City of Edmonton
Emissions Neutral Buildings:
Final Report

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October 13, 2020

Executive Summary

This Final Report was developed to provide an energy, emissions, and cost overview of the City of Edmonton's Emissions Neutral Buildings Technical Study. This work aligns with the City of Edmonton Council's declaration of a Climate Emergency on August 26th, 2019, and Climate Shift 3: Emissions Neutral Buildings, as outlined in the City's report contextualizing Edmonton's current Community Energy Transition Strategy.

The following trends have been observed throughout the completed energy and costing analyses:

- The building archetypes analyzed can achieve significant energy demand and GHG emissions reductions through energy efficiency, but to fully achieve emissions neutrality, renewable energy system must be integrated into building design.
- Due to the high emissions factor of Alberta's 2019 electric grid, full electrification of buildings will likely increase its GHG emissions unless significant renewable energy systems are implemented on-site, or the Alberta electric grid reduces its emissions factor considerably.
- To achieve an emissions neutral building on primarily large high-rise buildings, other primary, low-carbon energy sources would likely be required in addition to on-site renewables, such as:
    - low-carbon district energy systems, ground source heat pumps, cold climate air source heat pumps, and community scale renewable energy micro-grids.
- Buildings which have a large roof area compared to its total height, such as Part 9 buildings and the low-rise commercial building, can achieve annual emissions neutrality on-site through the implementation of solar PV renewable energy systems.
- Part 9 buildings, such as the detached single family home and row housing, have a higher percentage capital cost and NPV premium over the baseline than Part 3 buildings. This is likely to financially favour deployment of Part 3 over Part 9 emissions neutral buildings.
- When considering the 30-year NPV of the study, the Emissions Neutral Building (ENB) energy goal will cost more than the Intermediate target, due to the increased amount of high cost electricity used in that scenario when compared to natural gas.
- Implementing energy efficiency measures, such as envelope and airtightness improvements, in Part 3 buildings reduces or maintains the 30-year NPV of a building when compared to the baseline.
- The costing shown in this study only includes the hard costs of construction and does not consider the cost implications of different business models, skills development, or overhead. This costing aligns with other costing information received from various sources.

It should be noted that the Emissions Neutral Buildings (ENB) scenario represents a fully electrified building but may not be 100% "emissions neutral". This is due to the fact that high-rise buildings do not have enough space on-site to meet its annual energy demand when utilizing solar photovoltaic (PV) panels, and Alberta's electric grid having a high emissions factor (as of 2019). While Alberta's grid is continually becoming cleaner[1], it is challenging to forecast when it will have an emissions factor approaching zero. Therefore, if the grid emissions intensity does not improve in a sufficient

[1] AESO 2019 Long Term Outlook. https://www.aeso.ca/assets/Uploads/AESO-2019-LTO-updated-10-17-19.pdf

timeframe, buildings will have to close the energy gap by implementing other energy systems, such as a district energy system, a renewable microgrid, or other low emissions energy sources.

The following table summarizes the energy, emissions, and costing results in terms of Energy Improvement over Baseline, Energy Use Intensity, Thermal Energy Demand Intensity, Emissions Reduction from Baseline, Capital Cost Percentage Premium over the Baseline, and 30-Year Net Present Value (NPV) Percentage over the Baseline (utilizing a 3% discount rate). The baseline used for this study is the 2019 Alberta Building Code (ABC) Section 9.36 for single family home, and row housing, and the National Energy Code of Canada for Buildings (NECB) 2017 for the high-rise residential, high-rise commercial, and the low-rise commercial.

		Detached Single Family Home	Row house	High-Rise Residential	High-Rise Commercial	Low-Rise Commercial
Energy						
Energy Reduction from Baseline (%)	Intermediate	48%	52%	51%	48%	46%
	ENBR (Electrified)	63%	67%	53%	61%	59%
Energy Use Intensity (kWh/m2)	Baseline	175	187	229	254	226
	Intermediate	92	90	112	131	123
	ENBR (Electrified)	66	61	107	98	93
Thermal Energy Demand Intensity (kWh/m2)	Baseline	100	119	91	122	89
	Intermediate	36	36	28	35	36
	ENBR (Electrified)	36	38	27	35	36
Emissions						
Emissions Reduction from Baseline (%)	Intermediate	34%	37%	42%	34%	40%
	ENBR (Electrified)	20%	26%	12%	13%	38%
Cost						
Capital Cost Premium over Baseline (%)	Intermediate	6%	6%	3%	1%	2%
	ENBR (Electrified)	10%	11%	3%	1%	3%
30-Year NPV over Baseline (%)	Intermediate	2%	4%	0%	-1%	-2%
	ENBR (Electrified)	6%	9%	3%	0%	0%

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Abbreviations

AESO	Alberta Electric Systems Operator
ECM	Energy Conservation Measure
EUI	Energy Use Intensity
ENB	Emissions Neutral Building
ENBR	Emissions Neutral Building Ready
GHG	Greenhouse Gas
HVAC	Heating, Ventilation, Air Conditioning
NBC	National Building Code
NBC(AE)	National Building Code, Alberta Edition
NECB	National Energy Code of Canada for Buildings
NPV	Net Present Value
NRCan	Natural Resources Canada
O&M	Operations and maintenance
PV	Photovoltaic
REC	Renewable Energy Credit
TEDI	Thermal Energy Demand Intensity

Technical Terminology

AHU	Air Handling Unit	IGU	Insulated Glazing Unit
ASHP	Air Source Heat Pump	LPD	Lighting Power Density
BB	Baseboard	MUA	Make Up Air Unit
CHW	Chilled Water	OA	Outside Air
COG	Centre of Glass	RCP	Radiant Ceiling Panel
CW	Condenser Water	SFP	Specific Fan Power (W/CFM)
DHW	Domestic Hot Water	SHGC	Solar Heat Gain Coefficient
DOAS	Dedicated Outdoor Air System	SPP	Specific Pump Power (W/GPM)
DX	Direct Expansion	TB	Thermal Break
EA	Exhaust Air	TR	Tonnes of Refrigeration
ERV	Energy Recovery Ventilator	UH	Unit Heater
FCU	Fan Coil Unit	VAV	Variable Air Volume
HRV	Heat Recovery Ventilator	VSD	Variable Speed Drive
HRW	Heat Recovery Wheel	WWR	Windows to Wall Ratio
HW	Hot Water		

1 Introduction

1.1 Project Purpose

This Final Report was developed to provide an energy, emissions, and construction cost overview of the City of Edmonton's Emissions Neutral Buildings Technical Study. This work aligns with the City of Edmonton Council's declaration of a Climate Emergency on August 26th, 2019, and Climate Shift 3: Emissions Neutral Buildings, as outlined in the City's report contextualizing Edmonton's effort to update their Community Energy Transition Strategy.

1.2 Project Goals

The following project goals have been outlined as part of the Emissions Neutral Buildings (ENB) Study.

1.2.1 Energy Code Alignment

One of the goals of this study is to align with the in-development 2020 versions of the National Energy Code of Canada for Building (NECB)[2] and the National Building Code (NBC) Section 9.36[3] by the National Research Council Canada. The preliminary 2020 versions of NECB and NBC 9.36 currently provide a tiered approach to energy performance compliance and allow for buildings to achieve an energy performance tier by showing an energy improvement over the prescribed reference building. The energy tiers are as follows:

NBC 9.36 2020 Tiers

Energy Performance Tier	Overall Energy Performance Improvement over NBC 9.36	Envelope Energy Performance Improvement	Overall Energy Performance Improvement over NBC 9.36	Envelope Energy Performance Improvement
	Building over 230m² of conditioned space		Building under 230m² of conditioned space	
1	> 0%	N/A	> 0%	N/A
2	> 10%	> 5%	> 0%	> 0%
3	> 20%	> 10%	> 10%	> 5%
4	> 40%	> 20%	> 30%	> 15%
5	> 70%	> 50%	> 60%	> 35%

[2] Codes Canada Public Review 2020: Proposed Change 1527. National Research Council of Canada.
[3] Codes Canada Public Review 2020: Proposed Change 1617. National Research Council of Canada.

NECB 2020 Tiers

Energy Performance Tier	Overall Energy Performance Improvement over NECB
1	> 0%
2	> 25%
3	> 50%
4	> 60%

1.3 Process of Study

The overall Edmonton Emissions Neutral Buildings study was completed through a combined process of technical analysis utilizing energy, greenhouse gas emissions, and cost modelling, and industry engagement through steering and technical committee meetings.

1.3.1 Technical Analysis

The Technical Analysis portion of the study was completed through multiple iterations of building energy modelling and building cost assessment, based on consultation with the City of Edmonton and steering committee members. Once completed, a 30-year net present value and 30-year operational GHG emissions assessment were completed on each building archetype. This information contributes to the overall understanding of achieving an emissions neutral building in Edmonton and the construction costs likely to be incurred for their achievement.

1.3.2 Industry Engagement

The Industry Engagement portion of the study was completed through multiple Steering Committee meetings and various technical and industry specific discussions. This industry input helped to influence and guide the technical analysis and was invaluable in determining the emissions neutral building strategy. Additionally, the inclusion of local approaches and solutions to energy efficient building design helped to refine the costing analysis of this study to be better reflective of local conditions and challenges.

2 Methodology

2.1 Archetypes

The five building archetypes which were selected for analysis in this study were determined through consultation with the City of Edmonton and the members of the Steering Committee. These archetypes are meant to be representative of a majority of the future buildings which are expected to be constructed within the City of Edmonton. These archetypes are based on modelled buildings which could be constructed within the current market. The five building archetypes assessed in this study include: detached single family home, row housing, high-rise residential, high-rise commercial (office), and low-rise commercial (retail).

2.2 Energy Tiers

2.2.1 Baseline: NECB 2017 and ABC 9.36

The baseline energy tier is based on the current energy code applicable within the province of Alberta (as of 2019), the National Energy Code of Canada for Buildings 2017, and National Building Code, Alberta Edition [NBC(AE)] Section 9.36, which is based on NBC Section 9.36. Building archetypes designated as Part 9, including single family home, and row housing, are contingent upon achieving energy performance compliance with ABC 9.36. Archetypes which are designated as Part 3, including high-rise residential, high-rise commercial, and low-rise commercial, must achieve energy performance compliance with NECB 2017.

2.2.2 Intermediate Step

The intermediate energy step is based on achieving various mid range tiers in the upcoming NECB 2020 and NBC 9.36 2020 energy code. For Part 9 buildings, the intermediate step represented Tier 3 of NBC 9.36 2020, which requires an overall energy improvement of greater than 20% over the baseline, and an envelope energy improvement of greater than 10%. It should be noted that the ABC is expected to follow the NBC as it is updated. For Part 3 buildings, the intermediate step represented Tier 2 of NECB 2020, which requires an energy improvement of greater than 25% over the NECB 2020 baseline. Additionally, as the NECB 2020 baseline is anticipated to be 15-20% more stringent than NECB 2017[4], the intermediate step energy performance improvement will be 40-45% greater than the NECB 2017 baseline. These tier targets were chosen for this step based on the knowledge that the average building permit application currently outperforms NECB by 11% and 9.36 by 8.5%[5]. Since the industry average outperforms the first energy tier, more stringent energy targets were chosen to ensure buildings continue to prioritize energy efficiency.

2.2.3 Emissions Neutral Building

For the purposes of this study, an emissions neutral building has been defined as *"a building that is highly energy efficient and uses only renewable energy for its operations, or, produces and supplies onsite renewable energy in an amount sufficient to offset the annual greenhouse gas emissions associated with its operations."* Therefore, to achieve emissions neutrality, building energy performance was further improved, all building archetypes were fully electrified, and renewable solar photovoltaic (PV) systems were implemented on site to reduce emissions from the use of grid electricity.

[4] Codes Canada Public Review 2020: Proposed Change 1537. National Research Council of Canada.
[5] Building Permit Submissions. 2019. City of Edmonton.

Throughout this study, a building archetype which has been made energy efficient and electrified, but does not have any renewable energy systems associated with it, is referred to as Emission Neutral Building Ready (ENBR).

2.3 Energy Modelling

Energy modelling is a vital step towards a successful sustainable building design. It involves a set of simulations and calculations which estimate the energy use in buildings based on climate, architectural, mechanical, and electrical designs. It also assists owners and design teams in recognizing opportunities for energy efficiency via Energy Conservation Measures (ECMs) which ultimately leads to the reduction of building operational expenses.

A typical energy modelling workflow begins with reviewing different architectural features such as massing, envelope design, and airtightness. This was followed by a thorough analysis of mechanical and electrical designs including but not limited to: Heating, Cooling, Ventilation, Air Systems, Water Systems, Energy Recovery, Plumbing, Lighting, Power, and Control Systems.

The workflow above, when implemented in a design process, will bring architectural and engineering design elements together to anticipate how different building components will interact with each other. Analysis of these different options was conducted to minimize energy consumption at the lowest cost possible. It should be noted that certain factors were not assessed in this analysis, including building siting, orientation, specific façade design, and articulation.

To complete the energy analysis portion of this study, eQuest v3.65-7173[6] and HOT2000[7] energy simulation software was utilized. eQuest is a free DOE-2.2 based whole-building energy modelling software that was funded largely through the United States Department of Energy. It calculates energy use on an hourly basis and was chosen to model all Part 3 and commercial archetypes. HOT2000 is developed by Natural Resources Canada (NRCan) for low-rise residential buildings and was chosen to model all Part 9 archetypes. These modelling simulations are capable of producing reliable results when comparing the relative impact on energy performance of various design measures; and when showing compliance of the design with the selected reference energy standard.

2.3.1 Energy Conservation Measures

Energy Conservation Measures (ECMs) are critical to achieving the energy requirements demanded by each tier of the study. The process by which ECMs were selected was dependant on two key factors, applicability, and impact. Therefore, understanding of the building archetype and each tier's energy goals was paramount to choosing the most impactful and cost-effective ECMs.

ECMs that deal with Architectural design aspects are known to be "passive measures", which are assessed first in the design process, as was the recommended approach by the ENB Steering and Technical Committees. These ECMs typically have longer lifespans than mechanical and electrical systems, and can steer a building design towards energy efficiency. Architectural ECMs can include wall and roof insulation, window design, window-to-wall ratio, and floor and slab insulation. This is followed by "active measures", which are ECMs that fall under Mechanical and Electrical design

[6] eQuest. 2018. http://doe2.com/equest/index.html
[7] HOT2000. 2020. https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-homes/professional-opportunities/tools-industry-professionals/20596

aspects. Mechanical ECMs can include heating system design, boiler efficiency, fan and pump optimization, and ventilation rightsizing, while electrical ECMs can include indoor and outdoor lighting, and lighting controls. These systems are designed after fully optimizing the architectural design. Finally, after optimizing passive and active design, high quality construction practice and installation techniques must be applied. This ensures both active and passive measures are implemented through mechanical and electrical system commissioning, and envelope airtightness. Additionally, these ECM selections only represent one design path and are not indicative of every possible design. A different combination of ECMs could produce similar energy reductions.

2.3.2 The "Energy Gap"

To achieve an emissions neutral building, energy efficiency measures, or ECMs, must be applied to the building to reduce the energy demand of the building. However, as ECMs are implemented and energy demand reduced, diminishing returns will eventually impact energy efficiency, and a plateau will be reached. The remaining energy which is necessary to operate the building can be known as the "energy gap" and is shown in the figure below. To achieve an emissions neutral building and offset this energy gap in Alberta, which has a high electric grid emissions factor, renewable energy systems must be implemented. However, it should be noted that as the grid decarbonizes over time, this energy gap will decrease, and accordingly smaller renewable energy systems can be implemented by buildings.

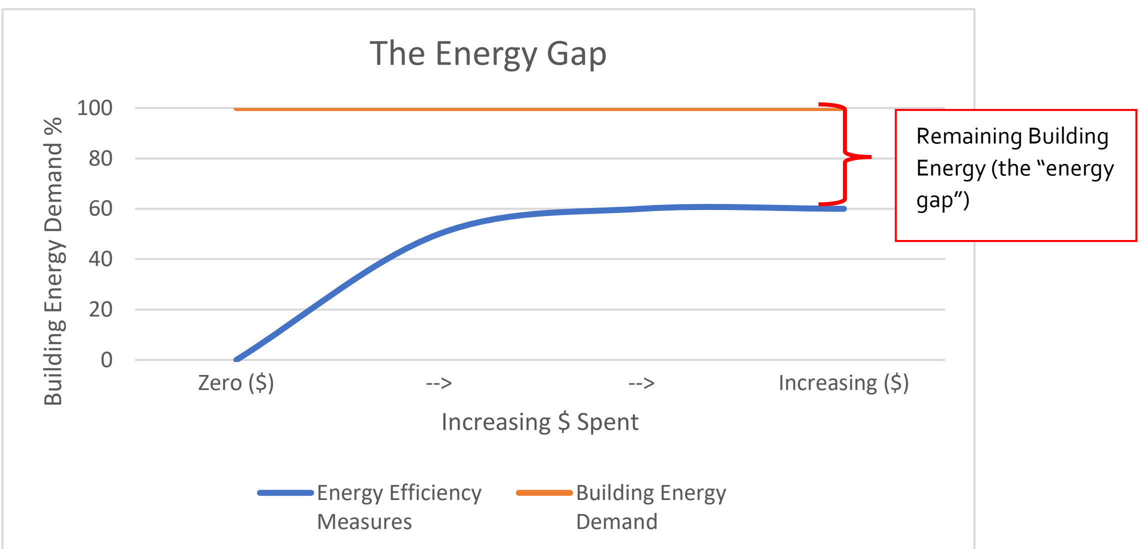


Figure 1: The "Energy Gap"

2.4 An Emissions Neutral Pathway

One possible path to achieve an emissions neutral building has been shown through the following figure, which describes the methodology shown in this study. On-site solar PV has been sized based on 75% of the area of roof space available.

