Home Energy Retrofit Priorities in Edmonton with a Decarbonizing Electricity Grid

by

Elizabeth Naa Larteley Lartey

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

Department of Mechanical Engineering
University of Alberta

Abstract

In 2021, the City of Edmonton (CoE) released an Energy Transition Strategy and Action Plan (ETSAP) outlining how Edmonton can achieve “net zero” greenhouse gas (GHG) emissions by 2050. The plan indicated that 83% of GHG emissions could be reduced between 2020 and 2050 through energy savings and emission reductions from fossil fuel combustion with the remaining 17% offset through carbon capture and sequestration along with nature based solutions. The ETSAP aligned with the Paris Agreement of limiting the overall global temperature from pre-industrial levels to 1.5°C and Canada’s goal of net zero by 2050. Historically, Alberta’s electricity system has been GHG intensive however, Alberta is in the process of phasing out its coal fleet. Forecasts for Alberta’s electricity grid anticipate a significant decrease in electricity emissions than previously modeled, potentially affecting the strategy outlined in the ETSAP.

This analysis examined how Alberta’s decarbonizing electricity grid could affect the priorities and outcomes for the CoE’s goal of achieving net zero by 2050 as it pertains to single family homes (SFHs) between 2024 and 2050. Edmonton’s residential sector accounted for 18% of GHG emissions in 2020 and the ETSAP focuses on reducing GHG emissions by a combination of rooftop solar PV systems, heat pumps, electric water heaters, building envelope, and lighting retrofits. To compare how this strategy is affected by the changes in the electricity system, a representative pre-2017 SFH in Edmonton was modeled using HOT2000 before and after installing a combination of the retrofits mentioned above. A diffusion of innovation (DOI) method was used to estimate the adoption of the various retrofits between 2024 and 2050.

The analysis compared the GHG emissions and energy cost savings using forecasts from the Environment and Climate Change Canada (ECCC) in 2023 as well as a 2022 model from the Alberta Electricity System Operator (AESO), and compared the results to the ECCC 2021 forecast which was the forecast at the time the ETSAP was released.

Previously, the focus was on reducing electricity consumption to reduce GHG emissions however, more recent electricity forecasts showed that GHG reductions were 29-50% higher when installing electric water heaters and/or heat pumps using the 2022-2023 forecasts. This result indicates that reducing electricity consumption could no longer be a focus with lower emission factors. Homes could increase electricity consumption when natural gas consumption is reduced and see GHG reductions. Combining solar PV with heat pumps and electric water heaters resulted in the highest GHG reduction using all considered electricity emission factor forecast. However, when comparing the GHG reductions between the electricity emission factor forecasts, GHG reductions are 3-12% less on the 2022-2023 forecasts. The CoE would need to increase the target of homes completing retrofits by 4-14% or homes would need to further reduce natural gas consumption by 2-45%.

Lastly, the cost analysis included a low and high energy cost scenarios with and without the federal carbon tax in place, to determine the financial viability of each retrofit combination. Homeowners are more likely to recoup project costs before the end of the solar PV system useful lifetime within the high energy cost scenario with solar PV exports and the carbon tax. If the CoE intends to meet the targets within the ETSAP as electricity emissions decrease, the priority should be on targeting more homes to install electric space and water heating systems with solar PV to reduce the most GHG emissions and solar PV exports assisting with reducing project costs.

Preface

A portion of the work presented in the thesis comes from a collaboration by the City of Edmonton (CoE) and Dr. Tim Weis for the Clean Energy Improvement Program (CEIP) along with Dr. Tim Weis. Chapters 3-4 include data collected from the CEIP as of March 2023. Appendix A is the final deliverable to the CoE. Additionally, Chapters 1 and 3 include data by Bhagwant Singh as part of his Masters of Engineering capstone report supervised by Dr. Tim Weis at the University of Alberta.

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Chapter 1

Introduction

Canada has a net zero greenhouse gas (GHG) emissions goal by 2050 to combat the risks of climate change on the environment and society [1]. Net zero is defined as "reduc[ing]emissions to the point that the [greenhouse gas] emissions that [is] produce[d] can be negated through measures like tree planting or carbon capture technologies" [1]. The net zero goal aligns with the Paris Agreement of limiting the global average temperature to 1.5°C by reducing 45% GHG emissions by 2030 and achieving net zero by 2050 [2, 3].

In 2017, buildings were responsible for one-third of global energy use and energy-related GHG emissions [4]. In 2018, Canada's overall GHG emissions were 725 $\mathrm{Mt}_{\mathrm{CO}_2}$ of which 65 $\mathrm{Mt}_{\mathrm{CO}_2}$ resulted from the residential sector [5]. GHG emissions from residential buildings in Canada increased to 13% in 2021, where Canada's GHG emissions were 670 $\mathrm{Mt}_{\mathrm{CO}_2}$ [3].

In 2020, Edmonton's GHG emissions were 2.5 $\mathrm{Mt}_{\mathrm{CO}_2}$ and residential buildings accounted for 18% (0.45 $\mathrm{Mt}_{\mathrm{CO}_2}$) [6]. The City of Edmonton (CoE) released the Energy Transition Strategy and Action Plan (ETSAP) in 2021 which outlined how Edmonton can achieve net zero by 2050 by aligning with the Paris Agreement and Canada's net zero goal [2]. The ETSAP outlined that 83% of the required GHG emission reductions to achieve net zero would come from retrofitting buildings, renewable energy, and transportation which was equivalent to a cumulative 500 $\mathrm{Mt}_{\mathrm{CO}_2}$ reductions between

2020 and 2050 [2]. Nature-based solutions along with carbon capture storage account for the remaining 17% of GHG emissions, equivalent to a cumulative 100 $\mathrm{Mt_{CO_2}}$ reductions for a total of 600 $\mathrm{Mt_{CO_2}}$ GHG emission reductions needed [2]. Within the ETSAP, buildings would deliver 19% of the required GHG emissions reductions (112 $\mathrm{Mt_{CO_2}}$ out of 600 $\mathrm{Mt_{CO_2}}$) through retrofitting building envelope and lighting within existing buildings and updating standards for future buildings [2]. As well, upgrading and installing energy systems would contribute to an additional 12% (74 $\mathrm{Mt_{CO_2}}$ out of 600 $\mathrm{Mt_{CO_2}}$) of the required GHG emission reductions [2]. The ETSAP identified that energy efficiency programs would be used to complete retrofits for existing homes [2].

An example of an energy efficiency program that has been implemented to align with the ETSAP is the pilot Clean Energy Improvement Program (CEIP). The pilot CEIP was a building retrofit Property Assessed Clean Energy (PACE) program where building retrofit costs are financed through property taxes. The pilot CEIP ran between 2021 and 2023. As of March 2023, the residential pilot CEIP had 26 participants who completed retrofits, where 22 of the applicants were pre-2017 detached single family homes (SFH), 3 were post-2017 detached SFHs, and 1 was a pre-2017 attached SFH. The commercial pilot CEIP had no applicants. The results from this program will be discussed throughout this document as the author worked with the CEIP team to estimate energy, GHG emissions, and cost savings for CEIP participants. The results assisted in the design and planning of the full-scale program currently under development at the time of writing this thesis. Along with the pilot CEIP, the CoE had rebate programs for residential and commercial buildings, including the Home Energy Retrofit Accelerator (HERA) for residential buildings, the Change Homes for Climate Solar program, and the Building Energy Retrofit Accelerator (BERA) for commercial buildings [7–9].

