present value, PV) total benefits and the (present value, PV) total costs in dollar terms over the lifetime of each purchased and installed efficiency measure, to determine the Net Present Value (NPV):

$$\text{NPV} = \text{PV avoided cost} - (\text{PV equipment cost} + \text{PV delivery cost})$$

The discounted streams of avoided costs, equipment costs and deliver costs are expressed as present values in 2010 dollars. If the estimated NPV is positive, this shows the magnitude of the dollar value increase in the wealth of Edmontonians from the program.

ASSUMPTIONS

Key assumptions under pinning the modeling are listed below. Default assumptions in the model have been modified to match those in the ETP Discussion Paper. The analysis is performed for the Reference Case only.

- Under the ETP Reference Case 42,840 new homes are constructed in Edmonton in 2015 (65% are SFD and 35% are SFA). The numbers increases to 113,790 new homes in 2025 (again, 65% are SFD and 35% are SFA).

- The GHG intensity of natural gas is 0.0509 t CO_2e per GJ under the Reference Case. This is assumed constant over the forecast period through 2050.
- The GHG intensity of electricity under the Reference Case is: 880 t CO_2e per GWh (2009), 628 t CO_2e per GWh (2024), and 538 t CO_2e per GWh (2044). The GHG intensity is assumed to follow a linear path between 2009 and 2024 and between 2024 and 2044. The trend between 2024 and 2044 is assumed to continue till 2050.
- Avoided energy supply costs are valued using the base case energy price projections in the ETP Discussion Paper.
- Avoided GHG emissions are valued at $40 per t CO2e (consistent with current practice by the City of Edmonton).
- The program is funded for five years (2015 Q1 through 2019 Q4). The model nonetheless captures the lifetime costs and benefits of new homes constructed in 2025 through 2050. For the purpose of illustration, the annual budget for the program is $1,000,000.
- The lifetime of the energy efficiency improvements installed at construction is assumed to be 25 years.
- Tiered incentives (rebates) target builders and developers consistent with "best practice" energy efficiency programs for residential new construction (Nowak, 2013). The program is open to builders of both SFD and SFA new homes. Three above code new SFA homes and three above code new SFD homes are incented:
    - Tier 1: New homes achieving an ERS = 80-81;
    - Tier 2: New homes achieving an ERS = 82-85; and
    - Tier 3: New (gas heated) homes achieving and ERS >85.
- The financial incentives offered builders are set to generate a simple payback time of 10 years (note that these levels of incentives are purely illustrative—builders and developers may prefer to see a larger fraction of the program budget allocated to technical assistance):
    - Tier 1: New homes achieving an ERS = 80-81 ($1,400 for SFA and $2,300 for SFD);
    - Tier 2: New homes achieving an ERS = 82-85 ($3,250 for SFA and $3,900 for SFD); and
    - Tier 3: New (gas heated) homes achieving and ERS >85 ($19,850 for SFA and $21,300 for SFD).
- Estimated energy savings for eligible new above code SFD and SFA homes is provided in Table 1 and Table 2, respectively. Estimated incremental construction costs for eligible new above code SFD and SFA homes is provided in Table 3 and Table 4, respectively. The analysis only considers the medium and low incremental cost estimates. The incentive levels listed above are based on the medium incremental cost estimates.

- The cost of a home energy assessment for newly constructed homes is $550; the results of the assessment (and accompanying label and energy rating) forms part of the verification process to be eligible for a rebate. The cost of the assessment is subsidized by $350 reducing the net cost to builders to $200.
- Personalized (integrated design) technical assistance is provided builders and developers from the planning stages through to construction. Technical assistance amount to 10% of the total program delivery costs.
- The program works with real estate agents to encourage them to list ERS rating labels on MLS® and builder specific new home marketing material. Indeed, educating consumers is vital to increase demand for highly energy efficient homes.
- The overall participation rate in a financial unconstrained program is assumed to encompass 40% of all new single family dwellings constructed per year in the Edmonton.[3] Given the annual budget constraint of $500,000 the participation rate does not affect the results—the annual budget is exhausted well before the a participation rate of 40% is reached. Based on observations from My Rebates total participating homes are split across the eligible new homes as follows:
    - 33% to Tier 1 new homes achieving an ERS = 80-81;
    - 52% to Tier 2 new homes achieving an ERS = 82-85; and
    - 15% to Tier 3 new (gas heated) homes achieving and ERS >85.
- Fixed program costs (i.e., marketing and outreach, development of the screening and application process, program management, evaluation and reporting) amount to 25% of the total program delivery costs.
- The free-ridership rate is assumed to be 21%; this rate was observed under the My Rebates new home program. This program incented home buyers and is likely to be pessimistic for a program that incents builders and developers.
- The impact of learning-by-doing (captured by a progress ratio and corresponding learning rate) on incremental costs is not modeled.