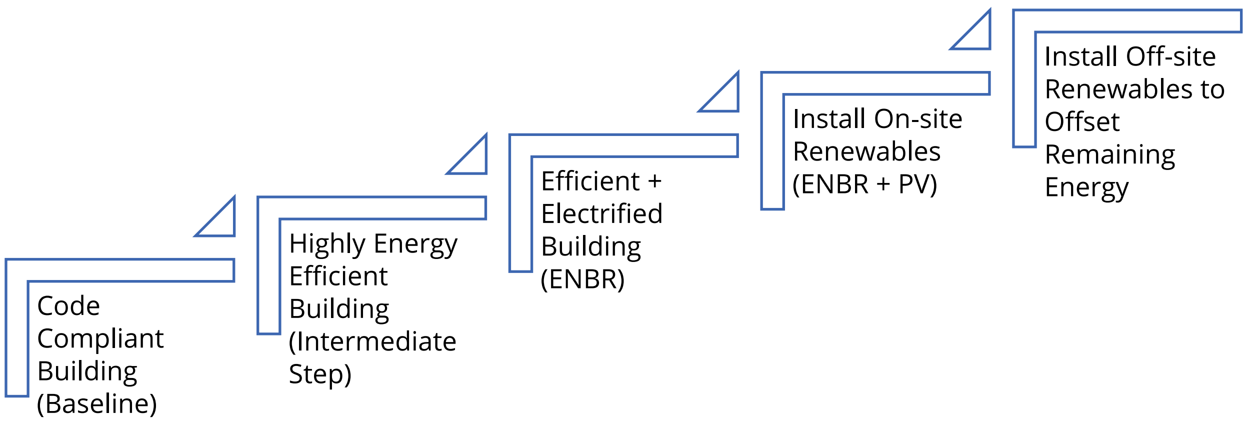


Figure 2: An Emissions Neutral Pathway

2.5 Cost Modelling

2.5.1 ECM Costing

To ensure transparency and completeness, a Class D cost estimate was completed by an independent cost consultant. In pricing the ECMs, the cost consultant employed its in-house database of unit rates, which lists thousands of construction components. These were aggregated into assemblies according to the definitions provided by the design. They were then adjusted for type, scale, and location of project based on the market knowledge and experience of the cost consultant. It should be noted that the purpose of pricing baseline and proposed costs for the ECMs is to arrive at a series of cost premiums, which when added together, represent the marginal cost of achieving a certain energy standard. In that context, the absolute cost of an item is of less importance than the relative costs of the base and proposed cases.

2.5.2 Net-Present Value Analysis

A 30-year net-present value (NPV) analysis has been completed on each building archetype and energy tier. This analysis considers the capital cost of the building and all applicable ECMs, the cost of natural gas and electricity, operations and maintenance (O&M) costs, and equipment replacement costs. Values are as follows:

- Discount Rate: 3%
- Electricity Cost: $0.1/kWh
- Natural Gas Cost: $5.5/GJ
- Installed Solar Photovoltaic Cost: $2/kWp
- O&M Rate: 2% of building capital cost
- Electricity Escalation Rate: 1%
- Natural Gas Escalation Rate: 2%
- Natural Gas Emissions Factor: 0.18 kg CO_2e/kWh
- 2019 Electricity Emission Factor: 0.585 kg CO_2e/kWh
- 2030 Electricity Emission Factor: 0.324 kg CO_2e/kWh

2.5.3 Comparative Costing Methodology

The Emissions Neutral Building project steering committee identified affordability as a critical success factor for the Emissions Neutral Buildings project. A cost consultant provided a Class D estimate of costs for the baseline, intermediate case, and carbon neutral case for each of the archetypes. Since a Class D estimate is a very high-level cost estimate, the project team gathered additional sources of cost information to determine if the capital cost premiums from the cost consultant aligns with other sources.

The comparative analysis focuses on the two Part 9 archetypes (Single Family Detached homes and Row Housing). Five additional sources are used to determine the cost premium relative to the baseline. The costing sources used in this comparative analysis are as follows:

- ENB Costing from project
    - This is the capital cost premium determined by the cost consultant on the ENB project. Costs were calculated using dollars per square foot of wall area, dollars per square foot of floor area, or an absolute cost from the cost consultant's database.
- HTAP (Housing Technology Assessment Platform)
    - Natural Resources Canada has developed a tool which allows users to investigate multiple packages of ECMs (energy conservation measures) for a Part 9 building and compare costs.
    - The project team extracted data from the HTAP costing database to determine the cost premium of the ECMs required to reach carbon neutrality from the baseline. The data in the HTAP costing database is in dollars per square foot of wall or floor area, or absolute costs. Units were converted as necessary to compare to the costing from the project.
    - The HTAP database contains costing data from across Canada which was collected through the LEEP (Local Energy Efficiency Partnerships) program. Costs primarily used in this analysis were collected in Manitoba and Ontario. The highest of the costs were used where multiple cost options were available for an ECM to be conservative.
- Geoexchange Consultant
    - A local consultant provided some costing on retrofitting geoexchange systems into existing homes to achieve net zero. The premium in this case is significantly higher than the other scenarios (17% vs. 7-10%), however replacing a system is significantly more expensive than installing a system during construction.
- Net Zero Home Builder
    - A local net zero home builder reviewed the costing from the project and confirmed an 11% cost premium for rowhousing seems reasonable given the 10% increase for detached single family dwellings.
- Canada Home Builders Association (CHBA) Net Zero Council
    - Costs from the CHBA Net Zero Housing Council align with the 10% premium for the single family detached home. The CHBA data states that a $36,000 premium (before PV) is required to go from code-built construction to net zero ready.

2.6 Metrics

The following metrics have been determined for each building archetype:

- Energy Code Improvement (NECB 2017, ABC 9.36): This describes the overall energy reduction of this scenario when compared to the baseline model, in percentage.
- Energy Use Intensity: This describes the total energy utilized by a building archetype, in kWh/m^2.
- Thermal Energy Demand Intensity: This describes the thermal (heat) energy utilized by a building archetype, in kWh/m^2.
- Greenhouse Gas Emissions: This describes the total annual greenhouse gas emissions associated with a building archetype, in t CO_2e.
- Incremental Building Cost: This describes the architectural, mechanical, and electrical ECM costs associated with energy efficiency upgrades, in 2020 CAD$.
- Net Present Value: This describes the NPV over a 30-year term, in 2020 CAD$ and includes annual operations and maintenance costs, annual electricity, and natural gas costs, with escalations.
- Simple Payback (Incremental Cost): This describes the length of time to pay back the incremental ECM and renewable energy system costs, in years. These are shown in Appendix C.

2.7 Limitations

The following limitations have been considered:

- Emissions Neutral Building Definition
  - Only the stated emissions neutral building definition was considered.
- Energy Budgeting
  - On-site solar PV will be utilized. This does not account for other renewables or zero carbon forms of energy which could be used, such as a low temp district energy system or solar thermal.
  - Generates an annual average energy budget based on climate zone, scheduling, etc.
  - Full emissions neutrality achieved through on-site energy generation.
- Renewable Energy Utility Costs
  - Does not account for potential electrical transmission and distribution costs which may be incurred due to grid infrastructure evolution, miscellaneous utility costs/fees, solar electricity storage for non-generating periods for solar PV (night hours), or periods when electricity must be pulled from the grid (peaking hours), etc. Additionally, potential utility connection cost and monthly operational savings associated with having only one utility connection (electricity for electrified buildings) was not included.
- Carbon Tax
  - A carbon tax has not been included in this study. This is due to two main reasons: 1) By not including a carbon tax, this study shows the most conservative valuation of the buildings over a 30-year timeframe. Including a carbon tax will only improve the

building's NPV outlook in comparison to a higher GHG emitting reference building. 2) A carbon tax may or may not be included in governmental policy going forward, and if it is included, it is difficult to forecast what buildings, industries, and strategies will be implemented.

- Full Electrification
    - This study may not capture the costs of all additional electrical equipment and building infrastructure which would be necessary to electrify a building.
- Current ECM Technology and Selection
    - Archetype ECM packages were selected based off stakeholder feedback, and represent only one path to a highly efficient building.
    - ECMs were selected based off current technology that could be implemented today.
- Alberta Electric Grid Emissions Projections
    - Emissions forecasts were built on the baseline scenario described by the Alberta Electric System Operator (AESO) 2019 Long-term Outlook. However, this scenario describes only one pathway impacting the Alberta grid emissions factor.
- Financial Rates
    - Inflation rate, Escalation rates, Discount rates, Electricity and Natural Gas costs, Operations and Maintenance costs, Renewable Energy Credit (REC) costs, Solar PV capital costs, etc., could change based on market fluctuations and other unforeseen factors. Electricity and natural gas costs can be especially impacted due to national and international factors.
- Building Size/Massing
    - Slim/narrow buildings have an inherently smaller roof area, therefore they will have a smaller solar photovoltaic area to generate renewable energy and reduce emissions. This building will have difficulty achieving a sufficient emissions reduction if it is too tall, and will have to increase it's energy efficiency to compensate. This increases cost and may prove to be unfeasible.
- Architectural Limitations
    - Individual building architectural design, such as orientation, façade articulation, and massing may impact energy metrics.

3 Building Archetypes

3.1 Part 9 Archetypes

The following Part 9 archetypes were assessed using HOT2000 modelling software. Detailed building archetype ECMs can be found in Appendix A.

3.1.1 Detached Single Family Home

The building archetype baseline statistics are as follows:

Number of floors: 2 (including floor level garage)

Total floor area: 180 m^2

Window-to-wall ratio: 20%

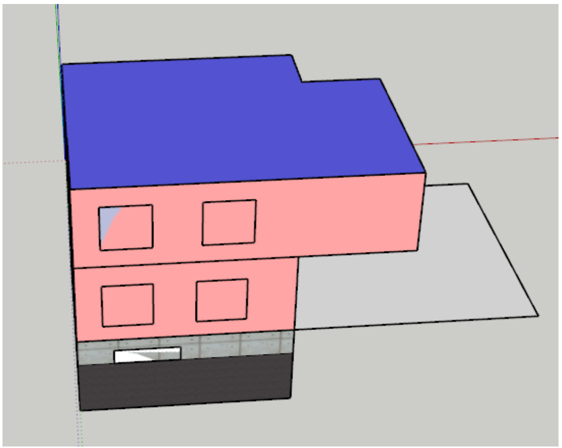


Figure 3: Detached Single Family Home Archetype

3.1.2 Row Housing

The building archetype baseline statistics are as follows:

Number of floors: 3 (including floor level garage)

Total floor area: 650 m^2

Window-to-wall ratio: 15%

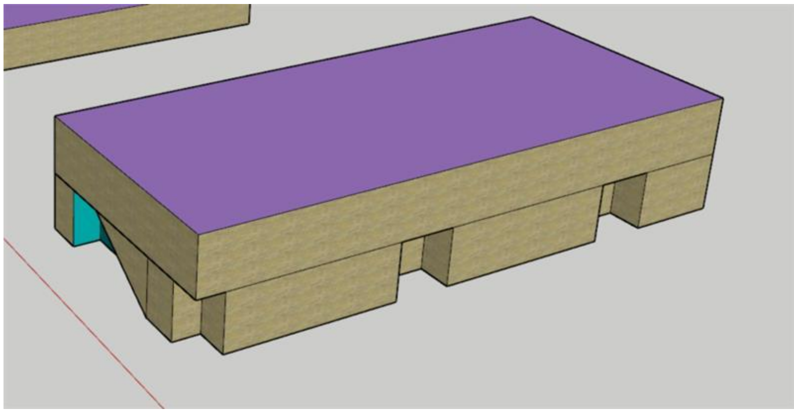


Figure 4: Row House Archetype

3.2 Part 3 Archetypes

The following Part 3 archetypes were assessed using eQUEST modelling software. Detailed building archetype ECMs can be found in Appendix A.

3.2.1 High-Rise Residential

The building archetype baseline statistics are as follows:

Number of floors: 29

Total floor area: 20,400 m^2

Window-to-wall ratio: 35%

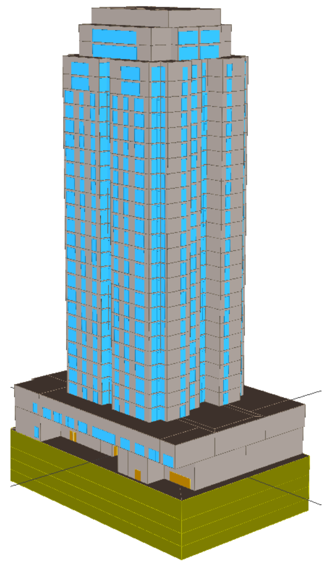


Figure 5: High-Rise Residential Archetype

3.2.2 High-Rise Commercial (Office)

The building archetype baseline statistics are as follows:

Number of floors: 18

Total floor area: 23,050 m^2

Window-to-wall ratio: 75%

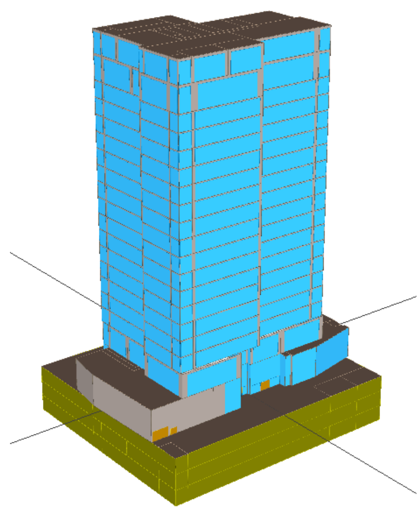


Figure 6: High-Rise Commercial Archetype

3.2.3 Low-Rise Commercial (Retail)

The building archetype baseline statistics are as follows:

Number of floors: 1

Total floor area: 1,400 m^2

Window-to-wall ratio: 30%

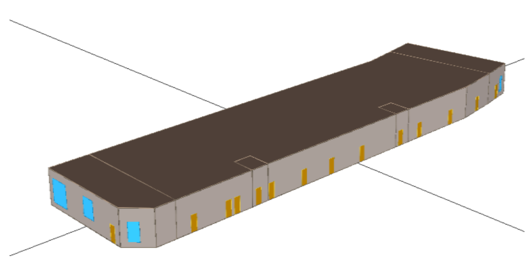


Figure 7: Low-Rise Commercial Archetype

4 Archetype Results

4.1 Detached Single Family Home

The following results describe the energy, GHG emissions, and costing metrics for a detached single-family home in Edmonton. Energy modelling simulations and analyses were completed for the baseline, intermediate, and ENBR energy targets. On-site solar photovoltaic energy systems have been implemented to offset the emissions required to achieve an emissions neutral building. This strategy is illustrated in the Emissions Neutral Pathway. Payback period for incremental costs are shown in Appendix C.

4.1.1 Energy, Emissions, and Cost Metrics

Table 1: Detached Single Family Home Results

	Baseline	Int. Step	ENBR	On-site PV (14 kWp)	Off-site PV (0 kWp)
Energy Metrics (Annual)					
Energy Code Improvement (%)	0	48%	63%	NA	NA
EUI (kWh/m^2)	175	92	66	NA	NA
TEDI (kWh/m^2)	100	36	36	NA	NA
Electricity Demand (kWh)	7,479	6,870	11,994	-14,952	NA
Nat. Gas Demand (kWh)	24,376	9,806	0	NA	NA
Greenhouse Gas Emissions Metrics (Annual)					
GHG Emissions (t CO^2e)	9	6	7	-9	0
GHG Emissions Intensity (kg CO_2e/m^2)	48	32	38	0	0
Cost Metrics					
Building Cost (2020 CAD$)	$300,993	$317,917	$329,973	NA	NA
Building Area Cost (2020 CAD$/m^2)	$1,645	$1,737	$1,803	NA	NA
Incremental ECM Cost (2020 CAD$)	$0	$16,924	$28,980	$24,000	$0
30-Year NPV (2020 CAD$)	$521,832	$532,695	$555,216	$6,833	$0

4.1.2 Emissions Neutral Pathway

The following figure describes the pathway which could be taken by a building to achieve emissions neutrality.