To achieve the targeted GHG reductions for residential buildings in Edmonton as outlined in the ETSAP, an unpublished analysis was completed to show a potential pathway for achieving the required GHG reductions between 2020 and 2050. A summary of the potential pathway for residential buildings is listed below:

- Water heaters: 75% of residential buildings install an electric water heater between 2020 and 2050. The assumption is that the future energy source for water heating will be hydrogen, electricity, natural gas, geothermal district energy, and renewable natural gas by 2065

- Standards for future residential buildings: "implementing the 2020 federal building code by 2025" with the goal of future residential buildings being "50% more energy efficient than [Alberta Building Code] ABC 2015 baseline" and achieving net zero between 2025 and 2050. The assumption is that the future space heating energy source will be renewable natural gas, electricity, hydrogen, natural gas, and renewable district energy by 2065

- Heat pumps: between 2022 and 2050, 55% of residential buildings would install ground source heat pumps (GSHP) or air source heat pumps (ASHP)

- Rooftop solar photovoltaic (PV) system: 85% of residential and commercial buildings would install a rooftop solar PV system, covering 60% of the building's electricity consumption

- Building envelope and lighting retrofits in buildings: Pre-2017 residential and commercial buildings would complete building envelope and lighting retrofits between 2021 and 2050, where buildings achieve 50% electricity and natural gas savings. The assumption is that the future space heating energy source will be hydrogen, district energy, natural gas, electricity, and renewable natural gas

- Hydrogen: In 2030, two neighbourhoods will transition from natural gas to hydrogen for space heating. Between 2030 and 2065, 96,000 residential buildings (25% of residential buildings) will transition to hydrogen space heating

The ETSAP had identified the requirement for retrofitting building envelope and lighting within pre-2017 residential buildings [2]. The CoE has a mapping tool that compiles EnerGuide audits completed in Edmonton [10]. EnerGuide audits are a tool developed by National Resource Canada (NRCan) which summarizes the energy consumption, estimated GHG emission, and recommended retrofit opportunities in the house after being audited by an energy advisor [10]. Reviewing EnerGuide audits completed as of May 2023, found that pre-2017 residential buildings consumed an average of 172 GJ of energy per year, while post-2017 residential buildings consumed on average of 93 GJ per year based on 3,885 EnerGuide audits completed between 2017 and 2023 [11]. Pre-2017 residential buildings consume 65% more energy than post-2017 residential buildings, contributing more towards GHG emissions [11]. Pre-2017 single detached family homes consumed 174 GJ of energy per year, semi-detached family homes consumed 160 GJ per year, and town homes consumed 136 GJ per year [11]. On average, 67% of energy consumption in pre-2017 SFHs was from space heating, 16% from water heating, 9% from other electrical outputs (like computers and televisions), and 7% from lighting and appliances [11]. The review of the EnerGuide audits shows that pre-2017 SFHs contribute the most to GHG emissions within residential buildings in Edmonton.

GHG emissions are calculated using an emission factor expressed in mass of carbon dioxide per energy generated. Alberta's natural gas emission factor within "the utility, industry, residential, commercial, and transport subsectors" is 1962 g_{CO_2}/m^3 or 0.05 t_{CO_2}/GJ [12]. For electricity, the CoE currently uses electricity emissions forecasts from the Environment and Climate Change Canada (ECCC). ECCC is a part of the Canadian government responsible for: "protecting and conserving [Canada's] natural heritage, predicting weather and environmental conditions, preventing and managing pollution, promoting clean growth and a sustainable environment for present and future generations" [13]. The ETSAP was released in 2021 where the 2021 forecasted completed by ECCC estimated the emission factor to be 0.2 t_{CO_2}/MWh by 2050 [14].

In 2023, the forecasted emission factors completed by ECCC estimated a decrease to 0.1 t_{CO_2}/MWh by 2050 showing a decarbonizing electricity grid [15]. With the decrease in emission factors between the 2021 and 2023 forecasts, GHG emission reductions could change.

This thesis examined how a potential decarbonizing electricity grid in Alberta could affect the priorities and outcomes for the CoE's goal of achieving net zero by 2050 for pre-2017 SFHs (referred to as "the SFH") between 2024 and 2050. The focus was on the SFHs as the ETSAP dedicated a category to pre-2017 buildings, which were identified as the highest energy consumer archetype based on the review of 3,885 EnerGuide audits. A reference house (referred to as "base house") was used to represent the average energy consumption for the SFHs in Edmonton. The energy consumption was calculated using HOT2000, an "energy simulation modelling software developed and maintained by Natural Resources Canada" that models electricity, oil, natural gas, propane, and wood systems for residential buildings [16]. This thesis will focus on the SFHs installing rooftop solar PV systems, heat pumps, electric water heaters, and completing building envelope and lighting retrofits (referred to as "retrofit categories"). The analysis utilized relevant assumptions from the unpublished analysis and further assumptions from applicants within the pilot CEIP. As applicants focused on reducing electricity and natural gas only the thesis will focus on how GHG reductions change when targeting electricity and natural gas consumption only on different electricity grid forecasts. The assumption is that homes would complete retrofits within a retrofit program aligning with the ETSAP for existing buildings. The analysis calculated and compared the GHG emissions for the SFHs on the 2021 forecasted emission factors by ECCC and 2022-2023 forecasts of Alberta's electricity emission factors, representing the decarbonizing electricity grids. A diffusion of innovation (DOI) model was used for an adoption method to estimate the number of homes completing retrofits per year. An energy cost analysis was also included to discuss how retrofitting affects homeowners financially.

1.1 Motivation

The ETSAP shows a potential pathway of achieving the required GHG reductions to achieve net zero by 2050. The estimated GHG reductions rely on the emission factor, which has changed significantly since the release of the ETSAP in 2021. 2022-2023 electricity forecasts in Alberta generally anticipate a decrease in electricity emission factors compared to 2021 forecasts potentially affecting the required GHG reductions discussed in the ETSAP. This work aims to analyze how the GHG reductions will change due to the changing emission factors.

1.2 Background

1.2.1 Energy Efficiency

Building GHG emissions can result directly from water and space heating and indirectly from energy consumed through non-renewable energy sources like coal and natural gas off-site [1]. Retrofitting existing buildings in energy efficiency programs has been a solution that governments have used to reduce building energy consumption and GHG emissions [1]. Energy efficiency is defined by the International Energy Agency (IEA) as “a way of managing and restraining the growth in energy consumption [where] something is more energy efficient if it delivers more services for the same energy input or the same services for less energy input” [17]. Energy efficiency programs are designed to assist building owners in completing energy-saving retrofits, educate consumers on energy consumption, and encourage energy-saving behavioural changes [18]. The term “retrofitting” often refers to upgrading equipment, installing energy-efficient appliances, upgrading windows and doors, insulation, sealing, fuel switching, and installing on-site renewable energy [1]. Using on-site renewable energy, (typically solar and possibly small-scale wind turbines), allows buildings to produce electricity for their consumption and potentially sell excess electricity back to the grid [1].

1.2.2 Edmonton Energy Transition Strategy and Action Plan for Residential Buildings

The ETSAP was created to define how Edmonton could achieve net zero as part of the ConnectEdmonton strategic plan and the City Plan Bylaw [2, 19, 20]. ConnectEdmonton details what Edmonton needs to change to achieve net zero by 2050 in the following four areas: healthy city, urban places, regional prosperity, and climate resilience [2]. Under climate resilience, a carbon budget is calculated to determine “how far and how fast” Edmonton must “move in terms of emission reductions, and the magnitude of change required” to achieve carbon neutrality “where the net per-person greenhouse gas emissions is zero” [2]. The City Plan Bylaw outlines how Edmonton can grow in areas such as open spaces, social networks, land usage, employment, and mobility systems [2].