RESULTS

Table 5 and Table 6 show estimated impacts for a three-tiered new construction program based on, respectively, the medium and low incremental construction cost estimates.

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[3] Efficiency Vermont's similar residential new construction program had approximately 61% of the new housing market participate in 2011 (based on participation numbers in Nowak, 2013 and newly privately owned housing in U.S. Department of Housing and Urban Development, 2011). Connecticut Light & Power and United Illuminating's similar residential new construction program had approximately 26% of the new housing market participate in 2011 (based on participation numbers in Nowak, 2013 and newly privately owned housing in U.S. Department of Housing and Urban Development, 2011). Therefore, we adopt a participation rate just below the average for these programs.

Table 5 Impacts of three tiered new home program over the 5-year period 2015-2019 (medium incremental construction costs)

Participation:	
Number of new homes	535
% of total new homes constructed over period	0.2%
Total lifetime costs (undiscounted):	
Incentive payments to builders and developers	$3.25 million
Technical assistance to builders and developers	$0.50 million
Administration and other program costs	$1.25 million
Total program budget	$5.00 million
Participant expenditures – before incentives	$5.52 million
Participant expenditures – after incentives	$2.27 million
Total lifetime benefits (undiscounted):	
Social benefits	$4.18 million
Participant benefits	$4.83 million
Economic indicators:	
Social net present value	-$3.74 million
Participant net present value	+$0.66 million
Participant benefit-cost ratio	1.3
Participant return on investment	30%
Marginal abatement cost	+$465 per t CO_2e
Total lifetime savings (physical units, undiscounted):	
Natural gas	330,900 GJ
Electricity	895 MWh (increase)
GHG emissions	16,400 t CO_2e

Purely in terms of acquiring immediate reductions in GHG emissions the results suggest that the program (as laid out above) does not represent a cost-effective investment by the City. It does nonetheless provide a net benefit in present value terms for home buyers (assuming builders pass only net incremental costs through to home buyers). Providing a program focused solely on Tier 1 and Tier 2 new homes performs slightly better than the program that also includes Tier 3 new homes (see Table 7). However, if the ultimate goal is to move toward near net zero new homes, then the program (at some point) needs to include Tier 3 new homes to build the required cumulative knowledge to bring costs down, as well as to increase consumer demand (and willingness to pay) for these homes. Not that the program modeled is purely illustrative and many issues (including the level of rebates, the allocation of dollars between rebates and technical assistance and builder education, and the relationship between builder costs, home price and consumers' willingness to pay) would need further exploration during the design of a "live" program.

Table 6 Impacts of three tiered new home program over the 5-year period 2015-2019 (low incremental construction costs)

Participation:	
Number of new homes	1,090
% of total new homes constructed over period	0.4%
Total lifetime costs (undiscounted):	
Incentive payments to builders and developers	$3.25 million
Technical assistance to builders and developers	$0.50 million
Administration and other program costs	$1.25 million
Total program budget	$5.00 million
Participant expenditures – before incentives	$7.96 million
Participant expenditures – after incentives	$4.71 million
Total lifetime benefits (undiscounted):	
Social benefits	$8.53 million
Participant benefits	$9.87 million
Economic indicators:	
Social net present value	-$3.00 million
Participant net present value	+$1.25 million
Participant benefit-cost ratio	1.3
Participant return on investment	27%
Marginal abatement cost	+$215 per t CO_2e
Total lifetime savings (physical units, undiscounted):	
Natural gas	675,260 GJ
Electricity	1,825 MWh (increase)
GHG emissions	33,435 t CO_2e