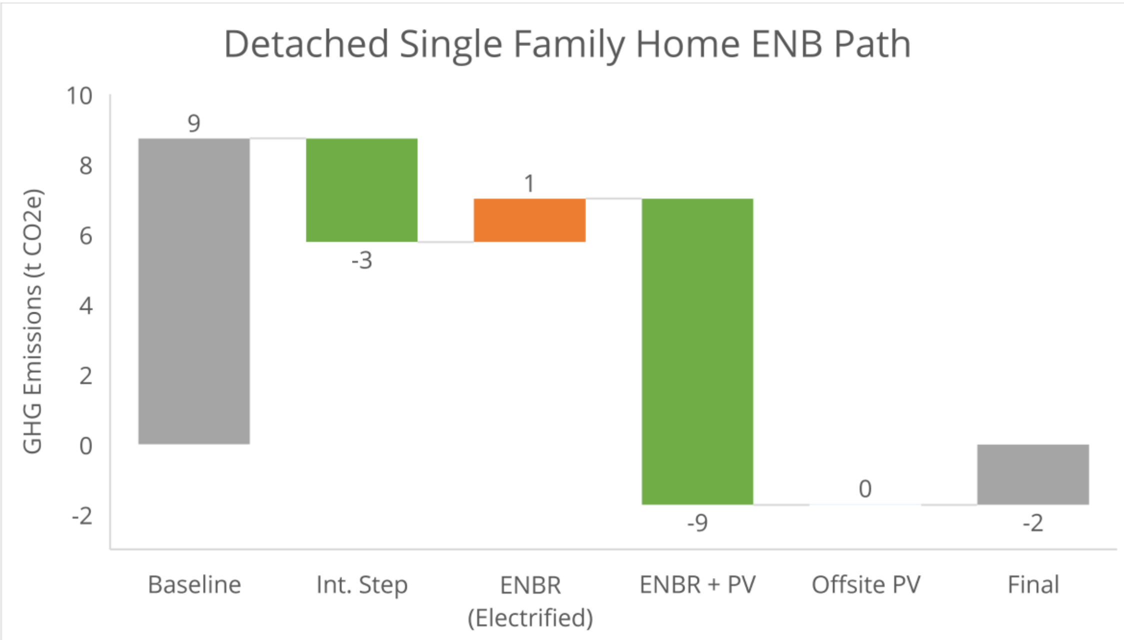


Figure 8: Detached Single Family Home ENB Path

The Baseline represents a code compliant building which meets ABC 9.36 and would produce 9 t CO2e of GHG emissions annually. By increasing energy efficiency to the Intermediate Step, 3 t CO_2e of GHG emissions would be reduced. When the building is fully electrified to ENBR, emissions would increase by 1 t CO_2e, due to the complete elimination of natural gas and exclusive use of electricity to power the building. This is due to the Alberta electric grid emissions factor which is about 3 times higher than natural gas. To fully offset these annual emissions, a 14 kWp on-site PV system could be installed, reducing GHG emissions to below zero. In this scenario, an off-site renewable energy system would not be required to achieve emissions neutrality.

4.2 Row Housing

The following results describe the energy, GHG emissions, and costing metrics for a row house building in Edmonton. Energy modelling simulations and analyses were completed for the baseline, intermediate, and ENBR energy targets. On-site photovoltaic energy systems have been implemented to offset the emissions required to achieve an emissions neutral building. This strategy is illustrated in the Emissions Neutral Pathway. Payback period for incremental costs are shown in Appendix C.

4.2.1 Energy, Emissions, and Cost Metrics

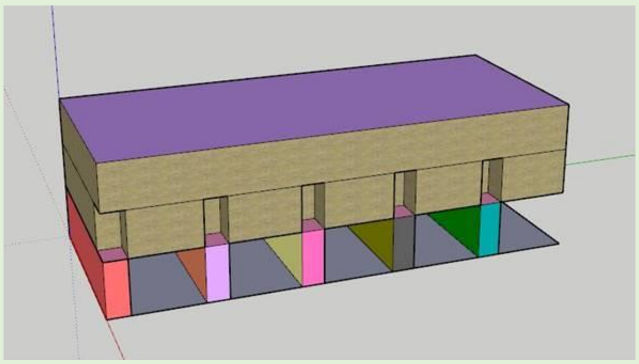
Table 2: Row Housing Results

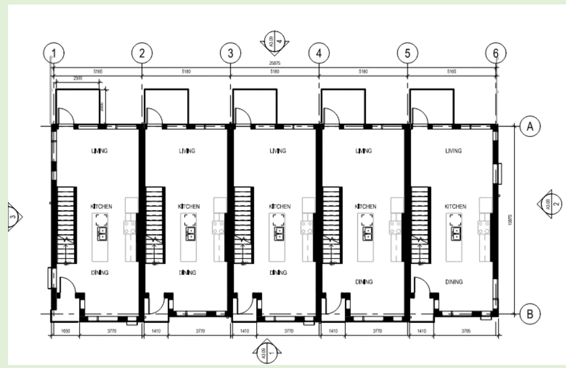
	Baseline	Int. Step	ENBR	On-site PV (40 kWp)	Off-site PV (0 kWp)
Energy Metrics (Annual)					
Energy Code Improvement (%)	0	52%	67%	NA	NA
EUI (kWh/m²)	187	90	61	NA	NA
TEDI (kWh/m²)	119	36	38	NA	NA
Electricity Demand (kWh)	23,822	22,991	39,583	-49,840	NA
Nat. Gas Demand (kWh)	96,396	34,902	0	NA	NA
Greenhouse Gas Emissions Metrics (Annual)					
GHG Emissions (t CO^2e)	31	20	23	-29	0
GHG Emissions Intensity (kg CO_2e/m^2)	48	30	36	0	0
Cost Metrics					
Building Cost (2020 CAD$)	$988,166	$1,051,497	$1,098,825	NA	NA
Building Area Cost (2020 CAD$/m²)	$1,527	$1,625	$1,698	NA	NA
Incremental ECM Cost (2020 CAD$)	$0	$63,330	$110,658	$80,000	$0
30-Year NPV (2020 CAD$)	$1,720,567	$1,794,200	$1,879,236	$22,778	$0

CASE STUDY: Energy Modelling – Row House

The value of energy modelling was clearly shown throughout this study as multiple energy model iterations were completed throughout the engagement and costing process.

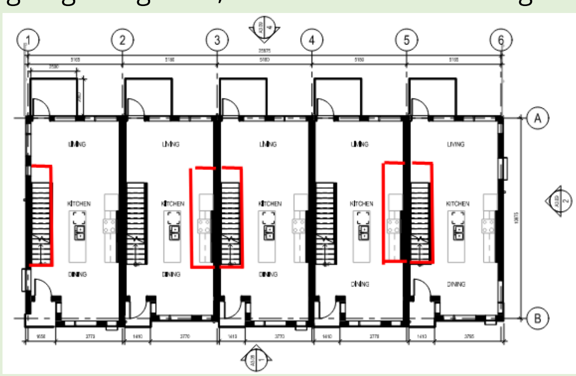
An example of this was seen through the row house modelling process. The initial row house design is seen in the 3D modelled figure and drawing below, which shows individual heated staircases for each unit.

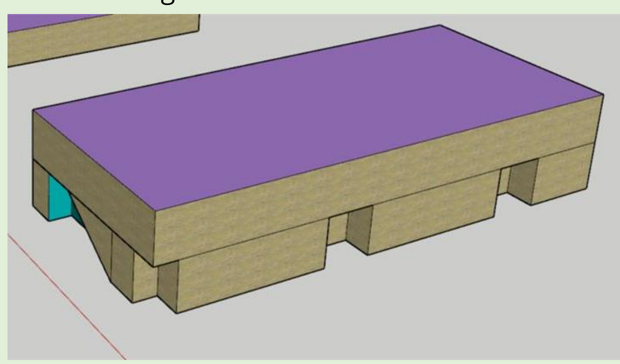




Due to this initial design, exterior wall insulation values (or R values) had to be sized as an R-30 and R-40 wall to meet the energy target requirements. This led to a large amount of expensive exterior insulation being applied to the exterior wall assembly, which caused an unexpectedly high increase in initial building cost.

To remedy this, the row house design was altered to shift all entryway staircases from the 1st floor garages together, as shown in the drawing and 3D rendering below.





Additionally, each stairway zone had its heating needs minimized, reducing the amount of energy required to heat the space. This simple design modification reduced the overall energy required by the building and allowed for a reduction in the exterior wall insulation values to R-24 and R-26. By reducing the exterior wall insulation, a wall assembly could be utilized which greatly reduced the row house cost, saving the building significant initial capital costs.

This simple example shows the significant value building energy modelling can have on a project and that there are many design solutions possible, which can improve energy consumption and reduce cost. By utilizing energy modelling early in building design, both energy and cost can be optimized for and reduced, achieving energy, emissions, and economic goals.

INTEGRAL GROUP

4.2.2 Emissions Neutral Pathway

The following figure describes the pathway which could be taken by a building to achieve emissions neutrality.

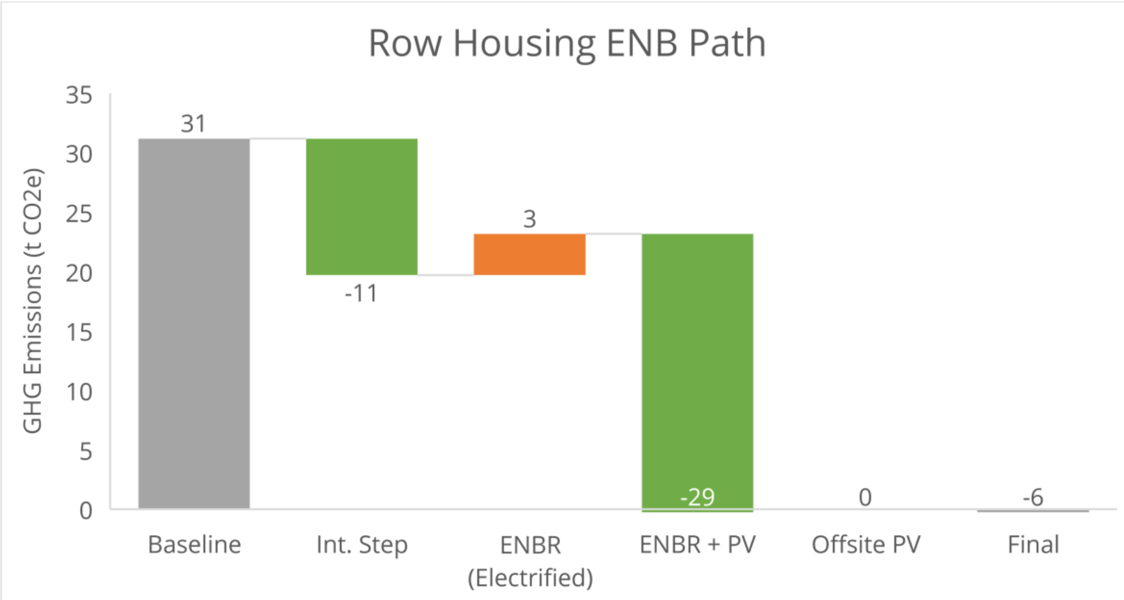


Figure 9: Row Housing ENB Path

The Baseline represents a code compliant building which meets ABC 9.36 and would produce 31 t CO2e of GHG emissions annually. By increasing energy efficiency to the Intermediate Step, 11 t CO_2e of GHG emissions would be reduced. When the building is fully electrified to ENBR, emissions would increase by 3 t CO_2e, due to the complete elimination of natural gas and exclusive use of electricity to power the building. This is due to the Alberta electric grid emissions factor which is about 3 times higher than natural gas. To fully offset these annual emissions, a 40 kWp on-site PV system could be installed, reducing GHG emissions to below zero. In this scenario, an off-site renewable energy system would not be required to achieve emissions neutrality.

4.3 High-Rise Residential

The following results describe the energy, GHG emissions, and costing metrics for a high-rise residential building in Edmonton. Energy modelling simulations and analyses were completed for the baseline, intermediate, and ENBR energy targets. On-site and off-site solar photovoltaic energy systems have been implemented to offset the emissions required to achieve an emissions neutral building. This strategy is illustrated in the Emissions Neutral Pathway. Payback period for incremental costs are shown in Appendix C.

4.3.1 Energy, Emissions, and Cost Metrics

Table 3: High-Rise Residential Results

	Baseline	Int. Step	ENBR	On-site PV (305 kWp)	Off-site PV (1925 kWp)
Energy Metrics (Annual)					
Energy Code Improvement (%)	0	51%	53%	NA	NA
EUI (kWh/m^2)	229	112	107	NA	NA
TEDI (kWh/m^2)	91	28	27	NA	NA
Electricity Demand (kWh)	2,207,989	1,387,824	2,767,649	-380,030	-2,398,550
Nat. Gas Demand (kWh)	3,072,398	1,452,430	0	NA	NA
Greenhouse Gas Emissions Metrics (Annual)					
GHG Emissions (t CO^2e)	1842	1072	1620	-222	-1404
GHG Emissions Intensity (kg CO_2e/m^2)	90	53	79	0	0
Cost Metrics					
Building Cost (2020 CAD$)	$58,647,288	$60,696,213	$60,629,517	NA	NA
Building Area Cost (2020 CAD$/m^2)	$2,877	$2,978	$2,974	NA	NA
Incremental ECM Cost (2020 CAD$)	$0	$2,048,925	$1,982,229	$610,000	$3,850,000
30-Year NPV (2020 CAD$)	$96,193,639	$96,514,753	$98,760,693	$173,679	$1,096,170

4.3.2 Emissions Neutral Pathway

The following figure describes the pathway which could be taken by a building to achieve emissions neutrality.

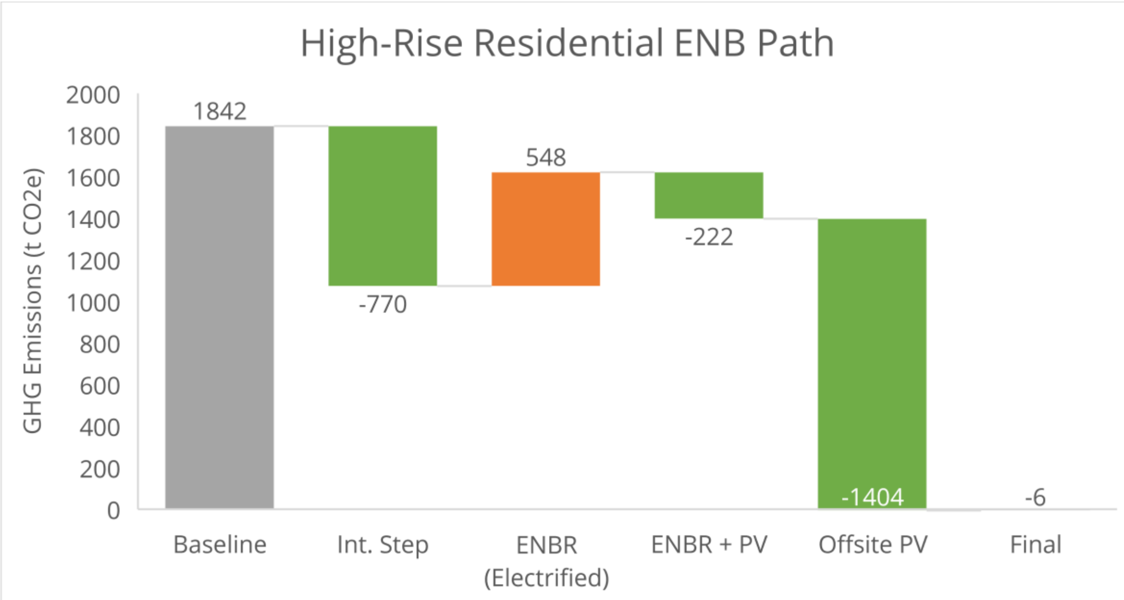


Figure 10: High-Rise Residential ENB Path

The Baseline represents a code compliant building which meets NECB 2017 and would produce 1842 t CO2e of GHG emissions annually. By increasing energy efficiency to the Intermediate Step, 770 t CO_2e of GHG emissions would be reduced. When the building is fully electrified to ENBR, emissions would increase by 548 t CO_2e, due to the complete elimination of natural gas and exclusive use of electricity to power the building. This is due to the Alberta electric grid emissions factor which is about 3 times higher than natural gas. To offset a portion of the annual emissions, a 305 kWp on-site PV system could be installed. The amount of solar PV installed on-site is based on the area of roof space. In this scenario, a 1925 kWp off-site renewable energy system would be required to achieve emissions neutrality.

4.4 High-Rise Commercial (Office)

The following results describe the energy, GHG emissions, and costing metrics for a high-rise commercial office building in Edmonton. Energy modelling simulations and analyses were completed for the baseline, intermediate, and ENBR energy targets. On-site and off-site solar photovoltaic energy systems have been implemented to offset the emissions required to achieve an emissions neutral building. This strategy is illustrated in the Emissions Neutral Pathway. Payback period for incremental costs are shown in Appendix C.