The ETSAP has set a goal of reducing GHG emissions by 35% by 2025 and 50% by 2030 compared to 2005 GHG levels [2]. Additionally, by 2030, energy consumption should be reduced by 35% per person compared to 2005 GHG levels while producing 10% of electricity in Edmonton [2]. By 2050, the goal is to achieve “net zero per person” [2]. To achieve the 2025, 2030, and 2050 goals, the total GHG reductions are planned to come from the below sectors [2]. The potential pathway from the unpublished analysis lists assumptions to achieve the required emission reductions. The assumptions for residential buildings that were used in the analysis will be discussed in the next section.

- Carbon capture, natural sinks, and offsets (up to 17%)
- Buildings (up to 19%)
- Transportation and urban plan (up to 28%)
- Energy systems (up to 36%)

1.2.3 Retrofit Categories Assumptions from Potential Pathways

Within the ETSAP, 370,000 pre-2017 residential buildings would upgrade lighting, improve building envelope insulation, and install efficient appliances to reach 50% natural gas and electricity reductions between 2021 and 2050. Assumptions considered for this thesis were:

- Excluding "business as usual" upgrades like replacing non-functioning furnaces
- Heating transitions from "86% natural gas, 9% electricity, 4% wood, and 2% heat pumps [in 2021] to 55% air or ground source heat pumps, 14% [hydrogen], 11% [renewable natural gas], 6% natural gas, 10% district energy, and 4% electric" by 2050

For the rooftop solar PV category, 85% of buildings would install solar PV systems between 2021 and 2041 where installations would continue after 2041. The buildings would reduce electricity consumption by 50% before installing a solar PV system that supplies at least 60% of the new electrical load (excluding electric vehicle charging). Within the water heater category, 75% of residential buildings would install heat pumps, electric water heaters, hydrogen water heaters, electric hybrid, or electric on demand heating water heaters between 2023 and 2050. Further assumptions considered for this thesis were:

- Electric water heaters are installed at the same time as building retrofits
- Buildings with electric space heating will install electric water heaters

The plan for the heat pump retrofit category was that 55% of residential buildings would install GSHP or ASHP between 2022 and 2050, where buildings would achieve 50% natural gas and electricity savings before installing the heat pumps. Further assumptions considered for this thesis are listed below. Since the focus of this analysis was on the SFHs, the assumption was that building retrofits completed within the heat pump and water heater category were tied to the building envelope and lighting retrofit category.

- Heat pumps are installed with building retrofits tied into the retrofitting building envelope and lighting retrofit category
- By 2030, 70,000 ASHP (65%) and 37,000 GSHP (35%) are estimated to be installed in residential buildings that have electrified space heating

1.2.4 Diffusion of Innovation

To calculate the number of homes completing retrofits per year, DOI was utilized. DOI is a theory that shows the process of people adopting an innovation over a period of time and is displayed in two curves shown in Figure 1.1 [21–23]. The S-shaped curve shown in blue represents the accumulation of people adopting the innovation [24]. The bell-shaped curve shown in red shows the rate of growth where the number of people adopting the innovation in dispersed into five categories [22]:

- Innovators are considered risk takers and enthusiasts who would be the first to adopt innovations without external influence [22, 25]
- Early adopters are considered to be trendsetters and visionaries trying the innovations [22]
- Early majority are individuals who do not take risks and instead wait to adopt innovations through references and recommendations [22]
- Late majority are individuals who adopt innovations through peer pressure and facts from a trusted source [22]
- Laggards do not like adopting or do not want to adopt innovations unless there are no other option [22]

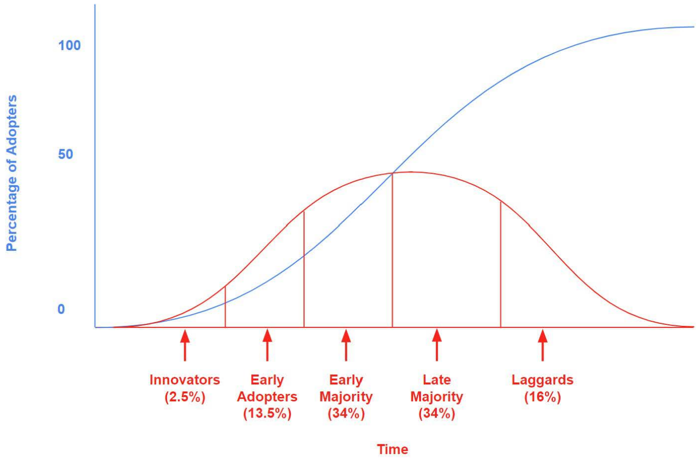

Figure 1.1: Diffusion of innovation curves [23]

1.3 Thesis Overview

Chapter 2 is a literature review on reports used to create the ETSAP related to this thesis work, decarbonization and electrification in residential buildings, Alberta's current electricity grid forecasts, modelling energy consumption with engineering models, and the DOI method used for the analysis. Chapter 3 discusses modelling the base house before and after retrofits within HOT2000. Chapter 4 discusses the energy consumption, GHG reductions, and energy cost savings of the retrofit categories using Alberta's electricity grid forecasts. Appendix A contains the submitted final report for the pilot CEIP to the CoE for applicant data as of October 31, 2023.

Chapter 2

Literature Review

2.1 Decarbonization and Electrification

Decarbonization is the process of eliminating GHG emissions by using non-carbon dioxide emitting sources to produce energy [26]. Decarbonization in residential buildings can be seen through electrifying space and water heating systems. The targeted retrofits for existing residential buildings in the ETSAP focus on decarbonizing and electrifying space heating systems through installing ASHP or GSHP and electrifying water heating systems. Supporting documents of the ETSAP further look into the energy, GHG reductions, and the cost of decarbonization and electrification in Edmonton.

In 2014, Climate Change Central (C3) completed an analysis to estimate the amount of public and private investments needed to fund renewable energy and energy efficiency measures for residential buildings, commercial buildings, industrial facilities, and electric vehicles between 2014 and 2044 in Edmonton [27, 28]. C3 was "an Alberta non-profit [organization] dedicated to addressing climate change" [28]. Three scenarios were used to model energy and GHG reductions along with the cumulative cost of each scenario for residential buildings compared to a base case [27]. The base case represented Edmonton's business as usual trend in 2009, where residential buildings consumed 34 PJ of energy and emitted 2.9 $\mathrm{Mt_{CO_2}}$ with an electricity emission factor of 880 $\mathrm{t_{CO_2}}$/GWh [29]. In 2009, Alberta emitted 117 $\mathrm{Mt_{CO_2}}$ and 2.9 $\mathrm{Mt_{CO_2}}$

represented 2% of GHG emitted that year [30]. The reference case was a 50% energy efficiency improvement (25% energy efficiency improvement from the 2010 NBC) by 2044 with an electricity emission factor of 628 t_{CO_2}/GWh by 2024 and reducing to 538 t_{CO_2}/GWh by 2044 [29]. The reduced carbon case was a 52.5% energy efficiency improvement by 2044 with an electricity emission factor of 580 t_{CO_2}/GWh by 2024 and reducing to 429 t_{CO_2}/GWh by 2044 [29]. The low carbon case was an 85% energy efficiency improvement by 2044, resulting in a 5% reduction in GHG emissions compared to the reference case, with an electricity emission factor of 442 t_{CO_2}/GWh by 2024 and reducing to 100 t_{CO_2}/GWh by 2044 [29].