Table 7 Impacts of two tiered new home program over the 5-year period 2015-2019 (medium incremental construction costs)

Participation:	
Number of new homes	945
% of total new homes constructed over period	0.3%
Total lifetime costs (undiscounted):	
Incentive payments to builders and developers	\$3.25 million
Technical assistance to builders and developers	\$0.50 million
Administration and other program costs	\$1.25 million
Total program budget	\$5.00 million
Participant expenditures – before incentives	\$6.76 million
Participant expenditures – after incentives	\$3.51 million
Total lifetime benefits (undiscounted):	
Social benefits	\$6.56 million
Participant benefits	\$7.60 million
Economic indicators:	
Social net present value	-\$3.25 million
Participant net present value	+\$1.14 million
Participant benefit-cost ratio	1.3
Participant return on investment	34%
Marginal abatement cost	+\$280 per t CO_2e
Total lifetime savings (physical units, undiscounted):	
Natural gas	522,315 GJ
Electricity	1,650 MWh (increase)
GHG emissions	25,715 t CO_2e

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APPENDIX A – BUILDING ARCHETYPES

Table 8 Structural characteristics of new SFD building archetype (baseline) for Edmonton

Characteristic	Variable
Total area (including basement) (m^2)	245.8
Total area (excluding basement) (m^2)	167.3
Footprint (m^2)	89.8
# of storeys	two
Number of windows	12.0
Location of windows	2nd floor: 3 N, 3S; 1st floor: 3N, 3S; base: 1N, 1S
Area of windows (m^2)	17.5
Number of doors	2.0
Location of doors	Main floor
Basement type	Full basement, concrete core wall
Total basement perimeter (m^2)	35.6
Net zero uninsulated slab area (m^2)	57.4
Net zero insulated slab area (m^2)	21.1
Attic size (m^2)	83.1
Wall area (m^2)	184.7
Header area (m^2)	16.6
Basement wall size (m^2)	89.3
Basement floor size (m^2)	78.5

Table 9 Structural characteristics of new SFA building archetype (baseline) for Edmonton

Characteristic	Variable
Total area (including basement) (m^2)	186.9
Total area (excluding basement) (m^2)	115.4
Footprint (m^2)	71.5
# of storeys	two
Number of windows	12.0
Location of windows	2nd floor: 3 N, 3S; 1st floor: 3N, 3S; base: 1N, 1S
Area of windows (m^2)	14.8
Number of doors	2.0
Location of doors	Main floor
Basement type	full basement, concrete core wall
Total basement perimeter (m^2)	33.4
Net zero uninsulated slab area (m^2)	42.0
Net zero insulated slab area (m^2)	18.9
Attic size (m^2)	65.2
Wall area (m^2)	109.9
Header area (m^2)	10.1
Basement wall size (m^2)	83.7
Basement floor size (m^2)	60.9

APPENDIX B – ENERGY EFFICIENCY ASSUMPTINGS FOR NEW HOMES IN EDMONTON TO MEET NEW BUILDING CODE

Table 10 Energy efficiency assumptions for new SFD home in Edmonton meeting new national building code

Characteristic	Assumption / outcome
Attic insulation	R 50 blown cellulose, wood structure: 2 x 10, 16 in spacing, inside gypsum and wood
Wall insulation	R 22 batt, wood structure: 2 x6, 16 inch spacing, 4 studs, sheathing: 1/2 in plywood, int.: gypsum and wood, ext.: hollow vinyl
Header insulation	R 20 batt, sheathing: 1/2" plywood, ext.: hollow vinyl
Foundation insulation	R 20 batt, wood structure: 2 x6, 16 in spacing, 3 studs, int.: gypsum and wood
Window type	Double glazing, low e (.25)hard coating, 9mm argon filled, insulating spacer, vinyl frame, picture and slider
Furnace efficiency	AFUE 90
Furnace motor	Auto
Ventilation	Heat recovery ventilator
Air exchange rate	2.5 ach
Domestic hot water heater	EF 62
Drain water heat recovery	None
Solar domestic hot water	None
ERS rating	79