4.4.1 Energy, Emissions, and Cost Metrics

Table 4: High-Rise Commercial Results

	Baseline	Int. Step	ENBR	On-site PV (305 kWp)	Off-site PV (2260 kWp)
Energy Metrics (Annual)					
Energy Code Improvement (%)	0	48%	61%	NA	NA
EUI (kWh/m^2)	254	131	98	NA	NA
TEDI (kWh/m^2)	122	35	35	NA	NA
Electricity Demand (kWh)	2,276,727	1,762,424	3,187,635	-371,190	-2,815,960
Nat. Gas Demand (kWh)	4,515,569	2,189,794	0	NA	NA
Greenhouse Gas Emissions Metrics (Annual)					
GHG Emissions (t CO^2e)	2140	1423	1865	-217	-1648
GHG Emissions Intensity (kg CO_2e/m^2)	93	62	81	0	0
Cost Metrics					
Building Cost (2020 CAD$)	$81,280,637	$82,227,192	$82,136,144	NA	NA
Building Area Cost (2020 CAD$/m^2)	$3,527	$3,568	$3,564	NA	NA
Incremental ECM Cost (2020 CAD$)	$0	$946,555	$855,507	$610,000	$4,520,000
30-Year NPV (2020 CAD$)	$133,213,430	$131,814,182	$133,571,831	$173,679	$1,286,933

4.4.2 Emissions Neutral Pathway

The following figure describes the pathway which could be taken by a building to achieve emissions neutrality.

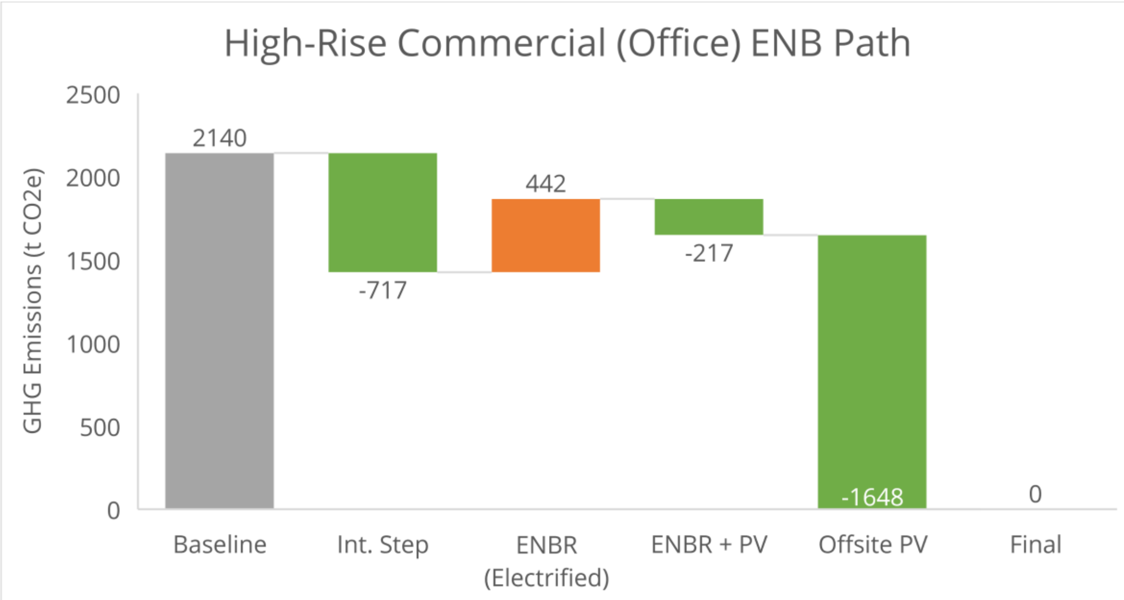


Figure 11: High-Rise Commercial ENB Path

The Baseline represents a code compliant building which meets NECB 2017 and would produce 2140 t CO2e of GHG emissions annually. By increasing energy efficiency to the Intermediate Step, 717 t CO_2e of GHG emissions would be reduced. When the building is fully electrified to ENBR, emissions would increase by 442 t CO_2e, due to the complete elimination of natural gas and exclusive use of electricity to power the building. This is due to the Alberta electric grid emissions factor which is about 3 times higher than natural gas. To offset a portion of the annual emissions, a 305 kWp on-site PV system could be installed. The amount of solar PV installed on-site is based on the area of roof space. In this scenario, a 2260 kWp off-site renewable energy system would be required to achieve emissions neutrality.

4.5 Low-Rise Commercial (Retail)

The following results describe the energy, GHG emissions, and costing metrics for a low-rise commercial retail building in Edmonton. Energy modelling simulations and analyses were completed for the baseline, intermediate, and ENBR energy targets. On-site solar photovoltaic energy systems have been implemented to offset the emissions required to achieve an emissions neutral building. This strategy is illustrated in the Emissions Neutral Pathway. Payback period for incremental costs are shown in Appendix C.

4.5.1 Energy, Emissions, and Cost Metrics

Table 5: Low-Rise Commercial Results

	Baseline	Int. Step	ENBR	On-site PV (130 kWp)	Off-site PV (0 kWp)
Energy Metrics (Annual)					
Energy Code Improvement (%)	0	46%	59%	NA	NA
EUI (kWh/m^2)	226	123	93	NA	NA
TEDI (kWh/m^2)	89	36	36	NA	NA
Electricity Demand (kWh)	160,564	102,843	127,982	-157,263	NA
Nat. Gas Demand (kWh)	151,422	66,364	0	NA	NA
Greenhouse Gas Emissions Metrics (Annual)					
GHG Emissions (t CO^{2}e)	121	72	75	-92	0
GHG Emissions Intensity (kg CO_2e/m^2)	88	52	54	0	0
Cost Metrics					
Building Cost (2020 CAD$)	$2,837,285	$2,887,953	$2,929,353	NA	NA
Building Area Cost (2020 CAD$/m^2)	$2,056	$2,093	$2,123	NA	NA
Incremental ECM Cost (2020 CAD$)	$0	$50,667	$92,067	$260,000	$0
30-Year NPV (2020 CAD$)	$5,049,495	$4,927,023	$5,070,787	$74,027	$0

4.5.2 Emissions Neutral Pathway

The following figure describes the pathway which could be taken by a building to achieve emissions neutrality.

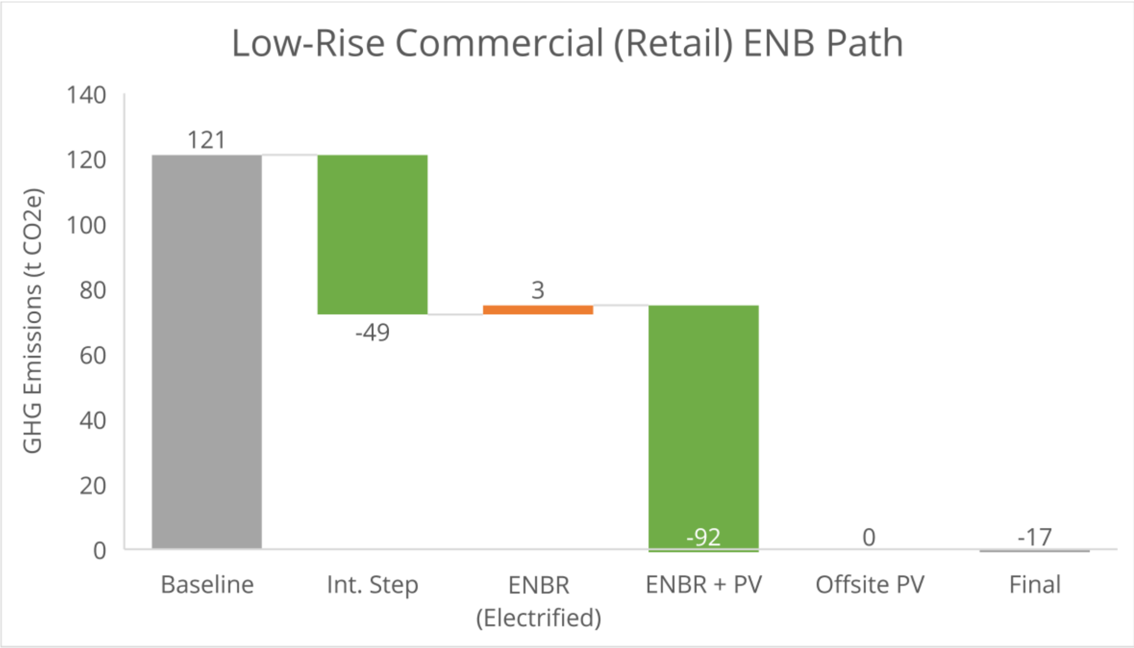


Figure 12: Low-Rise Commercial ENB Path

The Baseline represents a code compliant building which meets NECB 2017 and would produce 121 t CO2e of GHG emissions annually. By increasing energy efficiency to the Intermediate Step, 49 t CO_2e of GHG emissions would be reduced. When the building is fully electrified to ENBR, emissions would increase by 3 t CO_2e, due to the complete elimination of natural gas and exclusive use of electricity to power the building. This is due to the Alberta electric grid emissions factor which is about 3 times higher than natural gas. To fully offset these annual emissions, a 130 kWp on-site PV system could be installed, reducing GHG emissions to below zero. In this scenario, an off-site renewable energy system would not be required to achieve emissions neutrality.

4.6 Archetype Comparisons

The following figure shows the improvement over an energy code compliant baseline building, and therefore only shows the Intermediate and ENBR building targets. All Intermediate targets show energy demand reductions in the 40-50% range, with ENBR targets in the 50-65% energy reduction range.

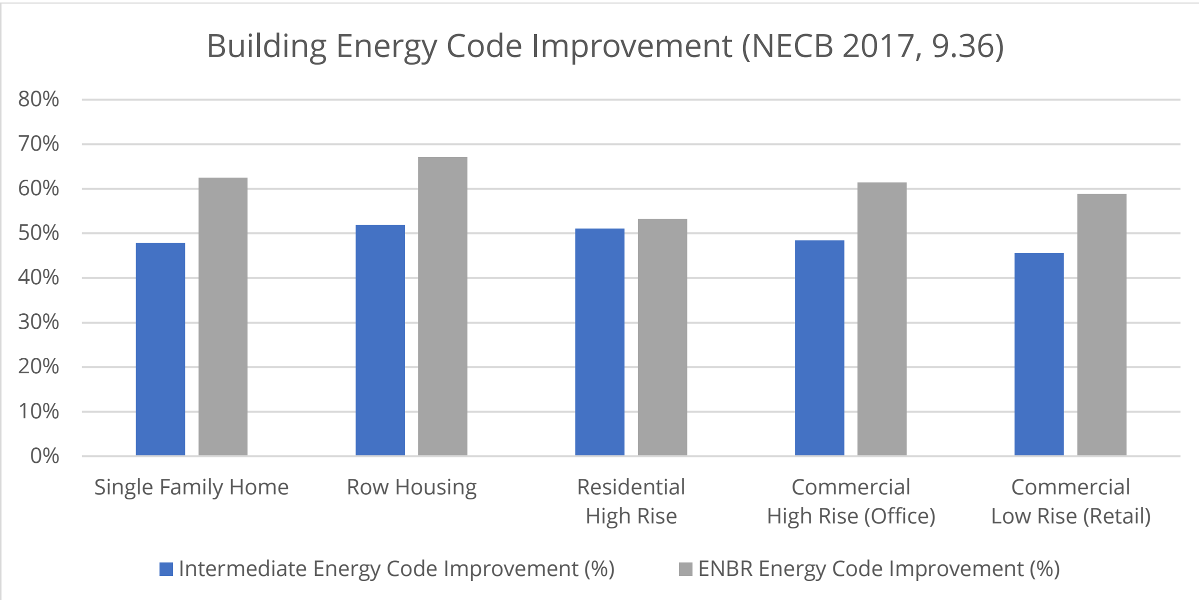


Figure 13: Building Energy Code Improvement Comparison

The following figure shows the energy use intensity of the Baseline, Intermediate, and ENBR targets for each building archetype. All Baseline EUI targets are above 150 kWh/m^2 and show significant reductions to the Intermediate target. ENBR EUI targets are in the 60-100 kWh/m^2 range.

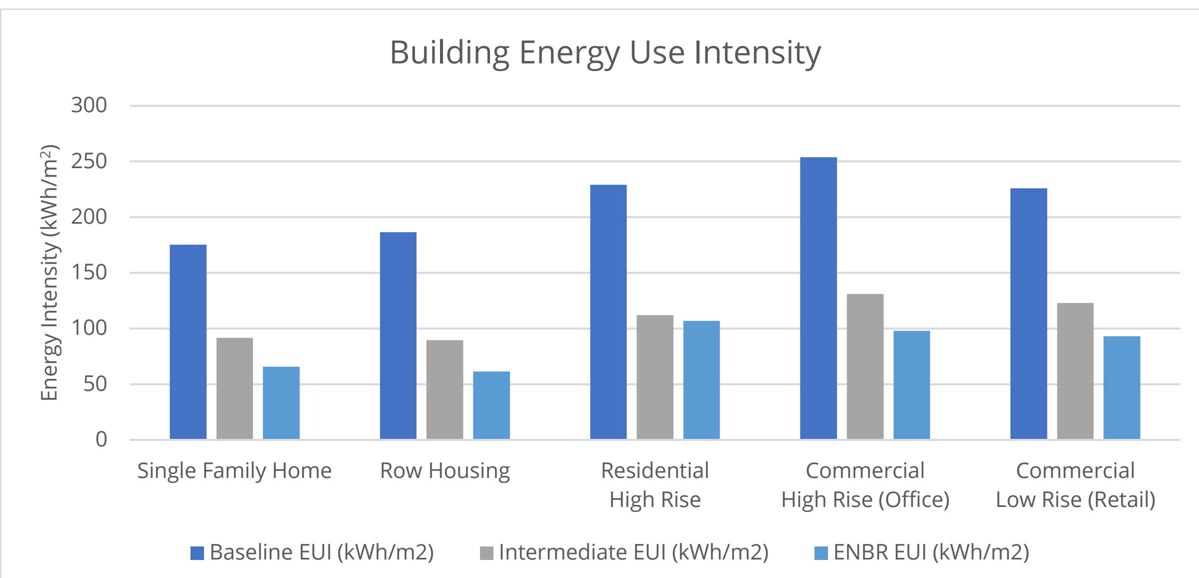


Figure 14: Building EUI Comparison

The following figure shows the thermal energy demand intensity of the Baseline, Intermediate, and ENBR targets for each building archetype. Baseline TEDI is shown to be in the 90-120 kWh/m² range, with Intermediate and ENBR TEDI values decreasing significantly to the 25-36 kWh/m² range.

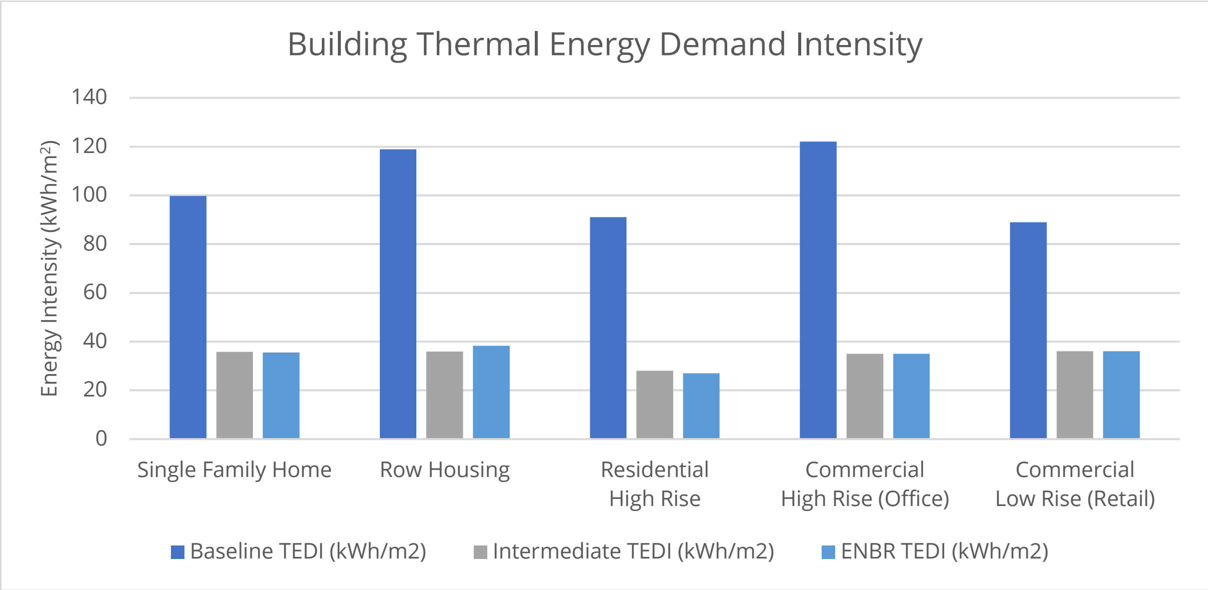


Figure 15: Building TEDI Comparison

The following figure shows the energy consumption intensity for each building archetype's energy target. This illustrates how the natural gas demand for each archetype is decreased to zero, producing zero emissions on-site. Electricity demand decreases with the Intermediate target but rises in the ENBR scenario as all building systems are electrified.

