UBC Modelling Study: Residential Archetypes | Project 9639.001

To Mr. Ralph Wells
UBC Campus and Community Planning
2260 West Mall
Vancouver BC V6T 1Z4

Submitted December 22, 2017 by
RDH Building Science Inc.
244 West 8th Avenue
Vancouver BC V5Y 1N5

Executive Summary

UBC has set ambitious GHG reduction goals, including a target of achieving carbon neutrality for the institutional campus by 2050[1], and has established an objective of a net-positive ready campus by 2035[2]. District energy has been established as a vehicle to substantially reduce GHG emissions. To support these goals, this study was completed to assess future energy performance targets aligning with the BC Energy Step Code, using whole-building energy modelling and economic analysis.

Two archetype models were developed, based on the expected form of development, and modelled with a variety of Energy Conservation Measures (ECMs) based on readily available technologies. The incremental capital costs of measures beyond the BC Building Code and UBC Residential Environmental Assessment Program (REAP)[3] mandatory measures were estimated based on data from the Lower Mainland marketplace, including least and highest cost “bookends” to define a range of financial impacts. The value of energy savings (and avoided carbon charges) were compared against incremental capital costs under a 30-year life cycle economic assessment. For each archetype, two variations were modelled, one with district energy connected systems (the primary focus of this report), and a second with gas/electric systems (presented in Appendices F, G, H).

ECMs were compiled into “bundles” of measures that achieve each Step Code level. The bundles are indicative of how ECMs can be effectively assembled to achieve different performance thresholds identified in the Energy Step Code, but are not intended to be prescriptive. The energy savings and economics of the bundles were assessed to understand the feasibility of achieving each Step.

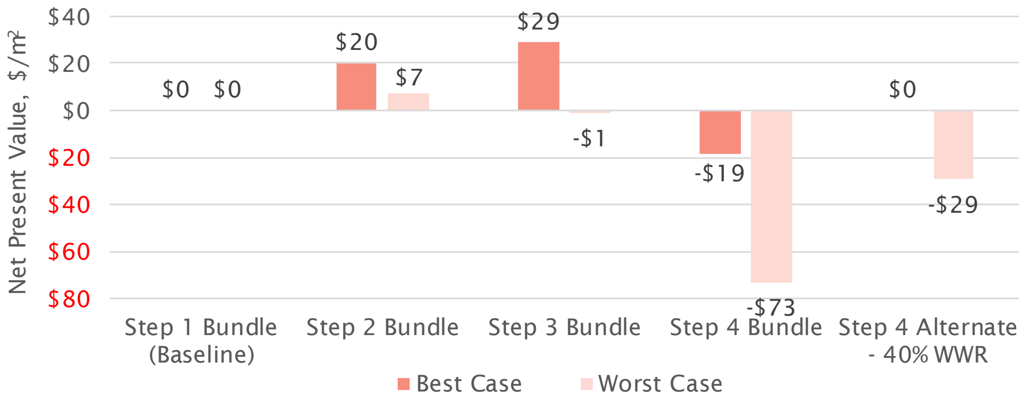
High-Rise Results

The graphs below show the net present value (NPV) and incremental capital costs of the high-rise bundles to meet each Step Code step. Steps 1 through 3 can be acheived with positive NPV, while Step 4 would yield negative NPV due to the current high capital costs of best performing windows, HRVs, and highly insulated wall systems. Achieving the Step Code targets is estimated to result in incremental capital costs of approximately 0.6%, 1%, and 3% for Steps 2, 3, and 4, respectively, based on average construction costs.

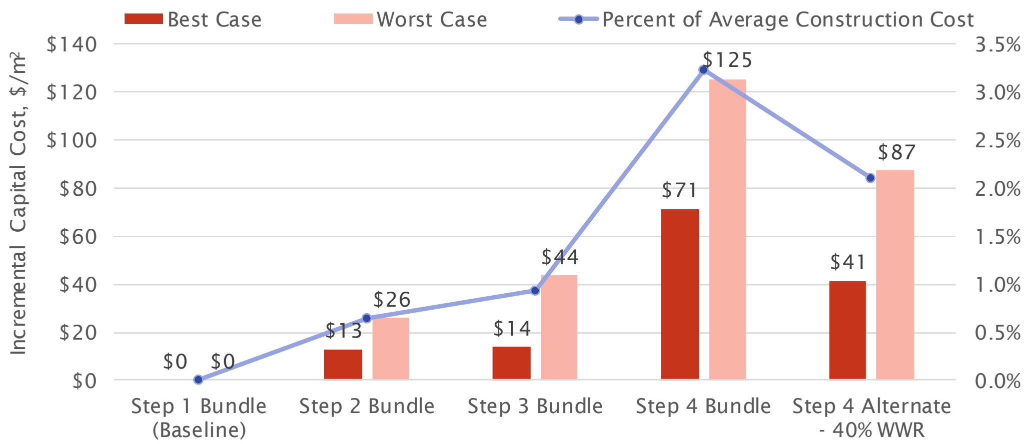
This analysis showed that the Total Energy Use Intensity (EUI) and Thermal Energy Demand Intensity (TEDI) modelled in the bundles for this study meet the Step Code targets. However, a reduction in corridor make-up air flow rates was required to meet the Step 3 and 4 targets; the implications of this design strategy requires further anlaysis.

The requirement for district energy connected systems may limit the EUI savings, beyond Step 4, that are achievable. For example, heat pump DHW could further reduce EUIs, but was not considered due to the district energy mandate. Despite this, the bundle results show that Step 4 is achievable with district energy connected systems.

1 https://sustain.ubc.ca/campus-initiatives/climate-energy/climate-action-plan
2 https://sustain.ubc.ca/our-commitment/strategic-plans-policies-reports/sustainability-plans/ubc-develops-strategy-next
3 Residential Environmental Assessment Program (REAP). University of British Columbia. Version 3.0. October 2014.



Net present value of bundles, $/m².



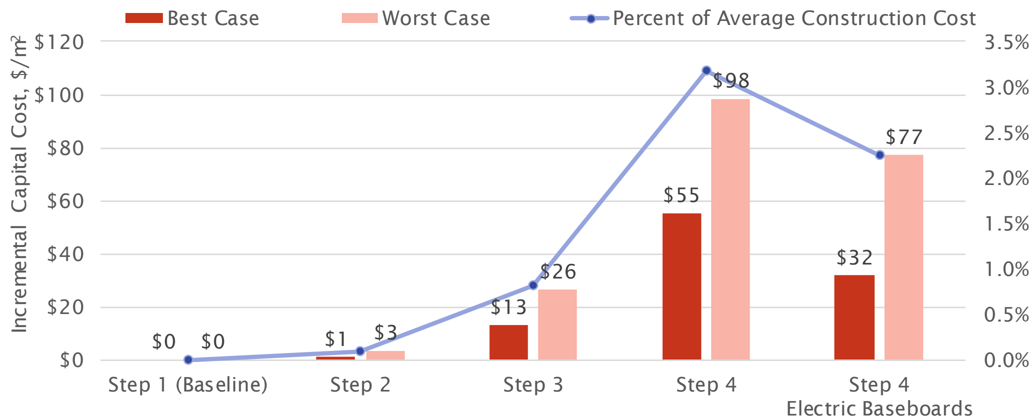
Range of incremental capital costs per m² of floor area for bundles. The incremental cost as a percent of average construction is provided using an average cost of high-rise construction of $283/sf[4].

Low-Rise Results

The graphs below show the NPV and incremental capital costs of the low-rise bundles to meet each Step Code step. Steps 1 through 3 can be acheived with positive NPV, while Step 4 would yield negative NPV due to the current high capital costs of best performing windows and HRVs. Achieving the Step Code targets is estimated to result in incremental capital costs of approximately 0%, 1%, and 3% for Steps 2, 3, and 4, respectively, based on average construction costs. It is anticipated that costs for these technologies will come down in the coming years due to the growing popularity of Passive House in the low-rise residential typology, improving the cost-effectiveness of Stpe 4.

[4] Altus Group 2017 Canadian Cost Guide

Net present value of bundles, $/m².



Range of incremental capital costs for bundles, $/m2 of floor area. The incremental cost as a percent of average construction is provided using an average cost of low-rise construction of $225/sf[5].

This analysis showed that the EUIs and TEDIs modelled in the bundles for this study meet the Step Code targets. Further, the baseline REAP scenario already meets the Step 2 targets without additional ECMs. Achieving the Step Code targets is more cost-effective in the low-rise scenario due to the better enclsoure energy performance as a result of wood frame construction. It is also important to note that a reduction in the corridor ventilation rate was required to meet the Step 4 target; the implications of this design strategy requires further anlaysis. As with the high-rise archetype, the requirement for district energy connected systems may limit the EUI savings beyond Step 4 that are achievable; however, the bundle results show that Step 4 is achievable with district energy systems.

Developer-Consumer Perspective

The NPV metric does not provide a strong business case for developers due to the split incentive, where the developer carries incremental capital costs while the owner realizes annual savings. To address this, the business case was analyzed from these two perspectives, considering incremental selling prices that yield positive financial returns for each party.

[5] Altus Group 2017 Canadian Cost Guide

The developer's perspective is analyzed by calculating the acceptable incremental selling price that allows them to maintain their internal rate of return. In other words, at what price premium does Step 2, 3, or 4 become profitable for the developer?

The consumer's perspective is analyzed by calculating the acceptable incremental selling price that is recovered via energy savings over time. In other words, what incremental price should consumers be willing to accept based on energy savings? This analysis neglects other benefits to the consumer, such as improved thermal comfort, and potential maintenance cost savings.

The results indicate incremental prices in the range of 0.5% to 0.7% are generally acceptable for both parties for Step 2 and Step 3. For the low-rise, there remains a gap for the high-rise between the developer's minimum and the consumer's maximum for Step 4. Overall, this analysis indicates that slightly higher sales prices for Steps 2, 3, and 4 would allow developers to recover their additional costs, while also delivering value to consumers in most cases. However, it is important to note in this analysis that the ability of both the developer and buyer to absorb the impact of higher construction costs is likely negligible in the context of rapidly increasing real estate prices across Metro Vancouver.

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1 Introduction

UBC has set ambitious GHG reduction goals, including a target of achieving carbon neutrality for the institutional campus by 2050[6], and established an objective of a net-positive ready campus by 2035[7]. This supports achievement of the Province's "Carbon Neutral Government" mandate for public sector organizations and is aligned with the Climate Leadership Plan objective of net-zero ready buildings by 2032[8]. Research is required to assess cost-effective strategies and energy conservation measures (ECMs) to support these goals.

In 2016, RDH completed an archetype modelling study to outline a path for UBC to achieve "net positive ready" campus buildings - that is, buildings with the lowest energy consumption and GHG emissions that allow economically viable low-carbon energy supply. This report builds upon the 2016 work to consider buildings specific to UBC's residential neighbourhoods, while also considering the provincial Energy Step Code targets.

The scope of this study includes new buildings in the residential neighbourhoods at UBC's Vancouver campus. The first study consisted of five building types, which are documented in the report *UBC New Positive Modelling Study*, dated June 27, 2016. Two building types were selected for this study, specific to buildings in UBC's residential neighbourhoods: a high-rise multi-unit residential complex complete with townhouses, and a low-rise multi-unit residential building.

This project was completed with the support of an engaged steering committee from UBC that provided a variety of important perspectives and direction. The results of this study are intended to inform the ongoing development of UBC's Green Building Plan.

6 https://sustain.ubc.ca/campus-initiatives/climate-energy/climate-action-plan
7 https://sustain.ubc.ca/our-commitment/strategic-plans-policies-reports/sustainability-plans/ubc-develops-strategy-next
8 http://climate.gov.bc.ca/

2 Methodology

A roadmap for future energy performance targets was developed using whole-building energy modelling. This roadmap is comprised of incremental steps which align with the Province of British Columbia Energy Step Code[9]. Two archetype buildings were selected for this study, and a list of potential Energy Conservation Measures (ECMs) were developed using readily available strategies and technologies. The incremental capital costs of measures beyond the BC Building Code and UBC Residential Environmental Assessment Program (REAP)[10] minimum energy standards were estimated based on data from the Lower Mainland marketplace, including least and highest known cost “bookends” to define a range of financial impacts. The value of energy savings (and avoided carbon charges) were compared against incremental capital costs under a 30-year, life cycle economic assessment that estimated three “cost-effectiveness” indicators.

2.1 Overview of Methodology

Four primary tasks were completed for this project:

→ Step 1: Create baseline archetype models

→ Step 2: Assess individual ECMs

→ Step 3: Assess bundles of ECMs

→ Step 4: Analyze the Developer’s Business Case

Step 1: Create Baseline Archetype Models

Two baseline energy models were developed based on the following archetype buildings: a high-rise multi-unit residential complex that includes townhouses, and a low-rise multi-unit residential building. Baseline models were developed to generally align with ASHRAE 90.1-2010 using construction and systems common to UBC buildings. In the case of the high-rise archetype, some trade-offs of the prescriptive requirements were necessary in order to reflect typical construction practices.

Following the baseline models, two additional models were developed based on the UBC REAP. These models are largely similar to the ASHRAE 90.1-2010 baseline models, with specific modifications to comply with REAP mandatory requirements. Modelling was completed following the City of Vancouver Energy Modelling Guidelines dated March 17, 2017[11].

Step 2: Assess Individual Energy Conservation Measures (ECMs)

ECMs were identified to build upon the previous study, with the addition of select ECMs specifically applicable to the residential archetypes (e.g. thermally broken balconies). Key ECMs were selected for the study based on measures that are readily available, however, the ECMs studied are not comprehensive, and other measures may also contribute to low energy buildings.

[9] See http://www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/energy-efficiency/energy-step-code
[10] Residential Environmental Assessment Program (REAP). University of British Columbia. Version 3.0. October 2014.
[11] http://vancouver.ca/files/cov/energy-modelling-guidelines-v1.0.pdf

Each ECM was modelled individually to determine the incremental energy savings compared to the baseline building. Measures cover all aspects of building energy consumption, including building enclosure, mechanical and service hot water systems, and lighting. Each of the ECMs was costed using published costing data (RS-Means), RDH's in-house database, review of the literature and direct contact with component suppliers. As noted previously, two costs were assigned to each ECM (high and low), assuming current market prices, excluding cost-reductions that may occur for those products/designs with significant increases in market share and competition between suppliers.

A life-cycle economic assessment was completed to estimate the net present value (NPV) and other financial metrics for each individual ECM. The assessment included utility costs projected for the district energy system; parameters are shown in Section 2.4.

Step 3: Create a Framework for Energy Step Code Targets

The results of the individual ECM analysis (Step 2) were used to establish logical bundles of ECMs generally based on the Step Code requirements (see Table 2.1) for Total Energy Use Intensity (EUI) and Thermal Energy Demand Intensity (TEDI). The bundles are indicative of how ECMs can be effectively assembled to achieve different performance thresholds identified in the Energy Step Code, but are not intended to be prescriptive. The following criteria were used to establish the bundles of ECMs in an additive manner, introducing ECMs with lower or negative NPV to achieve the more stringent Steps, and allowing for market transformation where applicable:

- The REAP baseline represents Step 1 of the Energy Step Code, and includes all measures that are commonly implemented in current UBC new construction projects.
- The second bundle is intended to align with Step 2 of the Energy Step Code (EUI of less than 130 kWh/m^2, TEDI of less than 45 kWh/m^2). This bundle includes additional ECMs that are cost-effective (demonstrate a positive NPV on an individual basis) using current and forecasted utility energy rates, and where the technology is readily available, industry capacity is established and implementation is straightforward.
- The third bundle is intended to align with Step 3 of the Energy Step Code (EUI of less than 120 kWh/m^2, TEDI of less than 30 kWh/m^2). This bundle includes additional ECMs with positive NPV and/or where market transformation is required (capacity building, availability, acceptance, demonstration projects, measurement and verification).
- The final bundle is intended to align with Step 4 of the Energy Step Code (EUI of less than 100 kWh/m^2, TEDI of less than 15 kWh/m^2). This bundle includes all measures.

TABLE 2.1 BC STEP CODE ENERGY PERFORMANCE REQUIREMENTS FOR PART 3 RESIDENTIAL OCCUPANCIES.

Step	Maximum Total Energy Use Intensity (kWh/m^2-year)	Maximum Thermal Energy Demand Intensity (kWh/m^2-year)
1	Conform to Part 8 of the NECB	
2	130	45
3	120	30
4	100	15

Step 4: Analyze the Developer's Business Case

The NPV/IRR/Payback metrics produced in Step 3 do not provide a strong business case for developers due to the split incentive where the developer carries incremental capital costs while the owner realizes annual savings. To address this, the business case was analyzed from these two perspectives, considering incremental selling prices that yield positive financial returns for each party.

Additional Scope: Non-District Energy Archetypes

To consider buildings are not connected to UBC's district energy system, two additional archetypes with gas/electric systems were also developed based on common practice. The high-rise archetype uses a similar fan coil heating/cooling system but with gas-fired boilers instead of a district energy connection, with gas make-up air and DHW. The low-rise version uses electric baseboard heating with gas make-up air and DHW. The results from the analysis of these gas/electirc archetypes are included in Appendices F, G, and H.

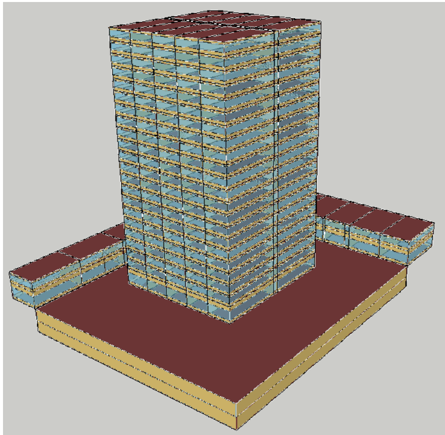
2.2 Building Archetypes

Two archetype buildings were identified to reflect typical new construction in UBC neighbourhoods (Figure 2.1). The archetypes were based generally on plans for several recent buildings; equipment efficiencies, enclosure R-values, and lighting power densities (LPDs) all meet ASHRAE 90.1-2010 performance requirements for Climate Zone 4. A second iteration of each baseline archetype was created with additional UBC REAP 3.0 requirements. Other model inputs followed the City of Vancouver Energy Modelling Guidelines dated March 17, 2017. Appendix A lists key energy model inputs.

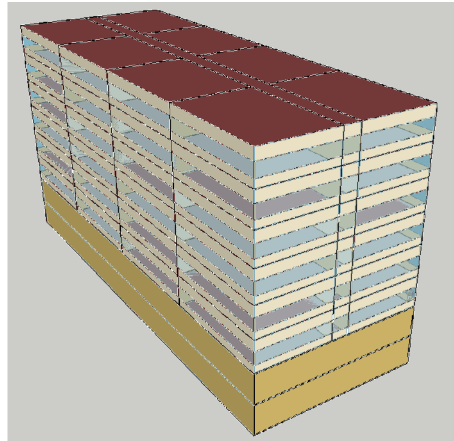
→ Archetype 1: High-Rise Multi-Unit Residential Complex with Townhouses
This archetype is based on early plans for an upcoming development on UBC South Campus. The development consists of a 22-storey, 24,100 m^2 (260,000 sf) high-rise multi-unit residential building, and sixteen 2-storey, 150 m^2 (1,600 sf) townhouses built on an 8,340 m^2 (90,000 sf) two-level parkade. The building enclosure consists of aluminum frame window wall with spandrel panels. The baseline building has fan coil units (FCUs) and standard efficiency heat recovery ventilators (HRVs) in suites, and constant volume ventilation supply to corridors (district heating, without heat recovery). Domestic hot water (DHW) is heated by district heating.

→ Archetype 2: Low-Rise Multi-Unit Residential Building
This 6-storey, 4,700 m^2 (51,000 sf) low-rise multi-unit residential building includes a 2-level 1,600 m^2 (17,000 sf) parkade, and is based loosely on plans for several upcoming developments at UBC. The building enclosure is wood framing with vinyl frame windows. The baseline building has hydronic in-floor radiant heating in suites, and constant volume ventilation supply to corridors (district heating, without heat recovery) with passive inlets in suites. Domestic hot water (DHW) is heated by district heating.

It is important to note that these archetype models have a simple geometry with good enclsoure-to-floor area. This benefits EUIs and TEDIs, and is a key design principle to reduce building energy consumption and heating demand. EUIs and TEDIs will be higher for more complex geometries.



Archetype 1: High-Rise Multi-Unit Residential Complex with Townhouses



Archetype 2: Low-Rise Multi-Unit Residential Building

Figure 2.1 Energy model geometry of two archetype buildings.

2.3 Energy Conservation Measures (ECMs)

Energy conservation measures (ECMs) were selected to reflect measures that are generally available in the Vancouver market using existing technology. While this list does not represent a comprehensive list of all possible ECMs, it does include many common measures that can reliably reduce building energy consumption.

A general description of the ECMs investigated follows; a complete list of ECMs applied to each archetype is presented in Appendix B.

Building Enclosure

Building enclosure measures that were investigated include: increasing wall and roof effective insulation R-values, high performance windows, airtight construction, thermally broken balconies, and exterior shading. Both metal and non-metal frame windows were considered for the high-rise; non-metal windows could include fibreglass, vinyl, or wood. Non-metal windows have some limitations in combustible buildings, though they can often be used with appropriate design strategies, typically limited window-to-wall ratios and non-combustible insulation and cladding systems. Fibreglass windows are typically preferred for durability, though vinyl or wood frame windows may also be feasible. Vinyl is currently widely used with wood frame construction.

Airtight construction targets are assumed to be achieved with whole building airtightness testing, coupled with air barrier design and quality assurance through construction.

Fixed exterior shading was investigated for the high-rise, but omitted for the low-rise since the later does not include cooling (therefore shading would not be an ECM). Future research should consider climate change adaptation needs considering prospective future heat events. Reducing the window to wall ratio (WWR) was also investigated as an ECM, though this measure was not included in the bundles.

Lighting

Lower lighting power densities (LPDs) were investigated, with two targets: 10% below ASHRAE 90.1-2010, corresponding to the ASHRAE 189.1 standard, and 25% below ASHRAE 90.1-2010, approximating a design with LED and T5 lighting. Occupancy sensors were included for all archetypes as part of the REAP baseline. Lighting measures were only applied to the corridor and parkade space within the residential archetypes, assuming that residents control the choice of light fixtures in residential spaces.

Heating, Cooling, and Ventilation

ECMs assessed in this study were limited to district energy connected (hydronic) systems; other systems such as heat pumps were not considered within this study.

For the high-rise residential complex, changing from standard efficiency to high efficiency heat recovery ventilation (HRVs) was investigated, along with implementing ECM motors within the fan coil units.

For the low-rise residential building, implementing both standard and high efficiency heat recovery ventilation in place of passive inlets were investigated. An additional scenario with electric baseboard heating was run to consider the cost savings compared to a district energy system when a high performance building enclosure is used.

Domestic or Service Hot Water (DHW)

Water heating measures that were investigated include low flow water fixtures, and, in the residential buildings, drain water heat recovery. Heat pump systems were not investigated due to the requirement to connect to district energy.

2.4 Life Cycle Economic Analysis Parameters

Financial analysis was completed for each individual ECM iteration, including calculation of net present value (NPV), internal rate of return (IRR), and discounted payback period for the ECMs. Energy prices used for each archetype were determined in consultation with UBC. The following summarizes rates and GHG emissions factors referenced for this study; additional details are provided in Appendix D.

District Heating System

The price of purchasing hot water from the Corix district heating system was provided by UBC and is displayed in Table 2.2. These prices incorporate an exponential escalator of 2.86% annually.

TABLE 2.2 CORIX DISTRICT ENERGY RATES.

Year	Variable Charge ($/kWh)
2017	0.0399
2018	0.0411
2019	0.0423
2020	0.0435
2021	0.0447
2022	0.0460
2023	0.0474
2024	0.0487
2025	0.0502

Utility Purchased Electricity

Electricity is purchased from BC Hydro at standard residential rates. BC Hydro pricing has two steps based on bimonthly consumption. For the purposes of this study, the average of the two prices was taken, which assumes a mix of heavy and light suite consumers. Electricity price escalation was based on announced price increases, with an incremental increase of 2% annually thereafter.

The 2017 BC Hydro residential electricity prices are as follows:

→ Step 1 – Up to 1,350 kWh/2 months: $0.0858/kWh

→ Step 2 – Over 1,350 kWh/2 months: $0.1287/kWh

→ Average Price: $0.1073/kWh

The rate rider of 5% is added to these rates; GST/PST are not included, since these also apply to incremental capital costs.

Multi-family residential buildings typically include two account types: residential rates billed to individual suite occupants for suite consumption, and general service rates for the common area consumption. General service rates also vary depending on peak demand - for example, the Small General Service Rate (less than 35 kW demand) is $0.1139/kWh, while the Medium General Service Rate (less than 150 kW demand) is $0.088/kWh. As the general service rates are reasonably close to the residential rates, only the residential rates were used to simplify the analysis.

Purchased Natural Gas

The secondary archetypes developed to consider systems not connected to district energy use natural gas for heating and hot water (Appendix F, G, H) use natural gas. Gas prices are based on FortisBC Small Commercial (Rate 2) for the Lower Mainland, including the carbon tax, for a total price of $7.90/GJ.

Other Parameters

GHG emission factors were based on the BC Best Practices methodology, in addition to a low carbon District Energy factor provided by UBC. The following GHG emissions factors were used (see Appendix D for additional detail on emissions factors by year):

→ Electricity: 10.67 t/GWh[12]

→ District Heating:

    → Natural gas with 85% system efficiency: 237.0 t/GWh[13]

    → UBC low carbon system: 93.6 t/GWh

→ Gas: 179.5 t/GWh (49.87 kg/GJ)[12]

The discount rates used in the economic analysis were 7%, 5.75%, and 3.75% for high, medium, and low risk ECMs, respectively. The specific discount rate applied to each ECM is shown in Appendix C.