Table 11 Energy efficiency assumptions for new SFA home in Edmonton meeting new national building code

Characteristic	Assumption / outcome
Attic insulation	R 50 blown cellulose, wood structure: 2 x 10, 16 in spacing, inside gypsum and wood
Wall insulation	R 22 batt, wood structure: 2 x6, 16 inch spacing, 4 studs, sheathing: 1/2 in plywood, int.: gypsum and wood, ext.: hollow vinyl
Header insulation	R 20 batt, sheathing: 1/2" plywood, ext.: hollow vinyl
Foundation insulation	R 20 batt, wood structure: 2 x6, 16 in spacing, 3 studs, int.: gypsum and wood
Window type	double glazing, low e (.25)hard coating, 9mm argon filled, insulating spacer, vinyl frame, picture and slider
Furnace efficiency	AFUE 90
Furnace motor	Auto
Ventilation	Heat recovery ventilator
Air exchange rate	2.5 ach
Domestic hot water heater	EF 62
Drain water heat recovery	None
Solar domestic hot water	None
ERS rating	81

APPENDIX C – ENERGY EFFICIENCY AND COST ASSUMPTINGS FOR ABOVE CODE SFD AND SFA HOMES

Table 12 Upgraded energy efficiency measures (relative to new building code) and associated costs for moderately insulated above code SFD home in Edmonton (ERS = 82)

Category	Upgrade details	High cost	Mid cost	Low cost	Source for costs
Insulation - walls	Add EPS 1.5 (R 7)	$2,455	$2,064	$1,673	EnerQuality & Leo and Associates, 2010; Proskiw, 2011; C3
Insulation - attic	Add R 20	$796	$613	$430	EnerQuality & Leo and Associates, 2010; Proskiw, 2011
Insulation - header	Add EPS 1.5 (R 7)	$221	$185	$150	EnerQuality & Leo and Associates, 2010; Proskiw, 2011; C3
ACH (ac/hr50)	1.75	$2,952	$2,188	$1,423	Carver, 2014
Total costs		**$6,424**	**$5,050**	**$3,676**	

Table 13 Upgraded energy efficiency measures (relative to new building code) and associated costs for moderately insulated above code SFA home in Edmonton (ERS = 83)

Category	Upgrade details	High cost	Mid cost	Low cost	Source for costs
Insulation - walls	Add EPS 1.5 (R 7)	$1,461	$1,228	$995	EnerQuality & Leo and Associates, 2010; Proskiw, 2011; C3
Insulation - attic	Add R 20	$625	$481	$337	EnerQuality & Leo and Associates, 2010; Proskiw, 2011
Insulation - header	Add EPS 1.5 (R 7)	$134	$113	$91	EnerQuality & Leo and Associates, 2010; Proskiw, 2011; C3
ACH (ac/hr50)	1.75	$2,245	$1,663	$1,082	Carver, 2014
Total costs		**$4,464**	**$3,485**	**$2,506**	

Table 14 Upgraded energy efficiency measures (relative to new building code) and associated costs for moderately insulated above code SFD home in Edmonton (ERS = 85)

Category	Upgrade details	High cost	Mid cost	Low cost	Source for costs
HRV	75 % efficiency	$421	$312	$203	EnerQuality & Leo and Associates, 2010
Heating system	Natural gas, 96 AFUE condensing	$461	$342	$222	Rivers, 2013
Furnace fan	Energy efficient, two speed	$1,574	$1,089	$605	Rivers, 2013
DHW	Instantaneous condensing EF 96	$1,464	$1,085	$706	Carver, 2014; C3
Insulation - walls	Add EPS 1.5 (R 7)	$2,455	$2,064	$1,673	EnerQuality & Leo and Associates, 2010; C3 research
Insulation - attic	Add R 20	$796	$613	$430	EnerQuality & Leo and Associates, 2010; Proskiw, 2011
Insulation - header	Add EPS 1.5 (R 7)	$221	$185	$150	EnerQuality & Leo and Associates, 2010; C3 research
ACH (ac/hr50)	1.75 ac/hr50	$4,067	$3,014	$1,961	Carver, 2014
Drain water heat recovery	42.4% efficient	$1,146	$992	$839	C3; Ontario Power Authority, 2011
Total costs		**$12,604**	**$9,696**	**$6,789**	