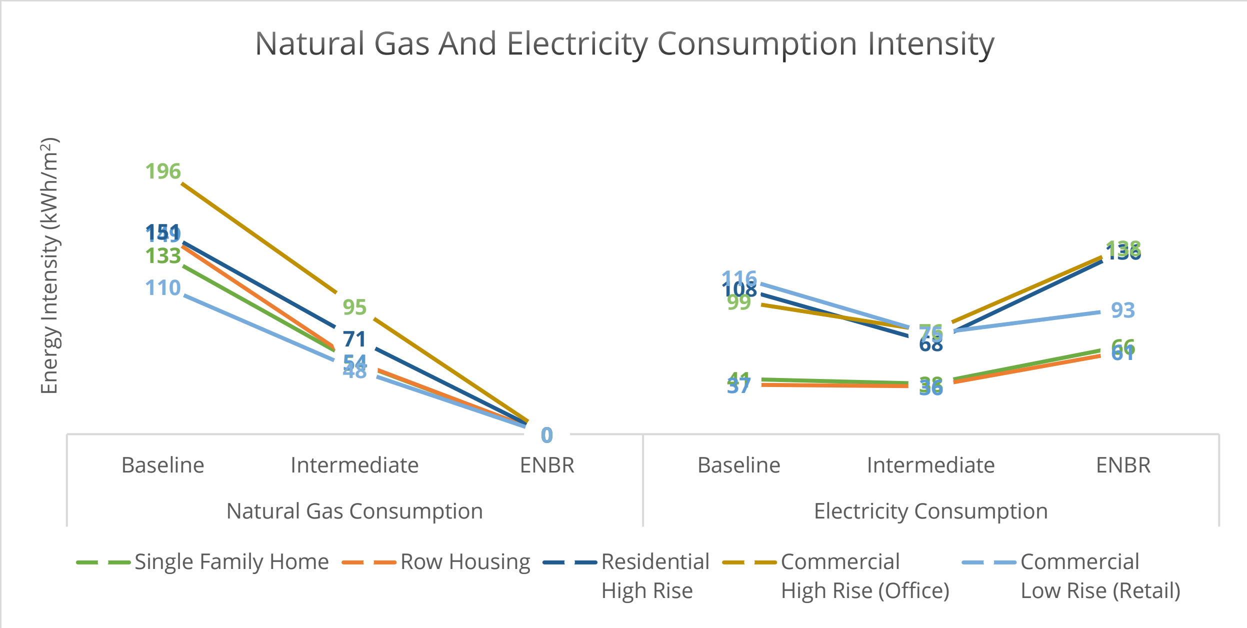


Figure 16: Energy Consumption Comparison

The figure below shows the emissions savings of each building archetype energy target when compared to the baseline code compliant building over a 30-year time period. The Int. + On-site PV and ENBR + On-site PV categories include only the On-site PV systems. As shown the residential and commercial high-rise buildings would require an additional off-site renewable system to achieve emissions neutrality.

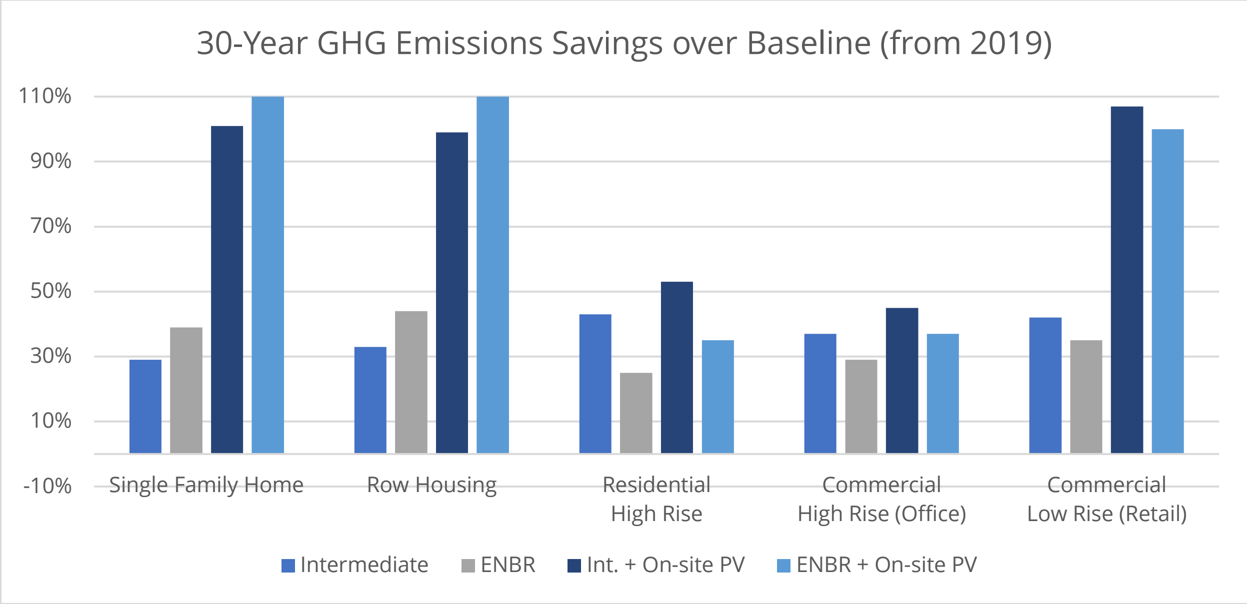


Figure 17: 30-Year GHG Emissions Savings Comparison (from 2019)

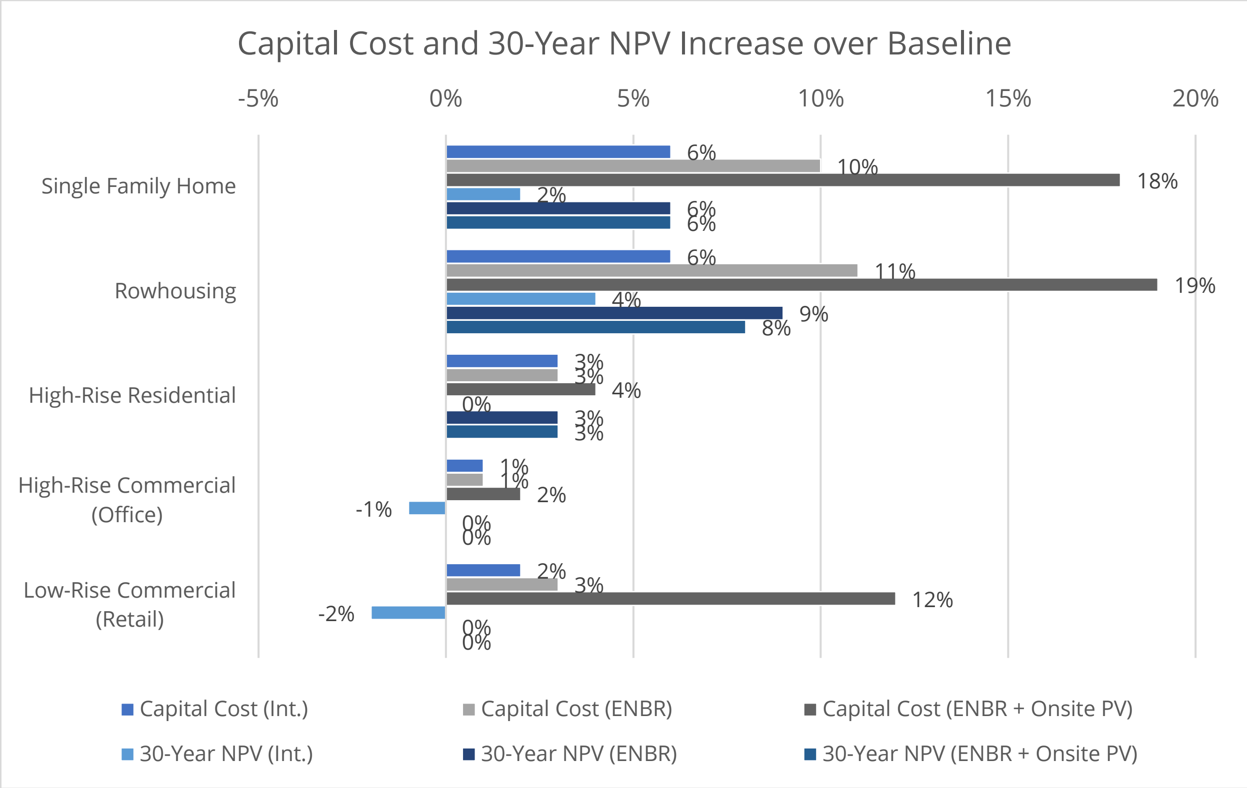


Figure 18: Capital Cost and 30-Year NPV Difference Comparison

The previous figure shows the Initial Capital Cost and 30-Year Net Present Value of each building archetype energy target over the code compliant baseline. The Part 9 buildings show very similar capital costs for each energy target, in the 6-11% range, whereas the Part 3 buildings show capital costs in the 1-3% range. NPV also shows a decreased percentage when compared to initial capital cost, which illustrates how energy efficient buildings can pay back their initial costs over time through fuel savings.

4.7 Selected Comparative Costing

The following cost results were found when compared to other costing resources for single family home and row housing. As noted in the tables below, the cost consultant premiums found in the study are similar to the comparative costing resources, varying by no more than 2-3%. Note that this costing is only for building efficiency improvement construction costing and does not include solar PV.

Table 6: Detached Single Family Home Cost Comparison

Detached Single Family Home			
Source	**Premium**	**Total Cost**	**% increase**
Code Compliant Baseline	0	$300,993.00	0
ENB Costing	$28,980.40	$329,973.40	9.63%
HTAP	$22,378.44	$323,371.44	7.43%
Geoexchange	$51,000.00	$351,993.00	16.94%
Net Zero Builder	$30,099.30	$331,092.30	10.00%
CHBA NZC	$36,000.00	$336,993.00	11.96%

Table 7: Row Housing Cost Comparison

Row Housing			
Source	**Premium**	**Total Cost**	**% increase**
Code Compliant Baseline	0	$980,733.99	0
ENB Costing	$118,090.78	$1,098,824.76	12.04%
HTAP	$147,667.08	$1,128,401.07	15.06%
Geoexchange	N/A	N/A	N/A
Net Zero Builder	$196,146.80	$1,176,880.79	20.00%
CHBA NZC	$124,412.00	$ 1,105,145.99	12.69%

The Geoexchange consultant did not have sufficient costing data for the row house and could not provide an estimate.

5 Summary

The following trends have been observed throughout the completed energy and costing analysis:

- The building archetypes analyzed can achieve significant energy demand and GHG emissions reductions through energy efficiency, but to fully achieve emissions neutrality, renewable energy system must be integrated into building design.
- Due to the high emissions factor of Alberta's 2019 electric grid, full electrification of buildings will likely increase its GHG emissions unless significant renewable energy systems are implemented on-site, or the Alberta electric grid reduces its emissions factor considerably (currently ~3 times more than natural gas).
- To achieve an emissions neutral building, other primary, low-carbon energy sources may be required in addition to on-site renewables, such as:
    - low-carbon district energy systems, ground source heat pumps, cold climate air source heat pumps, and community scale renewable energy micro-grids.
- Buildings which have a large roof area compared to its total height, such as Part 9 buildings and the low-rise commercial building, can achieve annual emissions neutrality on-site through the implementation of solar PV renewable energy systems.
- Part 9 buildings, such as the detached single family home and row housing, have a higher percentage capital cost and NPV premium over the baseline than Part 3 buildings.
- When considering the 30-year NPV of the study, the Emissions Neutral Building energy goal will cost more than the Intermediate target, due to the increased amount of high cost electricity used in that scenario when compared to natural gas.
- Implementing energy efficiency measures in Part 3 buildings reduces or maintains the 30-year NPV of a building when compared to the baseline.
- The costing shown in this study aligns with other costing information received from various sources.

6 Next Steps

This final report is to be used by the City of Edmonton to help inform and define a strategy to achieve Emissions Neutral Buildings in new construction by 2030 in alignment with the City of Edmonton's Energy Transition Strategy.

Appendices

Appendix A – Archetype ECMs and Costing

Detached Single Family Home

SR	Discipline	ECMs	Single Family Home [Baseline]	Cost	Whole Building Cost	Single Family Home [Intermediate]	Cost	Whole Building Cost	Single Family Home [Emissions Neutral Building]	Cost	Whole Building Cost
1	Architectural	Infiltration	4.0 ACH50	$1,560.00	$1,560.00	1.5 ACH @ 50Pa	$2,730.00	$2,730.00	0.6 ACH @ 50Pa	$2,730.00	$2,730.00
2	Architectural	WWR	20%	$0.00	$0.00/m²	20%	$0.00	$0.00/m²	20%	$0.00	$0.00/m²
3	Architectural	Walls	2x6 w/ R-22 batt (R-18-eff)	$226.00/m²	$33,448.00/m²	R-24 Walls metal vinyl cladding 1/2" plywood sheathing 2x8 studs @ 24" O.C. R-28 fibreglass batt insulation 1/2" gypsum board	$237.30/m²	$35,120.40/m²	R-26 Walls metal vinyl cladding 1/2" plywood sheathing 2x8 walls @ 24" O.C. R-32 fibreglass batt insulation 1/2" gypsum board	$239.30/m²	$35,416.40/m²
4	Architectural	Foundation Walls	R-17 (Code Min)	$359.00/m²	$30,515.00	R-17 Walls Concrete foundation walls 2x6 studs @ 24 in. O.C. R-22 fibreglass batt insulation inside cavity 1/2" gypsum board interior	$359.00/m²	$30,515.00	R-20 Walls Insulated Concrete Forms 2 1/2" EPS interior insulation 2 1/2" EPS exterior insulation **OR** 2x4 interior framing @ 24" O.C. w/ R-12 cavity insulation R-12 continuous cavity insulation behind studs	$362.00/m²	$30,770.00
5	Architectural	Exposed Floors	R-28 (code min)	$87.50/m²	$2,187.50/m²	R-28 Floor 3/4" plywood sheathing 2x10 joists @ 16" O.C. R-28 fibreglass batt cavity insulation	$87.50/m²	$2,187.50/m²	R-40 Floor 3/4" plywood sheathing 2x12 joists @ 16" O.C. R-40 fibreglass batt cavity insulation	$103.00/m²	$2,575.00/m²
6	Architectural	Roofs	R-50	$219.90/m²	$16,492.50/m²	R-50 Roof Attic / Gable Roof attic truss @ 24" O.C. R-51 loose blown insulation - 1.5ft or equivalent (RSI 9.0) Roof slope: 5/12 1/2" gypsum interior	$219.90/m²	$16,492.50/m²	R-60 Roof Attic / Gable Roof attic truss @ 24" O.C. R-60 loose blown insulation - 1ft 9in. or equivalent (RSI 10.57) Roof slope: 5/12 1/2" gypsum interior	$238.80/m²	$17,910.00/m²
7	Architectural	Window	1.6 W/m2K 0.26 SHGC	$710.00/m²	$26,270.00/m²	High-performance triple glazed R5.7, Example: All Weather Windows Model: 2500CASEMENT-HS3A-C1804MM|SE Specifications: U = 0.2, SHGC = 0.35 Triple Pane Window, Vinyl Frame Two Low-E Coatings, Argon Fill	$750.00/m²	$27,750.00/m²	High-performance triple glazed R5.7, Example: All Weather Windows Model: 2500CASEMENT-HS3A-C1804MM|SE Specifications: U = 0.2, SHGC = 0.35 Triple Pane Window, Vinyl Frame Two Low-E Coatings, Argon Fill	$750.00/m²	$27,750.00/m²
8	Architectural	SOG	Uninsulated slab	$80.00/m²	$4,320.00/m²	R-10 Slab 2" of XPS insulation under slab	$103.00/m²	$5,562.00/m²	R-10 Slab 2" of XPS insulation under slab	$103.00/m²	$5,562.00/m²
9	Mechanical	System Description (Sum of all mech Systems)	CodeMin Condensing Furnace (92% AFUE)	$92.00/m²	$17,940.00/m²	Natural gas furnace for heating linked to central HRV unit	$150.26/m²	$29,300.00/m²	Electric heating (DX, ASHP, or element)	$200.00/m²	$39,000.00/m²
	Mechanical	Heating	See System Description	$0.00	$0.00/m²	Condensing Furnace = 95% AFUE	$50.00/m²	$0.00/m²	Air Source Heat Pump, unrestricted operation, HSPF = 9.5 @ 8.3degF	$70.00	$0.00/m²
	Mechanical	Cooling	None	$0.00	$0.00/m²	N/A	$0.00	$0.00/m²	N/A	$0.00	$0.00/m²
10	Mechanical	Fans	Standard Fans	$12.00/m²	$0.00/m²	standard	$12.00/m²	$0.00/m²	energy efficient	$12.00/m²	$0.00/m²
11	Mechanical	Ventilation	ABC 9.32.3.3	$20.00/m²	$0.00/m²	9.32.3.3; no oversizing. Continuous Ventilation.	$30.00/m²	$0.00/m²	9.32.3.3; no oversizing. Continuous Ventilation.	$30.00/m²	$0.00/m²
12	Mechanical	Energy Recovery	None	$0.00/m²	$0.00/m²	Full recovery of all non-toxic exhaust with minimum 60% SRE @ 0 deg C	$20.00/m²	$0.00/m²	Full recovery of all non-toxic exhaust with minimum 70% SRE @ 0 deg C	$30.00/m²	$0.00/m²
13	Mechanical	Hot Water	EF = 0.67, 50 gal tank	$20.51/m²	$0.00/m²	Condensing Tank Nat gas	$40.00	$0.00/m²	Electric Integrated Heat Pump Hot Water Tank. Coil eff = 100%; HP COP = 2.5 (conservative)	$60.00/m²	$0.00/m²
14	Mechanical	Pumps	n/a	$0.00	$0.00/m²	N/A	$0.00	$0.00/m²	N/A	$0.00	$0.00/m²
15	Electrical	Interior LPD	Standard	$50.00/m²	$9,750.00/m²	standard	$50.00/m²	$9,750.00/m²	0.6 kWh/day - zero rated homes amount	$50.00/m²	$9,750.00/m²
16	Electrical	Exterior LPD	Standard	$10.00/m²	$1,950.00/m²	No change	$10.00/m²	$1,950.00/m²	No change	$10.00/m²	$1,950.00/m²
17	Electrical	Lighting Controls	N/A	$8.00/m²	$1,560.00/m²	N/A	$8.00/m²	$1,560.00	N/A	$8.00/m²	$1,560.00/m²