[12] BC Ministry of Environment. *2016/17 B.C. Best Practices Methodology for Quantifying Greenhouse Gas Emissions.* http://www2.gov.bc.ca/assets/gov/environment/climate-change/cng/methodology/2016-17-pso-methodology.pdf

[13] Average of natural gas system with 85% system efficiency based on BC Ministry of Environment *2016/17 B.C. Best Practices Methodology for Quantifying Greenhouse Gas Emissions.* http://www2.gov.bc.ca/assets/gov/environment/climate-change/cng/methodology/2016-17-pso-methodology.pdf

The life cycle economic analysis also takes into account the life span of ECMs by applying a renewal cost at the end of the measure life within the 30 year analysis window. For example, occupancy sensors that control lighting have an estimated lifespan of eight years. Thus, capital costs are incurred at the time of construction, in year eight, 16 and 24, with savings applied for all 30 years of analysis. The assumed life span for each ECM is shown in Appendix B. The challenge with this approach is that energy savings are "cut off" after year 30, albeit the discount rates would significantly reduce any benefits after year 30 and thus, the impact is minor.

Costing for ECM bundles includes capital cost savings for mechanical equipment as applicable (e.g. due to a higher performance building enclosure).

Many of the ECMs also provide non-energy related benefits. For example, high performance enclosure measures also deliver improved comfort, durability, acoustics, and reduced mechanical system maintenance and replacement. The Provincial Demand Side Measures Regulation under the *Utility Commission Act*, used by energy utilities to evaluate cost-effectiveness of energy efficiency programs, provides guidance of increasing the value of energy savings by 15% to account for these non-energy benefits. This has the effect of improving the cost-effectiveness calculations such as NPV, IRR and discounted payback period. The 15% multiplier is intended to apply to the full range of non-energy benefits noted above, and others, across the full range of energy efficiency projects.

3 Archetype 1: High-Rise

The following sections present the baseline energy model results for the high-rise multi-unit residential complex archetype, the analysis for individual ECMs, and the final ECM bundle results.

3.1 Baseline Model Results

Figure 3.1 shows the distribution of energy consumption by end-use for the high-rise multi-unit residential complex archetype. The baseline building inputs were based generally on ASHRAE 90.1-2010 performance path requirements (Climate Zone 4), using systems that are common at UBC.

Figure 3.2 shows the distribution of energy consumption by end-use for the same archetype, with specific modifications to meet UBC REAP requirements. The total energy use intensity (EUI) is 152 kWh/m² per year, and annual GHG emissions are 555 tonnes per year (20.9 kg/m²). Additional details on both baseline archetype energy models are provided in Appendix A.

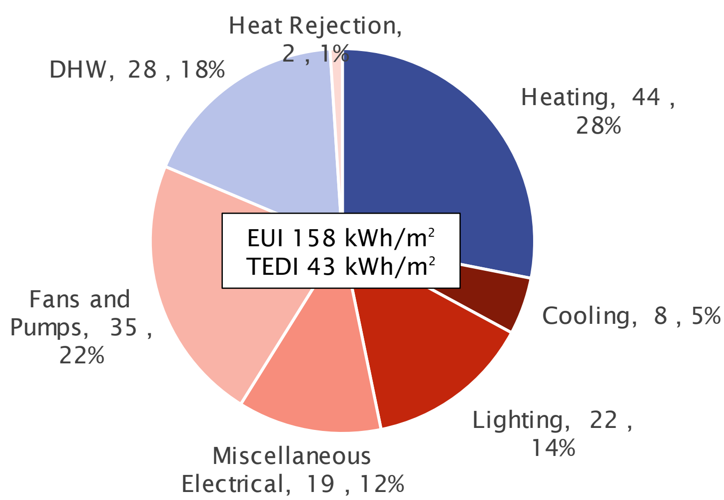


Figure 3.1 Baseline energy consumption by end-use for residence archetype, kWh/m² and percent of total.

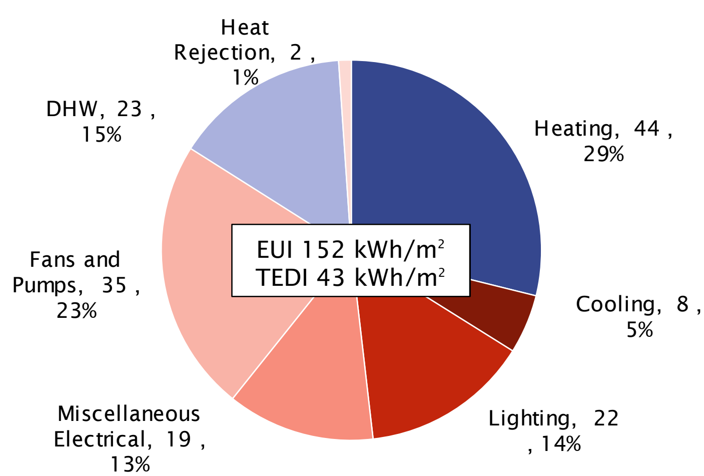


Figure 3.2 REAP Baseline energy consumption by end-use for residence archetype, kWh/m² and percent of total.

The modelled baseline EUIs of 158 and 155 kWh/m^2 are significantly lower than the average multifamily residential building energy consumption found in a study by RDH (215 kWh/m^2), as well as a REAP study[14] which shows an ASHRAE 90.1-2010 baseline of 205 kWh/m^2, likely due to standard assumptions used in this study following the City of Vancouver Energy Modelling Guidelines. This highlights the need for a better understanding of the "performance gap" between typical new construction model assumptions and metered consumption.[15]

3.2 Individual ECM Results

ECMs were modelled individually to compare the energy savings and financial feasibility of each individual measure. Complete results are presented in Appendix C.

These results should be viewed with the caveat that certain measures are better assessed as a bundle. Further to this, some enclosure ECMs had to be combined in order to view feasible results. For example, thermally broken balconies were combined with wall R-value improvements. This was necessary because the low thermal performance of the baseline spandrel wall assembly meant that adding thermally broken balconies would provide minimal energy savings, and this would not be a realistic approach.

Figure 3.3 shows the percent energy savings of each measure compared to the baseline archetype model. Measures with the greatest GHG savings include window and enclosure effective R-value improvements that reduce heating energy. Fan coil unit (FCU) ECM motors show negative GHG emission savings since they reduce electricity consumption, but increase DE consumption for heating.

Figure 3.4 shows the incremental capital cost of the individual ECMs per square metre of conditioned space. The large discrepancy between best and worst case costs for wall ECMs is based on prefabricated panelized construction versus traditional framed wall construction. Based on RDH's experience, with full industry adoption of panelized construction, high R-value walls in high-rise construction can be built and installed at, or below, the cost of spandrel systems. However, if high R-value walls were to be built using traditional framing practices, significant construction costs would result in a high cost premium over spandrel panel systems. Appendix A provides additional discussion on panelized construction in multifamily residential buildings.

[14] Concrete High-Rise, ASHRAE 90.1-2010 from the report *UBC Residential Environmental Assessment Program Energy Modeling Project* by EnerSys, Enerficiency Consulting, and Sustainability Solutions Group, April 5, 2012.
[15] For additional reading on the performance gap, see the following references:
RDH Blog Series: http://www.rdh.com/measured-energy-consumption-of-high-performance-buildings/
CIBSE Paper: http://www.cibse.org/getmedia/55cf31bd-d9eb-4ffa-b2e2-e567327ee45f/cb11.pdf.aspx

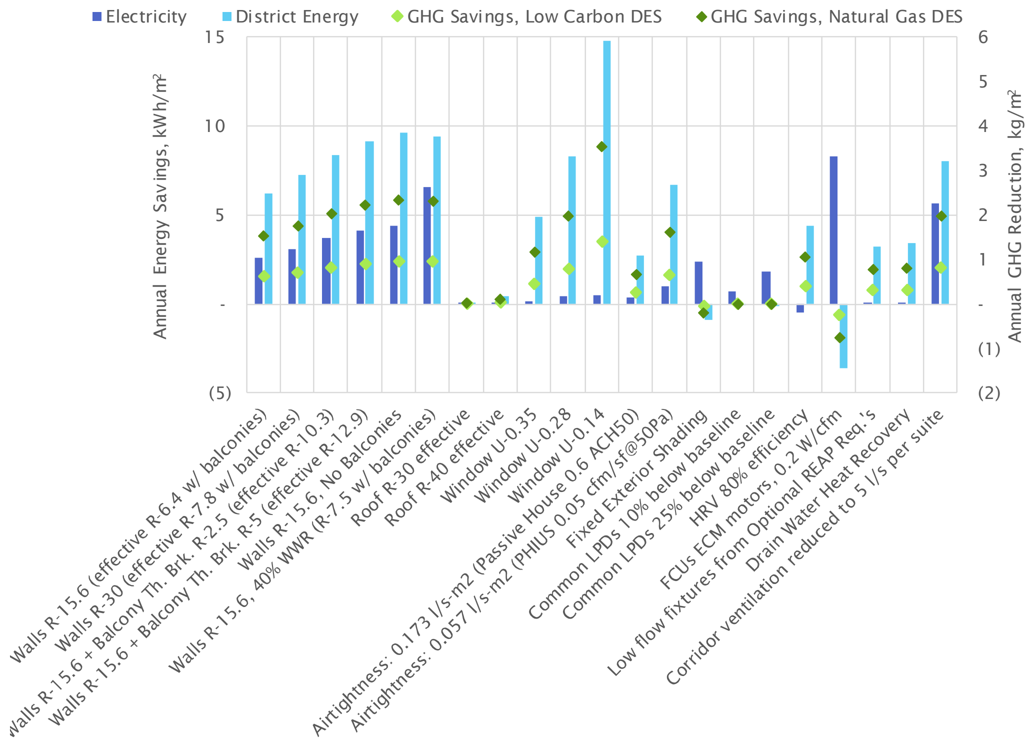


Figure 3.3 Annual energy savings and GHG emsisions reduction of individual ECMs.

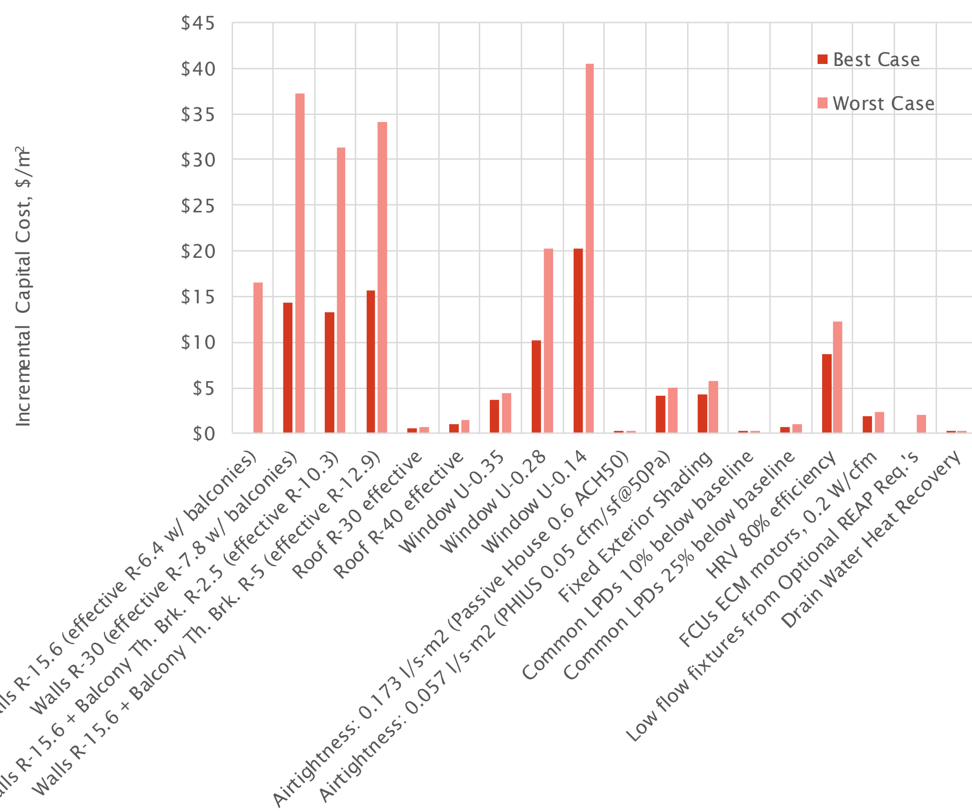


Figure 3.4 Incremental capital cost of individual ECMs, $/m2 of conditioned floor area. Significant worst case costs for insulated wall assembly ECMs are due to the added cost to move from spandrel to an exterior insulated wall assembly; best case costs are based on lower cost panelized construction.[16]

[16] The measure 40% WWR is not shown in the cost and NPV plots since there is no cost premium associated for this measure. It remains in the energy savings plots to show the savings associated with this change.

Figure 3.5 shows the NPV for each measure (normalized per m² of conditioned floor area), with ECMs ordered from best (highest) NPV to worst (lowest) NPV. About two thirds of the measures result in positive best case NPV, meaning they are cost-effective based on current energy costs, forecasted energy rates and emissions charges over 30 years.

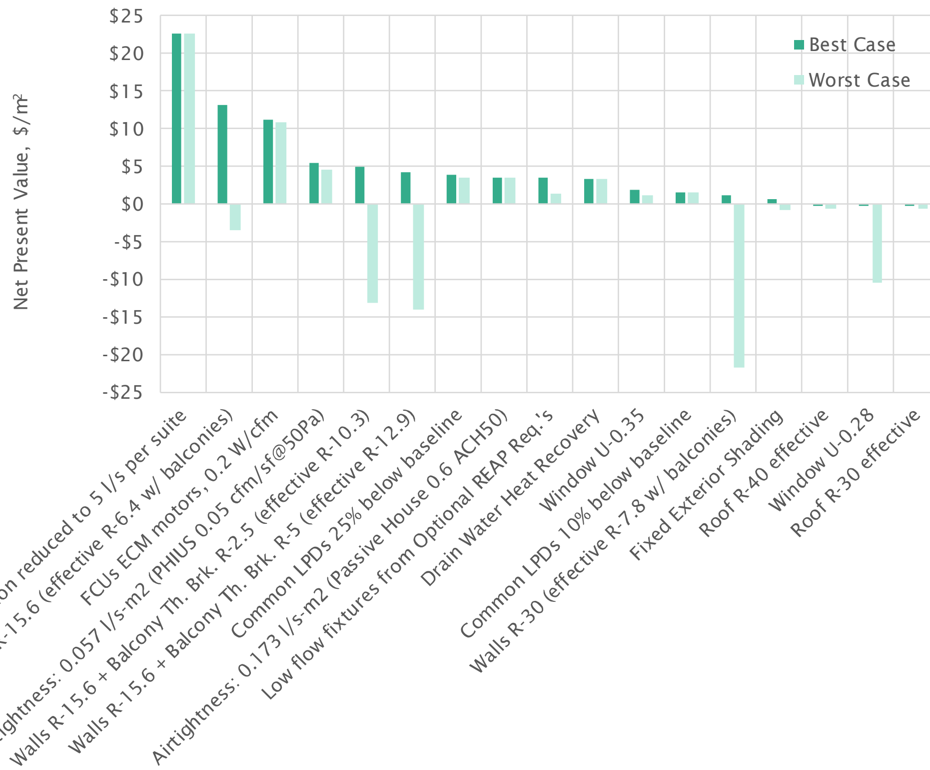


Figure 3.5 Net present value of individual ECMs ordered from highest to lowest, $/m2 of conditioned floor area. Negative worst case NPVs for ECMs that include insulated wall assemblies are due to the incremental cost to move from spandrel to an exterior insulated wall assembly, while best case NPVs were based on lower cost panelized construction.[7]

3.3 Bundle Results

The individual ECMs were combined into bundles of measures to assess how the BC Energy Step Code targets can be achieved. Bundles were selected based on the individual results, market readiness, and whole building design. Costs for some measures (e.g. high efficiency HRVs) are likely to decrease over time as the technology becomes more common.

The City of Vancouver modelling guidelines allow EUI and TEDI adjustments for pressurized corridor ventilation systems in high-rise residential buildings, where the design flow exceeds the minimum airflow rate required by the building code, as the industry transitions away from these systems. Instead of implementing this adjustment, decreased corridor airflows were incorporated into the bundles as an ECM, with greater reductions for higher performance bundles.

Table 3.1 shows the ECMs simulated within each of the three bundles. A variety of combinations may be possible to achieve each step, including ECMs not considered in this study; the bundles below are intended to illustrate one example of measures for analysis.

TABLE 3.1 SUMMARY OF ECMS IN EACH BUNDLE FOR HIGH-RISE ARCHETYPE.	
Step 1 **No EUI/TEDI Target**	**Step 2** **Target: EUI 130 kWh/m², TEDI 45 kWh/m²**
→ REAP Baseline Complies with NECB performance path plus REAP mandatory measures. Performance path includes 60% efficient HRVs (60% efficient) and improved window performance (U-0.45) as trade-offs for higher WWR and lower wall performance. *EUI 152 kWh/m², TEDI 43 kWh/m²*	Step 1+ → Common area LPDs 25% below baseline → FCUs with ECM motors, 0.2 W/cfm → REAP optional low-flow DHW fixtures → DHW drain water heat recovery → U-0.28 Windows → Passive House airtightness, 0.173 l/s-m² (0.6 ACH50) *EUI 126 kWh/m², TEDI 33 kWh/m²*
Step 3 **Target: EUI 120 kWh/m², TEDI 30 kWh/m²**	**Step 4** **Target: EUI 100 kWh/m², TEDI 15 kWh/m²**
Step 2+[17] → R-15 walls (R-6.4 effective) → R-30 Roof → Corridor ventilation reduced to 20 cfm/suite (9.5 l/s/suite) *EUI 116 kWh/m², TEDI 26 kWh/m²*	Step 3+ → R-30 walls with R-5 balcony thermal break → R-40 roof → U-0.14 windows → PHIUS airtightness, 0.057 l/s-m² (0.05 cfm/sf@50Pa) → High efficiency HRVs (80% efficient) → Fixed exterior shading at South and West elevations → Corridor ventilation reduced to 10 cfm/suite (4.7 l/s/suite) *EUI 100 kWh/m², TEDI 7 kWh/m²*

Figure 3.6 shows the annual energy and GHG emissions reduction for the bundles. Step 4 has lower electricity savings due to an increase in cooling for this bundle. The results show the significant energy and GHG savings associated with the Step 4 bundle.

An additional scenario was created to assess the use of a lower window-to-wall ratio to more cost-effectively achieve the Step 4 target. Reducing the window-to-wall ratio allows for a lower wall R-value or other changes (for example, removing thermally broken balconies).

[17] A variety of combinations of measures could achieve this bundle, including additional measures not included in this study. Higher performance windows may be a cost-effective strategy to achieve similar EUI/TEDI results. Interior spray foam insulation behind spandrel panels may also achieve overall effective R-6.4, provided moisture control is considered.

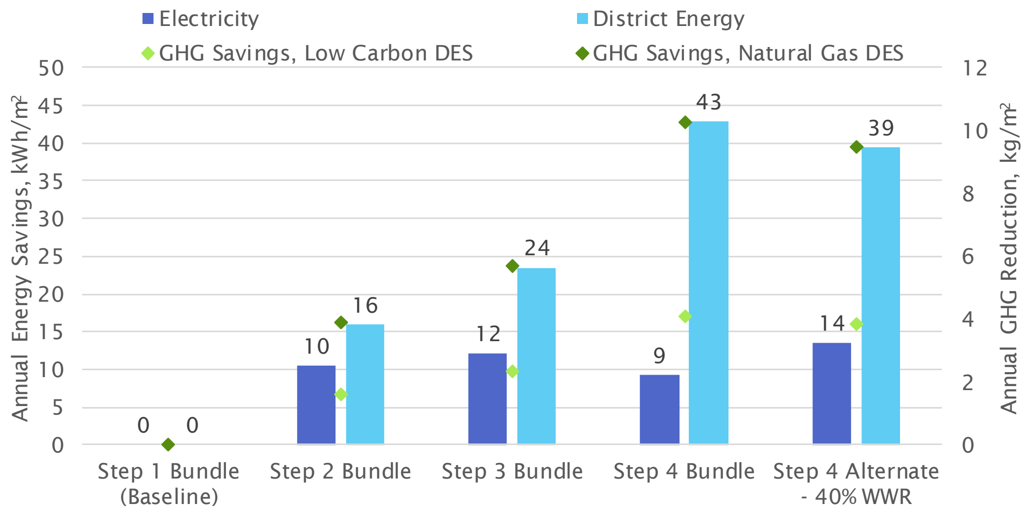


Figure 3.6 Annual energy and GHG emissions reduction for ECM bundles.

Figure 3.7 shows the incremental capital cost per square metre of conditioned floor area for each of the bundles. The significant range in Step 3 is due to the range in best and worst case wall system costs; this also impacts Step 4, plus a significant range for the best window ECM.

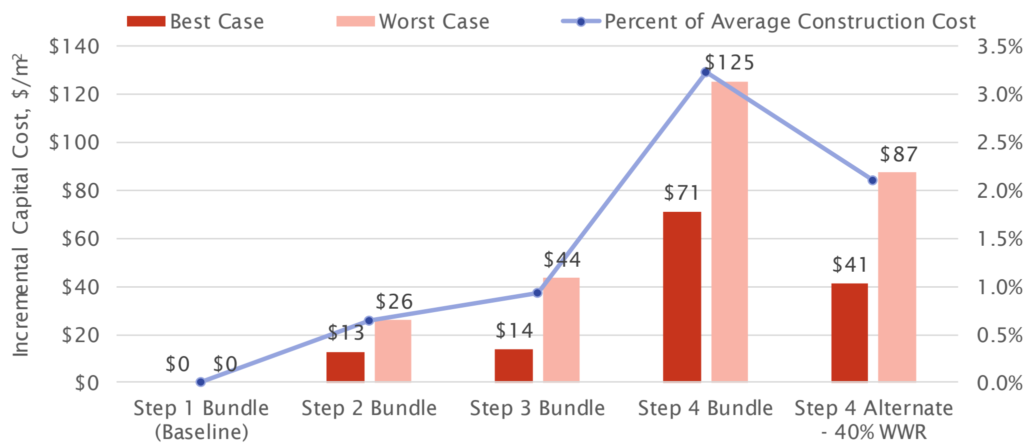


Figure 3.7 Range of incremental capital costs per m2 of floor area for bundles. The incremental cost as a percent of average construction is provided using an average cost of high-rise construction of $283/sf[18].

Figure 3.8 shows the NPV in $/m^2$ for the bundles. Table 3.2 and Table 3.3 show additional financial analysis results for the bundles.

The Step 2 bundle is cost-effective based on current technologies and energy prices.

The Step 3 bundle shows a range in cost-effectiveness. Considering other wall insulation approaches that fall between spandrel and exterior insulated systems in terms of performance, it is anticipated that this bundle can be achieved cost-effectively using current technology.

The Step 4 bundle has negative NPV, which is partly due to the inclusion of Passive House certifiable windows and high efficiency HRVs. As the cost of these technologies will likely decline over time, this analysis should be updated in 5 years to re-assess the economics.

[18] Altus Group 2017 Canadian Cost Guide

However, with a lower window-to-wall ratio and lower performing wall assembly, a breakeven NPV is achieved in the best case scenario.

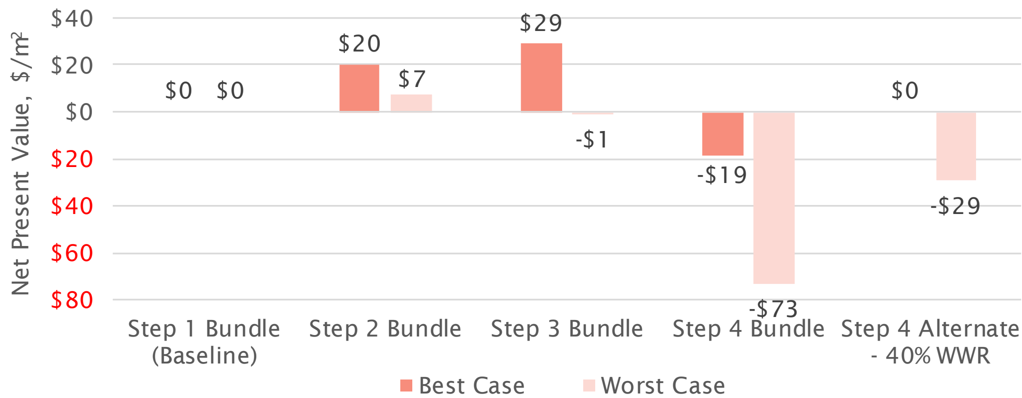


Figure 3.8 Net present value of bundles, $/m².

TABLE 3.2 INCREMENTAL CAPTIAL COSTS FOR ECM BUNDLES.				
Bundle	**Best Case**		**Worst Case**	
	$/m²	%[19]	$/m²	**%**
Step 2	$13	0.4%	$26	0.9%
Step 3	$14	0.5%	$44	1.4%
Step 4	$71	2.3%	$125	4.1%
Step 4 Alternate	$41	1.4%	$87	2.9%

TABLE 3.3 ECONOMIC ANALYSIS FOR ECM BUNDLES.								
	Annual Energy Savings	Annual GHG Savings NG DE [LC DE]	Net Present Value ($/m²)		Internal Rate of Return (IRR)		Discounted Payback Period (Years)	
Bundle	kWh/m²	kg/m²	Best	Worst	Best	Worst	Best	Worst
Step 2	26	3.9 [1.6]	$20.20	$7.32	16%	8%	7	13
Step 3	36	5.7 [2.3]	$28.87	($0.84)	19%	6%	6	16
Step 4	52	10.3 [4.1]	($18.74)	($72.89)	3%	0%	20	>30
Step 4 Alt.	53	9.5 [3.8]	$0.00	($29.10)	9%	3%	12	23

Figure 3.9 shows the sensitivity of cost-effectiveness (NPV) calculations to changes in the incremental capital costs of the bundles. The positive numbers show that capital costs could increase by 71% and 49% for the Step 2 and Step 3 bundles respectively, while still achieving a “break-even” economic outcome (i.e., discounted energy savings are equal to cost increases). The negative number shows that the Step 4 bundle would “break-even” with a 47% reduction in cost.