The energy, GHG emissions, and cost savings from the analysis for the reduced and low carbon cases compared to the reference case are shown in Table 2.1. Compared to the reduced carbon case, the low carbon case uses an electricity emission factor that is 77% lower resulting in a 76% increase in GHG emission reductions by 2050, showing the impact of a lower electricity emission factor on GHG reductions. Homeowners in the low carbon case would spend 75% more in retrofit costs and spend 99% more in installed renewable energy compared to the reduced carbon case. Therefore, the results indicate that achieving 76% more GHG reductions requires more than a 75% increase in retrofit costs.

In 2019, a cost, energy, and GHG emissions analysis for residential and commercial buildings in the Edmonton was completed by Integral Group (a consultant firm) to discuss how buildings can become emissions neutrality by 2030 [31, 32]. Emission neutrality is 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" like net zero [2]. Two storey detached single family homes were modeled in HOT2000 for three "energy tiers". The baseline tier combined the 2019 Alberta Building Code (ABC) and the 2017 National Energy Code of Canada (NECB) [31]. The ABC is Alberta's legal provincial code for buildings while the NECB is the

	Reduced Carbon	Low Carbon
Existing and Future Residential Buildings		
Energy Savings	71,387 TJ	358,321 TJ
Additional Installed Renewable Energy	729 TJ	29,052 TJ
Total GHG Emission Reductions	11.7 $\mathrm{Mt}_{\mathrm{CO}_2}$*	47.8 $\mathrm{Mt}_{\mathrm{CO}_2}$**
Total Cost	$719 million	$5,129 million
Existing Residential Buildings		
Cost of Retrofits	$146 million	$593 million
Cost of Additional Installed Renewable Energy	$10 million	$1,305 million

*9% of 2009 GHG emissions in Alberta

**41% of 2009 GHG emission in Alberta

Table 2.1: Cumulative results for residential buildings between 2014 and 2044 compared to reference case [27]

energy efficiency code for new buildings [33, 34]. The intermediate tier combined Canada's 2020 National Building Code (NBC) and the 2017 NECB [31]. The NBC is the national standard for residential buildings [35]. Compared to the baseline, the intermediate tier requires residential buildings to achieve 10% higher "energy improvement" for the building envelope and 20% higher "overall energy improvement" [31]. The emission neutral tier has buildings installing rooftop solar PV, electric space heating systems like heat pumps, and electric water heaters [31].

The assumptions for the analysis are listed below [31]. The building cost and incremental energy conservation measure (ECM) cost was completed by an "independent cost consultant" where ECM are measures that promote energy efficiency in buildings [31]. The ECM cost analysis included the net present value (NPV) which is "the current value of a future stream of payments" using a discount or interest rate [36]. The NPV is calculated using the escalation rate, natural gas cost, electricity cost, discount rate, and operation and maintenance (O&M) costs [31].

- 2019 and 2030 electricity emission factor was 0.585 $\mathrm{kg}_{\mathrm{CO}_2}$/kWh and 0.324 $\mathrm{kg}_{\mathrm{CO}_2}$/kWh, respectively, based on the baseline scenario within the 2019 Alberta Electric System Operator (AESO) long term outlook (LTO) report [31].

AESO is the independent system operator of Alberta's power grid where it operates the electricity market, dispatches electricity generators to balance supply and demand in real time, and plans future electricity transmission [37]. The LTO report forecasts the next 20 years of electricity generation and demand [38]

- The natural gas emission factor was 50 $\text{kg}_{\text{CO}_2}/\text{GJ}$ [31]
- Natural gas and electricity cost were \$5.5/GJ and \$0.1/kWh, respectively [31]
- O&M cost was "2% of building capital cost" [31]
- Electricity and natural gas escalation rate is 1% and 2%, respectively [31]
- Solar PV system cost is \$2/kWp where kWp is the peak kW [31, 39]
- The discount rate is 3% [31]

The results of the analysis are shown in Table 2.2 where the "on-site PV (14 kWp)" column represents homes installing rooftop solar PV systems to offset the remaining GHG emissions after building retrofits [31]. The analysis concluded that residential buildings aiming to achieve emission neutrality must install solar PV and electrify space and water heating [31]. Electrification will increase electricity and decrease emissions due to eliminating natural gas consumption while solar PV installation will offset the increase in GHG emissions [31].

The supporting documents show that decarbonization and electrification within the residential sector have been discussed and identified as the solution for reducing GHG emissions for years. The results show GHG reductions for different energy reduction targets where electrification is identified as the highest GHG reduction option. The thesis analysis will also look at GHG reductions for different energy efficiency cases based on retrofits completed in pilot CEIP along with the cost of investing in retrofits within these cases.

Metric	Baseline	Intermediate	ENBR	On-site PV (14 kW)
Electricity Demand (kWh)	7,479	6,870	11,994	(14,952)
Natural Gas Demand (kWh)	24,376	9,806	0	n/a
GHG Emissions (t_{CO_2})	9	6	7	(9)
Building Cost (2020 CAD)	$300,993	$317,917	$329,973	n/a
Incremental ECM Cost (2020 CAD)	$0	$16,924	$28,980	$24,000
30 Year NPV (2020 CAD)	$521,832	$532,695	$555,216	$6,833

Table 2.2: Energy, GHG emissions, and cost for detached single family homes for three energy scenarios within the "Emissions Neutral Buildings: Final Report" [31]

2.2 Decarbonizing Electricity Grids

In addition to decarbonization and electrification, decarbonizing electricity grids can also further reduce GHG emissions in residential buildings. In 2022, an analysis was done on the GHG reductions in the United States for 108 scenario combinations between house characteristics, electricity grids, housing stock, and renovations from 2020 to 2060 [40]. Focusing on the renovation and electricity grid combinations, the scenario groups are defined in Table 2.3 [40]. The electricity grid scenarios are compared to the National Renewable Energy Laboratory (NREL) reference scenario for the estimated 2020 electricity sector outlook [41]. NREL is an organization "transforming energy through research, development, commercialization, and deployment of renewable energy and energy efficiency technologies" [42]. There was an average of 7%, 8%, and 11% energy decrease within the regular renovation (representing current renovation in residential buildings), advanced renovation, and the extensive renovation scenario, respectively [43]. Within each renovation scenario, building envelope, water heating, and space heating retrofits were completed in single family homes, multi-family homes, and mobile homes built between 1940-2019 [43]. The analysis concluded that the best combination for reducing GHG emissions was a combination of the extensive renovation scenario in existing buildings on a "carbon-free electricity" grid with cumulative GHG emissions between 12.0-14.6 Gt_{CO_2} [40]. For reference, the worst combination was the regular renovation scenario in existing homes on a “mid-case electricity” grid with cumulative GHG emissions of 23.3-25.8 $\mathrm{Gt}_{\mathrm{CO}_2}$ [40]. Therefore, a combination of the extensive renovation scenario and carbon-free electricity scenario had 43-48% less cumulative GHG emissions. Fast decarbonizing electricity grid and extensive renovations are needed for large GHG reductions in existing buildings [40].