Row housing

SR	Discipline	ECMs	Row Housing [Baseline]	Cost	Whole Building Cost	Row Housing [Intermediate]	Cost	Whole Building Cost	Row Housing [Emissions Neutral Building]	Cost	Whole Building Cost
1	Architectural	Infiltration	4.0 ACH50	$5,200.00	$5,200.00	1.5 ACH @ 50Pa	$8,450.00	$8,450.00	0.6 ACH @ 50Pa	$8,450.00	$8,450.00
2	Architectural	WWR	15%	$0.00	$0.00	15%	$0.00	$0.00	15%	$0.00	$0.00
3	Architectural	Walls	2x6 w/ R-22 batt (R-18-eff)	$221.48/m²	$152,599.72	R-24 Walls metal vinyl cladding 1/2" plywood sheathing 2x8 studs @ 24" O.C. R-28 fibreglass batt insulation 1/2" gypsum board	$237.30/m²	$163,499.70/m²	R-26 Walls metal vinyl cladding 1/2" plywood sheathing 2x8 walls @ 24" O.C. R-32 fibreglass batt insulation 1/2" gypsum board	$239.30/m²	$164,877.70/m²
4	Architectural	Foundation Walls	N/A	$0.00/m²	$0.00	N/A - no below grade walls	$0.00/m²	$0.00	N/A - no below grade walls	$0.00/m²	$0.00
5	Architectural	Exposed Floors	R-28 (code min)	$94.08/m²	$19,286.40	R-40 Floor 3/4" plywood sheathing 2x12 joists @ 16" O.C. R-40 fibreglass batt cavity insulation	$100.94/m²	$20,692.70	R-40 Floor 3/4" plywood sheathing 2x12 joists @ 16" O.C. R-40 fibreglass batt cavity insulation	$100.94/m²	$20,692.70
6	Architectural	Roofs	R-50	$215.50/m²	$61,202.57	R-60 Roof Attic / Gable Roof attic truss @ 24" O.C. R-60 loose blown insulation - 1ft 9in. or equivalent (RSI 10.57) Roof slope: 5/12 1/2" gypsum interior	$234.02/m²	$66,462.82	R-70 Roof Attic / Gable Roof attic truss @ 24" O.C. R-70 loose blown insulation - 2ft or equivalent (RSI 12.3) Roof slope: 5/12 1/2" gypsum interior	$252.55/m²	$71,723.06
7	Architectural	Window	1.6 W/m2K 0.26 SHGC	$695.80/m²	$90,454.00	High-performance triple glazed R5.7, Example: All Weather Windows Model: 2500CASEMENT-HS3A-C1804MM|SE Specifications: U = 0.2, SHGC = 0.35 Triple Pane Window Vinyl Frame	$735.00/m²	$95,550.00	High-performance triple glazed R7 Example: Atlantic - All Weather Windows Model: ATL-K-51-00062-00001-CS Specifications U = 0.15, SHGC = 0.24 Triple Pane Window Vinyl Frame	$764.40/m²	$99,372.00
8	Architectural	SOG	R-16 under slab	$111.70/m²	$9,941.30	R-16 Slab 3" of XPS insulation under slab	$111.70/m²	$9,941.30	R-20 continuous w/ 2' skirt 4" XPS Insulation under slab	$123.70/m²	$11,009.30
9	Mechanical	System Description (Sum of all mech Systems)	Condensing Boiler (92% AFUE) - hydronic heating	$93.00/m²	$60,450.00	Condensing Furnace; 95% AFUE w/ unit HRVs	$160.00/m²	$104,000.00	Electric heating (DX, ASHP, or element)	$215.08/m²	$139,800.00
	Mechanical	Heating	See System Description	$0.00	$0.00	Boiler AFUE = 95%	$60.00	$0.00	Air Source Heat Pump, unrestricted operation, HSPF = 9.5 @ 8.3degF	$75.00	$0.00
	Mechanical	Cooling	None	$0.00	$0.00	N/A	$0.00	$0.00	N/A	$0.00	$0.00
10	Mechanical	Fans	Standard Fans	$13.00/m²	$0.00	energy efficient	$13.00/m²	$0.00	energy efficient	$13.00/m²	$0.00
11	Mechanical	Ventilation	ABC 9.32.3.3	$20.00/m²	$0.00	9.32.3.3; no oversizing. Continuous Ventilation.	$30.00/m²	$0.00	9.32.3.3; no oversizing	$30.00/m²	$0.00
12	Mechanical	Energy Recovery	None	$0.00	$0.00	Full recovery of all non-toxic exhaust with minimum 60% sensible effectiveness.	$20.00/m²	$0.00	Full recovery of all non-toxic exhaust with minimum 80% sensible effectiveness.	$35.00/m²	$0.00
13	Mechanical	Hot Water	EF = 0.67, 50 gal tank	$24.73/m²	$0.00	Condensing Tank Nat gas	$40.00/m²	$0.00	Electric Integrated Heat Pump Hot Water Tank. Coil eff = 100%; HP COP = 2.5 (conservative)	$60.00/m²	$0.00
14	Mechanical	Pumps	N/A	$0.00	$0.00	N/A	$0.00	$0.00	VSD	$5.00/m²	$0.00
15	Electrical	Interior LPD	Standard	$48.00/m²	$31,200.00	standard	$50.00/m²	$32,500.00	No change	$50.00/m²	$32,500.00
16	Electrical	Exterior LPD	Standard	$8.00/m²	$5,200.00	No change	$8.00/m²	$5,200.00	No change	$8.00/m²	$5,200.00
17	Electrical	Lighting Controls	N/A	$8.00/m²	$5,200.00	N/A	$8.00/m²	$5,200.00	N/A	$8.00/m²	$5,200.00

High-Rise Residential

SR	Discipline	ECMs	High-Rise Residential [Baseline]	Cost	Whole Building Cost	High-Rise Residential [Intermediate]	Cost	Whole Building Cost	High-Rise Residential [Emissions Neutral Building]	Cost	Whole Building Cost
1	Architectural	Infiltration	0.05 cfm/sqft	$22,320.00	$22,320.00	0.02 cfm/sqft	$31,124.80	$31,124.80	0.02 cfm/sqft	$31,124.80	$31,124.80
2	Architectural	WWR	35%	$0.00	$0.00	20%	$0.00	$0.00	20%	$0.00	$0.00
3	Architectural	Walls	AWR8.5	$684.50/m²	$6,121,275.50	R-42 Effective Wall Precast Concrete Sandwich Panel Gypsum Board Stud Cavity 3" Interior Concrete Panel 10" XPS Insulation or equivalent (to R-50) CC Connectors (16" x 16" spacing) 3" Exterior Concrete Panel Detail 6.1.10 in BC Hydro Thermal Bridging Guide, v.1.3	$765.00/m²	$6,841,162.54	R-42 Effective Wall Precast Concrete Sandwich Panel Gypsum Board Stud Cavity 3" Interior Concrete Panel 10" XPS Insulation or equivalent (to R-50) CC Connectors (16" x 16" spacing) 3" Exterior Concrete Panel Detail 6.1.10 in BC Hydro Thermal Bridging Guide, v.1.3	$765.00/m²	$6,841,162.54
4	Architectural	Foundation Walls	R12	$307.50/m²	$1,321,635.00	R12 2.5" XPS Insulation	$307.50/m²	$1,321,635.00	R12 2.5" XPS Insulation	$307.50/m²	$1,321,635.00
5	Architectural	Exposed Floors	R10	$303.00/m²	$76,144.73	N/A	$0.00/m²	$0.00	N/A	$0.00/m²	$0.00
6	Architectural	Roofs	Roof R31.25 Podium R35.7	$76.50/m²	$241,470.24	R30 6" XPS Insulation; Parapet thermally decoupled via polyurethane block Linear transmittance < 0.01 W/mK	$76.50/m²	$241,470.24	R30 6" XPS Insulation; Parapet thermally decoupled via polyurethane block Linear transmittance < 0.01 W/mK	$76.50/m²	$241,470.24
7	Architectural	Window	R3.4 0.31 SHGC	$700.00/m²	$2,689,378.94	Triple glazed R4.75, 0.31 SHGC U = 1.2 W/sq.mK Triple pane windows 1 low e coating Argon fill Thermally broken installation (Window installed onto XPS insulation w/ Aerogel Insulation against frame)	$730.00/m²	$2,804,638.04	Triple glazed R4.75, 0.31 SHGC U = 1.2 W/sq.mK Triple pane windows 1 low e coating Argon fill Thermally broken installation (Window installed onto XPS insulation w/ Aerogel Insulation against frame)	$730.00/m²	$2,804,638.04
8	Architectural	SOG	Uninsulated (parkade)	$80.00/m²	$164,400.00	Uninsulated (parkade)	$80.00/m²	$164,400.00	Uninsulated (parkade)	$80.00/m²	$164,400.00
9	Mechanical	System Description (Sum of all mech Systems)	2-Pipe FCUs with CHW and hydronic baseboards with Central HRV. Central DOAS with HRV for corridor and non-residential ventilation.	$164.00/m²	$3,646,048.00	2-Pipe FCUs with CHW and hydronic baseboards with Central HRV. Central DOAS with HRV for corridor and non-residential ventilation.	$211.00/m²	$4,690,952.00	Same as option 1 but with electric boilers and electric furnaces for MUA	$208.00/m²	$4,624,256.00
	Mechanical	Heating	See System Description	$0.00	$0.00	Decouple heating from ventilation and minimize pipe/duct runs MUA @ 92% eff	$0.00	$0.00	Decouple heating from ventilation and minimize pipe/duct runs MUA @ 92% eff	$0.00	$0.00
	Mechanical	Cooling	Air-cooled Chiller	$42.00/m²	$0.00	Air-cooled Chillers	$42.00/m²	$0.00	Air-cooled Chillers	$42.00/m²	$0.00
10	Mechanical	Fans	FCUs Avg 0.3W/CFM Corridor MUA 1 W/CFM	$60.00/m²	$0.00	NEMA high efficiency motors with low specific fan power: Fan Coil Units 0.7 W/cfm; Corridor MUAs < 1 W/cfm + intermittent controls	$60.00/m²	$0.00	NEMA high efficiency motors with low specific fan power: Fan Coil Units 0.7 W/cfm; Corridor MUAs < 1 W/cfm + intermittent controls	$60.00/m²	$0.00
11	Mechanical	Ventilation	ASHRAE 62.1-2010	$20.00/m²	$0.00	CoE requirements; no oversizing	$30.00/m²	$0.00	CoE requirements; no oversizing	$30.00/m²	$0.00
12	Mechanical	Energy Recovery	50% Corridor MUA	$18.00/m²	$0.00	Full recovery of all non-toxic exhaust with minimum 80% sensible effectiveness for DOAS HRV Recommended: Run-around glycol heat recovery for parkade (subject to budget) 40% effectiveness	$20.00/m²	$0.00	Full recovery of all non-toxic exhaust with minimum 80% sensible effectiveness for DOAS HRV Recommended: Run-around glycol heat recovery for parkade (subject to budget) 40% effectiveness	$20.00/m²	$0.00
13	Mechanical	Hot Water	EF = 0.67, 50 gal tank	$30.70/m²	$0.00	Condensing, 95% efficient	$35.00/m²	$0.00	Condensing, 95% efficient	$32.00/m²	$0.00
14	Mechanical	Pumps	VSD, NEMA Premium	$4.00/m²	$0.00	VSD	$4.00/m²	$0.00	VSD	$4.00/m²	$0.00
15	Electrical	Interior LPD	40% below NECB 2017	$52.00/m²	$1,156,064.00	55% below NECB 2017	$54.00/m²	$1,200,528.00	55% below NECB 2017	$54.00/m²	$1,200,528.00
16	Electrical	Exterior LPD	70% below NECB 2017	$3.00/m²	$66,696.00	85% below NECB 2017	$3.20/m²	$71,142.40	85% below NECB 2017	$3.20/m²	$71,142.40
17	Electrical	Lighting Controls	-	$0.00/m²	$0.00	Occupancy sensors in circulation/transient spaces. Daylight sensors in daylit areas.	$5.00/m²	$111,160.00	Occupancy sensors in circulation/transient spaces. Daylight sensors in daylit areas.	$5.00/m²	$111,160.00

High-Rise Commercial (Office)

SR	Discipline	ECMs	High-Rise Commercial (Office) [Baseline]	Cost	Whole Building Cost	High-Rise Commercial (Office) [Intermediate]	Cost	Whole Building Cost	High-Rise Commercial (Office) [Emissions Neutral Building]	Cost	Whole Building Cost
1	Architectural	Infiltration	0.05 cfm/sqft	$26,288.80	$26,288.80	0.02 cfm/sqft	$36,147.10	$36,147.10	0.02 cfm/sqft	$36,147.10	$36,147.10
2	Architectural	WWR	80%	$0.00/m²	$0.00	30%	$0.00/m²	$0.00	30%	$0.00/m²	$0.00
3	Architectural	Walls	AWR5	$795.50/m²	$8,085,978.93	R-30 Effective Wall Exterior Cladding 8" Semi-Rigid Exterior Insulation w/ thermally broken fibreglass clips & stainless steel screw fasteners 6" steel stud @ 16" O.C w/ R-22 batt insulation in stud cavity gypsum board interior	$841.50/m²	$8,553,552.82	R-30 Effective Wall Exterior Cladding 8" Semi-Rigid Exterior Insulation w/ thermally broken fibreglass clips & stainless steel screw fasteners 6" steel stud @ 16" O.C w/ R-22 batt insulation in stud cavity gypsum board interior	$841.50/m²	$8,553,552.82
4	Architectural	Foundation Walls	R17	$320.50/m²	$893,554.00	R-17 4" XPS Insulation	$320.50/m²	$893,554.00	R-17 4" XPS Insulation	$320.50/m²	$893,554.00
5	Architectural	Exposed Floors	R20	$354.75/m²	$0.00	N/A	$0.00/m²	$0.00	N/A	$0.00/m²	$0.00
6	Architectural	Roofs	R30	$84.15/m²	$336,602.80	R30 6" XPS Insulation; Parapet thermally decoupled via polyurethane block Linear transmittance < 0.01 W/mK	$84.15/m²	$336,602.80	R30 6" XPS Insulation; Parapet thermally decoupled via polyurethane block Linear transmittance < 0.01 W/mK	$84.15/m²	$336,602.80
7	Architectural	Window	R2.7 0.23 SHGC	$570.00/m²	$2,482,444.80	R4, 0.23 SHGC Double pane windows Vinyl Frame Low-E coating Argon Fill Thermally broken installation (Window installed onto XPS insulation w/ Aerogel Insulation against frame)	$600.00/m²	$2,613,099.79	R4.5, 0.31 SHGC U = 1.2 W/sq.mK Triple pane windows Low-E coating Argon fill Thermally broken installation (Window installed onto XPS insulation w/ Aerogel Insulation against frame)	$730.00/m²	$3,179,271.41
8	Architectural	SOG	Uninsulated (parkade)	$80.00/m²	$274,080.00	Uninsulated (parkade)	$80.00/m²	$274,080.00	Uninsulated (parkade)	$80.00/m²	$274,080.00
9	Mechanical	System Description (Sum of all mech Systems)	Central DOAS with EW HRV coupled with Decentralized CHW AHUs and perimeter RCPs	$264.00/m²	$8,675,304.00	Central DOAS with EW HRV coupled with Decentralized CHW AHUs and perimeter RCPs	$266.00/m²	$8,741,026.00	Same as option 1 but with electric boilers and electric furnaces for MUA	$246.00/m²	$8,083,806.00
	Mechanical	Heating	See System Description	$0.00	$0.00	Decouple heating from ventilation and minimize pipe/duct runs. Eliminate reheat coils.	$0.00	$0.00	Decouple heating from ventilation and minimize pipe/duct runs. Eliminate reheat coils.	$0.00	$0.00
	Mechanical	Cooling	Water-cooled chillers	$48.00/m²	$0.00	Cooling delivered by DOAS as economizer with Glycol Fluid Cooler or Water-cooled chillers for summer season	$50.00/m²	$0.00	Cooling delivered by DOAS as economizer with Glycol Fluid Cooler or Water-cooled chillers for summer season	$50.00/m²	$0.00
10	Mechanical	Fans	DOAS 1: 1.12 W/cfm Parkade MUA 0.6W/cfm AHUs 0.36 W/cfm	$70.00/m²	$0.00	Variable Flow NEMA high efficiency motors with low specific fan power: DOAS 1 1.12 W/cfm Parkade MUA 0.6W/cfm AHUs 0.36 W/cfm	$70.00/m²	$0.00	Variable Flow NEMA high efficiency motors with low specific fan power: DOAS 1 1.12 W/cfm Parkade MUA 0.6W/cfm AHUs 0.36 W/cfm	$70.00/m²	$0.00
11	Mechanical	Ventilation	ASHRAE 62.1-2010	$40.00/m²	$0.00	ASHRAE 62.1; no oversizing Demand Controlled Ventilation based on BMS schedule or CO2 Sensors.	$40.00/m²	$0.00	ASHRAE 62.1; no oversizing Demand Controlled Ventilation based on BMS schedule or CO2 Sensors.	$40.00/m²	$0.00
12	Mechanical	Energy Recovery	DOAS 1 EW 85% DOAS 2 0^=%	$20.00/m²	$0.00	Full recovery of all non-toxic exhaust with minimum 85% total eff for DOAS 1 and 80% for DOAS 2 Recommended: Chiller condenser heat recovery. Run-around glycol heat recovery for parkade (subject to budget) 40% effectiveness	$20.00/m²	$0.00	Full recovery of all non-toxic exhaust with minimum 85% total eff for DOAS 1 and 80% for DOAS 2 Recommended: Chiller condenser heat recovery. Run-around glycol heat recovery for parkade (subject to budget) 40% effectiveness	$20.00/m²	$0.00
13	Mechanical	Hot Water	-	$0.00	$0.00	Local electric water heaters per public washroom	$2.00/m²	$0.00	Local electric water heaters per public washroom	$2.00/m²	$0.00
14	Mechanical	Pumps	VSD, NEMA Premium	$4.00/m²	$0.00	VSD	$4.00/m²	$0.00	VSD	$4.00/m²	$0.00
15	Electrical	Interior LPD	35% below NECB 2017	$58.00/m²	$1,905,938.00	50% below NECB 2017	$60.00/m²	$1,971,660.00	50% below NECB 2017	$60.00/m²	$1,971,660.00
16	Electrical	Exterior LPD	10% below NECB 2017	$3.20/m²	$105,155.20	70% below NECB 2017	$3.50/m²	$115,013.50	70% below NECB 2017	$3.50/m²	$115,013.50
17	Electrical	Lighting Controls	-	$0.00/m²	$0.00	Occupancy sensors in circulation/transient spaces. Daylight sensors in daylit areas.	$6.00/m²	$197,166.00	Occupancy sensors in circulation/transient spaces. Daylight sensors in daylit areas.	$6.00/m²	$197,166.00