[19] Percent of average total construction cost based on Altus Group 2017 Canadian Cost Guide, high-rise construction, $283/sf. Excludes soft costs and land costs.

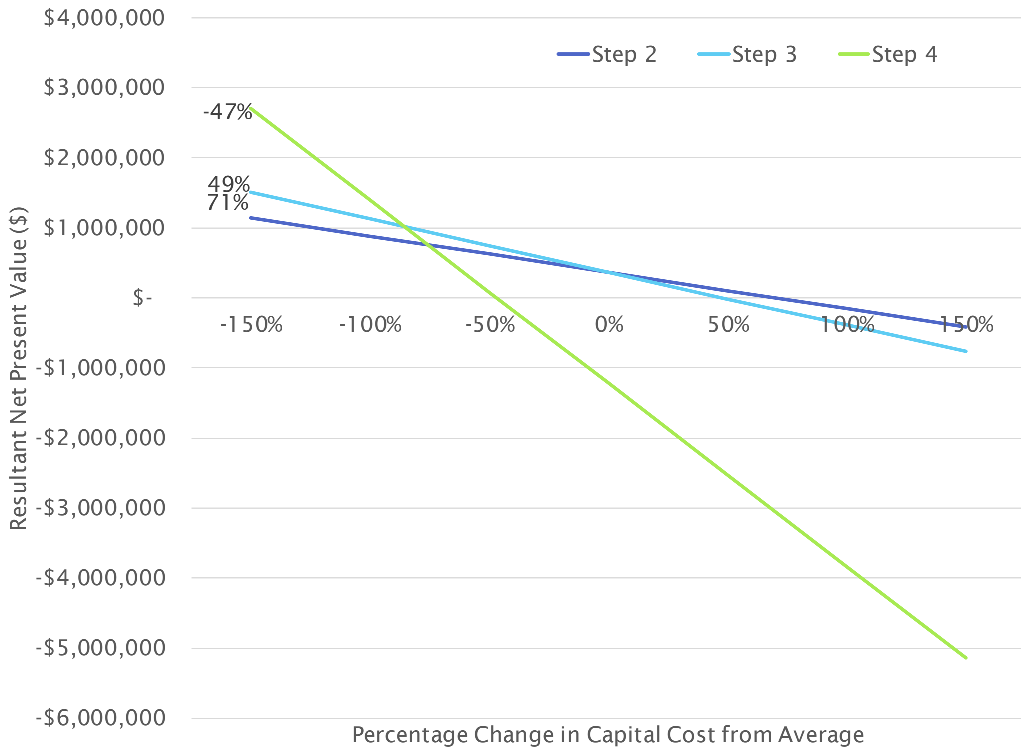
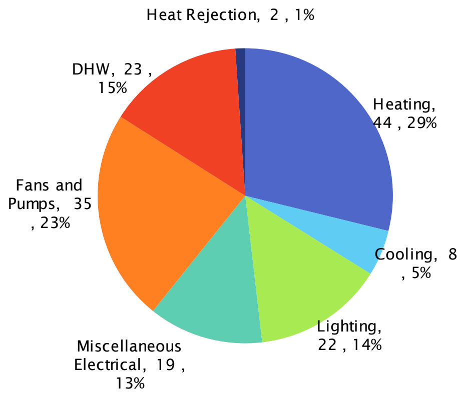
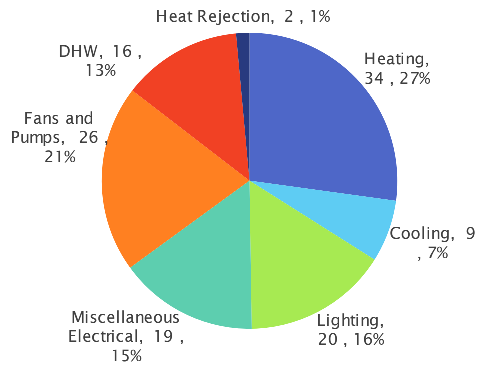


Figure 3.9 Sensitivity analysis of NPV to changes in capital costs.

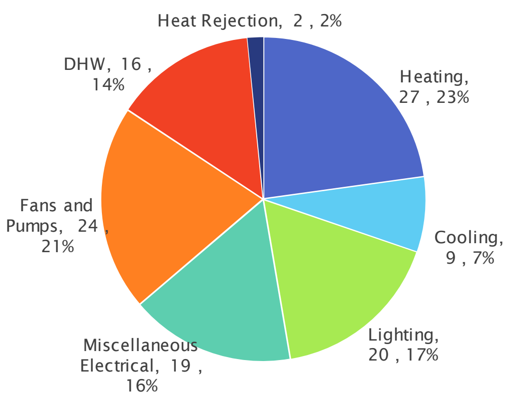
Figure 3.10 shows energy consumption by end use for the four bundles of ECMs, including both modelled and adjusted TEDI/EUI metrics. This can be compared to the baseline model consumption shown in Figure 3.1.



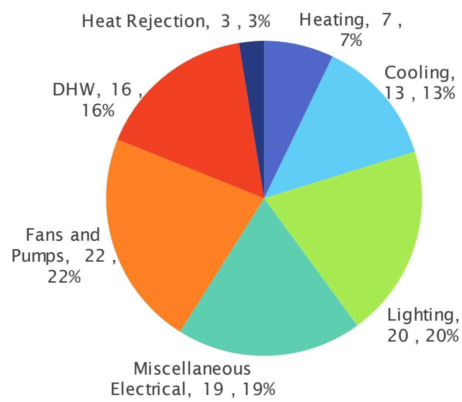
Step 1 (Baseline): EUI 152 kWh/m², TEDI 43 kWh/m²



Step 2: EUI 126 kWh/m², TEDI 33 kWh/m²



Step 3: EUI 116 kWh/m², TEDI 26 kWh/m²



Step 4: EUI 100 kWh/m², TEDI 7 kWh/m²

Figure 3.10 Energy consumption by end use for the ECM bundles.

Key findings from the high-rise bundles are as follows:

→ The EUIs and TEDIs modelled in these bundles meet the Step Code targets. It is important to note that a reduction in corridor make-up air flow rates was required in order to meet the targets for Steps 3 and 4 without relying on the adjustment factor currently included in the Energy Modelling Guidelines.

→ The requirement for district energy connected systems may limit the EUI savings beyond Step 4 that are achievable. For example, heat pump DHW that could further reduce EUIs were not considered due to this mandate. Despite this, the bundle results show that even Step 4 is achievable with district energy connected systems.

→ Overall, the economic analysis shows that Steps 1 through 3 can be acheived with positive NPV, while Step 4 requires significant investment due to the current high capital costs of best performing windows, HRVs, and wall systems.

4 Archetype 2: Low-Rise

The following sections present the baseline energy model results for the low-rise multi-unit residential building (MURB) archetype, the analysis for individual ECMs, and the final ECM bundle results.

4.1 Baseline Model Results

Figure 4.1 shows the distribution of energy consumption by end-use for the low-rise MURB archetype. The total energy use intensity is 135 kWh/m² per year, and annual GHG emissions are 113 tonnes per year (24 kg/m²). The baseline building inputs were based generally on ASHRAE 90.1-2010 performance path requirements (climate zone 4), using systems that are common at UBC.

Figure 4.2 shows the distribution of energy consumption by end-use for the same archetype, with specific modifications to meet UBC REAP requirements. The total energy use intensity is 123 kWh/m² per year, and annual GHG emissions are 96 tonnes per year (20.5 kg/m²). Details on the baseline archetype energy model are provided in Appendix A.

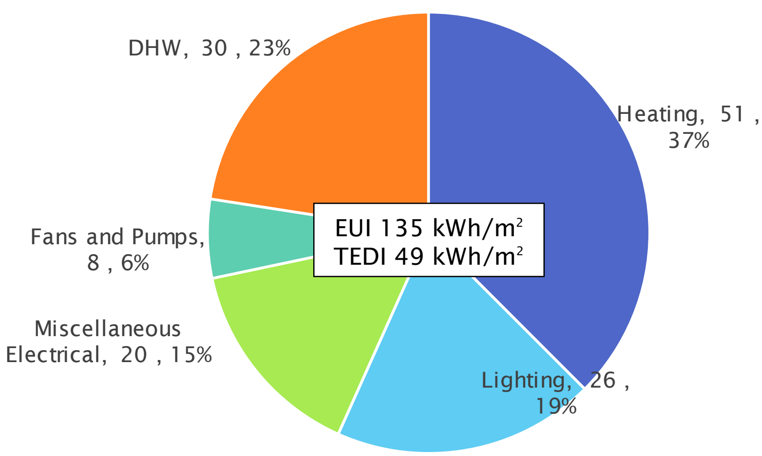


Figure 4.1 Baseline energy consumption by end use for low-rise MURB archetype, kWh/m² and percent of total.

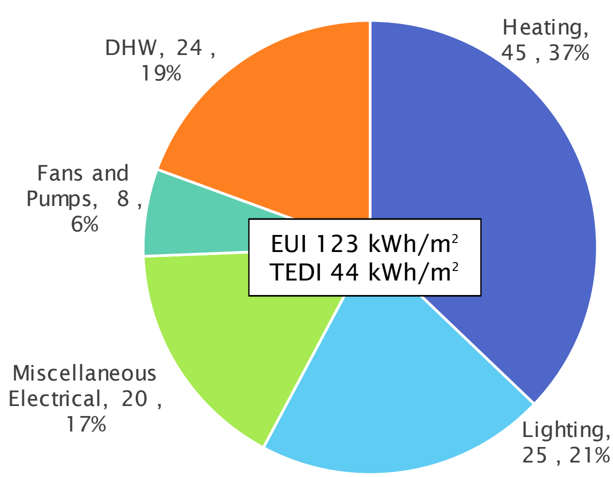


Figure 4.2 REAP Baseline energy consumption by end use for low-rise MURB archetype, kWh/m² and percent of total.

4.2 Individual ECM Results

ECMs were modelled individually to compare the energy savings and financial feasibility of each individual measure. Complete results are presented in Appendix C.

Figure 4.3 shows the annual energy savings of each measure compared to the baseline archetype model. Measures with the greatest GHG savings include windows and airtightness measures. Electric baseboards showed significant GHG savings due to fuel switching from natural gas based district energy to electricity.

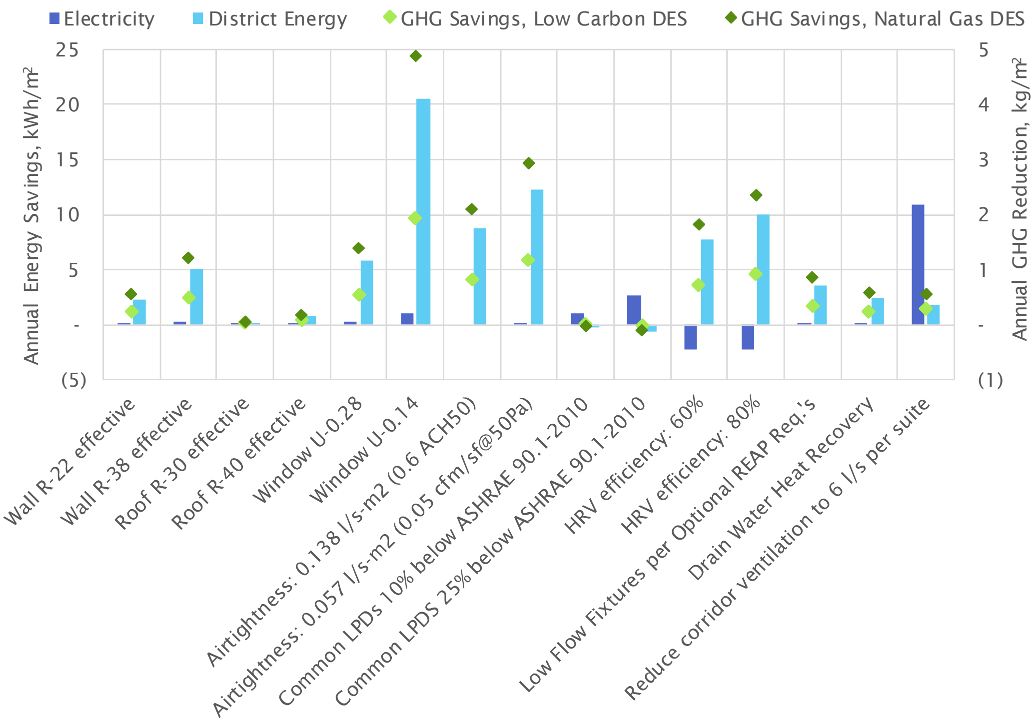


Figure 4.3 Annual energy savings and GHG emissions reduction of individual ECMs.

Figure 4.4 shows the incremental capital cost of the individual ECMs per square metre of conditioned space. Among the highest costs are Passive House certified windows and high efficiency HRVs, due to the limited number of products currently available in the Vancouver market.

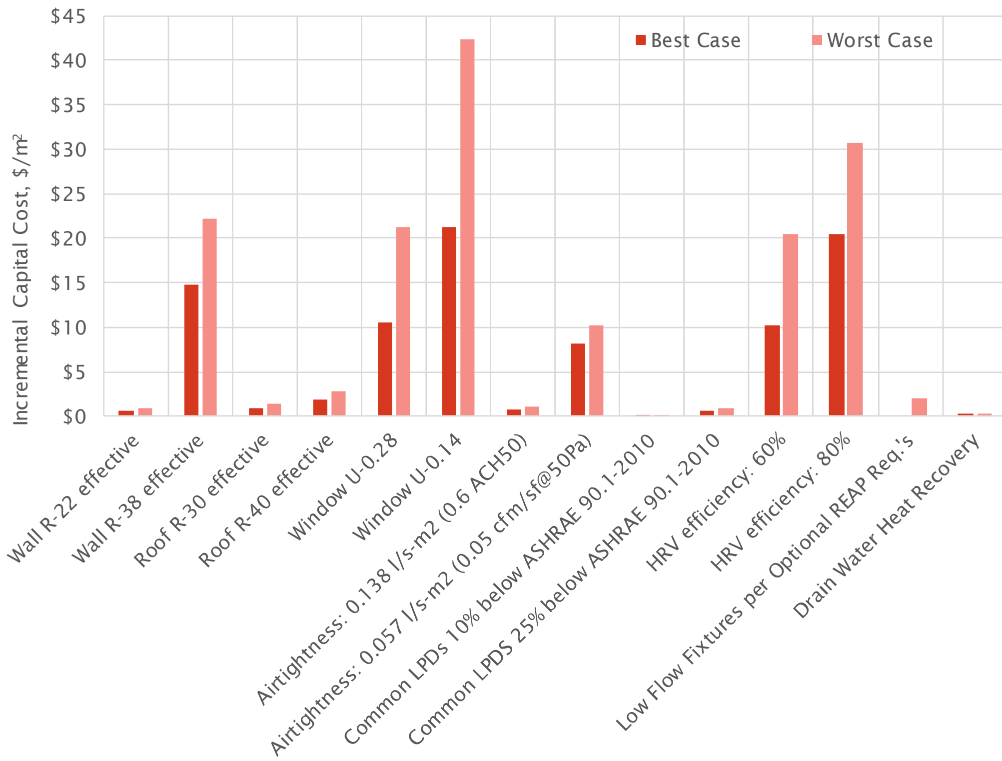


Figure 4.4 Incremental capital cost of individual ECMs, $/m2 of conditioned floor area.

Figure 4.5 shows the NPV for each measure (normalized per m² of interior floor area), with ECMs ordered from best (highest) NPV to worst (lowest) NPV. About half of the measures result in positive NPV, meaning they are cost-effective based on current implementation costs and forecast energy rates over a 30 year horizon.

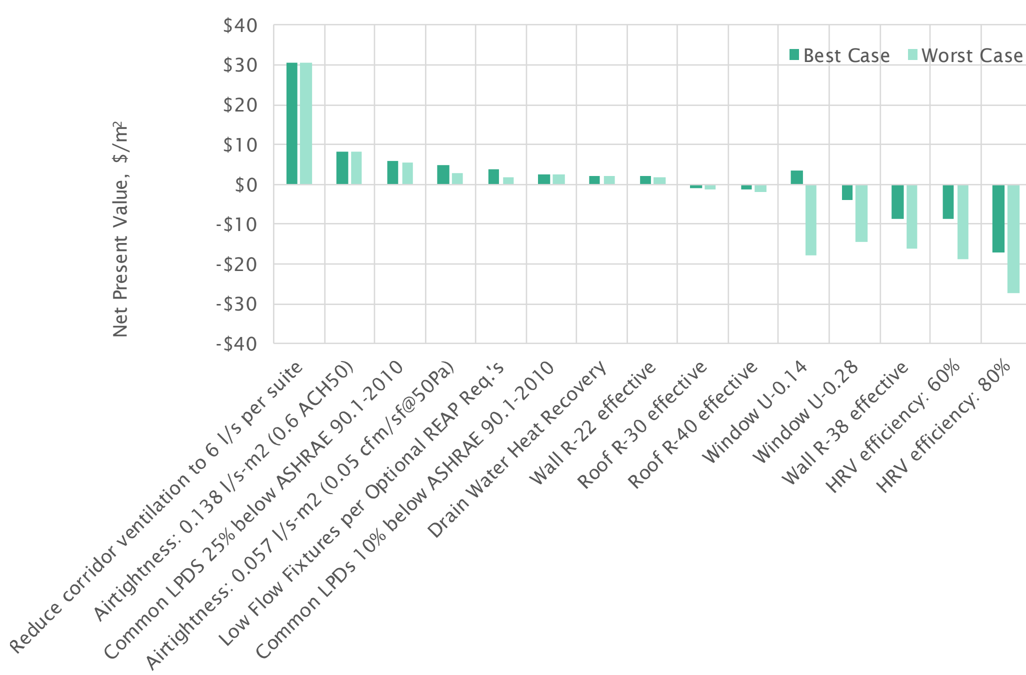


Figure 4.5 Net present value of individual ECMs ordered from highest to lowest, $/m² of floor area.

4.3 Bundle Results

The individual ECMs were combined into bundles of measures that make sense for the Step Code targets. Bundles were selected based on the individual results (NPV greater than zero), market readiness, and whole building design. While some of the enclosure measures had a negative NPV when simulated individually, capital cost savings of mechanical equipment are only captured when bundled with other high performance measures, and therefore have been included in the Step 3 and Step 4 bundles. Also, costs for some measures (e.g. high efficiency HRVs) are likely to decrease over time as the technology becomes more common.

The City of Vancouver modelling guidelines allow EUI and TEDI adjustments for pressurized corridor ventilation systems in MURBs where the design flow exceeds the minimum airflow rate required by the building code, as the industry transitions away from these systems. Instead of implementing this adjustment, decreased corridor airflows were incorporated into the bundles as an ECM. This measure was only needed to achieve the Step 4 targets, though it could also be considered as a measure to achieve Step 3.

Table 4.1 shows the ECMs simulated within each of the three bundles. A variety of combinations may be possible to achieve each Step, including ECMs not considered in this study; the bundles below are intended to illustrate one example of measures for analysis.

A second Step 4 bundle was simulated for the low-rise archetype to view the economic scenario where electric baseboard heating replaces in-floor radiant heating served by the district energy system.

TABLE 4.1 SUMMARY OF ECMS IN EACH BUNDLE FOR LOW-RISE ARCHETYPE	
Step 1 **No EUI/TEDI Target**	**Step 2** **Target: EUI 130 kWh/m², TEDI 45 kWh/m²**
→ REAP Baseline Complies with NECB prescriptive requirements plus REAP mandatory measures. *EUI 123 kWh/m², TEDI 44 kWh/m²*	Step 1+[20] → Common LPDs 25% below baseline → REAP optional low-flow fixture requirement → DHW drain water heat recovery *EUI 114 kWh/m², TEDI 45 kWh/m²*
Step 3 **Target: EUI 120 kWh/m², TEDI 30 kWh/m²**	**Step 4** **Target: EUI 100 kWh/m², TEDI 15 kWh/m²**
Step 2+ → R-22 Walls → U-0.28 Windows → Passive House Airtightness, 0.6 ACH50 (0.173 l/s-m²) *EUI 95 kWh/m², TEDI 27 kWh/m²*	Step 3+ → R-38 Walls → R-40 Roof → U-0.14 Windows → Standard efficiency HRVs (60% efficient) → PHIUS Airtightness, 0.05 cfm/sf@50Pa (0.057 l/s-m²) → Corridor ventilation reduced to 10 cfm/suite (5.7 l/s/suite) *EUI 83 kWh/m², TEDI 15 kWh/m²*

Figure 4.6 shows the annual energy and GHG emissions reduction for the bundles. The results show the significant savings achieved with the Step 4 bundle.

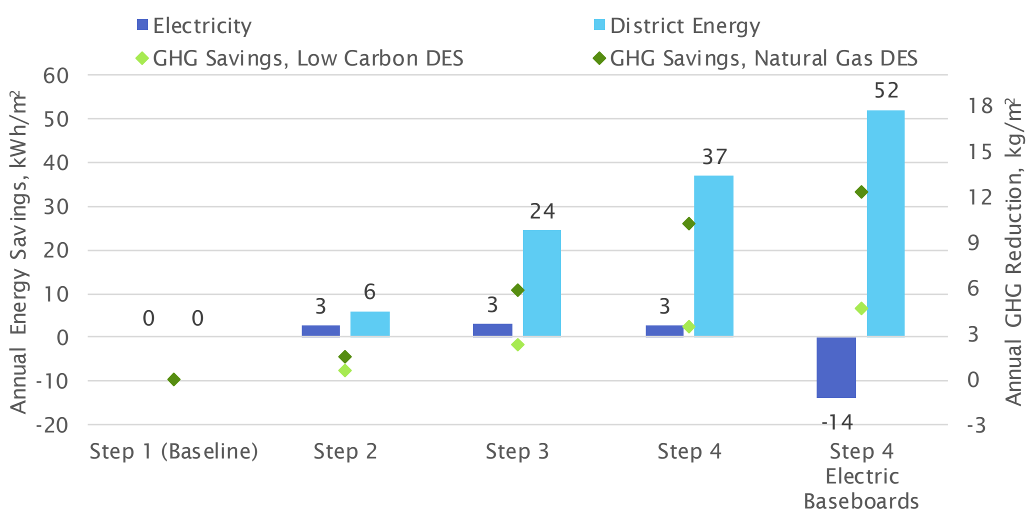


Figure 4.6 Annual energy and GHG emissions reduction for ECM bundles.

[20] The REAP baseline EUI/TEDI also comply with Step 2 for this archetype; additional ECMs were added to this bundle to show an additional scenario as they have low incremental cost and positive NPV.

Figure 4.7 shows the incremental capital cost per square metre of conditioned floor area for each of the bundles. The significant range in Step 4 is due to the range in cost for the best window ECM.

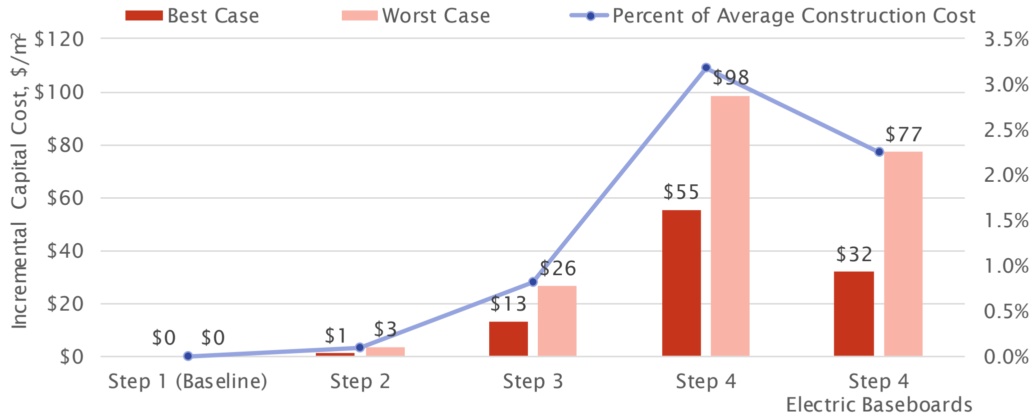


Figure 4.7 Range of incremental capital costs for bundles, $/m2 of floor area. The incremental cost as a percent of average construction is provided using an average cost of low-rise construction of $225/sf[21].

Figure 4.8 shows the NPV in $/m² for the bundles. Table 4.3 shows additional financial analysis results for the bundles. The Step 2 and 3 bundles are both cost-effective based on current technologies and energy prices. The Step 4 bundle has a positive best case NPV and negative worst case NPV. This is due to the range in costs for high performance windows. As the cost of these technologies will likely decline as more products enter the market, this analysis should be updated in 5 years to re-assess the economics.

Figure 4.8 Net present value of bundles, $/m2.

[21] Altus Group 2017 Canadian Cost Guide

TABLE 4.2 INCREMENTAL CAPTIAL COSTS FOR ECM BUNDLES.				
Bundle	**Best Case**		**Worst Case**	
	$/m²$	%[22]	$/m²$	**%**
Step 2	$1	0.0%	$3	0.1%
Step 3	$13	0.5%	$26	1.1%
Step 4	$55	2.3%	$98	4.1%
Step 4 Electric Baseboard	$32	1.3%	$77	3.2%

TABLE 4.3 ECONOMIC ANALYSIS FOR ECM BUNDLES.								
	Annual Energy Savings	Annual GHG Savings NG DE [LC DE]	Net Present Value ($/m²)		Internal Rate of Return (IRR)		Discounted Payback Period (Years)	
Bundle	kWh/m²	kg/m²	Best	Worst	Best	Worst	Best	Worst
Step 2	9	1.5 [0.6]	$9.46	$7.07	63%	19%	2	6
Step 3	28	5.8 [2.3]	$13.08	($0.35)	13%	6%	9	16
Step 4	46	8.8 [3.5]	($19.80)	($62.99)	3%	(1%)	23	>30
Step 4 Elec. BB	46	12.2 [4.7]	($18.41)	($63.75)	0%	(4%)	29	>30

Figure 4.9 shows the sensitivity of cost-effectiveness (NPV) calculations to changes in the incremental capital costs of the bundles. The positive numbers show that capital costs could increase by 390% and 32% for the Step 2 and Step 3 bundles respectively, while still achieving a “break-even” economic outcome (i.e., discounted energy savings are equal to cost increases). The negative number shows that the Step 4 bundle would “break-even” with a 48% reduction in cost.