Table 15 Upgraded energy efficiency measures (relative to new building code) and associated costs for moderately insulated above code SFA home in Edmonton (ERS = 85)

Category	Upgrade details	High cost	Mid cost	Low cost	Source for costs
HRV	75 % efficiency	$421	$312	$203	EnerQuality & Leo and Associates, 2010
Heating system	Natural gas, 96 AFUE condensing	$461	$342	$222	Rivers, 2013
Furnace fan	Energy efficient, two speed	$1,574	$1,089	$605	Rivers, 2013
DHW	Instantaneous condensing EF 96	$1,464	$1,085	$706	Carver, 2014; C3
Insulation - walls	Add EPS 1.5 (R 7)	$2,455	$1,228	$1,673	EnerQuality & Leo and Associates, 2010; C3 research
Insulation - attic	Add R 20	$796	$613	$430	EnerQuality & Leo and Associates, 2010; Proskiw, 2011
Insulation - header	Add EPS 1.5 (R 7)	$221	$185	$150	EnerQuality & Leo and Associates, 2010; C3 research
ACH (ac/hr50)	1.75 ac/hr50	$3,092	$2,291	$1,491	Carver, 2014
Drain water heat recovery	42.4% efficient	$1,146	$992	$839	C3; Ontario Power Authority, 2011
Total costs		**$11,630**	**$8,138**	**$6,319**	

Table 16 Upgraded energy efficiency measures (relative to new building code) and associated costs for moderately insulated above code SFD home in Edmonton (ERS = 87)

Category	Upgrade details	High cost	Mid cost	Low cost	Source for costs
HRV	75 % efficiency	$421	$312	$203	Carver, 2014
Heating system	Natural gas, 96 AFUE condensing	$1,691	$1,016	$342	C3; Ontario Power Authority, 2011
Furnace fan	Energy efficient, two speed	$1,574	$1,089	$605	Carver, 2014
DHW	Instantaneous condensing EF 96	$1,464	$1,085	$706	C3; Ontario Power Authority, 2011
Windows	U Value: 0.256, triple-glazed, low-e, hard coat (.35), argon fill (9mm), insulated spacers, fiberglass frame	$12,160	$10,808	$9,457	RS Means
Insulation - walls	R 52 blown cellulose high density, double stud wall	$10,425	$7,725	$5,026	EnerQuality & Leo and Associates, 2011; C3
Insulation - foundation	R 20 = R12 batt, R 8 XPS 2" exterior	$1,450	$1,074	$699	C3
Insulation - slab	R 12, edge P6	$489	$362	$236	C3
Insulation - attic	R 100 blown cellulose high density	$1,990	$1,533	$1,075	EnerQuality & Leo and Associates, 2010; Proskiw, 2011
Insulation - header	R 52 blown cellulose high density, double stud wall	$936	$694	$451	EnerQuality & Leo and Associates, 2010; C3
ACH (ac/hr50)	0.6 ac/hr50	$5,034	$3,731	$2,427	Carver, 2014
Drain water heat recovery	42.4% efficient	$1,146	$992	$839	C3; Ontario Power Authority, 2011
Total costs		**$38,780**	**$30,423**	**$21,862**	

Table 17 Upgraded energy efficiency measures (relative to new building code) and associated costs for moderately insulated above code SFA home in Edmonton (ERS = 87)