Renovating Existing Homes Scenarios	
Regular Renovation	Historical rates of renovations with ”moderate efficiency improvements and slow electrification of space/water heating”
Advanced Renovation	1.5 x historical rates of renovations ”with higher-efficiency improvements and a moderate increase in the electric share of space/ water heating equipment replacements”
Extensive Renovation	Higher rates of heat pumps for water and space heating; replaces gas space heating with electric space heating (heat pumps) starting in 2025
Electricity Grid Scenarios	
Mid-case Electricity	Average emission factor of 169 $\mathrm{g}_{\mathrm{CO}_2}$/kWh by 2050 based on NREL reference scenario
Low Renewable Energy Cost Electricity	Average emission factor of 82 $\mathrm{g}_{\mathrm{CO}_2}$/kWh by 2050 based on NREL reference scenario
Carbon-free Electricity by 2035	0 $\mathrm{g}_{\mathrm{CO}_2}$/kWh by 2035
NREL is the National Renewable Energy Laboratory	

Table 2.3: Existing homes and electricity grid scenario’s [40]

2.2.1 2023 Electricity Grid Forecasts for Alberta

Looking at emission factors in Alberta, forecasts shows decarbonization where the emission factor are close to zero. At the time of writing, the most recent LTO report completed by AESO was released in 2021, looking out to 2041 [38]. The forecast includes four possible scenarios: reference, clean-tech, robust, and stagnant which are further explained in Appendix B.1. The emission factor is calculated using equation 2.1:

$$EF_{GHG} = \frac{GHG_{emissions}}{Gen_{electricity}} \tag{2.1}$$

where the $GHG_{emissions}$ represent the tonnes of carbon dioxide in a given year, $Gen_{electricity}$ represents the electricity generation in a given year, and EF_{GHG} is the emission factor. GHG emissions used in calculating the emission factor come from coal plants, cogeneration, combined cycle, coal to gas steam boiler, and simple cycle [44]. The electricity generation comes from solar, net imports (imported electricity minus exported electricity), combined cycle (includes converting coal systems to gas systems in the clean-tech scenario), coal, simple cycle, coal to gas steam boilers, hydro, solar storage (solar PV with lithium-ion batteries), storage (lithium battery and clean tech scenario includes hydro storage), other (waste heat, geothermal for clean-tech scenario only, and biomass), and wind [44, 45].

The electricity emission factors are shown in Figure 2.1 [37]. As the thesis analysis focuses on 2024 to 2050, the electricity emission factors from 2042-2050 was forecasted using linear regression analysis (LRA) where the future values are predicted using historical data using equation 2.2 [46]:

$$y_i = \hat{\beta_0} + \hat{\beta_1} x_i \tag{2.2}$$

where β_0 is the y-intercept and β_1 is the slope [46]. The y-intercept is found using equation 2.3:

$$\hat{\beta_0} = \overline{y} - \beta_1 \overline{x} \tag{2.3}$$

where $\overline{x}$ and $\overline{y}$ is the average x and y values of the historical data [46]. The slope can be found using equation 2.4:

$$\hat{\beta_1} = \frac{\Sigma(y_i - \overline{y})(x_i - \overline{x})}{\Sigma(x_i - \overline{x})^2} \tag{2.4}$$

where x_i and y_i is each x and y value from the historical data [46]. LRA was used to predict the 2042-2050 emission factors as the electricity emission factor decrease linearly.

In 2022, AESO published a net zero emissions pathway report that considered potential pathways for Alberta's electricity grid to be carbon neutral by 2035 [47].

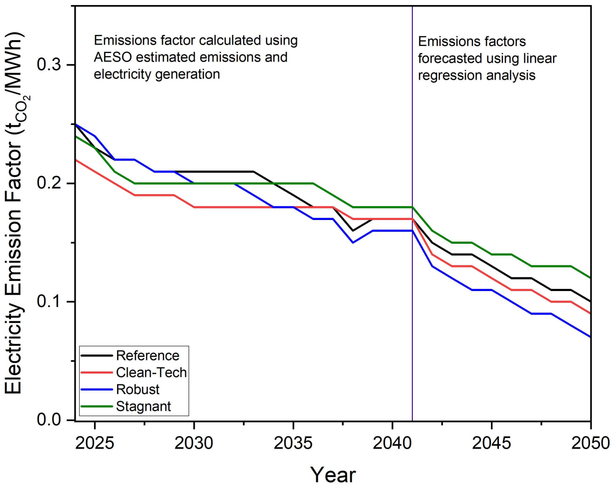

Figure 2.1: Annual electricity emission factors from AESO's long-term outlook scenarios from 2024-2041 with estimated electricity emission factors from 2042-2050 [44]

This report outlined three potential carbon neutral pathways between 2021-2041: dispatchable dominant scenario, first mover advantage scenario, and renewables and storage rush scenario which are further explained in Appendix B.2 [48]. The annual emission factors were calculated using equation 2.1 where the emissions come from cogeneration, combined cycle with carbon and storage (CCS) (or carbon capture utilization and storage (CCUS) utilized in the data file), coal to gas steam boiler, and simple cycle [49]. The electricity generation comes from solar, net imports (imported electricity minus exported electricity), combined cycle (dispatchable and first mover scenario), simple cycle (natural gas and hydrogen), coal to gas steam boilers, hydro, battery storage in renewable scenario (lithium-ion batteries), hydro storage in the renewable scenario, compressed air storage in the renewable scenario, other (not specified), and wind [48, 49].

The electricity emission factors for the three scenarios are shown in Figure 2.2. Annual electricity emission factors from 2042-2050 were estimated using LRA, where negative values were assumed to represent 0 t_{CO_2}/MWh. Figure 2.2 shows a large drop between 2041 and 2042 showing the electricity emission factor reaching zero in

2042 from an emission factor of 0.03-0.04 t_{CO_2}/MWh in 2041.

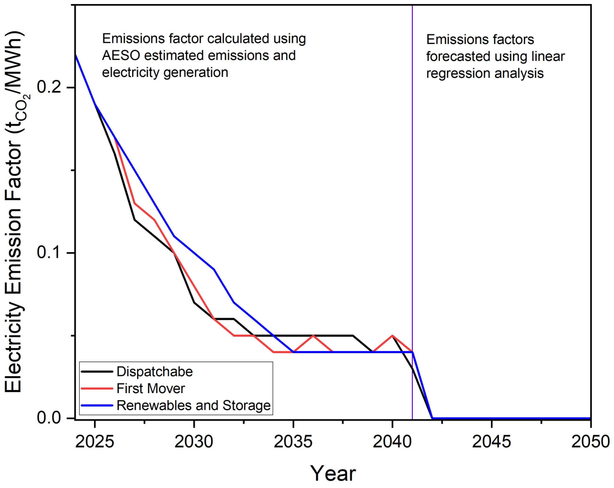

Figure 2.2: Annual electricity emission factors from AESO's net zero emissions pathway scenarios from 2024-2041 with forecasted electricity emission factors from 2042-2050 [49]

Environment and Climate Change Canada (ECCC) annually forecasts emission factors which are used for GHG emissions modeling in the CoE. As the ETSAP was released in 2021, the 2021 ECCC forecast was used to represent the higher GHG emission factors within the analysis. Currently, the CoE uses the reference case within the 2023 forecast, which assumes that coal is phased out by 2030 in Alberta [50]. The exact systems considered for calculating the electricity emission factor are not specified however, based on the AESO reports and the 2023 ECCC emission factors excel sheet, the GHG emissions include biomass, electricity losses, renewable natural gas emissions, and emissions from electricity production from coal and natural gas where imports and exports are assumed to have a zero emission factor [15, 50]. The electricity generation comes from renewables (hydro, solar, wind), geothermal, renewable natural gas, natural gas, and coal (until 2030) [50]. The 2024-2050 electricity emission factors from the 2021 and 2023 forecasts are shown in Figure 2.3.