Figure 4.10 shows energy consumption by end use for the four bundles of ECMs. This can be compared to the baseline model consumption shown in Figure 4.1.

[22] Percent of average total construction cost based on Altus Group 2017 Canadian Cost Guide, low-rise construction, $225/sf. Excludes soft costs and land costs.

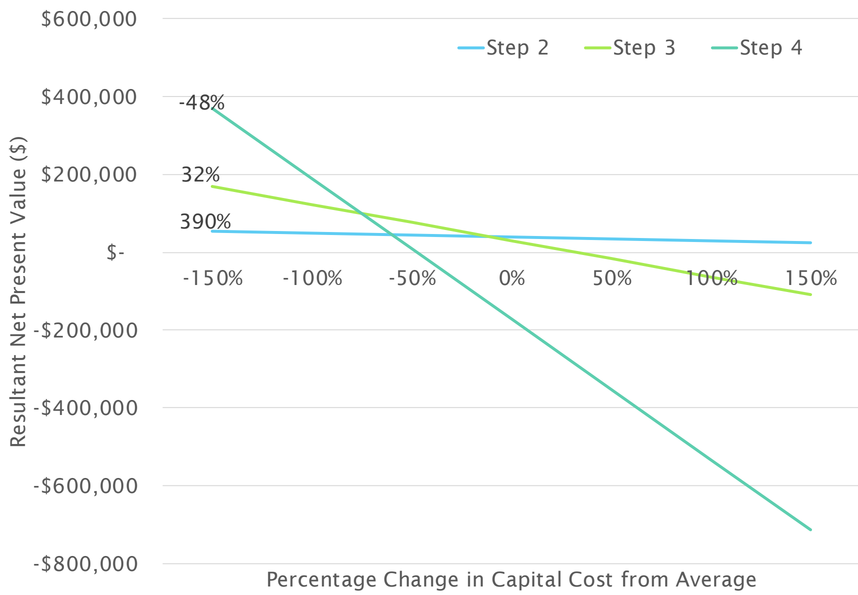


Figure 4.9 Sensitivity analysis of NPV to changes in capital costs.

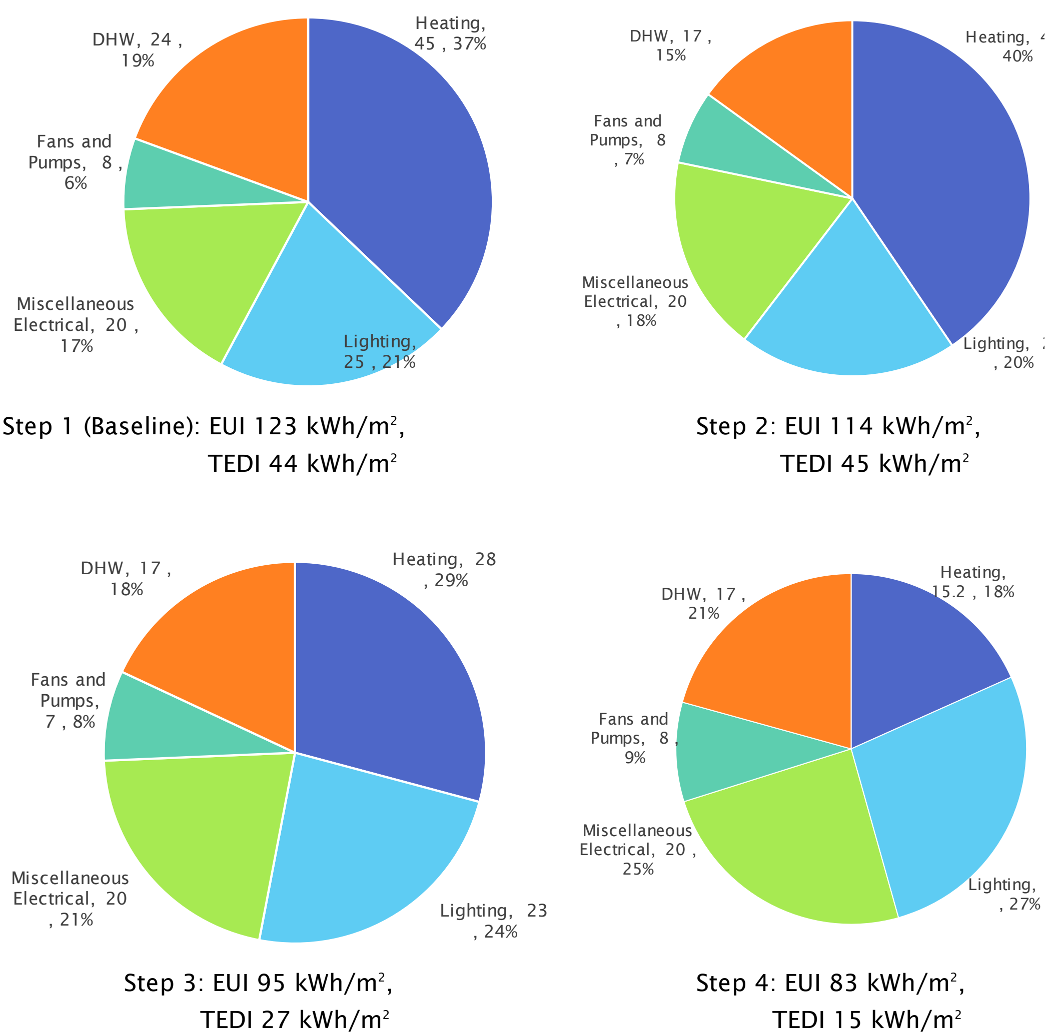


Figure 4.10 Energy consumption by end use for the ECM bundles.

Key findings from the low-rise bundles are as follows:

→ The EUIs and TEDIs modelled in these bundles generally meet the respective Step Code targets. This is partly due to the better enclsoure energy performance as a result of wood frame construction. It is also important to note that a reduction in the corridor ventilation rate was required to meet the Step 4 target without relying on the adjustment factor currently included in the Energy Modelling Guidelines.

→ This archetype model has a simple geometry with good enclsoure–to-floor area; EUIs and TEDIs will be higher for more complex geometries.

→ The requirement for district energy connected systems may limit the EUI savings beyond Step 4 that are achievable. For example, heat pump DHW that could further reduce EUIs were not considered due to this mandate. Despite this, the bundle results show that even Step 4 is achievable with district energy connected systems.

→ Overall, the economic analysis shows that Steps 1 through 3 can be acheived with positive NPV, while Step 4 requires a higher investment due to the current high capital costs of best performing windows. It is anticipated that costs for these technologies will come down in the coming years due to the growing popularity of Passive House in the low-rise residential typology, making Step 4 cost-effective in the near future.7

5 Business Case Analysis

The NPV/IRR/Payback metrics shown in the previous sections do not provide a strong business case for developers due to the split incentive, where the developer carries incremental capital costs while the owner realizes annual savings. To address this, the business case was analyzed from these two perspectives, considering incremental selling prices that yield positive financial returns for each party.

Several studies indicate buildings with “green” ratings sell for higher price premiums. While there is little data in the BC residential market, the study *The Business Case for Passive House*[23] notes several US-based studies that highlight price premiums for LEED® and ENERGY STAR® certified residential and commercial buildings.

The developer’s perspective is analyzed by calculating the acceptable incremental selling price that allows them to maintain their internal rate of return. In other words, at what price premium does Step 2, 3, or 4 become profitable for the developer?

The consumer’s perspective is analyzed by calculating the acceptable incremental selling price that is recovered via energy savings over time. In other words, what incremental price should consumers be willing to accept based on energy savings? This analysis neglects other benefits to the consumer, such as improved thermal comfort, and potential maintenance cost savings.

It is important to note in this analysis that the ability of both the developer and buyer to absorb the impact of higher construction costs is likely negligible in the context of rapidly increasing real estate prices across Metro Vancouver. Nominal increases to construction costs are likely to be absorbed by developers without a significant reduction to their ROI. In an industry driven by market pricing, costs are not likely to be passed on to the buyer.

5.1 Developer Perspective

The developer’s return on investment (ROI) was calculated for the Step 2, 3, and 4 bundles at price increases of 0.5%, 1%, and 2%. This was used to assess the incremental price that delivers an equivalent ROI, considering the incremental costs to build to a higher Step. A significant variable in this analysis is the assumed sale price. Two data points were assessed: $1,000/sf, based on current listings for low- and high-rise condominium list prices at UBC’s Wesbrook Village, and $682/sf based on the average new home for Metro Vancouver per Altus Group’s 2017 Canadian Cost Guide. ROIs are calculated as the incremental sale price less the incremental cost, divided by the incremental cost. Incremental costs use the average cost determined in the previous analysis.

Table 5.1 shows the resulting ROI at price premiums of 0.5%, 1%, and 2% for each step. The results show that Step 2 outperforms the baseline at a small price premium of less than 0.5%. At the sale price of $1,000/sf, Step 3 requires a price premium of 0.62% for the high-rise, and less than 0.5% for the low-rise. Step 4 requires a price premium of 1.5% for the high-rise and 0.87% for the low-rise.

[23] Synergy Sustainability Institute, May 2015. Available online: http://www.passivehousecanada.com/downloads/Business_Case_for_Passive_House.pdf

As part of this analysis, incremental costs as a percent of total construction costs were calculated for the Step 2, 3, and 4 bundles. Costs are based on the average incremental costs shown in Sections 3 and 4 of this report, plus an estimate for increase in soft costs associated with higher design fees for higher Steps. Table 5.2 shows the resulting incremental costs in $/sf and as a percentage of typical construction costs.

TABLE 5.1 DEVELOPER ROI FOR STEPS 2, 3, AND 4 VERSUS BASELINE.

Price Premium	Step 2		Step 3		Step 4	
	High-Rise	Low-Rise	High-Rise	Low-Rise	High-Rise	Low-Rise
Sale price $1,000/sf						
0.5%	20%	97%	(20%)	(12%)	(66%)	(60%)
1%	142%	296%	62%	78%	(29%)	(18%)
2%	385%	693%	226%	258%	44%	65%
Sale price $680/sf						
0.5%	(19%)	33%	(46%)	(12%)	(78%)	(62%)
1%	64%	168%	10%	78%	(52%)	(22%)
2%	229%	439%	121%	257%	(3%)	58%

TABLE 5.2 INCREMENTAL COSTS FOR DEVELOPER.

	Range in Total Incremental Cost, $/sf (Best Case to Worst Case)		Percentage Increase (Including Land) (Best Case to Worst Case)+	
	High-Rise	Low-Rise	High-Rise*	Low-Rise**
Step 2	$3.20 – $4.40	$2.10 – $2.30	0.6% - 0.8%	0.5% - 0.9%
Step 3	$4.30 – $7.00	$4.20 – $5.50	0.8% - 1.3%	0.9% - 2.2%
Step 4	$10.30 – $15.00	$8.60 – $12.50	2.0% - 2.9%	1.8% - 4.8%

+Values differ from those presented in Sections 3 and 4 as they include soft costs and land costs.
*Percentage calculated based on high-rise typical cost baseline of $283/sf construction costs plus $28/sf soft costs, per Altus Group 2017 Canadian Cost Guide.
**Percentage calculated based on low-rise typical cost baseline of $225/sf construction costs plus $23/sf soft costs, per Altus Group 2017 Canadian Cost Guide.

5.2 Consumer Perspective

The consumer's internal rate of return was calculated at these same incremental sale prices, 0.5%, 1%, and 2%, using the incremental price and the annual energy savings over a 30-year period. While many consumers will not calculate an IRR or payback on higher sales prices (a task made particularly difficult with rapidly changing real estate prices), as noted above, research does indicate that consumers do recognize value in "green" buildings and are willing to pay a premium for this feature.

Table 5.3 and Table 5.4 show the consumer's IRR and payback period for varying price premiums for the high and low-rise archetype, respectively. For the high-rise building, the results show that a price premium of 0.5% delivers positive IRR for all Steps; a 1% price premium is tolerable for Step 4. For the low-rise building, a 0.5% price premium is tolerable for Steps 3 and 4, but not for Step 2.

TABLE 5.3 HIGH-RISE CONSUMER IRR AND PAYBACK FOR STEPS 2, 3, AND 4.						
Price Premium	**Step 2**		**Step 3**		**Step 4**	
	IRR	**Payback**	**IRR**	**Payback**	**IRR**	**Payback**
Sale price $1,000/sf						
0.5%	3%	23 yrs	4%	19 yrs	6%	16 yrs
1%	(2%)	>30 yrs	0%	>30 yrs	1%	27 yrs
2%	(5%)	>30 yrs	(4%)	>30 yrs	(3%)	>30 yrs
Sale price $680/sf						
0.5%	5%	17 yrs	7%	14 yrs	9%	12 yrs
1%	1%	28 yrs	2%	24 yrs	4%	20 yrs
2%	(3%)	>30 yrs	(2%)	>30 yrs	(1%)	>30 yrs

TABLE 5.4 LOW-RISE CONSUMER NPV AND PAYBACK FOR STEPS 2, 3, AND 4.						
Price Premium	**Step 2**		**Step 3**		**Step 4**	
	IRR	**Payback**	**IRR**	**Payback**	**IRR**	**Payback**
Sale price $1,000/sf						
0.5%	(3%)	23 yrs	2%	19 yrs	5%	16 yrs
1%	(6%)	>30 yrs	(2%)	>30 yrs	1%	27 yrs
2%	(9%)	>30 yrs	(5%)	>30 yrs	(3%)	>30 yrs
Sale price $680/sf						
0.5%	(1%)	>30 yrs	5%	18 yrs	9%	13 yrs
1%	(5%)	>30 yrs	0%	29 yrs	3%	21 yrs
2%	(8%)	>30 yrs	(3%)	>30 yrs	(1%)	>30 yrs

Another consumer perspective looks at the difference between total monthly costs for the baseline and Step Code levels, considering mortgage payments and energy costs. Table 5.5 shows the estimated change in monthly costs, assuming no change in operation and maintenance costs. The results show only the Step 4 high-rise at 0.5% premium results in no increase to monthly cost at the sale price of $1,000/sf.

TABLE 5.5 CHANGE IN MONTHLY COSTS COMPARED TO BASELINE.*						
Price Premium	**Step 2**		**Step 3**		**Step 4**	
	High-Rise	**Low-Rise**	**High-Rise**	**Low-Rise**	**High-Rise**	**Low-Rise**
Sale price $1,000/sf						
0.5%	$4	$13	$0	$7	($3)	$1
1%	$20	$31	$17	$25	$14	$19
2%	$54	$66	$54	$60	$47	$54
Sale price $680/sf						
0.5%	($1)	$8	($5)	$1	($8)	($4)
1%	$10	$20	$6	$13	$3	$8
2%	$32	$44	$29	$38	$26	$32

*Mortgage payment calculations assume an interest rate of 3% and 35-year amortization.

In the scenarios above (Table 5.5), annual energy savings will still be recouped over the life of the mortgage in most scenarios as utility prices increase. As an example, Figure 5.1 and Figure 5.2 show the annual increase in mortgage costs compared to the annual energy savings with the parameters used in the financial analysis.

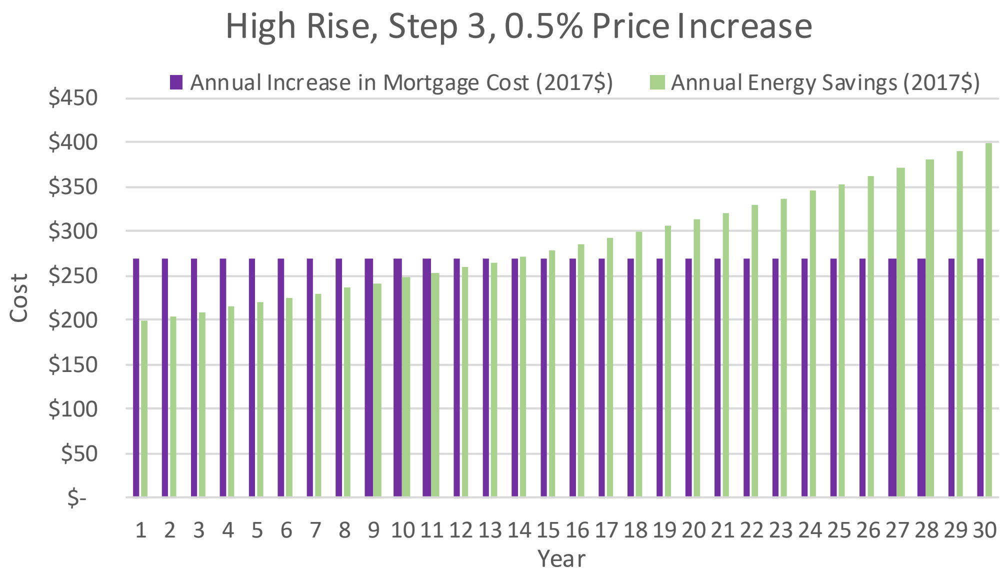


Figure 5.1 Annual mortage cost increase and energy savings for the owner, for the high-rise Step 3 bundle, assuming a 0.5% increase in sale price (2017 dollars).

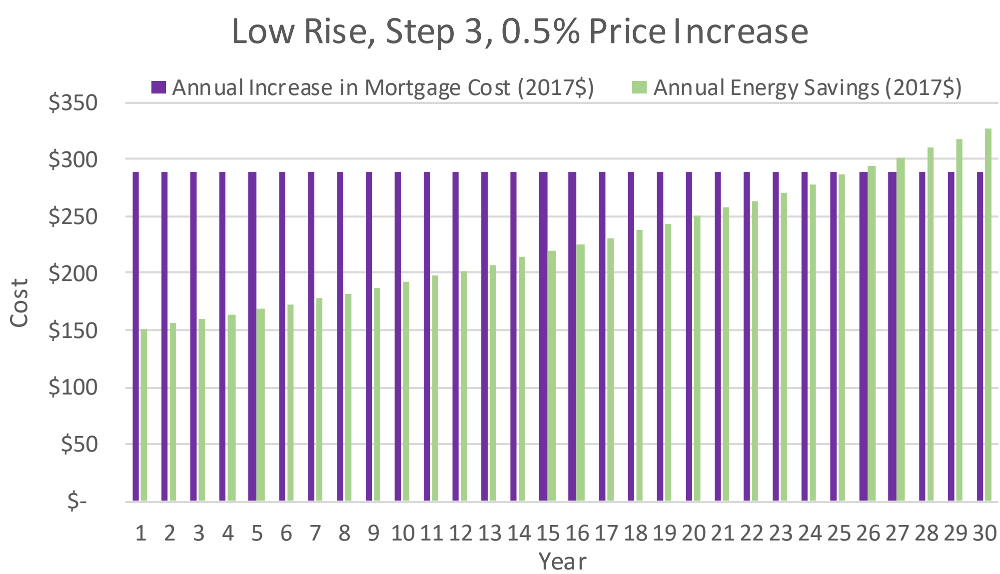


Figure 5.2 Annual mortage cost increase and energy savings for the owner, for the low-rise Step 3 bundle, assuming a 0.5% increase in sale price (2017 dollars).

5.3 Discussion

Combining the developer and consumer perspectives, the breakeven price premiums can be compared to see if an incremental sales price makes sense for both parties. Table 5.6 shows the minimum incremental price acceptable to the developer and the maximum incremental price acceptable to the consumer, based on the above analysis.

The results indicate incremental prices in the range of 0.5% to 0.7% are generally acceptable for both parties for Step 2 and Step 3. For the low-rise, there remains a gap for the high-rise between the developer's minimum and the consumer's maximum for Step 4.

TABLE 5.6 BREAKEVEN PRICE PREMIUMS AT BASE SALE PRICE OF $1,000/SF						
	Step 2		**Step 3**		**Step 4**	
	High-Rise	**Low-Rise**	**High-Rise**	**Low-Rise**	**High-Rise**	**Low-Rise**
Developer Minimum	<0.5%	<0.5%	0.6%	0.6%	1.4%	1.2%
Consumer Maximum	0.8%	<0.5%	1.0%	0.8%	1.3%	1.1%

Overall, this analysis indicates that slightly higher sales prices for Steps 2, 3, and 4 would allow developers to recover their additional costs, while also delivering value to consumers in most cases. This analysis should be updated over time as capital costs change with mature market pricing for the best-performing ECMs in Step 4, and as market real estate prices evolve.

6 Conclusions and Recommendations

The archetype modelling completed in this study demonstrated that all four Step Code EUI and TEDI targets are generally achievable for both the low- and high-rise residential archetypes using available Energy Conservation Measures (ECMs). The targets are also achievable within the context of district energy connected systems. The economic analysis showed that Steps 1 through 3 can be achieved with positive NPV, while Step 4 still requires significant investment due to the current high capital costs of best performing windows, HRVs, and wall systems. It is anticipated that costs for these technologies will come down in the coming years due to the growing popularity of Passive House, making Step 4 cost-effective in the near future.

Several important takeaways and key findings emerged through this study:

- Corridor ventilation
  - Lower corridor ventilation rates (coupled with direct suite ventilation via HRVs) lead to energy savings and make it easier to achieve the Step Code targets. However, a better understanding of corridor ventilation rates to maintain indoor air quality (i.e. rates in excess of code minimum), and the implications of reducing corridor ventilation rates, is needed.
  - This study found that lower corridor ventilation rates were needed in order to meet many of the Step Code targets. The current City of Vancouver Energy Modelling Guidelines include an allowance for additional corridor ventilation; however, future buildings will need to reduce reliance on this strategy. This could be achieved through lower corridor airflow rates, or by changing to balanced ventilation systems with heat recovery serving corridors.
- Sub-metered heat and hot water
  - The final City of Vancouver Energy Modelling guidelines added a guideline on sub-metering as follows:
    Research indicates that MURB projects that do not sub-meter hot water for space heating at the suite level typically use 15% additional heating energy or more when compared to sub-metered suites. To account for this increase in heating energy use, projects where suite hot water for space heating is not sub-metered must add 15% to their modelled heating energy end-use.
  - The 15% increase was not added to the archetype model results in this study. It is important to note, however, that suite sub-metering of gas and district energy is not common at the present time.
- REAP Airtightness
  - The geometry of large buildings is often more variable than for typical single-family residential housing, which can lead to significant difference in surface area to volume ratios for different building arrangements. Buildings with large surface-area-to-volume ratios will require very airtight enclosures to achieve volumetric

airtightness targets, while buildings with low surface-area-to-volume ratios can have leakier enclosures while achieving the same ACH50.

  - The REAP mandatory requirement of 3.5 ACH50 would lead to significant infiltration for large buildings due to the volumetric metric. We recommend changing this requirement to a flow per enclosure area metric, in line with the City of Vancouver and Step Code airtightness requirements.
  - Airtightness testing is also recommended as a mandatory requirement to ensure the value is achieved in practice.

- Construction costs to achieve an airtight building
  - Costs associated with airtightness may be difficult to quantify, aside from testing costs. Experience in Washington State has shown that the baseline airtightness target proposed in the Step Code is highly achievable with good air barrier design and quality control through construction[24]. Further, a continuous air barrier is already required by Part 5 of the building code. As such, incremental costs for airtightness targets should be limited to testing costs. In reality, design and construction teams may experience a learning curve to incorporate improved air barrier design and detailing. Higher airtightness targets may require a different approach to material selection and detailing. Buildings that fail to achieve the required test results may incur costs to locate and correct problems, and re-test.
- REAP minimum exterior wall insulation
  - The REAP mandatory requirement of R-15.6 is written as "a minimum thermal resistance of effective (overall) R-15.6"; however in discussions with UBC it is not clear what thermal bridging is and isn't considered in determining this R-value, and modelling for campus buildings use a range of methods. The City of Vancouver modelling guidelines should be followed to determine building enclosure R-values; a prescriptive maximum may not be necessary if performance targets are implemented in line with the Step Code and City of Vancouver modelling guidelines.
- Overall assessment of Step Code targets for the high- and low-rise archetypes
  - Current REAP construction plus the Step Code airtightness requirement (with airtightness testing) meets Step 1 for the archetypes in this study.
  - Steps 2 and 3 are cost-effectively achieved for the archetypes in this study
  - Step 4 has negative NPV for the high-rise archetype, primarily due to significant costs for insulated walls, high performance windows, and high efficiency HRVs. Additional market transformation is needed for this to be cost effective, including more products for high-rise (non-combustible) construction, and increase in capabilities for prefabricated construction for high-rise construction.
  - The low-rise archetype showed a range in positive to negative NPV; while some incremental costs are still significant (e.g. high performance windows and HRVS),

[24] For example, see the following references:
Building Enclosure Airtightness Testing in Washington State – Lessons Learned about Air Barrier Systems and Large Building Testing Procedures. Available online: http://rdh.com/wp-content/uploads/2014/10/ASHRAE-2014-Annual-Conference-Building-Enclosure-Airtightness-in-WA-Final.pdf
Impact of Large Building Airtightness Requirements. Available online: http://www.buildingsciencelabs.com/wp-content/uploads/2016/12/Ricketts-Large-Building-Airtightness-Requirements.pdf

these costs are rapidly decreasing due to the growth in popularity of Passive House for this archetype. It is expected that Step 4 will have positive NPV in the short term, if not already.