Category	Upgrade details	High cost	Mid cost	Low cost	Source for costs
HRV	75 % efficiency	$421	$312	$203	Carver, 2014
Heating system	Natural gas, 96 AFUE condensing	$1,691	$1,016	$342	C3; Ontario Power Authority, 2011
Furnace fan	Energy efficient, two speed	$1,574	$1,089	$605	Carver, 2014
DHW	Instantaneous condensing EF 96	$1,464	$1,085	$706	C3; Ontario Power Authority, 2011
Windows	U Value: 0.256, triple-glazed, low-e, hard coat (.35), argon fill (9mm), insulated spacers, fiberglass frame	$10,548	$9,375	$8,203	RS Means
Insulation - walls	R 52 blown cellulose high density, double stud wall	$10,425	$7,725	$5,026	EnerQuality & Leo and Associates, 2011; C3
Insulation - foundation	R 20 = R12 batt, R 8 XPS 2" exterior	$1,360	$1,008	$656	C3
Insulation - slab	R 12, edge P6	$1,407	$1,042	$678	C3
Insulation - attic	R 100 blown cellulose high density	$1,562	$1,202	$843	EnerQuality & Leo and Associates, 2010; Proskiw, 2011
Insulation - header	R 52 blown cellulose high density, double stud wall	$936	$694	$451	EnerQuality & Leo and Associates, 2010; C3
ACH (ac/hr50)	0.6 ac/hr50	$3,828	$2,837	$1,845	Carver, 2014
Drain water heat recovery	42.4% efficient	$1,146	$992	$839	C3; Ontario Power Authority, 2011
Total costs		**$36,361**	**$28,379**	**$20,397**	

Table 18 Upgraded energy efficiency measures (relative to new building code) and associated costs for moderately insulated above code SFD home in Edmonton (ERS = 88)

Category	Upgrade details	High cost	Mid cost	Low cost	Source for costs
HRV	75 % efficiency	$421	$312	$203	Carver, 2014
Heating system	Electric baseboards	-$6,244	-$4,627	-$3,010	Carver, 2014
DHW	Air source heat pump (COP 2)	$1,132	$955	$779	Carver, 2014
Windows	U Value: 0.256, triple-glazed, low-e, hard coat (.35), argon fill (9mm), insulated spacers, fiberglass frame	$12,160	$10,808	$9,457	RS Means
Insulation - walls	R 52 blown cellulose high density, double stud wall	$8,542	$8,134	$7,725	Carver, 2014
Insulation - foundation	R 20 = R12 batt, R 8 XPS 2" exterior	$1,450	$1,074	$699	C3
Insulation - slab	R 12, edge P6	$489	$362	$236	C3
Insulation - attic	R 100 blown cellulose high density	$1,990	$1,533	$1,075	EnerQuality & Leo and Associates, 2010; Proskiw, 2011
Insulation - header	R 52 blown cellulose high density, double stud wall	$936	$694	$451	EnerQuality & Leo and Associates, 2010; C3
ACH (ac/hr50)	0.6 ac/hr50	$5,034	$3,731	$2,427	Carver, 2014
Drain water heat recovery	42.4% efficient	$1,146	$992	$839	C3; Ontario Power Authority, 2011
Total costs		**$27,056**	**$23,968**	**$20,880**	

Table 19 Upgraded energy efficiency measures (relative to new building code) and associated costs for moderately insulated above code SFA home in Edmonton (ERS = 88)

Category	Upgrade details	High cost	Mid cost	Low cost	Source for costs
HRV	75 % efficiency	$421	$312	$203	Carver, 2014
Heating system	Electric baseboards	-$6,244	-$4,627	-$3,010	Carver, 2014
DHW	Air source heat pump (COP 2)	$1,132	$955	$779	Carver, 2014
Windows	U Value: 0.256, triple-glazed, low-e, hard coat (.35), argon fill (9mm), insulated spacers, fiberglass frame	$12,160	$10,808	$9,457	RS Means
Insulation - walls	R 52 blown cellulose high density, double stud wall	$8,542	$8,134	$7,725	Carver, 2014
Insulation - foundation	R 20 = R12 batt, R 8 XPS 2" exterior	$1,450	$1,074	$699	C3
Insulation - slab	R 12, edge P6	$489	$362	$236	C3
Insulation - attic	R 100 blown cellulose high density	$1,990	$1,533	$1,075	EnerQuality & Leo and Associates, 2010; Proskiw, 2011
Insulation - header	R 52 blown cellulose high density, double stud wall	$936	$694	$451	EnerQuality & Leo and Associates, 2010; C3
ACH (ac/hr50)	0.6 ac/hr50	$3,828	$2,837	$1,845	Carver, 2014
Drain water heat recovery	42.4% efficient	$1,146	$992	$839	C3; Ontario Power Authority, 2011
Total costs		**$25,850**	**$23,074**	**$20,299**	