Technology Innovation and Emissions Reduction (TIER) regulation is an emission

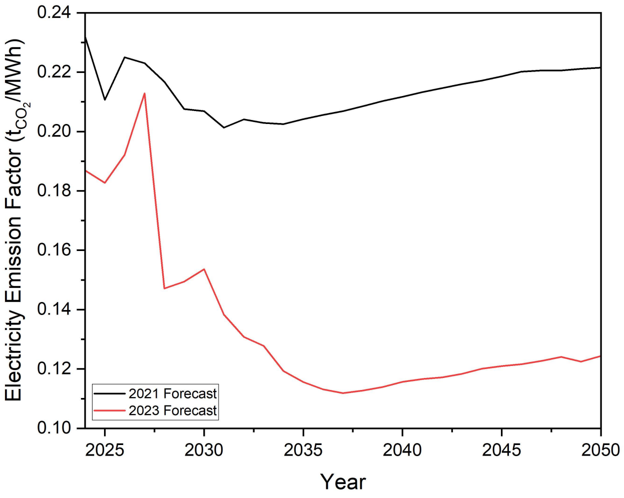

Figure 2.3: Annual electricity emission factor from environment and climate change Canada for the 2021 and 2023 forecast from 2024-2050 [14, 15]

factor bench-marking tool that industrial plants must comply with to help “find innovative ways to reduce emissions and invest in clean technology to stay competitive and save money” [51]. The TIER regulation aims to reduce the emission factor by 2% annually starting in 2022 and is shown in Figure 2.4.

2.3 Estimating Energy Savings Using HOT2000

Along with the emission factor, the energy consumption in the SFHs before and after retrofits is needed where the analysis uses HOT2000. With any engineering model, there is a possibility that modeled energy consumption differs from actual energy consumption seen in homes. For example, the actual energy consumption between September 2014 and August 2015 was compared to the HOT2000 modeled energy consumption of a net zero SFH in Edmonton [53, 54]. The two storey SFH had an “air source heat pump with electric resistant heater as backup”, an heat recover ventilator (HRV), solar PV, and an “air source heat pump hot water tank” [53, 54]. It was found that HOT2000 overestimated the total energy consumption (excluding solar PV generation) by 14% compared to the actual energy consumption [55]. Factors

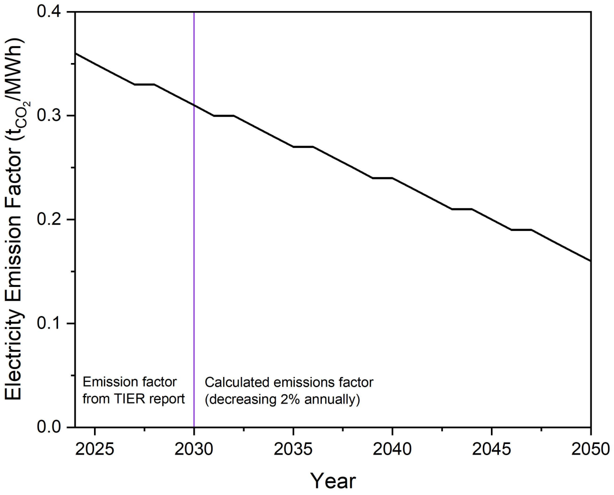

Figure 2.4: Annual electricity emission factor from TIER report from 2024-2030 with calculated emission factors from 2031-2050 [52]

contributing to the difference between were different annual weather data, less energy consumption by appliances compared to model estimations, and the HRV schedules used in the house differed from what was estimated in the model [54]. Including solar PV generation, the modeled energy consumption was 6% higher than the actual energy consumption [55]. The actual solar PV system generated less energy between November 2014 and February 2015 due to snow, decreasing the difference between modeled and actual energy consumption [54].

Another example shows that HOT2000 underestimated the total energy consumption by 52% for an SFH in Quebec [56]. The two-storey SFH had a ground source heat pump, an electric heat pump water heater with pre-heat storage, solar PV, HRV, and a passive solar building envelope design where the home uses ”energy-efficiency strategies” to reduce cooling and heating loads with solar energy used to account for the remaining loads [56, 57]. The actual energy consumption was collected between December 2009 and 2010 [56].

There were numerous factors contributing to HOT2000 underestimating the actual energy consumption. The heating and cooling energy consumption was lower in

HOT2000 due to cooling not being considered in the model, the house installed a larger GSHP than what was used in the model, and the difference in heating and cooling setpoints (1.5°C difference in heating setpoint and 1.0°C difference in cooling setpoint) [56]. The water heating energy consumption was higher in the model as HOT2000 could not model the building-integrated photovoltaic/thermal (BIPV/T) system (solar energy is converted to thermal energy and electricity) used to heat water and HOT2000 did not have the drain water heat recovery system used in the house [56]. For air cleaning, the model underestimated energy consumption as air cleaning was included after the modeled was completed [56]. The solar PV generation was higher in HOT2000 as the solar PV was affected by snow more than expected due to the angle of the system [56]. The modeled plug loads were less than the actual due to occupant behaviour as the model did not consider loads from major events in the home, and additional lighting was installed after the model was completed [56]. As well, the model did not include 2,900 kWh/year of electricity in areas of heat pump re-circulation, heat pump auxiliary heater, garage heater, and BIPV/T pump or fan controls [56].

The differences in actual and modeled energy consumption based on the SFHs in Edmonton and Montreal using HOT2000 is due to factors like outdoor weather assumptions and occupant behaviour. For this analysis, the assumption will be that factors causing overestimation or underestimation of energy consumption remain unchanged between 2024 and 2050 to focus on the gap between GHG reductions on different electricity emission factor forecasts. As the CoE implements retrofit programs to align with the ETSAP, there is an opportunity to observe energy consumption data in homes that complete retrofits to compare to model results for further research into the gap between actual and modeled energy consumption.

2.4 Diffusion of Innovation

DOI method was used in this thesis analysis to predict the number of homes adopting each retrofit category between 2024 and 2050. The solar PV and building envelope and lighting retrofit categories within the potential pathway had different methods for estimating the number of buildings adopting the retrofit combinations per year as seen in Figure 2.5 and Figure 2.6, respectively. For simplicity, this thesis analysis will use the same method. DOI was specifically chosen as the cumulative adoption of household appliances like refrigerators or air-conditioners in homes between 1900-2005 resemble an s-shaped curve, aligning with the DOI theory [58]. The retrofit categories can be considered as household-related systems and were assumed to follow the DOI theory.

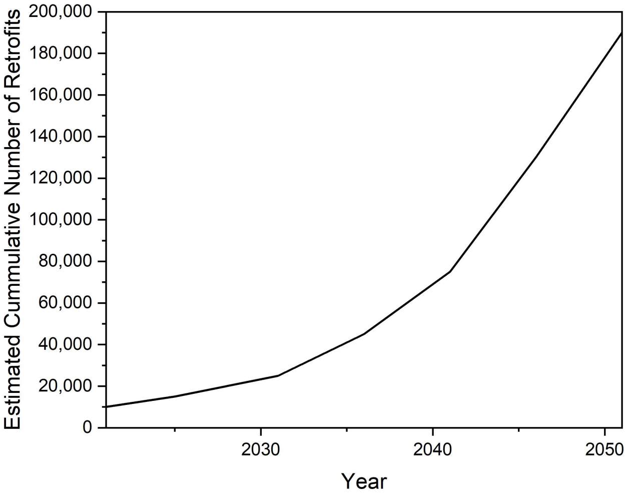

Figure 2.5: Cumulative number of retrofits completed for building envelope and lighting retrofit category within ETSAP for pre-2017 single detached homes from the unpublished analysis