  - → The bundles are indicative of how ECMs can be effectively assembled to achieve different performance thresholds identified in the Energy Step Code, but are not intended to be prescriptive.

- → Developer-Consumer perspective
  - → Although the NPV/IRR/Payback metrics do not provide a strong business case for developers who carry incremental capital costs while owners realize annual savings, slightly higher sales prices for Steps 2, 3, and 4 would allow developers to recover their additional costs, while also delivering value to consumers in most cases. A gap remains for Step 4 for the high-rise archetype.
  - → The ability of both the developer and buyer to absorb the impact of higher construction costs is likely negligible in the context of rapidly increasing real estate prices across Metro Vancouver.

Appendix A

Baseline and Bundle Energy Model Inputs

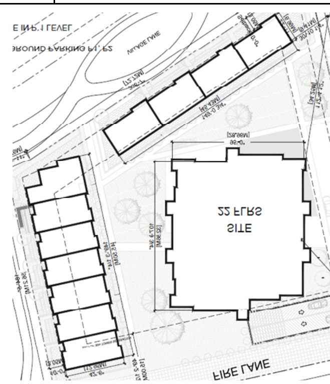
TABLE A.1 KEY MODEL INPUTS FOR THE HIGH-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Building Geometry					
Storeys	-	Tower: 22 Townhouse: 2 Parkade: 2	Model geometry from Binning development	-	-
Total Conditioned Area	m^2	25,000	Model geometry from Binning development	-	-
Breakdown of Space Type	-	Tower Suites Tower Corridors Townhouse Parkade	Model geometry from Binning development	-	-
Schematics	-			-	
Other Notes		ASHRAE 90.1-2010 + City of Vancouver Energy Modelling Guidelines Text in blue represents differences from prescriptive baseline where model trade-offs will be used to reflect typical current practice.		Building geometry inputs same as baseline.	

TABLE A.1 KEY MODEL INPUTS FOR THE HIGH-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Internal Loads and Schedules					
Occupant Density	ppl/suite	Townhouse: 3.0 Tower: 2.8	2 people for first bedroom + 1 for each bedroom thereafter (CoV modelling guidelines) Average occupancy from Binning	-	-
Average Suite Size	Sf	TH: 1,600 Tower: 850	Average suite sizes from Binning		
Heating Set Point	˚C	22	NECB 2011 Table A-8.4.3.2(1)G CoV modelling guidelines	-	
Heating Set Back	˚C	18	NECB 2011 Table A-8.4.3.2(1)G CoV modelling guidelines	-	No change for EA M8 (programmable thermostats), setback included in baseline
Cooling Set Point	˚C	24	NECB 2011 Table A-8.4.3.2(1)G CoV modelling guidelines	-	-
Cooling Set Back	˚C	24	NECB 2011 Table A-8.4.3.2(1)G CoV modelling guidelines	-	-
Plug Loads - Suites	W/m^2	5.0	CoV modelling guidelines	-	No change for EA M7 (Energy Star appliances)
Plug Loads – Elevators	kW	3 @ 3 kW	CoV modelling guidelines		
Lighting Power Density - Suites	W/m^2	5.0	CoV modelling guidelines	-	-
Lighting Power Density - Corridors	W/m^2	7.1	ASHRAE 90.1-2010 space-by-space method – corridor/transition		No change for EA M9 (fluorescent, CFL, or LED lighting)
Lighting Controls – Corridors		-	None	10% LPD reduction	EA M10 Parkade and corridor lighting controls

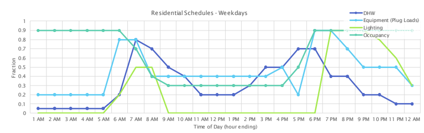
TABLE A.1 KEY MODEL INPUTS FOR THE HIGH-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Lighting Power Density - Parkade	W/m²	2.0	ASHRAE 90.1-2010 space-by-space method – parking garage		
Lighting Controls – Parkade		10% LPD Reduction	ASHRAE 90.1-2010 9.4.1.3		No change for EAM10 (parkade and corridor lighting controls)
Exterior Lighting	W	1200	ASHRAE 90.1-2010 Table 9.4.3B Zone 2 allowance for building exterior plus allowance for entrances and walkways	-	-
DHW Peak Flow Rate	L/s/pers	0.0016	CoV modelling guidelines		Reduce for WE M4 (low flow shower heads 8.5 L/min), WE M3 (low flow faucet aerators 3.8 L/min kitchen, 6.8 L/min bathroom)
Schedules	-	Fractional	NECB 2011 Table A-8.4.3.2(1)G (See attached schedule plots) 	-	-
Other Notes				Optional EA credits not included in REAP baseline as long as model EUI meets REAP requirement of 160 kWh/m².	

TABLE A.1 KEY MODEL INPUTS FOR THE HIGH-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Building Enclosure – Climate Zone 4					
Exterior Wall R-Value **Exterior Wall U-Value**	hr-sqft-F/Btu Btu/hr-sqft-F	R-4.0 U-0.25	Spandrel panels[25] Note performance below ASHRAE 90.1-2010 prescriptive value is traded off with HRVs in the model		No change; EA M2 requires "exterior insulated wall area" to have an effective R-value of15.6.
Exterior Balconies		Non-thermally broken balconies	Balcony lengths to be measured from Binning plans		
Roof R-value **Roof U-Value**	hr-sqft-F/Btu Btu/hr-sqft-F	R-20.8 U-0.048	ASHRAE 90.1-2010 CZ4 Residential Insulation Above Deck	R-28 U-0.035	EA M1
First Floor R-Value **First Floor U-Value**	hr-sqft-F/Btu Btu/hr-sqft-F	R-13.5 U-0.074	ASHRAE 90.1-2010 CZ4 Residential Mass Floor (Floor above parkade)	R-15.6 U-0.064	EA M3
Window U-Value	Btu/hr-sqft-F	0.45	Reduced as trade-off for higher WWR (U-0.55 ASHRAE 90.1-2010 CZ4 Residential Metal Framing eg. window wall)		No change, below EA M4 (U-0.45)
Window SHGC		0.40	ASHRAE 90.1-2010 CZ4 Residential		
Window-to-Wall Ratio	%	55	Typical current practice		
Infiltration Rate	$m^3/s\text{-}m^2$ @ 5 Pa	0.00025	CoV modelling guidelines		
Infiltration Schedule	-	Fractional	Always on		
Other Notes				Optional EA credits not included in REAP baseline as long as model EUI meets REAP requirement of 160 kWh/m^2.	

[25] Spandrel panel R-values typically range from approximately R4 to R6 accounting for 3-dimensional thermal bridging, as demonstrated by 3D modelling in the Building Envelope Thermal Bridging Guide (https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/power-smart/builders-developers/building-envelope-thermal-bridging-guide-1.1-appendix-b.pdf). With interior insulation, spandrel assemblies can achieve up to R10.

TABLE A.1 KEY MODEL INPUTS FOR THE HIGH-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Mechanical Systems					
System Description		Suite fan coil units provide heating, cooling, and continuous outdoor air with 60% efficient ERVs Corridor make-up air unit with district energy heating, chilled water cooling (EUIs/TEDIs adjusted per CoV modelling guidelines for corridor pressurization) Water cooled chiller, heating from district energy system Domestic Hot Water (DHW) from district energy Suite exhaust fans run 2 hours/day			
Fan Coil Units					
Outdoor Air – Suites (ERVs)	cfm/suite	Townhouse 65 Tower 60	ASHRAE 62.1-2001 Minimum exhaust based on 25 cfm for kitchen, 20 cfm per bathroom); no allowance for dryer exhaust		
Heat Recovery?	-	Yes	Sensible plate HX		
Heating Sensible Effectiveness	-	60%	-		
Cooling Sensible Effectiveness	-	60%	-		
HRV Supply Fan	W	29	Based on HRV Venmar Constructo 1.0		
HRV Exhaust Fan	W	31	Based on HRV Venmar Constructo 1.0		
FCU Fan Schedule	-	On 24/7		-	
FCU Fan Power	W/cfm	0.30			
Suite Kitchen Exhaust Fans	cfm/suite	100	ASHRAE 62.1-2001; continuous exhaust rate		

TABLE A.1 KEY MODEL INPUTS FOR THE HIGH-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Suite Kitchen Exhaust Fan Power	W/suite	35			
Suite Kitchen Exhaust Fan Schedule		2 hours/day	CoV modelling guidelines		
Make-Up Air Unit (MUA)					
Outdoor Air – Corridor (MUA)	cfm/suite	25	Pressurized corridor system provides 25 cfm/suite		
Fan Schedule	-	On 24/7			
Fan Power	W/cfm	0.76			
Heating & Cooling					
Cooling Equipment Type	-	Water cooled chiller			
Cooling Efficiency	COP (W/W)	4.53	ASHRAE 90.1-2010 Table 6.8.1C Leaving water temp = 44 F		
Heating Equipment Type	-	District heating			
District Energy Heat Exchanger Efficiency	%	97%	Assumes site heating energy, not accounting for district heating plant efficiency and distribution losses		
Pump Power	W/gpm	19	ASHRAE 90.1-2010		
Domestic Hot Water					
District Energy Heat Exchanger Efficiency	%	97%	Assumes site heating energy, not accounting for district heating plant efficiency and distribution losses		

TABLE A.1 KEY MODEL INPUTS FOR THE HIGH-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Other					
Parkade Exhaust Fan	cfm/sf	1.50	ASHRAE 62.1-2001		
Parkade Exhaust Fan Power	W/cfm	0.10			
Parkade Fan Schedule		4 hours/day	CoV modelling guidelines		
Other Notes		ASHRAE 90.1 Appendix G baseline system for this archetype (residential building with purchased heat) is packaged terminal air conditioner (PTAC) with constant volume fans, DX cooling, hot-water fossil fuel boiler.		Inputs same as baseline.	

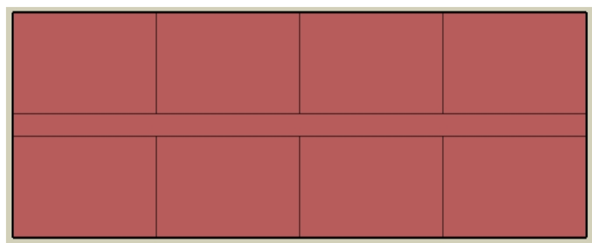
TABLE A.2 KEY MODEL INPUTS FOR THE LOW-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Building Geometry					
Storeys	-	Residential: 6 Parkade: 2	Model geometry from previous archetype study	-	-
Total Conditioned Area	m^2	4,700	Model geometry from previous archetype study Average suite size 100 m^2, 2.3 bedrooms/suite based on current UBC low-rise projects.	-	-
Breakdown of Space Type	-	48 Suites Corridors Parkade	Model geometry from previous archetype study	-	-
Schematics	-			-	
Other Notes		ASHRAE 90.1-2010 + City of Vancouver Energy Modelling Guidelines		Building geometry inputs same as baseline.	

TABLE A.2 KEY MODEL INPUTS FOR THE LOW-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Internal Loads and Schedules					
Occupant Density	ppl/suite	3.3	2 people for first bedroom + 1 for each bedroom thereafter (CoV modelling guidelines) Average occupancy from several UBC low-rise project examples	-	-
Heating Set Point	˚C	22	NECB 2011 Table A-8.4.3.2(1)G CoV modelling guidelines	-	
Heating Set Back	˚C	18	NECB 2011 Table A-8.4.3.2(1)G CoV modelling guidelines See schedule below	-	No change for EA M8 (programmable thermostats), setback included in baseline
Cooling Set Point	˚C	N/A	No cooling	-	-
Cooling Set Back	˚C	N/A	No cooling	-	-
Plug Loads - Suites	W/m²	5.0	CoV modelling guidelines	-	No change for EA M7 (Energy Star appliances)
Plug Loads – Elevators	kW	2 @ 3 kW	CoV modelling guidelines		
Lighting Power Density - Suites	W/m²	5.0	CoV modelling guidelines	-	-
Lighting Power Density - Corridors	W/m²	7.1	ASHRAE 90.1-2010 space-by-space method – corridor/transition		No change for EA M9 (fluorescent, CFL, or LED lighting)
Lighting Controls – Corridors		-	None	10% LPD reduction	EA M10 Parkade and corridor lighting controls
Lighting Power Density - Parkade	W/m²	2.0	ASHRAE 90.1-2010 space-by-space method – parking garage		

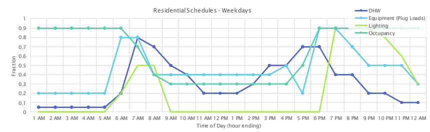
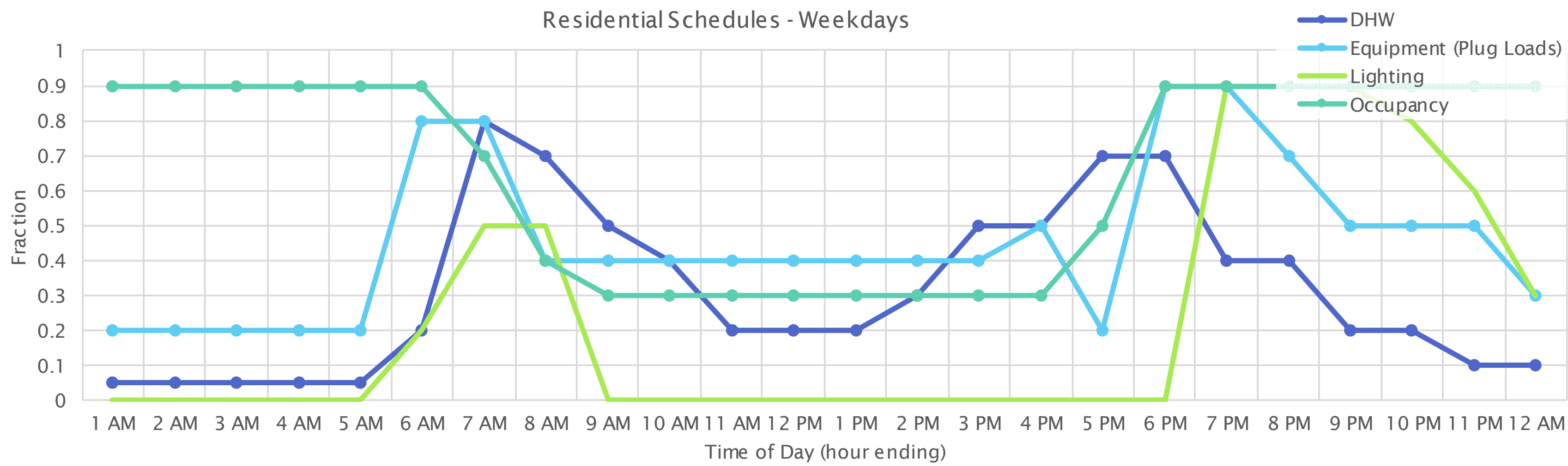
TABLE A.2 KEY MODEL INPUTS FOR THE LOW-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Lighting Controls – Parkade		10% LPD Reduction	ASHRAE 90.1-2010 9.4.1.3		No change for EAM10 (parkade and corridor lighting controls)
Exterior Lighting	W	1200	ASHRAE 90.1-2010 Table 9.4.3B Zone 2 allowance for building exterior plus allowance for entrances and walkways	-	-
DHW Peak Flow Rate	L/s/pers	0.0016	CoV modelling guidelines		Reduce for WE M4 (low flow shower heads 8.5 L/min), WE M3 (low flow faucet aerators 3.8 L/min kitchen, 6.8 L/min bathroom)
Schedules	-	Fractional	NECB 2011 Table A-8.4.3.2(1)G (See attached schedule plots) 	-	-
Other Notes				Optional EA credits not included in REAP baseline as long as model EUI meets REAP requirement of 160 kWh/m².	

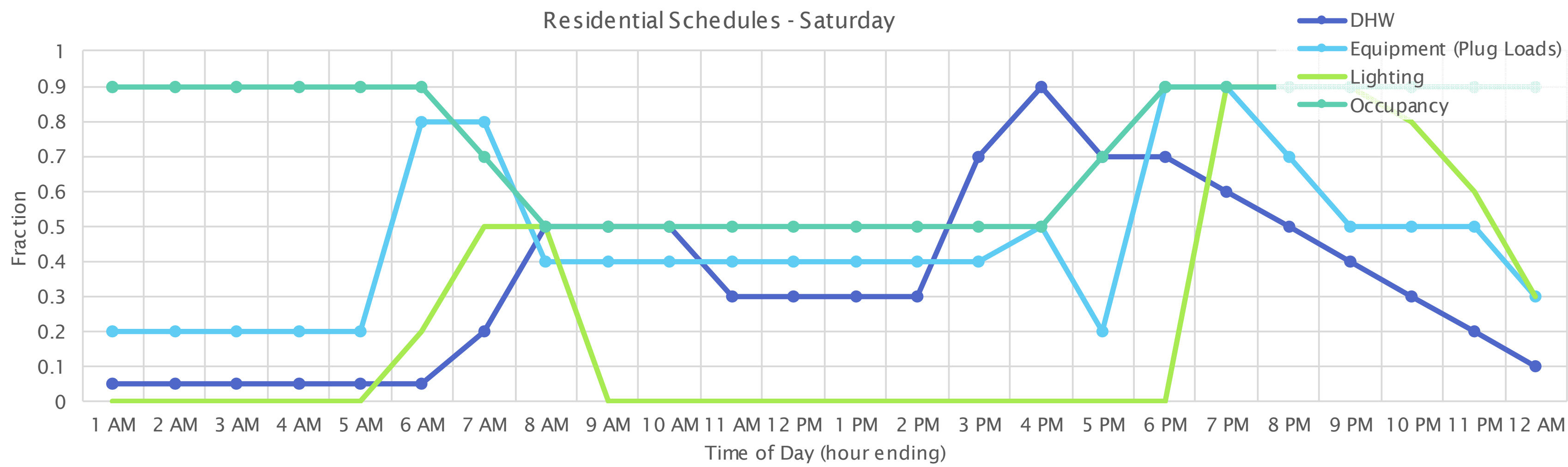
TABLE A.2 KEY MODEL INPUTS FOR THE LOW-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Building Enclosure – Climate Zone 4					
Exterior Wall R-Value **Exterior Wall U-Value**	hr-sqft-F/Btu Btu/hr-sqft-F	R-15.6 U-0.064	ASHRAE 90.1-2010 CZ4 Residential Wood-Framed		No change, EA M2 is same as baseline
Roof R-value **Roof U-Value**	hr-sqft-F/Btu Btu/hr-sqft-F	R-20.8 U-0.048	ASHRAE 90.1-2010 CZ4 Residential Insulation Above Deck	R-28 U-0.035	EA M1
First Floor R-Value **First Floor U-Value**	hr-sqft-F/Btu Btu/hr-sqft-F	R-13.5 U-0.074	ASHRAE 90.1-2010 CZ4 Residential Mass Floor (Floor above parkade)	R-15.6 U-0.064	EA M3
Window U-Value	Btu/hr-sqft-F	0.40	ASHRAE 90.1-2010 CZ4 Residential Non-Metal Framing	U-0.35	EA M4
Window SHGC		0.40	ASHRAE 90.1-2010 CZ4 Residential		
Window-to-Wall Ratio	%	40	ASHRAE 90.1-2010 CZ4 Prescriptive Maximum		
Infiltration Rate	$m^3/s\text{-}m^2$ @ 5 Pa	0.00025	CoV modelling guidelines		
Infiltration Schedule	-	Fractional	Always on		
Other Notes				Optional EA credits not included in REAP baseline as long as model EUI meets REAP requirement of 160 kWh/m^2.	

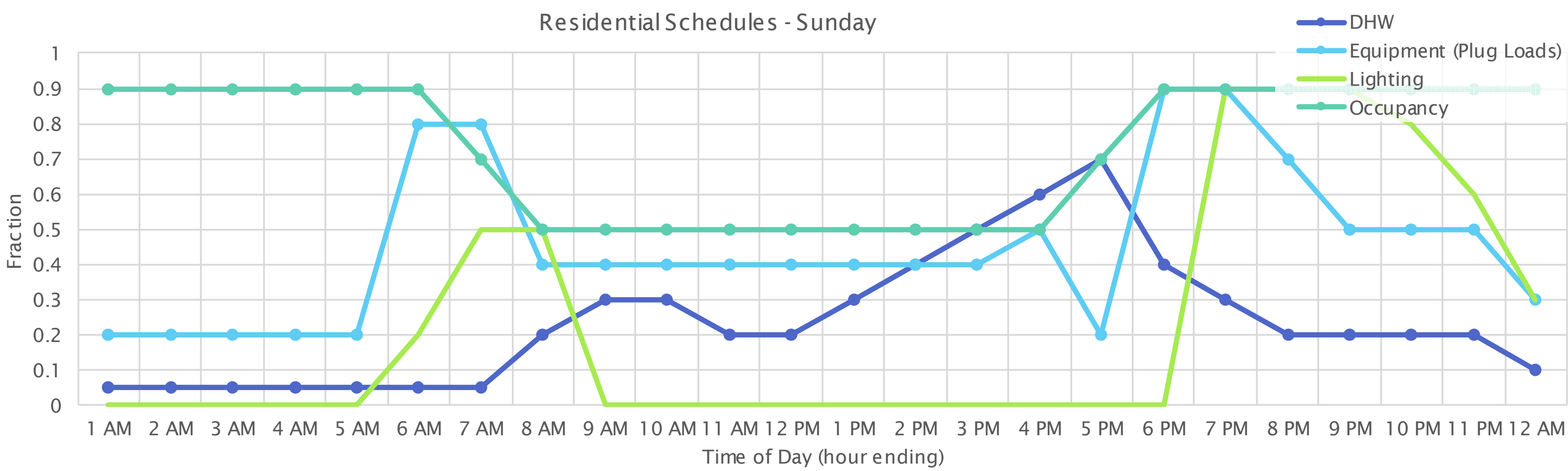
TABLE A.2 KEY MODEL INPUTS FOR THE LOW-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Mechanical Systems					
System Description		In-floor radiant heating, no cooling, heating from district energy system Continuous exhaust fans in suites with passive outdoor air vents Corridor make-up air unit with district energy heating (EUIs/TEDIs adjusted per CoV modelling guidelines for corridor pressurization) Domestic Hot Water (DHW) from district energy			
Make-Up Air Unit (MUA)					
Outdoor Air – Corridor (MUA)	cfm/suite	25	Pressurized corridor system provides 25 cfm/suite		
Fan Schedule	-	On 24/7			
Fan Power	W/cfm	0.76	Typical (based on total static pressure 4.2 in. wg., fan efficiency 0.7, motor efficiency 0.9)		
Suite Ventilation					
Suite Ventilation	cfm/suite	65	ASHRAE 62.1-2001 Minimum exhaust 65 cfm (25 cfm for kitchen, 40 cfm for two bathrooms); no allowance for dryer exhaust Minimum living area 50 cfm based on 15 cfm/person, average 3.3 people/suite		
Suite Exhaust Fan Power	W/suite	35	Typical		
Suite Exhaust Fan Schedule		Always On			

TABLE A.2 KEY MODEL INPUTS FOR THE LOW-RISE RESIDENTIAL ARCHETYPE.					
		BASELINE		**REAP BASELINE**	
	Units	**Value**	**Notes and References**	**Value**	**Notes and References**
Heating & Cooling					
Cooling Equipment Type	-	N/A	No cooling		
Cooling Efficiency	COP (W/W)	N/A			
Heating Equipment Type	-	District heating			
District energy heat exchanger efficiency	%	97%	Assumes site heating energy, not accounting for district heating plant efficiency and distribution losses		
Pump Power	W/gpm	19	ASHRAE 90.1-2010		
Domestic Hot Water					
District energy heat exchanger efficiency	%	97%	Assumes site heating energy, not accounting for district heating plant efficiency and distribution losses		
Other					
Parkade Exhaust Fan	cfm/sf	1.50	ASHRAE 62.1-2001		
Parkade Exhaust Fan Power	W/cfm	0.10			
Parkade Fan Schedule		4 hours/day	CoV modelling guidelines		
Other Notes		ASHRAE 90.1 Appendix G baseline system for this archetype (residential building with purchased heat) is packaged terminal air conditioner (PTAC) with constant volume fans, DX cooling, hot-water fossil fuel boiler.		Inputs same as baseline.	

Schedules – NECB Operating Schedule G





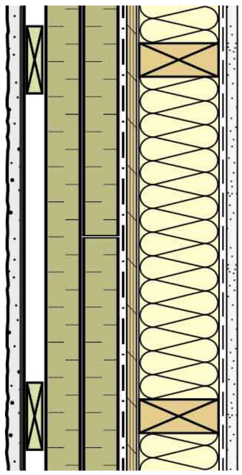

Residential Schedules - Sunday
DHW
Equipment (Plug Loads)
Lighting
Occupancy
Fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1 AM
2 AM
3 AM
4 AM
5 AM
6 AM
7 AM
8 AM
9 AM
10 AM
11 AM
12 PM
1 PM
2 PM
3 PM
4 PM
5 PM
6 PM
7 PM
8 PM
9 PM
10 PM
11 PM
12 AM
Time of Day (hour ending)

Appendix B
Building Enclosure Assemblies

Building Enclosure Assemblies

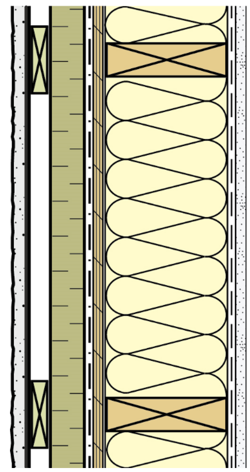
This report references effective R-values for all building enclosure assemblies, including baseline values and ECMs. There are various assemblies that can be used to meet these values in practice. The following section outlines examples of assemblies that achieve the wall R-values used in this study.