Low-Rise Commercial (Retail)

SR	Discipline	ECMs	Low-Rise Commercial (Retail) [Baseline]	Cost	Whole Building Cost	Low-Rise Commercial (Retail) [Intermediate]	Cost	Whole Building Cost	Low-Rise Commercial (Retail) [Emissions Neutral Building]	Cost	Whole Building Cost
1	Architectural	Infiltration	0.05 cfm/sqft	$2,760.00	$2,760.00	0.02 cfm/sqft	$4,140.00	$4,140.00	0.02 cfm/sqft	$4,140.00	$4,140.00
2	Architectural	WWR	25%	$0.00/m²	$0.00	15%	$0.00	$0.00	15%	$0.00/m²	$0.00
3	Architectural	Walls	R17.5	$975.00/m²	$712,295.78	5" XPS Exterior Insulation (R-25) Exterior Insulated Concrete Block Wall with Armadillo FRR Horizontal Z-Girts Supporting Cladding R-27.6 clear field Detail 6.1.11 in BC Hydro Thermal Bridging Guide, v.1.3	$975.00/m²	$712,295.78	5" XPS Exterior Insulation (R-25) Exterior Insulated Concrete Block Wall with Armadillo FRR Horizontal Z-Girts Supporting Cladding R-27.6 clear field Detail 6.1.11 in BC Hydro Thermal Bridging Guide, v.1.3	$975.00/m²	$712,295.78
4	Architectural	Foundation Walls	N/A	$0.00/m²	$0.00	N/A	$0.00/m²	$0.00	N/A	$0.00/m²	$0.00
5	Architectural	Exposed Floors	N/A	$0.00/m²	$0.00	N/A	$0.00/m²	$0.00	N/A	$0.00/m²	$0.00
6	Architectural	Roofs	R27	$80.30/m²	$110,814.00	R30 6" XPS Insulation; Parapet thermally decoupled via polyurethane block Linear transmittance < 0.01 W/mK	$84.15/m²	$116,127.00	R30 6" XPS Insulation; Parapet thermally decoupled via polyurethane block Linear transmittance < 0.01 W/mK	$84.15/m²	$116,127.00
7	Architectural	Window	R2.5 fixed, R2 operable 0.23 SHGC	$560.00/m²	$72,081.61	High-performance double glazed R3.5 for operable and fixed (Window installed onto XPS insulation w/ Aerogel Insulation against frame)	$580.00/m²	$74,655.95	High-performance double glazed R3.5 for operable and fixed (Window installed onto XPS insulation w/ Aerogel Insulation against frame)	$580.00/m²	$74,655.95
8	Architectural	SOG	R10 for 4ft	$104.80/m²	$144,624.00	R-10 insulation under slab R10 thermal break between slab and footing (4FT) - 2" XPS	$104.80/m²	$144,624.00	R-10 insulation under slab R10 thermal break between slab and footing (4FT) - 2" XPS	$104.80/m²	$144,624.00
9	Mechanical	System Description (Sum of all mech Systems)	Rooftop units with gas furnace and electric baseboards	$180.00/m²	$248,400.00	Gas furnace rooftop units with electric baseboards	$200.00/m²	$276,000.00	ASHP COP 2.9	$230.00/m²	$317,400.00
	Mechanical	Heating	See System Description	$0.00	$0.00	See above	$0.00	$0.00	See above	$0.00	$0.00
	Mechanical	Cooling	DX Cooling	$70.00/m²	$0.00	DX Cooling	$70.00/m²	$0.00	ASHP COP 3.3	$120.00/m²	$0.00
10	Mechanical	Fans	RTU 0.42 W/CFM	$55.00/m²	$0.00	NEMA high efficiency motors with low specific fan power: RTUs 0.35 W/CFM	$50.00/m²	$0.00	NEMA high efficiency motors with low specific fan power: RTUs 0.35 W/CFM	$50.00/m²	$0.00
11	Mechanical	Ventilation	ASHRAE 62.1-2010	$35.00/m²	$0.00	ASHRAE 62.1; no oversizing Demand Controlled Ventilation based on BMS schedule or CO2 Sensors.	$40.00/m²	$0.00	ASHRAE 62.1; no oversizing Demand Controlled Ventilation based on BMS schedule or CO2 Sensors.	$40.00/m²	$0.00
12	Mechanical	Energy Recovery	50% for most RTUs	$0.00/m²	$0.00	75% sensible heat recovery on all RTUs	$20.00/m²	$0.00	75% sensible heat recovery on all RTUs	$20.00/m²	$0.00
13	Mechanical	Hot Water	-	$0.00	$0.00	None	$0.00	$0.00	None	$0.00	$0.00
14	Mechanical	Pumps	VSD, NEMA Premium	$0.00/m²	$0.00	N/A	$0.00	$0.00	N/A	$0.00	$0.00
15	Electrical	Interior LPD	32% above NECB 2017	$62.00/m²	$85,560.00	50% below NECB 2017	$65.00/m²	$89,700.00	50% below NECB 2017	$65.00/m²	$89,700.00
16	Electrical	Exterior LPD	10% below NECB 2017	$5.00/m²	$6,900.00	70% below NECB 2017	$6.00/m²	$8,280.00	70% below NECB 2017	$6.00/m²	$8,280.00
17	Electrical	Lighting Controls	-	$0.00/m²	$0.00	Occupancy sensors in circulation/transient spaces.	$6.00/m²	$8,280.00	Occupancy sensors in circulation/transient spaces.	$6.00/m²	$8,280.00

Appendix B – Archetype Net-Present Value: Full Results

Detached Single Family Home

	Baseline	Intermediate	ENBR	Int. + On-site PV	ENBR + On-site PV	On-site PV	Off-site PV
First Costs	**$300,993**	**$317,917**	**$329,973**	**$341,917**	**$353,973**	**$24,000**	**$0**
Annual Total Utility Expense ($/yr)	**$1,244**	**$1,008**	**$1,202**	**($487)**	**($293)**	**($1,495)**	**$0**
Annual Electricity Expense ($/yr)	$759	$747	$1,202	($748)	($293)	($1,495)	$0
Annual Natural Gas Expense ($/yr)	$485	$261	$0	$261	$0	$0	$0
Annual Maintenance Expense ($/yr)	**$6,200**	**$6,200**	**$6,200**	**$6,200**	**$6,200**	**$40**	**$0**
30-yr NPV ($)	**$521,832**	**$532,695**	**$555,216**	**$528,856**	**$551,378**	**$6,833**	**$0**
30-yr GHG Production (t CO2e/yr) (from 2019)	**216**	**154**	**133**	**(1)**	**(22)**	**(155)**	**$0**
30-yr GHG Production (t CO2e/yr) (from 2030)	**201**	**139**	**109**	**13**	**(17)**	**(127)**	**$0**
First Costs ($/m²)	**1,544**	**1,630**	**1,692**	**1,753**	**1,815**		

Difference Compared to Baseline	Intermediate	ENBR	Int. + On-site PV	ENBR + On-site PV
First Cost Difference ($)	**$16,924**	**$28,980**	**$40,924**	**$52,980**
First Cost Difference (%)	**6%**	**10%**	**14%**	**18%**
Annual Utility Expense Difference ($/yr)	**($236)**	**($42)**	**($1,731)**	**($1,537)**
Annual Utility Expense Difference (%)	**-19%**	**-3%**	**-139%**	**-124%**
Annual Electricity Expense Difference ($/yr)	($12)	$443	($1,507)	($1,052)
Annual Nat. Gas Expense Difference ($/yr)	($224)	($485)	($224)	($485)
30-yr NPV Difference ($)	**$10,863**	**$33,385**	**$7,025**	**$29,546**
30-yr NPV Difference (%)	**2%**	**6%**	**1%**	**6%**
30-yr GHG Savings (t CO2e/yr) (from 2019)	**(62)**	**(83)**	**(217)**	**(238)**
30-yr GHG Savings (%) (from 2019)	**29%**	**39%**	**101%**	**110%**
30-yr GHG Savings (t CO2e/yr) (from 2030)	**(62)**	**(92)**	**(189)**	**(219)**
30-yr GHG Savings (%) (from 2030)	**31%**	**46%**	**94%**	**109%**

Row Housing

	Baseline	Intermediate	ENBR	Int. + On-site PV	ENBR + On-site PV	On-site PV	Off-site PV
First Costs	**$988,166**	**$1,051,497**	**$1,098,825**	**$1,131,497**	**$1,178,825**	**$80,000**	**$0**
Annual Total Utility Expense ($/yr)	**$4,312**	**$3,338**	**$3,968**	**($1,646)**	**($1,016)**	**($4,984)**	**$0**
Annual Electricity Expense ($/yr)	$2,397	$2,360	$3,968	($2,624)	($1,016)	($4,984)	$0
Annual Natural Gas Expense ($/yr)	$1,915	$977	$0	$977	$0	$0	$0
Annual Maintenance Expense ($/yr)	**$21,600**	**$21,600**	**$21,600**	**$21,600**	**$21,600**	**$133**	**$0**
30-yr NPV ($)	**$1,720,567**	**$1,794,200**	**$1,879,236**	**$1,781,405**	**$1,866,442**	**$22,778**	**$0**
30-yr GHG Production (t CO2e/yr) (from 2019)	**787**	**527**	**438**	**10**	**(79)**	**(517)**	**0**
30-yr GHG Production (t CO2e/yr) (from 2030)	**740**	**481**	**361**	**59**	**(61)**	**(422)**	**0**
First Costs ($/m²)	**1,520**	**1,618**	**1,690**	**1,741**	**1,814**		

Difference Compared to Baseline	Intermediate	ENBR	Int. + On-site PV	ENBR + On-site PV
First Cost Difference ($)	**$63,330**	**$110,658**	**$143,330**	**$190,658**
First Cost Difference (%)	**6%**	**11%**	**15%**	**19%**
Annual Utility Expense Difference ($/yr)	**($974)**	**($344)**	**($5,958)**	**($5,328)**
Annual Utility Expense Difference (%)	**-23%**	**-8%**	**-138%**	**-124%**
Annual Electricity Expense Difference ($/yr)	($36)	$1,572	($5,020)	($3,412)
Annual Nat. Gas Expense Difference ($/yr)	($938)	($1,915)	($938)	($1,915)
30-yr NPV Difference ($)	**$73,633**	**$158,669**	**$60,838**	**$145,874**
30-yr NPV Difference (%)	**4%**	**9%**	**4%**	**8%**
30-yr GHG Savings (t CO2e/yr) (from 2019)	**(260)**	**(349)**	**(776)**	**(866)**
30-yr GHG Savings (%) (from 2019)	**33%**	**44%**	**99%**	**110%**
30-yr GHG Savings (t CO2e/yr) (from 2030)	**(259)**	**(379)**	**(681)**	**(801)**
30-yr GHG Savings (%) (from 2030)	**35%**	**51%**	**92%**	**108%**

High-Rise Residential

	Baseline	Intermediate	ENBR	Int. + On-site PV	ENBR + On-site PV	On-site PV	Off-site PV
First Costs	**$58,647,288**	**$60,696,213**	**$60,629,517**	**$61,306,213**	**$61,239,517**	**$610,000**	**$3,850,000**
Annual Total Utility Expense ($/yr)	**$281,649**	**$167,549**	**$276,765**	**$129,546**	**$238,762**	**($38,003)**	**($239,855)**
Annual Electricity Expense ($/yr)	$220,799	$138,782	$276,765	$100,779	$238,762	($38,003)	($239,855)
Annual Natural Gas Expense ($/yr)	$60,851	$28,766	$0	$28,766	$0	$0	$0
Annual Maintenance Expense ($/yr)	**$1,234,800**	**$1,234,800**	**$1,234,800**	**$1,234,800**	**$1,234,800**	**$1,017**	**$6,417**
30-yr NPV ($)	**$96,193,639**	**$96,514,753**	**$98,760,693**	**$96,417,193**	**$98,663,133**	**$173,679**	**$1,096,170**
30-yr GHG Production (t CO2e/yr) (from 2019)	**40,948**	**23,152**	**30,530**	**19,212**	**26,590**	**(3,941)**	**(24,871)**
30-yr GHG Production (t CO2e/yr) (from 2030)	**36,663**	**20,460**	**25,160**	**17,242**	**21,942**	**(3,218)**	**(20,310)**
First Costs ($/m^2)	**2,638**	**2,730**	**2,727**	**2,758**	**2,755**		

Difference Compared to Baseline	Intermediate	ENBR	Int. + On-site PV	ENBR + On-site PV
First Cost Difference ($)	**$2,048,925**	**$1,982,229**	**$2,658,925**	**$2,592,229**
First Cost Difference (%)	**3%**	**3%**	**5%**	**4%**
Annual Utility Expense Difference ($/yr)	**($114,101)**	**($4,885)**	**($152,104)**	**($42,888)**
Annual Utility Expense Difference (%)	**-41%**	**-2%**	**-54%**	**-15%**
Annual Electricity Expense Difference ($/yr)	($82,017)	$55,966	($120,020)	$17,963
Annual Nat. Gas Expense Difference ($/yr)	($32,084)	($60,851)	($32,084)	($60,851)
30-yr NPV Difference ($)	**$321,114**	**$2,567,054**	**$223,554**	**$2,469,494**
30-yr NPV Difference (%)	**0%**	**3%**	**0%**	**3%**
30-yr GHG Savings (t CO2e/yr) (from 2019)	**(17,795)**	**(10,417)**	**(21,736)**	**(14,358)**
30-yr GHG Savings (%) (from 2019)	**43%**	**25%**	**53%**	**35%**
30-yr GHG Savings (t CO2e/yr) (from 2030)	**(16,204)**	**(11,503)**	**(19,422)**	**(14,721)**
30-yr GHG Savings (%) (from 2030)	**44%**	**31%**	**53%**	**40%**

High-Rise Commercial (Office)