To calculate the rate of growth within the DOI theory from now until a future point in time, equation 2.5 is used [23]:

$$\frac{dN(t)}{dt} = (g(t))(m - N(t)) \tag{2.5}$$

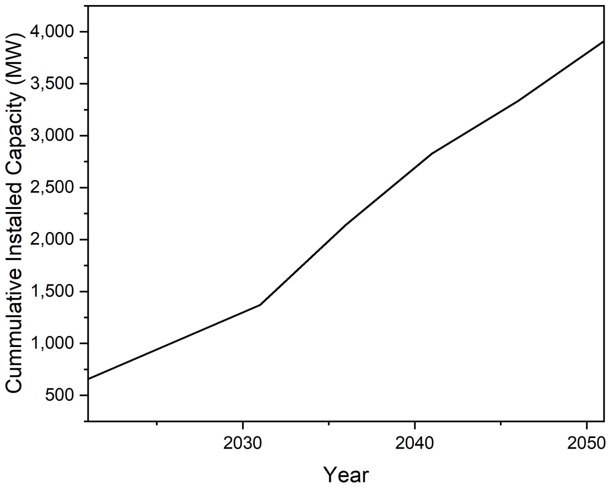

Figure 2.6: Cumulative install capacity for rooftop solar PV retrofit category within ETSAP for residential and commercial buildings from the unpublished analysis

where:

- $N(t)$ is the cumulative number of adopters at time t [23]
- $g(t)$ is the coefficient or rate of diffusion [23]
- m is the maximum number of potential adopters, eliminating the possibility of more adopters adopting the innovation during the time period [23, 25]

The rate of diffusion can change depending on factors like time, communication, and innovation [23]. The most common way to calculate the rate of diffusion is the "mixed-influence model" (or Bass model) theorized by Frank Bass [23]. The Bass model looks only at the initial adoption at a given time, excluding replacement purchases and assuming infrequent adoption [59]. It also assumes a relatively linear relationship between the number of previous buyers and the probability of adoption at a specified time [59]. The model is represented with equation 2.6 and 2.7 [23]:

$$g(t) = p + \frac{q}{m}N(t) \tag{2.6}$$

$$\frac{dN(t)}{dt} = (p + \frac{q}{m}N(t))(m - N(t)) \tag{2.7}$$

where $g(t)$ represents the adoption at a given time assuming no purchase has been made, p is the coefficient of innovation where interested adopters are influenced by organizations like governments and market agents, and q is the coefficient of imitation which shows the relationships between future and existing adopters [23, 59, 60]. Equation 2.7 can also be written as:

$$F(t) = \frac{N(t)}{m} \tag{2.8}$$

$$\frac{dF(t)}{dt} = (p + qF(t))(1 - F(t)) \tag{2.9}$$

where $F(t)$ is the fraction of adopters of the innovation at time t assuming the maximum number of adopters is constant [23]. To integrate equation 2.9, it is rearranged to equation 2.10 [59]:

$$\int_0^t dt = \int_0^F \frac{dF}{p + (q - p)F(t) - q(F(t))^2} \tag{2.10}$$

Integrating equation 2.10 yields the following results [59]:

$$F(t) = \frac{q - pe^{-(t+c)(p+q)}}{q + qe^{-(t+c)(p+q)}} \tag{2.11}$$

where c is a constant [59]:

$$c = \frac{1}{(p + q)} \ln \frac{q}{p} \tag{2.12}$$

The final equation for the cumulative number of adopters, assuming no adopters at $t = 0$, is [59]:

$$N(t) = m\frac{1 - e^{-(p+q)t}}{1 + \frac{q}{p}e^{-(p+q)t}} \tag{2.13}$$

The coefficient of innovation and imitation will determine how much of the maximum number of adopters will adopt the technology during a given time period [23]. Generally, the higher the coefficient of innovation, the more rapid the diffusion of the innovation while the higher the coefficient of imitation, the more gradual the adoption

[61]. In bass models, the number of imitators is larger than the number of innovators which is shown in literature [61]. For example, between 2019 and 2021, 526 homes completed retrofits within the sustainable energy authority of Ireland's pilot deep retrofit grant program [60]. The deep retrofit grant program had homes completing floor, wall, and roof insulation, upgrading windows and doors, installing heat recovery ventilation, whole house ventilation system, biomass boiler, solar PV, wood burning stove, heat pump, and/or a combined heat and power system [62]. For the 526 residential buildings, the coefficient of innovation and imitation was calculated to be 0.02 and 0.2, respectively [60]. Also in Ireland, 170,000 completed retrofits between 2009 and 2015 within the Better Energy Home (BEH) energy efficiency program [63]. BEH offered grants to owners of pre-2006 residential buildings to complete a maximum of four retrofits between solar PV systems, attic and roof insulation, upgrading space heating systems (oil or gas), and wall insulation [63]. The coefficient of innovation and imitation was calculated to be 0.01 and 0.06, respectively, with the influence of investment and advertising [63].

The average coefficient of innovation and imitation is 0.03 and 0.4, respectively based on the meta-analysis of DOI models for technologies including CAT scanners, televisions, refrigerators, air-conditioners, dryers, and dishwashers between 1957-1987 [64]. The average coefficient of innovation and imitation changes to 0.02 and 0.5, respectively, for the reports done in the United States for technologies used in homes only like televisions, refrigerators, air-conditioners, dryers, and dishwashers. The summary of data from the meta-analysis to calculate the coefficient of innovation and imitation for household technologies is shown in Appendix C.

Chapter 3

Model

3.1 Base House

A proposed house within section 9.36.5.2 of the 2020 NBC is "a modeled replica of the actual house under consideration, in which some elements covered in subsections 9.36.2. to 9.36.4. are specific to the actual house, while other elements not covered in those subsections, but necessary for calculating the annual energy consumption, are assigned default values" [35]. Subsections 9.36.2 to 9.36.4 discuss the building envelope, heating, ventilation, and air conditioning (HVAC), and water heating systems requirements for residential buildings [35]. Having access to EnerGuide audits completed in the pilot CEIP, a proposed house model was used where the HOT2000 default inputs were used for inputs not specified in the EnerGuide audit.

As of March 2023, 22 single family detached homes had completed retrofits in the pilot CEIP, where 16 were two storey homes and 6 were one storey. The average annual energy consumption for one and two storey homes was 131 GJ and 175 GJ, respectively. Modeling both archetypes was considered however, the CoE does not have records on the ratio between one and two storey homes in the CoE to represent the building types in the analysis. Two storey SFHs represent almost 75% of SFHs in the pilot program and therefore, the base house was chosen to be a two storey SFH. To determine which home in the pilot CEIP to use for this analysis, the average house dimensions and number of house components (like number of doors and windows)

Component	Average	Base House
Built	1981	1984
Square Footage	2808	2765
Number of Ceiling Types	3	1
Ceiling (ft^2)	1227	972
Number of Walls	3	3
Wall (ft^2)	2344	1795
Number of Exposed Floors	1	1
Exposed Floor	133	8
Number of Windows	23	22
Window (ft^2)	311	266
Number of Doors	3	3
Door (ft^2)	72	56
Exterior/Interior Wall (ft^2)	978	1007
Number of Foundation Header	1	2
Foundation Header (ft^2)	92	98
Foundation Slab (ft^2)	971	917
Above Grade (ft^2)	169	172
Below Grade (ft^2)	89	85

Table 3.1: Average pre-2017 single family home and base house characteristics for participants within pilot CEIP as of March 2023

were calculated based on the 16 two storey homes and are shown in Table 3.1 titled “Average”. The base house chosen had the closest average dimensions and number of house components which is shown in Table 3.1 titled “Base House”.