Wood Frame Archetype (Low-Rise)



2x4 studs with batt and exterior mineral wool with screws through insulation

- → Baseline effective R-19.6 (ASHRAE 90.1-2010 Table 5.5-4)
  - → 2.5" exterior mineral wool
- → ECM effective R-25
  - → 3.5" exterior mineral wool

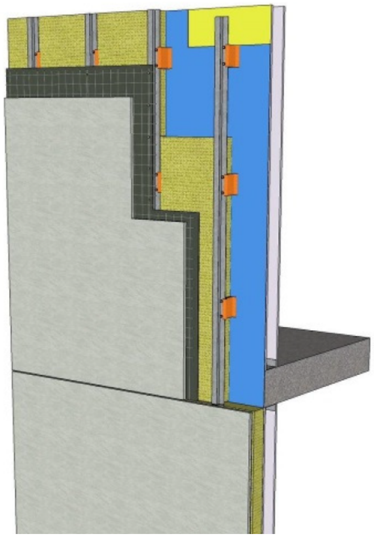


2x6 studs with batt and exterior mineral wool with screws through insulation

- → Baseline effective R-19.6 (ASHRAE 90.1-2010 Table 5.5-4)
  - → 1" exterior mineral wool
- → ECM effective R-25
  - → 2.5" exterior mineral wool
- → ECM effective R-38
  - → 5.5" exterior mineral wool

Balconies at wood frame archetypes may be insulated to achieve the above overall effective R-values with insulation installed between wood framing at the balconies.

Non-Combustible Construction Archetype (High-Rise)



3-5/8" steel studs with batt insulation and exterior mineral wool insulation with low conductivity cladding attachment

- → Baseline effective R-15.6 (ASHRAE 90.1-2010 Table 5.5-4)
  - → 3.5" exterior mineral wool insulation
- → ECM effective R-20
  - → 4" exterior mineral wool insulation
- → ECM effective R-25
  - → 6" exterior mineral wool insulation

Thermal Bridging

Thermal bridging can account for significant heat loss in buildings. The degree to which thermal bridging impacts a particular building depends on many factors, including the geometry and massing, assemblies, detailing, etc. The assemblies presented above and assessed in this study, use exterior insulation so that thermal bridging can be minimized. The archetypes modelled also have simple geometries that also reduce complex details, corners, transitions, and associated thermal bridging.

Projects that make use of less optimal geometries and assemblies may see an increase in EUI and TEDI. Designers should carefully consider how thermal bridging can be minimized through assembly selection, and by optimizing building enclosure details to maintain a continuous thermal barrier.

For additional reading on thermal bridging in Part 3 buildings, refer to the *Building Envelope Thermal Bridging Guide* located here:https://www.bchydro.com/powersmart/business/programs/new-construction.html#thermal

For additional resources on strategies for balconies, see the following RDH report series:

- → Report 1: Impact of Slab Thermal Breaks on Effective R-Values and Energy Code Compliance
  http://rdh.com/wp-content/uploads/2014/07/Part-1-The-Importance-of-Slab-Edge-Balcony-Thermal-Bridges.pdf
- → Report 2: Impact of Slab Thermal Breaks on Thermal Comfort and Condensation Control
  http://rdh.com/wp-content/uploads/2014/07/Part-2-Balcony-Slab-Edge-and-Thermal-Comfort.pdf
- → Report 3: Energy Consumption and Cost Savings of Slab Thermal Breaks
  http://rdh.com/wp-content/uploads/2014/07/Part-3-EnergySavings.pdf
- → Report 4: Thermal Modeling Considerations for Balconies and Various Thermal Break Strategies
  http://rdh.com/wp-content/uploads/2014/07/Part-4-Other-Considerations.pdf

Prefabricated Construction in High-Rise Buildings

While panelized construction may be an option for both high- and low-rise buildings, in this study it was considered as a strategy to achieve highly insulated wall assemblies that are cost-effective when compared to traditionally lower-cost spandrel systems.

RDH is working on several projects that are making use of panelized construction, with projects both complete and in progress. Based on our experience, with full industry adoption of panelized construction, high R-value walls in high-rise construction can be built and installed at or below the cost of spandrel systems.

One such project, Brock Commons, was recently completed at UBC's Vancouver campus. Details of this project are provided below. Additional recommended reading on prefabricated construction is available on our RDH Building Science Laboratories website:

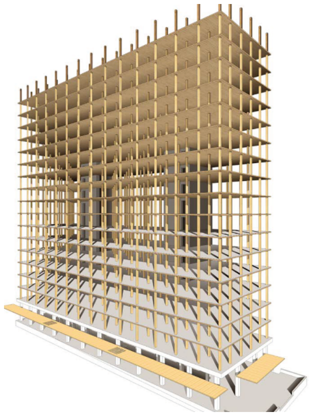
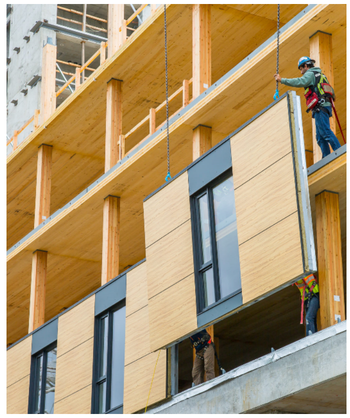
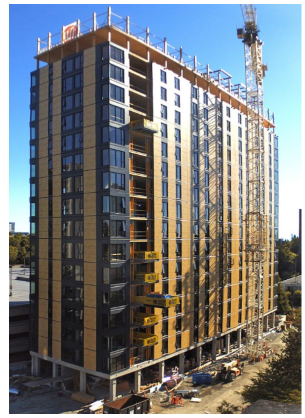
http://www.buildingsciencelabs.com/prefabricated-construction-reading-list/

Project Example: UBC Brock Commons Tall Wood Residence

Brock Commons is slated to become the tallest wood hybrid building in the world at 174 feet tall. This student residence includes housing for over 400 students, fitness facilities, and common areas.

The building enclosure had ambitious goals to be thermally efficient at >R-16 effective walls and budgeted at <$50 per square foot of wall area.

To ensure that the project could be installed within schedule and on budget, an innovative prefabricated wood hybrid panel was developed to be dropped into place for efficient installation. The cladding and windows were both pre-installed so that once it was flown into place, it was complete. The unique panel allowed for efficient installation where two entire floors could be completed in a day. Images of the design and panel installation at Brock Commons are below.

Images of UBC Brock Commons tall wood student residence with pannelized construction.

Appendix C

Complete List of ECMs

TABLE C.1 COMPLETE LIST OF ECMS				
			Archetypes	
ECM	**Description**	**Measure Life (years)**	**1: High-Rise**	**2: Low-Rise**
E01A	Wall insulation: effective R15.6	50	X	
E01A	Wall insulation: effective R22 (wood frame)	50		X
E01B	Wall insulation: effective R30	50	X	
E01B	Wall insulation: effective R38 (wood frame)	50		X
E02A	Roof insulation: effective R30	50	X	
E02B	Roof insulation: effective R40	50	X	X
E03A	Windows: U-0.35 (double glazed vinyl frame)	30	X	X
E03B	Windows: U-0.28 (double glazed low conductivity or high performance curtain wall)	30	X	X
E03C	Windows: U-0.14 (Passive House level)	30	X	X
E04A	Airtightness: 3.5 ACH50 (REAP Voluntary credit) Low-Rise: 0.804 l/s-m2 at operating pressure High-Rise: 1.01 l/s-m2 at operating pressure	50	X	X
E04B	Airtightness: Passive House standard 0.6 ACH50 (0.11 L/s-m^2 at operating pressure) Low-Rise: 0.138 l/s-m2 at operating pressure High-Rise: 0.173 l/s-m2 at operating pressure	50	X	X
E04C	Airtightness: PHIUS Target of 0.05 cfm/sf @ 50 Pa (= 0.057 l/s-m2 at operating pressure)	50	X	X
E05A	Exterior shading: fixed overhangs at S, W	50	X	
E06A	Thermally broken balconies: R-2.5 thermal break, wall insulation: effective R-15.6	50	X	
E06B	Thermally broken balconies: R-5 thermal break, wall insulation: effective R-15.6	50	X	
E06C	No balconies	50	X	
E07	WWR to 40%, wall insulation effective R-15.6	50	X	
L01A	Reduced LPD: 10% below ASHRAE 90.1-2010 (residential buildings – corridors only)	16	X	X
L01B	Reduced LPD: 25% below ASHRAE 90.1-2010 (residential buildings – corridors only)	16	X	X
M01A	HRV in residential suites: 60% efficient	20		X
M01B	HRV in residential suites: 80% efficient	20	X	X
M02	Electric baseboard heating	20		X

TABLE C.1 COMPLETE LIST OF ECMS				
			Archetypes	
ECM	**Description**	**Measure Life (years)**	**1: High-Rise**	**2: Low-Rise**
M03	FCU fans with ECM motors, 0,2 W/cfm	20	X	
M04	Lower corridor ventilation rate	30	X	X
M05	High Efficiency Condensing Heating (boiler & MUA, 92%) *Gas/electric archetypes only	20	X	X
M06	High Efficiency Condensing DHW (92%) *Gas/electric archetypes only	20	X	X
S01	Low flow water fixtures from REAP optional credit	30	X	X
S03	Drain water heat recovery	30	X	X

Appendix D

Costing

<table>
<tr><th colspan="8">TABLE D.1 ECM COSTS</th></tr>
<tr><th>ECM Name</th><th>ECM #</th><th>Discount Rate</th><th>1: High-rise</th><th>2: Low Rise</th><th>Incremental Cost</th><th>Notes</th></tr>
<tr><td>Walls R-15.6 (effective R-6.4 w/ balconies)</td><td>EEM_E01A</td><td>3.75%</td><td>X</td><td></td><td>$0-10/sf
• Cost based on wall area
• Assuming R-4 spandrel as baseline cost</td><td rowspan="2">• Insulated wall assembly ~$80/sf
• Curtain wall spandrel ~$70/sf
• $10-15/sf premium for insulated wall assembly
• Window wall spandrel ~$45-55/sf
• Panelized wall assembly ~$50-60/sf
• R-15.6 Assembly insulation cost is $5.27 to $9.85/sf for insulation and clips.
• R-30 Assembly insulation cost is $8.66 to $12.48/sf for insulation and clips added to cost of R-15.6 wall
• Costs from previous projects and RS Means</td></tr>
<tr><td>Walls R-30 (effective R-7.8 w/ balconies)</td><td>EEM_E01B</td><td>3.75%</td><td>X</td><td></td><td>$8.66-22.48/sf
• Cost based on wall area
• Assuming R-4 spandrel as baseline cost</td></tr>
<tr><td>Walls R-22 effective</td><td>EEM_E01A</td><td>3.75%</td><td></td><td>X</td><td>$0.05-0.08/sf
• Cost based on floor area
• Assuming R-15.6 stud wall as baseline cost</td><td>• Overall effective wall R-value to R-22 through 2x6 wood studs, batt and 1" exterior mineral wool insulation with screws</td></tr>
</table>

TABLE D.1 ECM COSTS						
ECM Name	**ECM #**	**Discount Rate**	**1: High-rise**	**2: Low Rise**	**Incremental Cost**	**Notes**
Walls R-38 effective	EEM_E01B	3.75%		X	**$1.37-2.06/sf** • Cost based on floor area • Assuming R-15.6 stud wall as baseline cost	• Overall effective wall R-value to R-38 through 2x4 wood studs, batt, 8" exterior mineral wool and 10" screws • Costs from RS Means
Walls R-15.6 + Balcony Thermal Break. R-2.5 (effective R-10.3)	EEM_E06A	3.75%	X		**$195-217/m** • Cost based on linear length of balcony + **$0-10/sf** • Cost based on wall area • Assuming R-4 spandrel as baseline cost	• Costs for balcony thermal break from German manufacturer Schoeck • Costs for R-15.6 Walls as described previously
Walls R-15.6 + Balcony Thermal Break. R-5 (effective R-12.9)	EEM_E06B	3.75%	X		**$232-259/m** • Cost based on length of balcony + **$0-10/sf** • Cost based on wall area • Assuming R-4 spandrel as baseline cost	

TABLE D.1 ECM COSTS						
ECM Name	**ECM #**	**Discount Rate**	**1: High-rise**	**2: Low Rise**	**Incremental Cost**	**Notes**
Walls R-15.6, No Balconies	EEM_E06C	3.75%	X		**$0-10/sf** • Cost based on wall area • R-4 spandrel is baseline cost	
Walls R-15.6, 40% WWR (R-7.5 w/ balconies)	EEM_E07	3.75%	X		**$0-10/sf** • Cost based on wall area • R-4 spandrel is baseline cost	• Costs for R-15.6 Walls as described previously • There would likely be some additional cost savings from the reduced window area
Roof R-30 effective	EEM_E02A	3.75%	X	X	**$0.54-0.76/sf** • Cost based on roof area • Assuming R-28 as baseline cost	• 2” XPS ranges from $1.07-1.52/sf. • R-30 requires an extra 1" of exterior insulation. • R-40 would require an extra 2" of exterior insulation. • Costs based on RS Means
Roof R-40 effective	EEM_E02B	3.75%	X	X	**$1.07-1.56/sf** • Cost based on roof area • Assuming R-28 as baseline cost	
Window U-0.35	EEM_E03A	3.75%	X		**$1.8-2.2/sf** • Cost based on window area • Material only	• U-0.35 Windows are included in the Low-rise REAP baseline. For the high-rise, the cost range of $1.8-2.2/sf is for high-performance double glazed aluminum.

TABLE D.1 ECM COSTS

ECM Name	ECM #	Discount Rate	1: High-rise	2: Low Rise	Incremental Cost	Notes
Window U-0.28	EEM_E03B	3.75%	X	X	**$5-10/sf** • Cost based on window area • Material only	• U-0.28 Windows assume a low-conductivity frame material with high-performance double glazed IGUs. • U-0.14 Windows are roughly based on Cascadia Universal series, which are triple glazed IGUs with fiberglass frames. • All costs based on previous project experience.
Window U-0.14	EEM_E03C	3.75%	X	X	**$10-20/sf** • Cost based on window area • Material only	
Airtightness: REAP 3.5 ACH50	EEM_E04A	3.75%	X	X	**N/A** • This case is worse than the baseline	• All buildings require a continuous air barrier, and improved performance should be achieved through detailed design, a higher level of quality control, and airtightness testing. Alternate material selection may impact costs for the most stringent airtightness targets. For this study, the most stringent airtightness target assumes additional material and labour costs to change to a more robust fully adhered system. • In Seattle, an airtightness testing requirement has been in place for
Airtightness: Passive House 0.6 ACH50	EEM_E04B	3.75%	X	X	**Low-rise test: $4,000-4,800** **High Rise test: $6,600-7,900** • Cost based on budget for one day of testing for low-rise, two days for high-rise	

TABLE D.1 ECM COSTS						
ECM Name	**ECM #**	**Discount Rate**	**1: High-rise**	**2: Low Rise**	**Incremental Cost**	**Notes**
Airtightness: PHIUS 0.05 cfm/sf@50Pa	EEM_E04C	3.75%	X	X	**Low-rise test: $8,000-9,500** **High-rise test: $13,200-15,800** **Addtl. labour & materials $0.34-0.76/sf** • Cost based on two days of testing for low-rise, four days for high-rise, corrections between tests	several years. In our experience, the presence of this requirement has raised awareness and quality control among local contractors, such that projects often far exceed the airtightness target when subjected to airtightness testing. • The incremental costs assume that additional testing may be required in order to achieve higher levels of airtightness. The added tests serve to inform the contractors of deficiencies during construction.
Fixed Exterior Shading	EEM_E05	3.75%	X		**$30-40/lf** • Cost based on linear length of shading projections	• Based on price estimate from Architectural Louvers for H6JN8 basic system. Supply and freight included.
Common LPDs 10% below baseline	ECM_L01A	3.75%	X	X	**$0.02-0.03/sf** • Cost based on floor area	• Baseline cost based on previous project experience. • 10% reduction from reducing the number of fixtures • 25% reduction based on higher efficiency fixtures.
Common LPDs 25% below baseline	ECM_L01B	3.75%	X	X	**$0.06-0.09/sf** • Cost based on floor area	

TABLE D.1 ECM COSTS

ECM Name	ECM #	Discount Rate	1: High-rise	2: Low Rise	Incremental Cost	Notes
HRV 60% efficiency	ECM_M01A	5.75%		X	**$1000-2000/unit** • Cost per suite • Low-rise baseline has passive vents	• Costs based on previous project experience, as well as RS Means
HRV 80% efficiency	ECM_M01B	5.75%	X	X	**60% HRV + $1000-2000/unit** • Cost per suite • Low-rise baseline has passive vents • High-rise baseline includes 60% HRV	
Electric Baseboard Heating	ECM_M02	5.75%		X	**$(2.18)-(1.98)/sf** • Cost per suite	• Baseline is radiant in floor heating. • Radiant floor heating costs approximately $2.47/sf from RS Means. • From previous project experience, electric baseboard heating costs approximately $304-515/suite • Negative incremental costs indicate savings.
FCUs ECM motors, 0.2 W/cfm	ECM_M03	5.75%	X		**$182-218/motor** • Cost per motor, one FCU/suite	• Estimates from ASHRAE 6 ECM motor example, assuming 1/4 HP motor

TABLE D.1 ECM COSTS						
ECM Name	**ECM #**	**Discount Rate**	**1: High-rise**	**2: Low Rise**	**Incremental Cost**	**Notes**
Low flow fixtures from Optional REAP Req.'s	ECM_S01	3.75%	X	X	**$0.00-0.19/sf** • Cost based on floor area	• Assumes no labour premium. • Low range assumes no incremental cost. • Some fixtures can have premiums. Costs are based on RS Means.
Drain Water Heat Recovery	ECM_S02	3.75%	X	X	**$1300-1400/DWHR** • Cost per drain water heat recovery system	• Data from manufacturer includes 45-minute install • Low price from ThermoDrain, high price from Power Pipe • Assume 20% markup • Cost assumes practical based on plumbing design at the building; may vary from project to project.
High Efficiency Condensing Boiler & MUA (92%) (Gas/Electric archetype only)	ECM_M05	5.75%	X	X	**$0.15-0.20/sf**	• Cost based on previous project experience
High Efficiency Condensing DHW (92%) (Gas/Electric archetype only)	ECM_M06	5.75%	X	X	**$0.15-0.19/sf**	• Cost based on previous project experience

Appendix E

Energy and Economic Analysis Results

Archetype 1: High-rise

TABLE E.2 ENERGY SAVINGS AND GHG EMISSIONS REDUCTION FOR HIGH RISE ARCHETYPE.										
			Annual Energy Savings			Annual GHG Reductions	ICC		NPV	
ECM Name	ECM #	Discount Rate	Electricity kWh/m²	District Energy kWh/m²	Total %	kg/m²	Best $/m²	Worst $/m²	Best $/m²	Worst $/m²
Step 1 Bundle (Baseline)	B_01	5.75%	-	-	-	-	-	-	-	-
Step 2 Bundle	B_02	5.75%	10.48	15.88	29.4%	1.6	$13	$26	$20.20	$7.32
Step 3 Bundle	B_03	5.75%	12.18	23.52	39.8%	2.3	$14	$44	$28.87	($0.84)
Step 4 Bundle	B_04	5.75%	9.25	42.86	58.1%	4.1	$71	$125	($18.74)	($72.89)
Step 4 Bundle Alternate (40% WWR)	B_04 Alt	5.75%	13.54	39.41	59.0%	3.8	$41	$87	($6.12)	(29.10)
Walls R-15.6 (effective R-6.4 w/ balconies)	E01A	3.75%	2.59	6.23	9.8%	0.6	$0	$17	$13.12	$4.83
Walls R-30 (effective R-7.8 w/ balconies)	E01B	3.75%	3.08	7.26	11.5%	0.7	$14	$37	$1.14	($10.32)
Walls R-15.6 + Balcony Thermal Break R-2.5 (effective R-10.3)	E06A	3.75%	3.69	8.40	13.5%	0.8	$13	$31	$4.96	($4.06)
Walls R-15.6 + Balcony Thermal Break R-5 (effective R-12.9)	E06B	3.75%	4.11	9.12	14.8%	0.9	$16	$34	$4.29	($4.91)
Walls R-15.6, No Balconies	E06C	3.75%	4.38	9.62	15.6%	0.9	$0	$17	$21.23	$12.94
Walls R-15.6, 40% WWR (R-7.5 w/ balconies)	E07	3.75%	6.59	9.38	17.8%	0.9	$0	$17	$26.53	$18.25
Roof R-30 effective	E02A	3.75%	0.04	0.09	0.1%	0.0	$1	$1	($0.35)	($0.46)

TABLE E.2 ENERGY SAVINGS AND GHG EMISSIONS REDUCTION FOR HIGH RISE ARCHETYPE.

ECM Name	ECM #	Discount Rate	Annual Energy Savings: Electricity kWh/m²	Annual Energy Savings: District Energy kWh/m²	Annual Energy Savings: Total %	Annual GHG Reductions kg/m²	ICC: Best $/m²	ICC: Worst $/m²	NPV: Best $/m²	NPV: Worst $/m²
Roof R-40 effective	E02B	3.75%	0.11	0.45	0.6%	0.0	$1	$1	($0.22)	($0.44)
Window U-0.35	E03A	3.75%	0.17	4.88	5.6%	0.5	$4	$4	$1.94	$1.54
Window U-0.28	E03B	3.75%	0.42	8.26	9.7%	0.8	$10	$20	($0.33)	($5.38)
Window U-0.14	E03C	3.75%	0.52	14.79	17.1%	1.4	$20	$41	($3.31)	($13.46)
Airtightness: 1.01 l/s-m² (REAP 3.5 ACH50)	E04A	3.75%	(5.21)	(28.86)	(38.0%)	(2.8)	$0	$0	($43.66)	($43.66)
Airtightness: 0.173 l/s-m² (Passive House 0.6 ACH_{50})	E04B	3.75%	0.33	2.74	3.4%	0.3	$0	$0	$3.47	$3.44
Airtightness: 0.057 l/s-m² (PHIUS 0.05 cfm/sf_{50})	E04C	3.75%	0.97	6.70	8.6%	0.6	$4	$5	$5.39	$4.96
Fixed exterior shading	E05	3.75%	2.35	(0.92)	1.6%	(0.1)	$4	$6	$0.65	-$0.07
Common LPDs 10% lower	L01A	3.75%	0.74	(0.04)	0.8%	0.0	$0	$0	$1.60	$1.60
Common LPDs 25% lower	L01B	3.75%	1.83	(0.10)	1.9%	0.0	$1	$1	$3.88	$3.71
HRV 80% efficiency	M01B	5.75%	(0.47)	4.40	4.4%	0.4	$9	$12	($6.06)	($7.86)
FCU ECM motors, 0.2 W/cfm	M03	5.75%	8.28	(3.58)	5.2%	(0.2)	$2	$2	$11.27	$11.07
Low flow fixtures from optional REAP Req.'s	S01	3.75%	0.00	3.25	3.6%	0.3	$0	$2	$3.44	$2.42
Drain water heat recovery	S02	3.75%	0.00	3.39	3.8%	0.3	$0	$0	$3.31	$3.30
Corridor ventilation reduced to 5 l/s per suite	M04	3.75%	5.65	8.01	15.2%	0.8	$0	$0	$22.71	$22.71

Archetype 2: Low-rise

TABLE E.3 ENERGY SAVINGS AND GHG EMISSIONS REDUCTION FOR LOW RISE ARCHETYPE.

ECM Name	ECM #	Discount Rate	Annual Energy Savings Electricity kWh/m²	Annual Energy Savings District Energy kWh/m²	Annual Energy Savings Total %	Annual GHG Reductions kg/m²	ICC Best $/m²	ICC Worst $/m²	NPV Best $/m²	NPV Worst $/m²
Step 1 (Baseline)	B_01	5.75%	-	-	-	-	-	-	-	-
Step 2	B_02	5.75%	2.70	6.03	13.9%	1.46	$1	$3	$9.46	$7.07
Step 3	B_03	5.75%	3.09	24.43	43.7%	5.84	$13	$26	$13.08	($0.35)
Step 4	B_04	5.75%	2.73	36.98	63.0%	8.80	$55	$98	($19.80)	($62.99)
Step 4 Alternate – electric baseboards	B_04 Alt	5.75%	(14.02)	52.11	60.5%	12.20	$32	$77	($18.41)	(63.75)
Wall R-22 effective	E01A	3.75%	0.12	2.31	3.9%	0.55	$1	$1	$2.19	$1.89
Wall R-38 effective	E01B	3.75%	0.27	5.04	8.4%	1.20	$15	$22	($8.71)	($16.09)
Roof R-30 effective	E02A	3.75%	0.01	0.16	0.3%	0.04	$1	$1	($0.81)	($1.23)
Roof R-40 effective	E02B	3.75%	0.03	0.74	1.2%	0.18	$2	$3	($1.06)	($1.87)
Window U-0.28	E03A	3.75%	0.27	5.79	9.6%	1.38	$11	$21	($3.76)	($14.35)
Window U-0.14	E03B	3.75%	1.08	20.51	34.3%	4.88	$21	$42	$3.37	($17.81)
Airtightness: 0.804 l/s-m² (3.5 ACH50)	E04A	3.75%	-	(24.15)	(38.3%)	(5.74)	$0	$0	($25.53)	($25.53)
Airtightness: 0.138 l/s-m² (0.6 ACH50)	E04B	3.75%	-	8.75	13.9%	2.08	$1	$1	$8.40	$8.24
Airtightness: 0.057 l/s-m² (0.05 cfm/sf@50Pa)	E04C	3.75%	0.01	12.32	19.6%	2.93	$8	$10	$4.89	$2.85

TABLE E.3 ENERGY SAVINGS AND GHG EMISSIONS REDUCTION FOR LOW RISE ARCHETYPE.										
			Annual Energy Savings			Annual GHG Reductions	ICC		NPV	
ECM Name	**ECM #**	**Discount Rate**	**Electricity kWh/m²**	**District Energy kWh/m²**	**Total %**	**kg/m²**	**Best $/m²**	**Worst $/m²**	**Best $/m²**	**Worst $/m²**
Common LPDs 10% below ASHRAE 90.1-2010	L01A	3.75%	1.08	(0.24)	1.3%	(0.04)	$0	$0	$2.39	$2.39
Common LPDS 25% below ASHRAE 90.1-2010	L01B	3.75%	2.70	(0.59)	3.3%	(0.11)	$1	$1	$5.87	$5.55
HRV efficiency: 60%	M01A	5.75%	(2.28)	7.73	8.7%	1.81	$10	$20	($8.64)	($18.85)
HRV efficiency: 80%	M01B	5.75%	(2.24)	9.99	12.3%	2.35	$20	$31	($16.96)	($27.17)
Electric baseboard heating	M02	5.75%	(28.87)	31.26	3.8%	7.12	$23	$21	($10.39)	($12.55)
Low flow fixtures per optional REAP Req.'s	S01	3.75%	0.01	3.60	5.7%	0.86	$0	$2	$3.83	$1.78
Drain water heat recovery	S02	3.75%	0.00	2.40	3.8%	0.57	$0	$0	$2.27	$2.25
Reduce corridor ventilation to 6 l/s per suite	M04	3.75%	10.85	1.77	20.0%	0.54	$0	$0	$30.63	$30.63

Appendix F

Archetype 1A – High-Rise Gas/Electric

Archetype 1A: High-Rise Gas/Electric

The primary archetypes in this study focused on buildings with district energy (DE) connected heat and hot water. Parallel archetypes were developed to analyze a building without DE systems. This section presents the high-rise gas/electric archetype baseline, ECM, and bundle results.