	Baseline	Intermediate	ENBR	Int. + On-site PV	ENBR + On-site PV	On-site PV	Off-site PV
First Costs	**$81,280,637**	**$82,227,192**	**$82,136,144**	**$82,837,192**	**$82,746,144**	**$610,000**	**$4,520,000**
Annual Total Utility Expense ($/yr)	**$317,106**	**$219,612**	**$318,763**	**$181,609**	**$280,760**	**($38,003)**	**($281,596)**
Annual Electricity Expense ($/yr)	$227,673	$176,242	$318,763	$138,239	$280,760	($38,003)	($281,596)
Annual Natural Gas Expense ($/yr)	$89,433	$43,370	$0	$43,370	$0	$0	$0
Annual Maintenance Expense ($/yr)	**$1,671,294**	**$1,671,294**	**$1,671,294**	**$1,671,294**	**$1,671,294**	**$1,017**	**$7,533**
30-yr NPV ($)	**$133,213,430**	**$131,814,182**	**$133,571,831**	**$131,716,622**	**$133,474,271**	**$173,679**	**$1,286,933**
30-yr GHG Production (t CO2e/yr) (from 2019)	**49,499**	**31,266**	**35,163**	**27,326**	**31,222**	**(3,941)**	**(29,200)**
30-yr GHG Production (t CO2e/yr) (from 2030)	**45,081**	**27,847**	**28,978**	**24,629**	**25,760**	**(3,218)**	**(23,845)**
First Costs ($/m^2)	**2,473**	**2,502**	**2,500**	**2,521**	**2,518**		

Difference Compared to Baseline	**Intermediate**	**ENBR**	**Int. + On-site PV**	**ENBR + On-site PV**
First Cost Difference ($)	**$946,555**	**$855,507**	**$1,556,555**	**$1,465,507**
First Cost Difference (%)	**1%**	**1%**	**2%**	**2%**
Annual Utility Expense Difference ($/yr)	**($97,494)**	**$1,657**	**($135,497)**	**($36,346)**
Annual Utility Expense Difference (%)	**-31%**	**1%**	**-43%**	**-11%**
Annual Electricity Expense Difference ($/yr)	($51,430)	$91,091	($89,433)	$53,088
Annual Nat. Gas Expense Difference ($/yr)	($46,063)	($89,433)	($46,063)	($89,433)
30-yr NPV Difference ($)	**($1,399,249)**	**$358,401**	**($1,496,809)**	**$260,841**
30-yr NPV Difference (%)	**-1%**	**0%**	**-1%**	**0%**
30-yr GHG Savings (t CO2e/yr) (from 2019)	**(18,233)**	**(14,336)**	**(22,173)**	**(18,276)**
30-yr GHG Savings (%) (from 2019)	**37%**	**29%**	**45%**	**37%**
30-yr GHG Savings (t CO2e/yr) (from 2030)	**(17,235)**	**(16,103)**	**(20,453)**	**(19,321)**
30-yr GHG Savings (%) (from 2030)	**38%**	**36%**	**45%**	**43%**

Low-Rise Commercial (Retail)

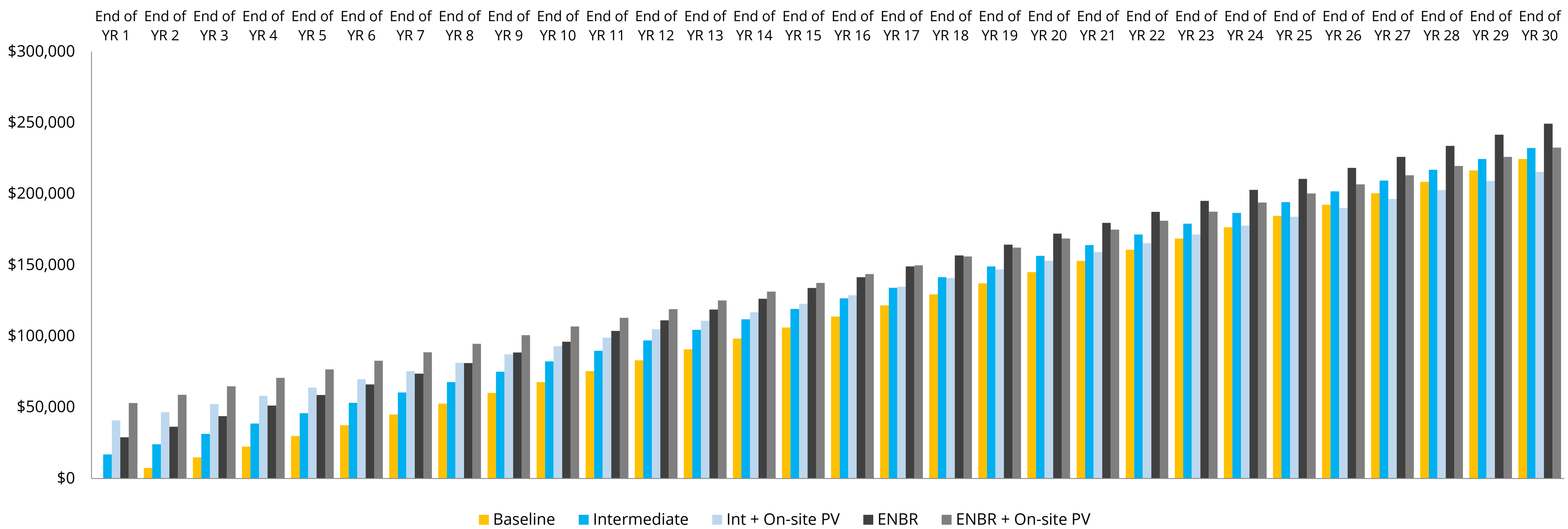
	Baseline	Intermediate	ENBR	Int. + On-site PV	ENBR + On-site PV	On-site PV	Off-site PV
First Costs	**$2,837,285**	**$2,887,953**	**$2,929,353**	**$3,147,953**	**$3,189,353**	**$260,000**	**$0**
Annual Total Utility Expense ($/yr)	**$19,055**	**$11,599**	**$15,230**	**($4,599)**	**($968)**	**($16,198)**	**$0**
Annual Electricity Expense ($/yr)	$16,056	$10,284	$15,230	($5,914)	($968)	($16,198)	$0
Annual Natural Gas Expense ($/yr)	$2,999	$1,314	$0	$1,314	$0	$0	$0
Annual Maintenance Expense ($/yr)	**$58,154**	**$58,154**	**$58,154**	**$58,154**	**$58,154**	**$433**	**$0**
30-yr NPV ($)	**$5,049,495**	**$4,927,023**	**$5,070,787**	**$4,885,440**	**$5,029,204**	**$74,027**	**$0**
30-yr GHG Production (t CO2e/yr) (from 2019)	**2,589**	**1,493**	**1,680**	**(187)**	**0**	**(1,680)**	**0**
30-yr GHG Production (t CO2e/yr) (from 2030)	**2,277**	**1,293**	**1,385**	**(78)**	**13**	**(1,372)**	**0**
First Costs ($/m²)	**2,056**	**2,093**	**2,123**	**2,281**	**2,311**		

Difference Compared to Baseline	Intermediate	ENBR	Int. + On-site PV	ENBR + On-site PV
First Cost Difference ($)	**$50,667**	**$92,067**	**$310,667**	**$352,067**
First Cost Difference (%)	**2%**	**3%**	**11%**	**12%**
Annual Utility Expense Difference ($/yr)	**($7,457)**	**($3,825)**	**($23,655)**	**($20,023)**
Annual Utility Expense Difference (%)	**-39%**	**-20%**	**-124%**	**-105%**
Annual Electricity Expense Difference ($/yr)	($5,772)	($826)	($21,970)	($17,024)
Annual Nat. Gas Expense Difference ($/yr)	($1,685)	($2,999)	($1,685)	($2,999)
30-yr NPV Difference ($)	**($122,472)**	**$21,292**	**($164,055)**	**($20,291)**
30-yr NPV Difference (%)	**-2%**	**0%**	**-3%**	**0%**
30-yr GHG Savings (t CO2e/yr) (from 2019)	**(1,096)**	**(909)**	**(2,776)**	**(2,588)**
30-yr GHG Savings (%) (from 2019)	**42%**	**35%**	**107%**	**100%**
30-yr GHG Savings (t CO2e/yr) (from 2030)	**(984)**	**(893)**	**(2,356)**	**(2,264)**
30-yr GHG Savings (%) (from 2030)	**43%**	**39%**	**103%**	**99%**

Appendix C – Incremental Cost Simple Payback

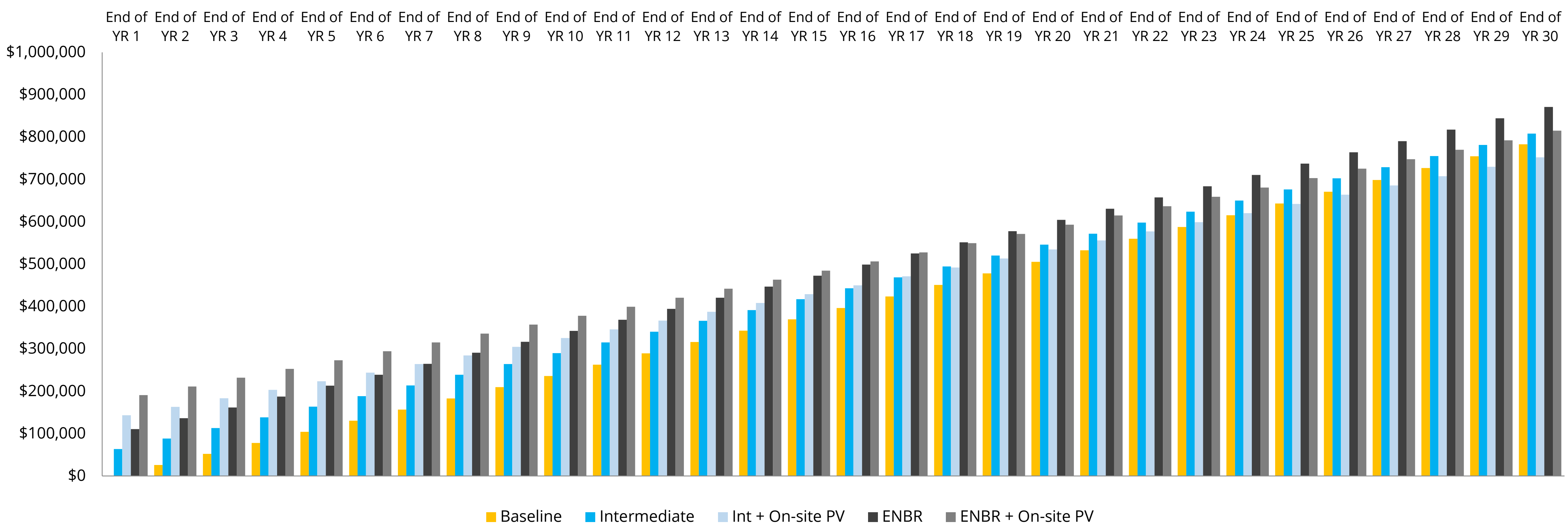
Detached Single Family Home

Incremental Cost Simple Payback Comparison

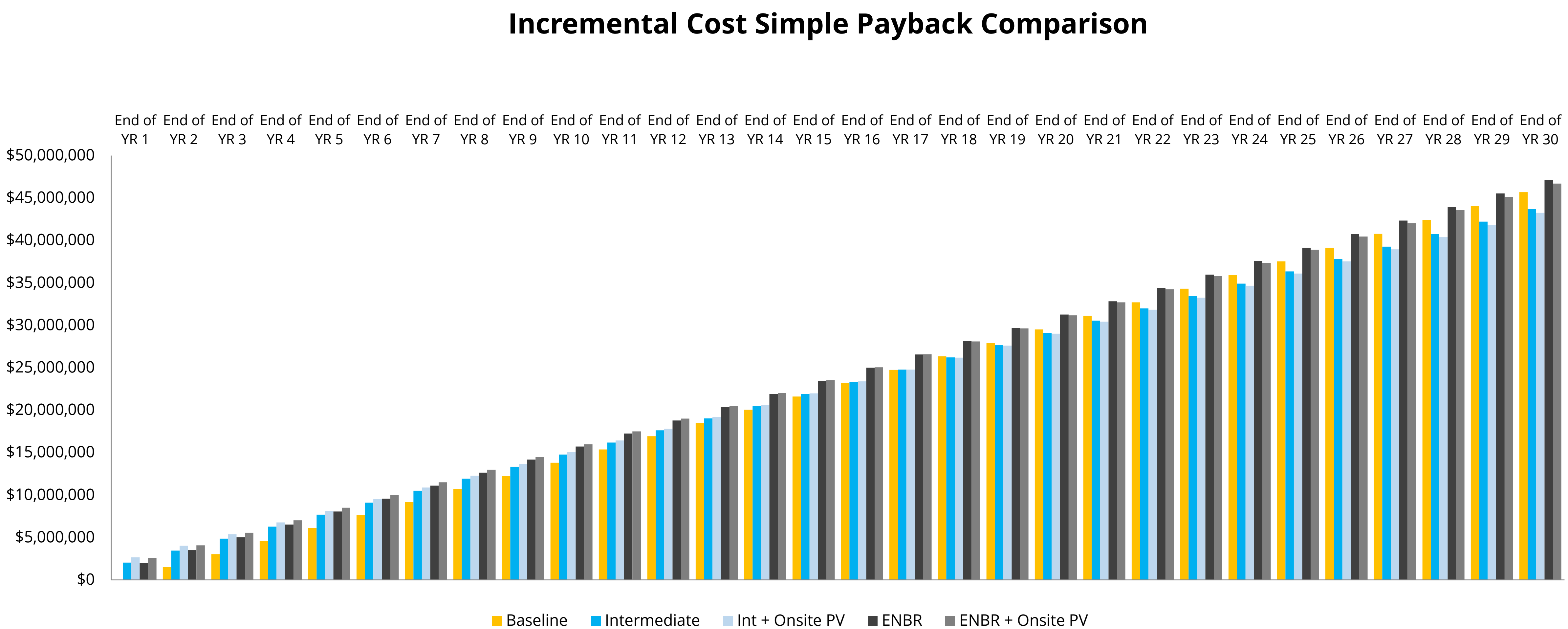


Row House

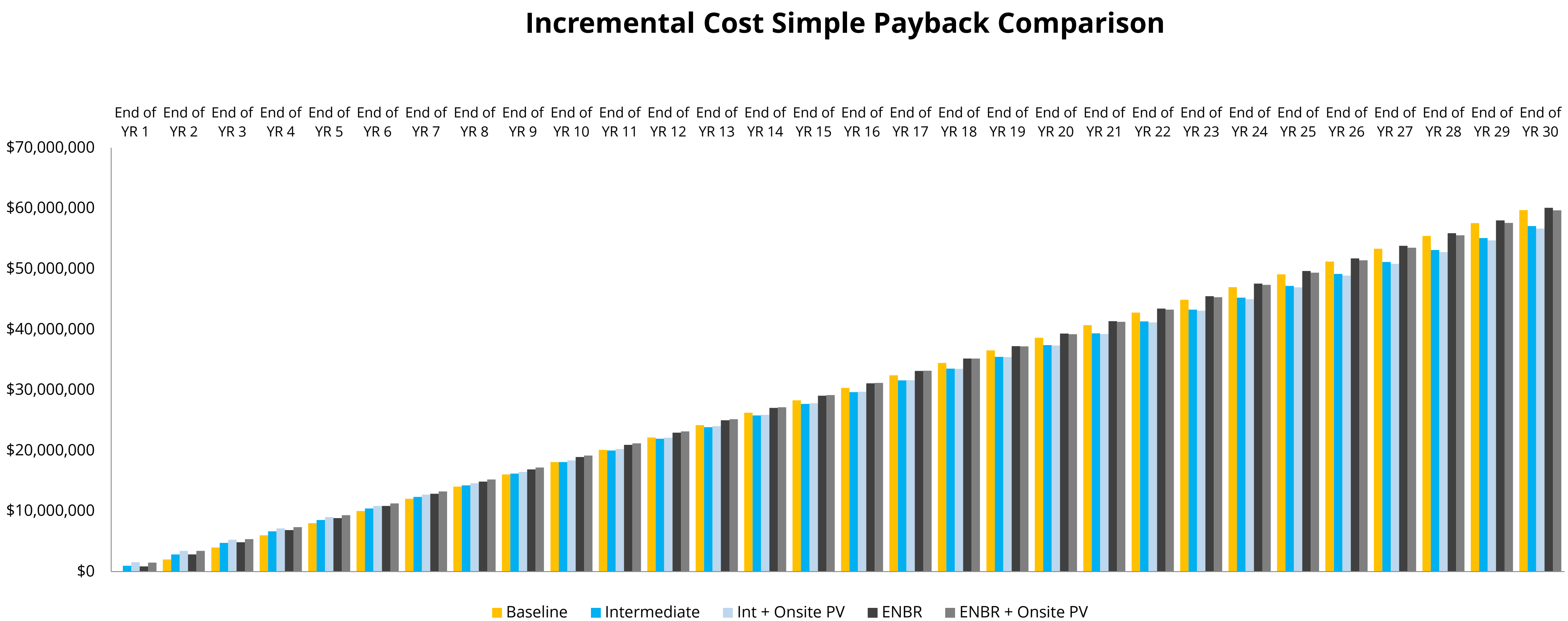
Incremental Cost Simple Payback Comparison



High-Rise Residential



High-Rise Commercial (Office)



Low-Rise Commercial (Retail)