F.1 Baseline Model Results

The high-rise residential archetype was modified to remove district-energy connected systems and replace with gas or electric equipment:

- → Keeping the fan coil heating and cooling system, change the district energy connection to a gas-fired boiler (84% thermal efficiency per REAP EA Mandatory Credit M5)
- → Change MUA to gas heating coil with 84% efficiency
- → Change DHW to gas storage tank type (84% thermal efficiency per REAP EA Mandatory Credit M6)

Figure F.1 shows the distribution of energy consumption by end-use for the same archetype, with specific modifications to meet UBC REAP requirements. The total energy use intensity (EUI) is 160 kWh/m² per year, and annual GHG emissions are 400 tonnes per year (15.1 kg/m²). The non-DE archetype has a higher EUI due to the efficiency of the gas-fired boilers applied at the building (rather than district energy, which is modelled as purchased energy). The gas GHG emission factor is lower than the standard DE system (due to the efficiency losses with DE) and higher than the low-carbon DE system.

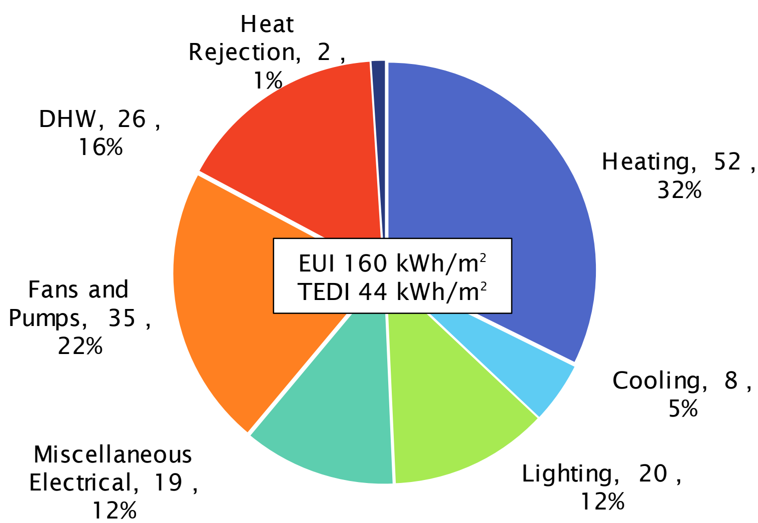


Figure F.1 REAP Baseline energy consumption by end-use for high-rise gas/electric archetype, kWh/m² and percent of total.

F.2 Individual ECM Results

ECMs were modelled individually to compare the energy savings and financial feasibility of each individual measure. Figure F.2 shows the annual EUI savings of each measure compared to the baseline archetype model. Measures with the greatest energy savings include window and enclosure effective R-value improvements that reduce gas heating.

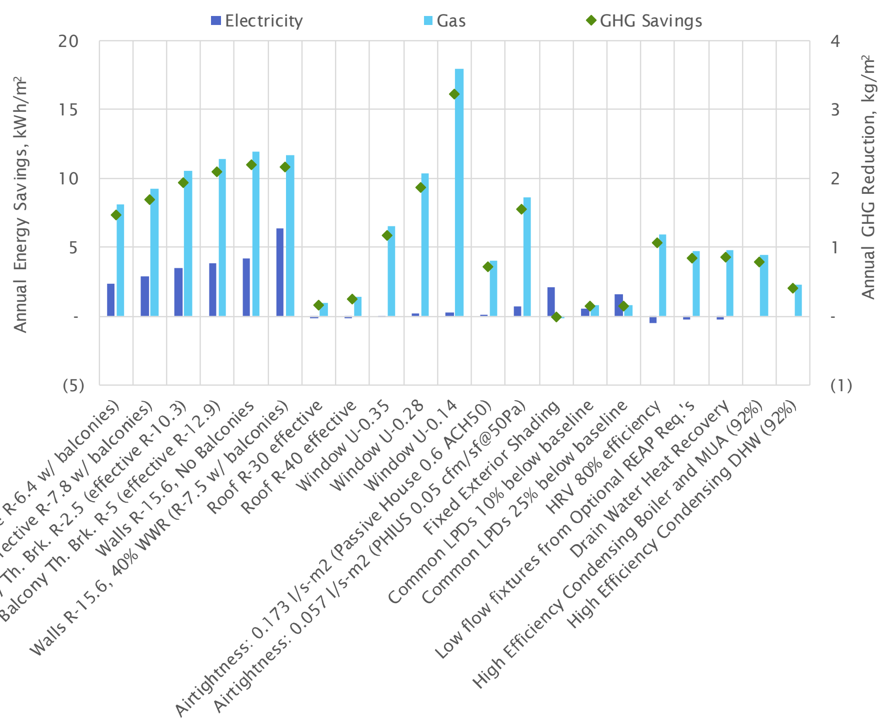


Figure F.2 Annual energy savings and GHG emsisions reduction of individual ECMs.

Figure F.3 shows the NPV for each measure (normalized per m² of conditioned floor area), with ECMs ordered from best (highest) NPV to worst (lowest) NPV. As with the DE archetype, negative worst case NPVs for ECMs that include insulated wall assemblies are due to the incremental cost to move from spandrel to an exterior insulated wall assembly, while best case NPVs were based on lower cost panelized construction.

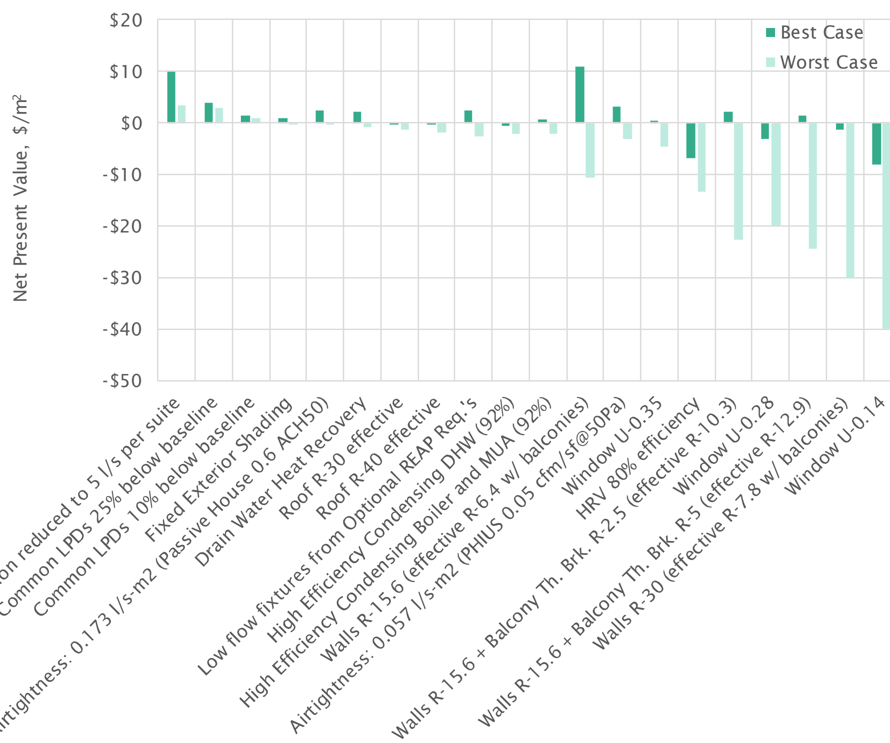


Figure F.3 Net present value of individual ECMs ordered from highest to lowest (best case), $/m² of conditioned floor area.

F.3 Bundle Results

Figure F.1 shows the ECMs simulated within each of the three bundles. A variety of combinations may be possible to achieve each step, including ECMs not considered in this study; the bundles below are intended to illustrate one example of measures for analysis. Figure F.4 shows the annual energy and GHG emissions reduction for the bundles.

Compared to the high-rise district energy archetype, two additional ECMs were required to meet Steps 2 and 3: upgrading gas equipment to high-efficiency condensing units for heating (boiler), make-up air, and DHW. An additional change was required at Step 4, adding heat recovery to corridor make-up air. Alternate approaches to meet Step 4 could include heat pump heating and hot water systems; these may be required in some instances, but for the archetype assessed in this study, Step 4 can be achieved with the fan coil unit and gas boiler/DHW systems.

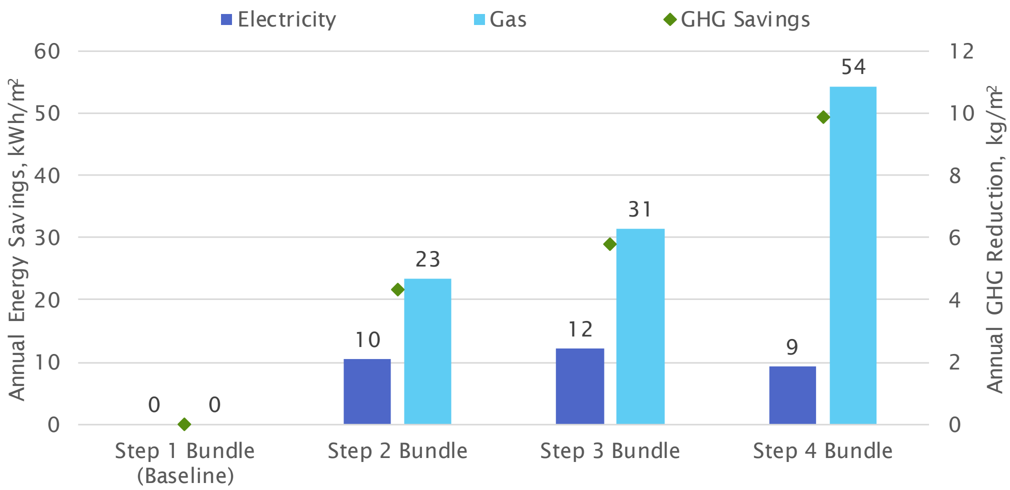


Figure F.4 Annual energy and GHG emissions reduction for ECM bundles.

TABLE F.1 SUMMARY OF ECMS IN EACH BUNDLE FOR HIGH-RISE GAS/ELECTRIC ARCHETYPE.	
Step 1 **No EUI/TEDI Target**	**Step 2** **Target: EUI 130 kWh/m², TEDI 45 kWh/m²**
REAP Baseline → Common area LPDs 25% below baseline Complies with NECB performance path plus REAP mandatory measures and REAP EUI requirement of 160 kWh/m². *EUI 160 kWh/m², TEDI 44 kWh/m²*	Step 1+ → FCUs with ECM motors, 0.2 W/cfm → REAP optional low-flow DHW fixtures → DHW drain water heat recovery → U-0.28 Windows → Passive House airtightness, 0.173 l/s-m² (0.6 ACH50) → High-efficiency condensing gas equipment (92% boiler, MUA, DHW) *EUI 128 kWh/m², TEDI 33 kWh/m²*
Step 3 **Target: EUI 120 kWh/m², TEDI 30 kWh/m²**	**Step 4** **Target: EUI 100 kWh/m², TEDI 15 kWh/m²**
Step 2+[26] → R-15 walls (R-6.4 effective) → R-30 Roof → Corridor ventilation reduced to 20 cfm/suite (9.5 l/s/suite) *EUI 119 kWh/m², TEDI 26 kWh/m²*	Step 3+ → R-30 walls with R-5 balcony thermal break → R-40 roof → U-0.14 windows → PHIUS airtightness, 0.057 l/s-m² (0.05 cfm/sf@50Pa) → High efficiency HRVs (80% efficient) → Fixed exterior shading at South and West elevations → Heat recovery on corridor ventilation (80% efficient) *EUI 100 kWh/m², TEDI 6 kWh/m²*

Figure F.5 shows the incremental capital cost per square metre of conditioned floor area for each of the bundles. The significant range in Step 3 is due to the range in best and worst case wall system costs; this also impacts Step 4, plus a significant range for the best window ECM. Bundle costs are slightly higher than for the DE scenarios due to the added ECM of high efficiency condensing gas boiler, MUA, and DHW.

[26] A variety of combinations of measures could achieve this bundle, including additional measures not included in this study. Higher performance windows may be a cost-effective strategy to achieve similar EUI/TEDI results. Interior spray foam insulation behind spandrel panels may also achieve overall effective R-6.4, provided moisture control is considered.

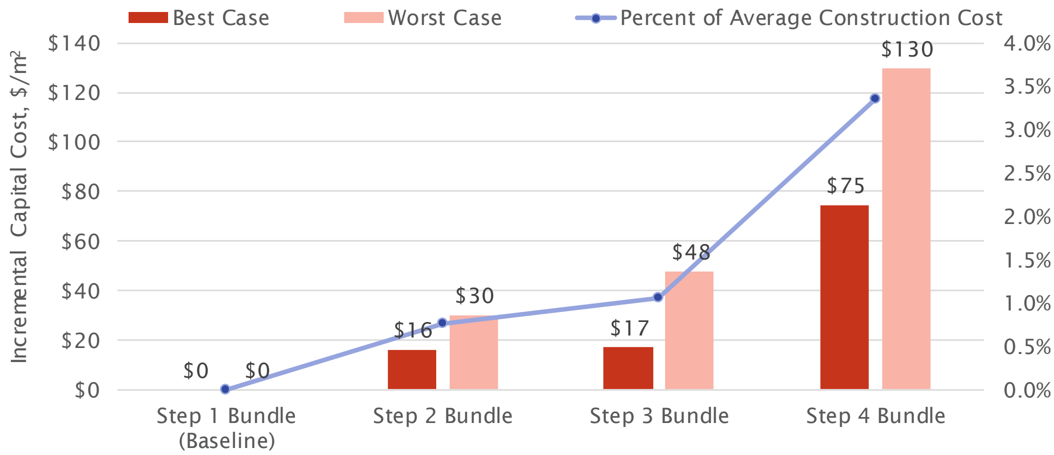


Figure F.5 Range of incremental capital costs per m² of floor area for bundles. The incremental cost as a percent of average construction is provided using an average cost of high-rise construction of $283/sf[27].

Figure F.6 shows the NPV in $/m² for the bundles. Table F.2 and Table F.3 show additional financial analysis results for the bundles.

NPVs are lower for this gas-heated archetype than for the DE archetype due to the lower cost of gas. Otherwise, the trends are similar, where Steps 2 and 3 have a range in positive to negative NPV for best and worst case costing, while Step 4 has a negative NPV in both scenarios.

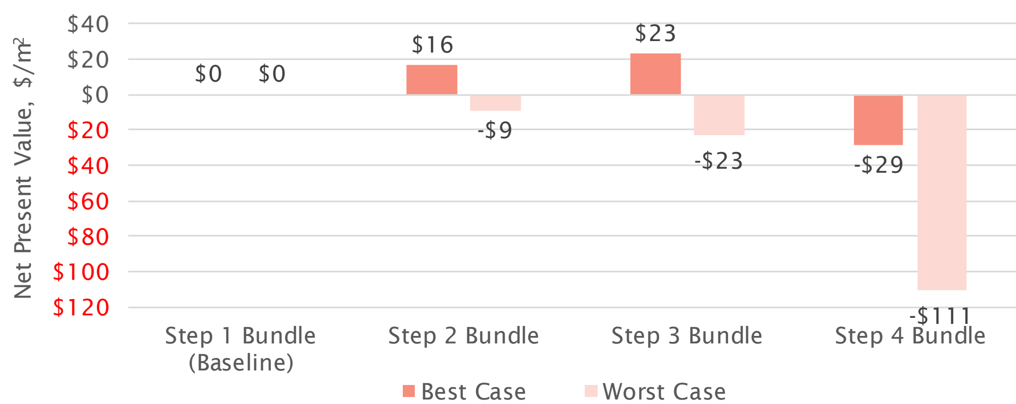


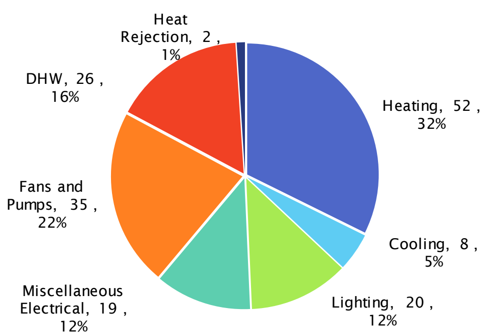
Figure F.6 Net present value of bundles, $/m².

TABLE F.2 INCREMENTAL CAPTIAL COSTS FOR ECM BUNDLES.				
Bundle	**Best Case**		**Worst Case**	
	$/m²	%[28]	$/m²	%
Step 2	$15	0.5%	$29	1.0%
Step 3	$16	0.6%	$47	1.6%
Step 4	$74	2.4%	$129	4.3%

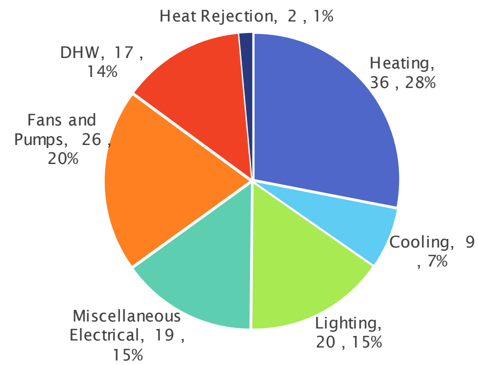
[27] Altus Group 2017 Canadian Cost Guide
[28] Percent of average total construction cost based on Altus Group 2017 Canadian Cost Guide, high-rise construction, $283/sf.

TABLE F.3 ECONOMIC ANALYSIS FOR ECM BUNDLES.								
	Annual Energy Savings	Annual GHG Savings	Net Present Value ($/m²)		Internal Rate of Return (IRR)		Discounted Payback Period (Years)	
Bundle	kWh/m²	kg/m²	Best	Worst	Best	Worst	Best	Worst
Step 2	34	4.3	$16.44	-$8.69	13%	3%	9	22
Step 3	44	5.8	$22.95	-$23.01	15%	1%	8	28
Step 4	64	9.9	-$28.93	-$110.65	2%	-6%	24	>30

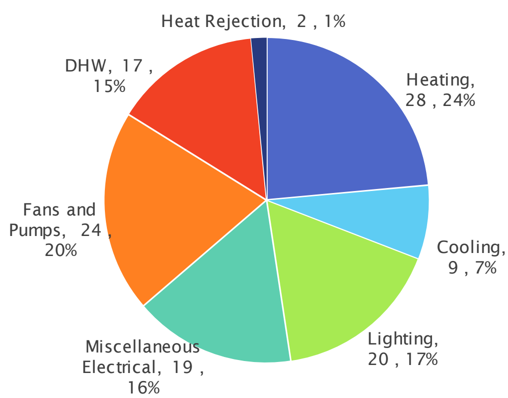
Figure F.7 shows energy consumption by end use for the four bundles of ECMs, including both modelled and adjusted TEDI/EUI metrics. This can be compared to the baseline model consumption shown in Figure 3.2.



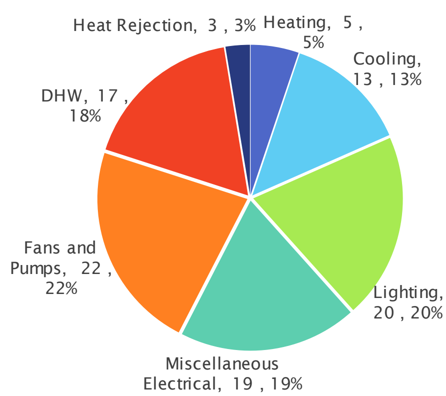
Step 1 (Baseline): EUI 160 kWh/m², TEDI 44 kWh/m²



Step 2: EUI 128 kWh/m², TEDI 33 kWh/m²



Step 3: EUI 119 kWh/m², TEDI 26 kWh/m²



Step 4: EUI 100 kWh/m², TEDI 6 kWh/m²

Figure F.7 Energy consumption by end use for the ECM bundles.

Key findings from the high-rise gas/electric bundles are as follows:

→ TEDIs generally align with the DE archetype as these values are primarily dependent on the enclsoure and heat recovery ventilation, and largely independent of mechancial system type.

- → The EUI is higher than the DE archetype due to the gas efficiency applied at the building level for heating and hot water, instead of district energy which is modelled as purchased energy (ie. without the plant efficiency).
- → Ovearll, this archetype demonstrates the Step Code metrics can be more or less difficult to achieve based on a variety of variables including mehcanical system selection. This archetype is just able to achieve Step 4 with the gas heat and hot water equipment. At Step 4, similar buildings with gas equipment could be pushed towards heat pump heat and hot water systems to meet the EUI, either as a requirement, or as a more cost-effective approach.

Appendix G

Archetype 2A – Low-Rise Gas/Electric

Archetype 2A: Low-Rise Gas/Electric

The primary archetypes in this study focused on buildings with district energy (DE) connected heat and hot water. Parallel archetypes were developed to analyze a building with non-DE systems, focusing on more traditional multifamily HVAC approaches with electric baseboard heating and gas-fired MUA and DHW. This section presents the low-rise non-district energy archetype baseline, ECM, and bundle results.

G.1 Baseline Model Results

The low-rise residential archetype was modified to remove district-energy connected systems and replace them with gas or electric equipment:

→ Remove the hydronic in-floor radiant heating system and add electric baseboard heating

→ Change MUA to gas heating coil with 80% efficiency

→ Change DHW to gas storage tank type with 84% efficiency

Figure G.1 shows the distribution of energy consumption by end-use for the gas/electric REAP baseline. The total energy use intensity is 132 kWh/m^2 per year, and annual GHG emissions are 44 tonnes per year (9.4 kg/m^2). The gas/electric archetype has a higher EUI than the DE archetype due to the building-level efficiency of gas MUA and DHW equipment (rather than district energy, which is modelled as purchased energy). GHG emissions are lower due to the change to electric baseboard heating.

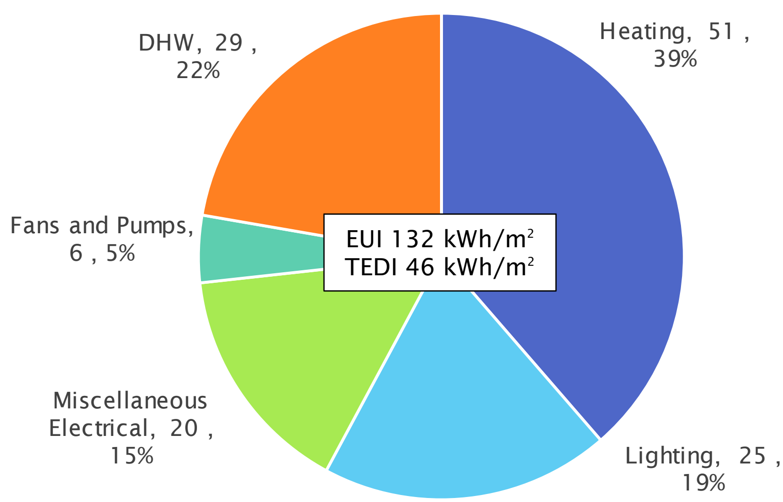


Figure G.1 REAP Baseline energy consumption by end use for low-rise MURB gas/electric archetype, kWh/m^2 and percent of total.

G.2 Individual ECM Results

ECMs were modelled individually to compare the energy savings and financial feasibility of each individual measure. Figure G.2 shows the percent energy savings of each measure compared to the baseline non-DE archetype model. Measures with the greatest GHG savings include windows, HRVs, and airtightness measures.

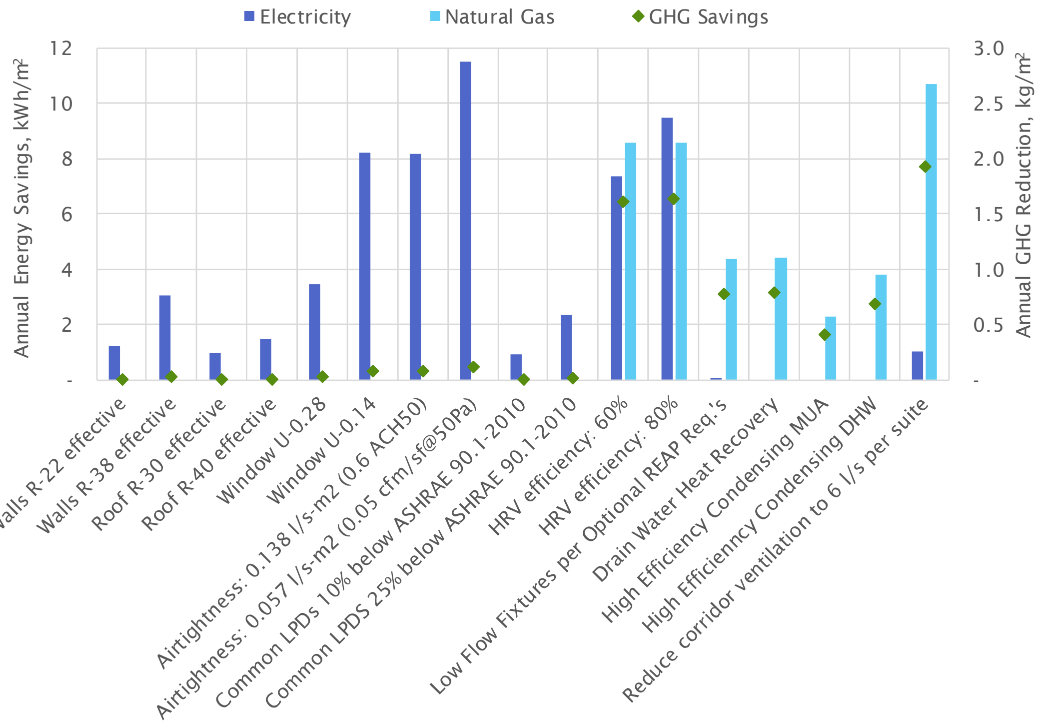


Figure G.2 Annual energy savings and GHG emissions reduction of individual ECMs.

Figure G.3 shows the NPV for each measure (normalized per m² of interior floor area), with ECMs ordered from best (highest) NPV to worst (lowest) NPV (incremental costs for ECMs are shown in Section 4 for the DE archetype). About half of the measures result in positive NPV, meaning they are cost-effective based on current implementation costs and forecast energy rates over a 30 year horizon.

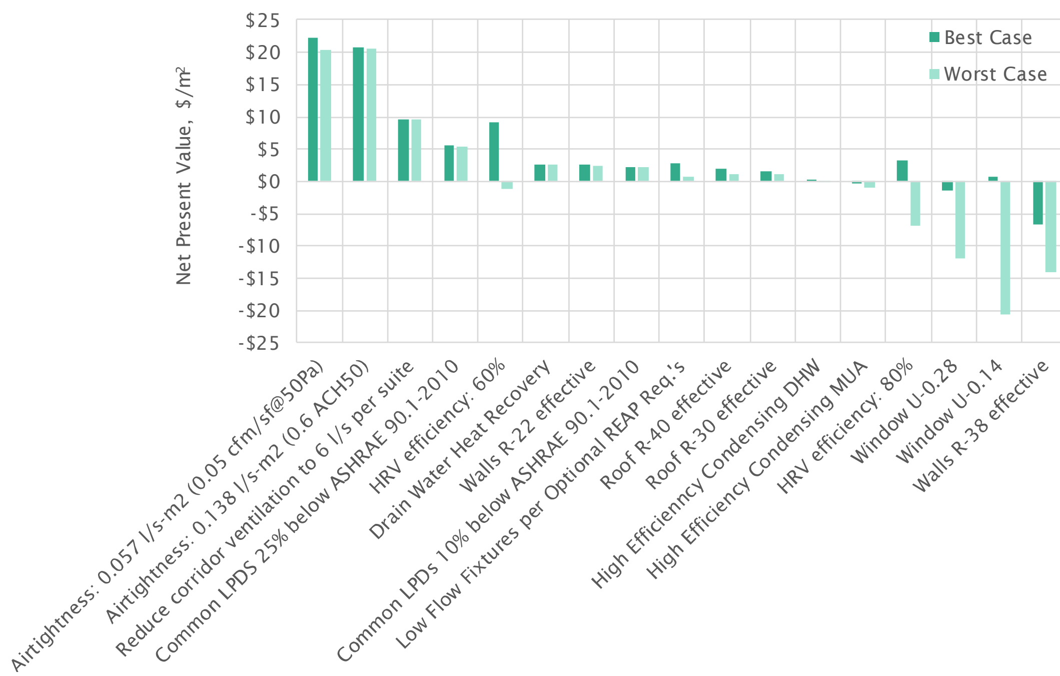


Figure G.3 Net present value of individual ECMs ordered from highest to lowest, $/m² of floor area.

G.3 Bundle Results

Table G.1 shows the ECMs simulated within each of the three bundles. A variety of combinations may be possible to achieve each Step, including ECMs not considered in this study; the bundles below are intended to illustrate one example of measures for analysis.

Compared to the DE archetype, no additional ECMs were required for Steps 3 and 4. One additional measure was required for Step 2 as the REAP baseline (Step 1) TEDI was slightly higher than the Step 2 TEDI limit; exterior wall insulation (walls to R22) was added to bring the TEDI below the Step 2 limit. It is also noteworthy that high efficiency condensing gas equipment was not required to meet the EUI limits for the low-rise archetype (compared to the high-rise where it was required).

TABLE G.1 SUMMARY OF ECMS IN EACH BUNDLE FOR LOW-RISE GAS/ELECTRIC ARCHETYPE

Step 1 **No EUI/TEDI Target**	**Step 2** **Target: EUI 130 kWh/m^2, TEDI 45 kWh/m^2**
→ REAP Baseline *EUI 130 kWh/m^2, TEDI 46 kWh/m^2*	Step 1+[29] → REAP optional low-flow fixture requirement → DHW drain water heat recovery *EUI 121 kWh/m^2, TEDI 45 kWh/m^2*
Step 3 **Target: EUI 120 kWh/m^2, TEDI 30 kWh/m^2**	**Step 4** **Target: EUI 100 kWh/m^2, TEDI 15 kWh/m^2**
Step 2+ → R-22 Walls → U-0.28 Windows → Passive House Airtightness, 0.6 ACH50 (0.173 l/s-m^2) *EUI 106 kWh/m^2, TEDI 29 kWh/m^2*	Step 3+ → R-38 Walls → R-40 Roof → U-0.14 Windows → Standard efficiency HRVs (60% efficient) → PHIUS Airtightness, 0.05 cfm/sf@50Pa (0.057 l/s-m^2) → Corridor ventilation reduced to 10 cfm/suite (5.7 l/s/suite) *EUI 90 kWh/m^2, TEDI 15 kWh/m^2*

Figure G.4 shows the annual energy and GHG emissions reduction for the bundles. The results show the significant savings achieved with the Step 4 bundle.

[29] The REAP baseline EUI/TEDI also comply with Step 2 for this archetype; additional ECMs were added to this bundle to show an additional scenario as they have low incremental cost and positive NPV.

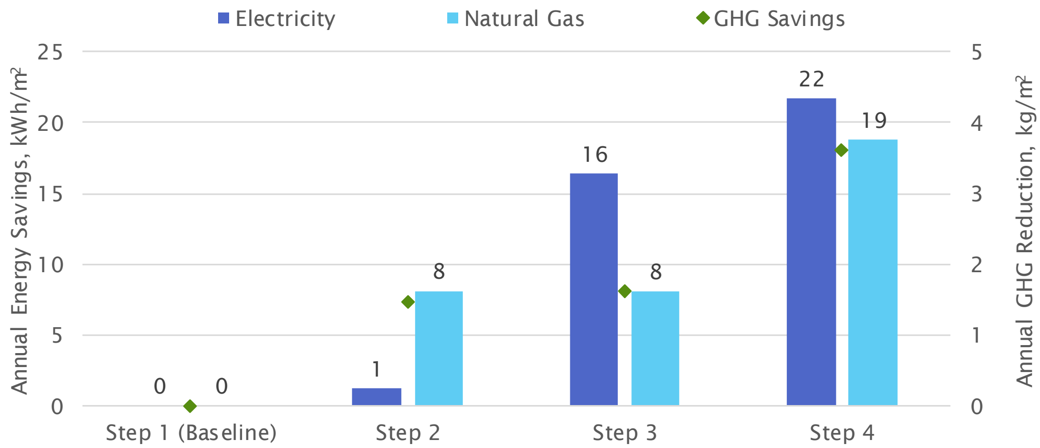


Figure G.4 Annual energy and GHG emissions reduction for ECM bundles.

Figure G.5 shows the incremental capital cost per square metre of conditioned floor area for each of the bundles. The costs are only slightly different from the DE archetype as the bundles had only minor changes.

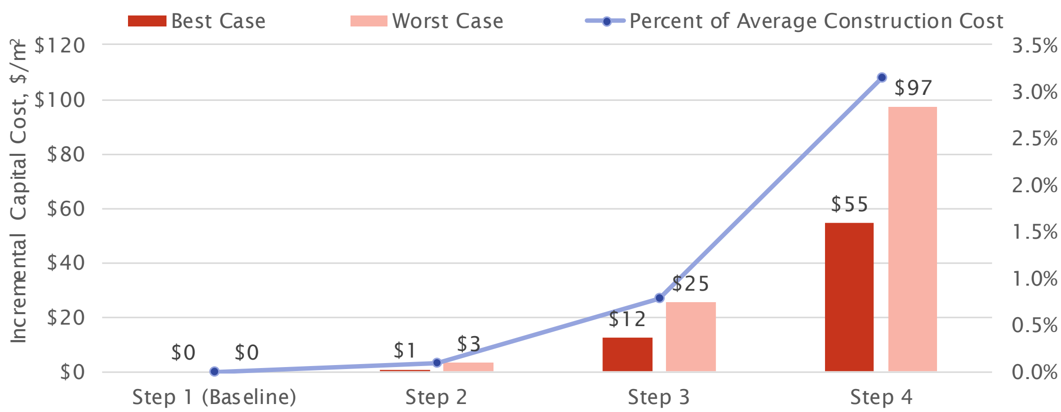


Figure G.5 Range of incremental capital costs for bundles, $/m² of floor area. The incremental cost as a percent of average construction is provided using an average cost of low-rise construction of $225/sf[30].

Figure G.6 shows the NPV in $/m² for the bundles. Table G.2 and Table G.3 shows additional financial analysis results for the bundles. Compared to the DE archetype, the economics are generally slightly better due to the higher cost of electricity compared to district energy; Step 4 nearly achieves zero NPV in the best case scenario for this archetype.

[30] Altus Group 2017 Canadian Cost Guide

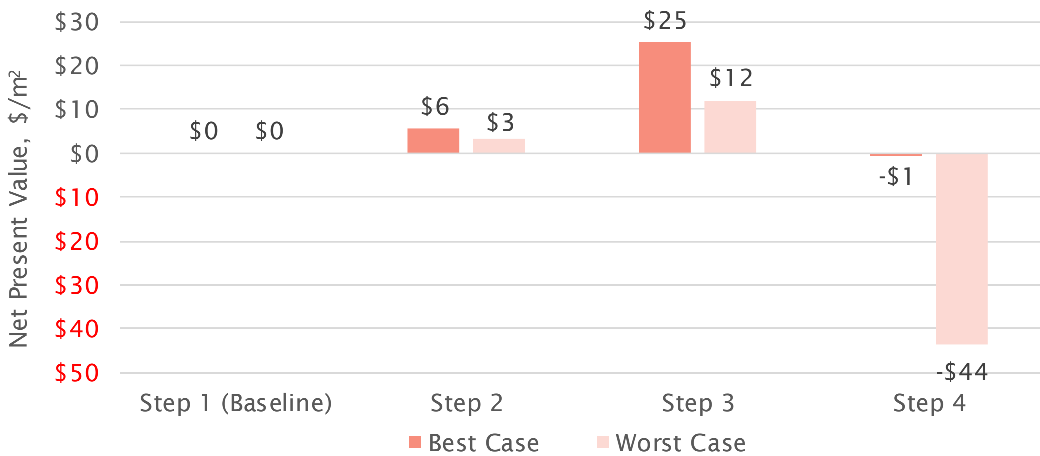


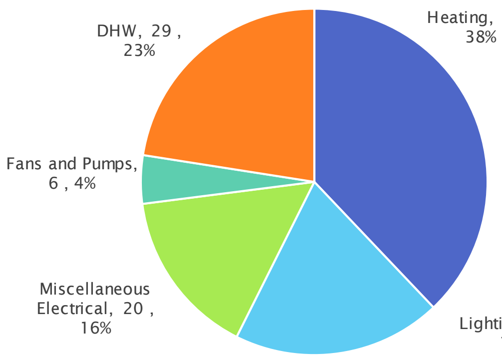
Figure G.6 Net present value of bundles, $/m².

TABLE G.2 INCREMENTAL CAPTIAL COSTS FOR ECM BUNDLES.				
Bundle	**Best Case**		**Worst Case**	
	$/m²	%[31]	$/m²	%
Step 2	$1	0.0%	$3	0.1%
Step 3	$12	0.5%	$25	1.0%
Step 4	$55	2.3%	$97	4.0%

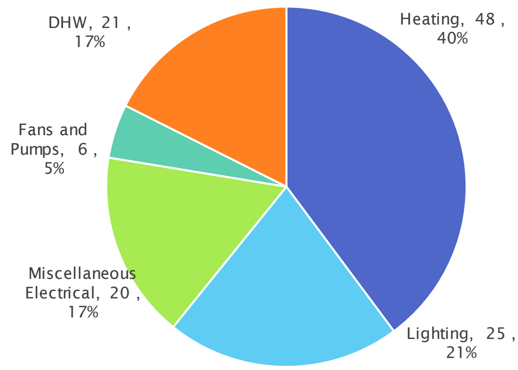
TABLE G.3 ECONOMIC ANALYSIS FOR ECM BUNDLES.								
	Annual Energy Savings	Annual GHG Savings	Net Present Value ($/m²)		Internal Rate of Return (IRR)		Discounted Payback Period (Years)	
Bundle	kWh/m²	kg/m²	Best	Worst	Best	Worst	Best	Worst
Step 2	9	1.5	$5.65	$3.29	46%	13%	3	9
Step 3	24	1.6	$25.24	$12.14	19%	9%	6	11
Step 4	41	3.6	($0.78)	($43.64)	6%	1%	16	25

Figure G.7 shows energy consumption by end use for the four bundles of ECMs. This can be compared to the baseline model consumption shown in Figure 4.2.

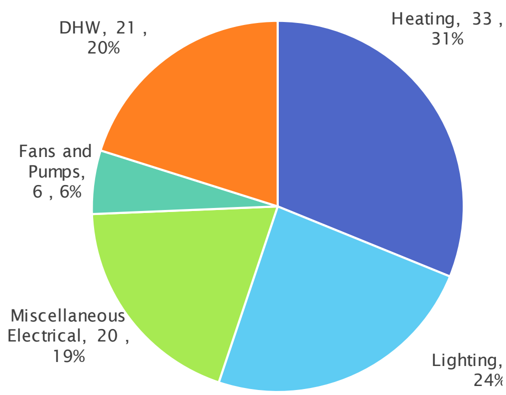
[31] Percent of average total construction cost based on Altus Group 2017 Canadian Cost Guide, low-rise construction, $225/sf.



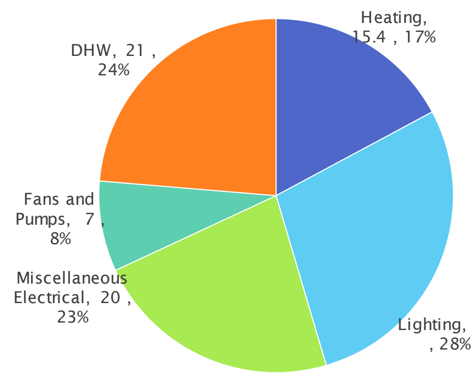
Step 1 (Baseline): EUI 130 kWh/m², TEDI 46 kWh/m²



Step 2: EUI 121 kWh/m², TEDI 45 kWh/m²



Step 3: EUI 106 kWh/m², TEDI 29 kWh/m²



Step 4: EUI 90 kWh/m², TEDI 15 kWh/m²

Figure G.7 Energy consumption by end use for the ECM bundles.

Key findings from the low-rise gas/electric archetype are as follows:

→ TEDIs generally align with the DE archetype as these values are primarily dependent on the enclsoure and heat recovery ventialation, and largely independent of mechancial system type. However, the baseline TEDI is slightly higher for the gas/electric archetype due to the electric baseboard heating, which required an additional ECM to push the bundle into Step 2.

→ Aside from minor changes to the Step 2 bundle, the same bundles may be used for the non-DE archetype as the DE archetype.

→ Economics are slightlgy better for the gas/electric archetype due to electric baseboard savings and the higher cost of electricity.

→ GHG savings are lower for this archetype due to the use of electric baseboard heating. Since EUIs are well within the Step Code limits, gas savings and associated GHG emissions are low until Step 4 where MUA must be reduced to meet the TEDI requirement.

→ This archetype is an example where a GHGI would be more effective to reduce emissions than the TEDI and EUI targets in the Step Code. If GHG emissions are the goal, UBC could consider adding a GHGI limit.

Appendix H

Gas/Electric Archetype Results

Archetype 1A: High-Rise Gas/Electric

TABLE H.1 ENERGY SAVINGS AND GHG EMISSIONS REDUCTION FOR HIGH-RISE GAS/ELECTRIC ARCHETYPE.

ECM Name	ECM #	Discount Rate	Annual Energy Savings Electricity kWh/m²	Annual Energy Savings Gas kWh/m²	Annual Energy Savings Total %	Annual GHG Reductions kg/m²	ICC Best $/m²	ICC Worst $/m²	NPV Best $/m²	NPV Worst $/m²
Step 1 Bundle (Baseline)	B_01	5.75%	-	-	-	-	-	-	-	-
Step 2 Bundle	B_02	5.75%	10.48	23.43	20.7%	4.3	$16	$29	$16.44	($8.69)
Step 3 Bundle	B_03	5.75%	12.18	31.48	26.6%	5.8	$16	$47	$22.95	($23.01)
Step 4 Bundle	B_04	5.75%	9.25	54.30	38.7%	9.9	$74	$129	($28.93)	($110.7)
Walls R-15.6 (effective R-6.4 w/ balconies)	E01A	3.75%	2.35	8.06	6.3%	1.5	$0	$17	$11.07	($10.65)
Walls R-30 (effective R-7.8 w/ balconies)	E01B	3.75%	2.84	9.24	7.4%	1.7	$14	$37	($1.23)	($30.06)
Walls R-15.6 + Balcony Thermal Break R-2.5 (effective R-10.3)	E06A	3.75%	3.45	10.56	8.5%	1.9	$13	$31	$2.23	($22.57)
Walls R-15.6 + Balcony Thermal Break R-5 (effective R-12.9)	E06B	3.75%	3.87	11.39	9.3%	2.1	$16	$34	$1.33	($24.37)
Walls R-15.6, No Balconies	E06C	3.75%	4.14	11.97	9.8%	2.2	$0	$17	$18.11	($6.13)
Walls R-15.6, 40% WWR (R-7.5 w/ balconies)	E07	3.75%	6.35	11.69	11.0%	2.2	$0	$17	$23.49	($0.56)
Roof R-30 effective	E02A	3.75%	(0.21)	0.97	0.5%	0.2	$1	$1	($0.44)	($1.28)
Roof R-40 effective	E02B	3.75%	(0.14)	1.38	0.8%	0.2	$1	$1	($0.43)	($1.74)
Window U-0.35	E03A	3.75%	(0.07)	6.49	3.9%	1.2	$4	$4	$0.33	($4.63)

TABLE H.1 ENERGY SAVINGS AND GHG EMISSIONS REDUCTION FOR HIGH-RISE GAS/ELECTRIC ARCHETYPE.										
			Annual Energy Savings			Annual GHG Reductions	ICC		NPV	
ECM Name	**ECM #**	**Discount Rate**	**Electricity kWh/m²**	**Gas kWh/m²**	**Total %**	**kg/m²**	**Best $/m²**	**Worst $/m²**	**Best $/m²**	**Worst $/m²**
Window U-0.28	E03B	3.75%	0.18	10.40	6.5%	1.9	$10	$20	($3.02)	($19.78)
Window U-0.14	E03C	3.75%	0.28	17.94	11.1%	3.2	$20	$41	($8.07)	($39.86)
Airtightness: 1.01 l/s-m² (REAP 3.5 ACH50)	E04A	3.75%	(5.46)	(32.46)	(23.1%)	(5.9)	$0	$0	($34.55)	($13.77)
Airtightness: 0.173 l/s-m² (Passive House 0.6 ACH_{50})	E04B	3.75%	0.08	4.02	2.5%	0.7	$0	$0	$2.53	($0.09)
Airtightness: 0.057 l/s-m² (PHIUS 0.05 cfm/sf_{50})	E04C	3.75%	0.73	8.60	5.7%	1.6	$4	$5	$3.19	($3.16)
Fixed exterior shading	E05	3.75%	2.11	(0.20)	1.2%	(0.0)	$4	$6	$0.88	($0.43)
Common LPDs 10% lower	L01A	3.75%	0.49	0.81	0.8%	0.2	$0	$0	$1.55	$1.03
Common LPDs 25% lower	L01B	3.75%	1.59	0.75	1.4%	0.2	$1	$1	$3.84	$3.04
HRV 80% efficiency	M01B	5.75%	(0.55)	5.94	3.3%	1.1	$9	$12	($6.81)	($13.35)
FCU ECM motors, 0.2 W/cfm	M03	5.75%	8.04	(3.27)	2.9%	(0.5)	$2	$2	$12.06	$13.29
Low flow fixtures from optional REAP Req.'s	S01	3.75%	(0.24)	4.70	2.7%	0.8	$0	$2	$2.41	($2.65)
Drain water heat recovery	S02	3.75%	(0.24)	4.79	2.8%	0.9	$0	$0	$2.18	($0.91)
Condensing Boiler & MUA (92%)	M05	5.75%	-	4.40	2.7%	0.8	$2	$2	$0.60	($2.17)
Condensing DHW (92%)	M06	5.75%	-	2.28	1.4%	0.4	$2	$2	($0.51)	($2.00)
Corridor ventilation reduced to 5 l/s per suite	M04	3.75%	1.36	10.20	7.0%	1.9	$0	$0	$9.95	$3.42

Archetype 2A: Low-Rise Gas/Electric

TABLE H.2 ENERGY SAVINGS AND GHG EMISSIONS REDUCTION FOR LOW RISE GAS/ELECTRIC ARCHETYPE.

			Annual Energy Savings			Annual GHG Reductions	ICC		NPV	
ECM Name	ECM #	Discount Rate	Electricity kWh/m²	Gas kWh/m²	Total %	kg/m²	Best $/m²	Worst $/m²	Best $/m²	Worst $/m²
Step 1 (Baseline)	B_01	5.75%	-	-	-	-	-	-	-	-
Step 2	B_02	5.75%	1.22	8.11	13.9%	1.5	$1	$3	$5.65	$3.29
Step 3	B_03	5.75%	16.39	8.08	43.7%	1.6	$12	$25	$25.24	$12.14
Step 4	B_04	5.75%	21.72	18.80	63.0%	3.6	$55	$97	($0.78)	($43.64)
Wall R-22 effective	E01A	3.75%	1.22	-	0.9%	0.0	$1	$1	$2.64	$2.34
Wall R-38 effective	E01B	3.75%	3.05	-	2.3%	0.0	$15	$22	($6.66)	($14.04)
Roof R-30 effective	E02A	3.75%	0.97	-	0.7%	0.0	$1	$1	$1.56	$1.14
Roof R-40 effective	E02B	3.75%	1.48	-	1.1%	0.0	$2	$3	$1.99	$1.17
Window U-0.28	E03A	3.75%	3.48	-	2.7%	0.0	$11	$21	($1.37)	($11.95)
Window U-0.14	E03B	3.75%	8.24	-	6.3%	0.1	$21	$42	$0.66	($20.51)
Airtightness: 0.804 l/s-m² (3.5 ACH50)	E04A	3.75%	(23.30)	-	(17.9%)	(0.2)	$0	$0	($61.72)	($61.72)
Airtightness: 0.138 l/s-m² (0.6 ACH50)	E04B	3.75%	8.15	-	6.3%	0.1	$1	$1	$20.76	$20.60
Airtightness: 0.057 l/s-m² (0.05 cfm/sf@50Pa)	E04C	3.75%	11.50	-	8.8%	0.1	$8	$10	$22.31	$20.27
Common LPDs 10% below ASHRAE 90.1-2010	L01A	3.75%	0.95	-	0.7%	0.0	$0	$0	$2.30	$2.30

TABLE H.2 ENERGY SAVINGS AND GHG EMISSIONS REDUCTION FOR LOW RISE GAS/ELECTRIC ARCHETYPE.

ECM Name	ECM #	Discount Rate	Annual Energy Savings: Electricity kWh/m²	Annual Energy Savings: Gas kWh/m²	Annual Energy Savings: Total %	Annual GHG Reductions kg/m²	ICC Best $/m²	ICC Worst $/m²	NPV Best $/m²	NPV Worst $/m²
Common LPDS 25% below ASHRAE 90.1-2010	L01B	3.75%	2.36	-	1.8%	0.0	$1	$1	$5.60	$5.27
HRV efficiency: 60%	M01A	5.75%	7.36	8.57	12.2%	1.6	$10	$20	$9.10	($1.11)
HRV efficiency: 80%	M01B	5.75%	9.48	8.57	13.9%	1.6	$20	$31	$3.23	($6.98)
Electric baseboard heating	M02	5.75%	7.12	23.40	23.5%	4.3	$23	$21	$49.67	$47.52
Low flow fixtures per optional REAP Req.'s	S01	3.75%	0.01	4.37	3.4%	0.8	$0	$2	$2.82	$0.78
Drain water heat recovery	S02	3.75%	-	4.40	3.4%	0.8	$0	$0	$2.54	$2.52
Condensing MUA (92%)	M05	5.75%	-	2.30	1.8%	0.4	$2	$2	($0.44)	($1.02)
Condensing DHW (92%)	M06	3.75%	-	3.84	3.0%	0.7	$2	$2	$0.27	($0.10)
Reduce corridor ventilation to 6 l/s per suite	M04	3.75%	1.03	10.68	9.0%	1.9	$0	$0	$9.56	$9.56