To accurately represent the average pre-2017 SFH, the average energy consumption from the EnerGuide review and pilot CEIP participants is used. Hence, the base house will use proposed house modelling as a starting point and adjustments will be made to ensure that the average energy consumption is achieved. For modeled homes in the pilot CEIP, proposed house modelling was used as a starting point and the energy consumption was adjusted to ensure that the energy consumption before retrofits within the models resembled the EnerGuide audit values. Inputs changed to achieve the desired energy consumption include occupancy, air temperature, and/or electrical load and will be the same inputs changed within the base house to achieve the average energy consumption.

3.2 Before Upgrades HOT2000 Modelling

This section discusses the HOT2000 inputs used in modelling the base house's energy consumption before retrofits were completed using the EnerGuide audit (refereed to as "audit") for the base house and HOT2000 default values for under the proposed house modelling layout in the 2020 NBC and the 2019 ABC.

3.2.1 House Specifications

The inputs for the general specifications of the base house within HOT2000 are shown in Table 3.2 based on the audit and a Google map search of the house. Proposed house modelling uses the actual building envelope areas and effective thermal resistance, with a solar absorbance of 0.4 for roofs [33, 35]. The effective mass fraction is used to specify the ratio for thermal masses within the HOT2000 file and was left at the default value assuming one thermal mass [65]. The general specifications section in HOT2000 also includes inputs for the weather data with frost line depth, fuel cost, and window air tightness (information purposes only) which were left to default values (not shown in Table 3.2).

Category	Input	Source
Building Type	House, single detached	Audit
Storeys	Two	Audit
Thermal Mass	Light, wood frame	Default
Effective Mass Fraction	1.00	Default
Foundation Soil	Normal conductivity	Default
Water Table Level	Normal	Default
House Shape	L-shape	Google maps
Front Facing	Northeast	Google maps
Year Built	1980-89	Audit
Wall Colour	0.4 solar absorptance	Default/[33, 35]
Roof Colour	0.4 solar absorptance	Default/[33, 35]
Default Roof Cavity	Utilized	Default
Above Grade Area	171.7 m^2	Audit
Below Grade Area	85.2 m^2	Audit

Table 3.2: Base house HOT2000 house specifications inputs

3.2.2 Ceiling

The HOT2000 inputs for the base house ceiling are shown in Table 3.3. The length of the ceiling and the heel height were left to the default values, as these values were not specified in the audit. The base house roof slope was assumed to have a pitch of 4/12, as defined in a rooftop solar PV system quote completed for the house within the pilot CEIP.

Category	Input	Source
Construction	Attic/gable	Audit
Effective R-value	5.88 RSI	Audit
Length	3.16 m	Default
Area	90.3	Audit
Roof Slope	4/12	Solar PV quote
Heel Height	0.13 m	Default

Table 3.3: Base house HOT2000 ceiling inputs

3.2.3 Walls

The HOT2000 inputs for the base house walls are shown in Table 3.4. For all walls, the height was assumed to be 2.5 m which is the minimum wall height requirement in residential buildings outlined in the building codes [33, 35]. The perimeter of the walls was calculated using the assumed wall height and area specified in the audit. The base house included a wall adjacent to the garage which was assumed to be unconditioned. For walls adjacent to unconditioned spaces, HOT2000 adds an additional 0.16 RSI to the wall insulation [65]. The audit reports the wall adjacent to the garage has a thermal resistance of 2.69 RSI so a thermal resistance of 2.53 RSI was inputted in HOT2000.

3.2.4 Foundation

The base house has one foundation and two foundation headers with the HOT2000 inputs shown in Table 3.5. Floor headers are the "exterior, exposed portion of a

Category	Input	Source
Main Floor Wall		
Effective R-value	2.99 RSI	Audit
Height	2.46 m	Default
Perimeter	33.9 m	Calculated
Area	83.5 m^2	Audit
Second Floor Wall		
Effective R-value	2.98 RSI	Audit
Height	2.46 m	Default
Perimeter	27.5 m	Calculated
Area	67.6 m^2	Audit
Wall Adjacent to Garage		
Effective R-value	2.69 RSI	Audit
Height	2.46 m	Default
Perimeter	6.30 m	Calculated
Area	15.6 m^2	Audit

Table 3.4: Base house HOT2000 wall inputs

horizontal structure element that separates two floors of a house" and are "attached to walls" [65]. The foundation was assumed to be a basement with a height of 2.0 m based on the minimum height requirement for the only basement specification within the building codes (unfinished basements with laundry areas) [33, 35]. Basements are classified as foundations with a total height greater than 1.2 m and a below grade height greater than 0.6 m [65]. Above grade walls with heights greater than 0.6 m are considered pony walls [65]. Pony walls were not reported in the base house audit therefore the base house was assumed to have a below grade height of 1.4 m and an above grade height of 0.6 m. The type and area for the door separating the basement and main floor along with the effective thermal resistance of the floors above the foundation were left to the default value as these inputs were not specified in the audit.

Category	Input	Source
Foundation		
Perimeter	42.6 m	Calculated
Total Area	85.2 m^2	Audit
Opening to Upstairs	1.56 m^2	Default
Wall Insulation Configuration	Full length insulation	Audit
Effective R-value	2.68 RSI	Audit
Floors Above Foundation	0.468 RSI	Default
Foundation Header 1		
Effective R-value	3.70 RSI	Audit
Height	0.250 m	Default
Perimeter	6.00 m	Calculated
Area	1.50 m^2	Audit
Foundation Header 2		
Effective R-value	3.83	Audit
Height	0.250 m	Default
Perimeter	30.4 m	Calculated
Area	7.60 m^2	Audit

Table 3.5: Base house HOT2000 foundation and foundation header inputs

3.2.5 Windows and Doors

The base house has 22 windows and three steel medium density spray foam doors. The location of all windows and doors were not specified in the audit and were estimated based on the Google maps search of the house. Based on the Google maps search, two doors were put on the main floor wall adjacent to the garage and one door was put on the main floor. For simplicity, the doors were assumed to have the same area with a width of 810 mm which is the minimum width requirement for doors outlined in the building codes [33, 35]. The total door area specified in the audit was 5.2 m^2 where each door would have an area of 1.7 m^2. With a total area of 1.7 m^2 per door and a width of 0.81 m, the height of each door is 2.1 m.

The following assumptions were made for the windows:

- Based on a Google map search of the home, one slider window in the basement is visible. The audit had three slider windows with the same specifications and were assumed to be in the basement

- One fixed window was placed on the entrance door as required by the building codes stating that entrance doors must have a window or sidelight
- The remaining 18 windows were divided in half between the main and second floor where nine hinged windows were placed on the second floor based on the requirement of at least one non-fixed window without sashes in bedrooms [33, 35]
- The remaining nine windows were fixed, slider, and hinged windows and were placed on the first floor

Moving the windows between the first and second floor or changing the number of windows on the first or second floor resulted in no change to the energy consumption. Moving the windows above and below grade affected the energy consumption and therefore, the heat loss will be compared to the audit results to justify the window placements once the average energy consumption is achieved in the base house.

The three windows in the basement were assumed to be 0.6 x 0.6 m which is the assumed height of the above ground portion of the foundation walls. The basement windows were spread out along the southwest, northwest, and southeast walls as the Google search of the house shows no foundation window on the northeast wall. The window on the entrance door was also assumed to be 0.6 x 0.6 m (0.36 m^2) as the area was not specified in the audit but complied with the maximum allowable glass area for doors in the building codes (0.36 m^2 is less than all areas listed in the table) [33, 35]. The 18 windows on the main and second floor walls were assumed to be 1.1 x 1.1 m to comply with the total window area listed in the audit minus the areas of the foundation windows, doors, and main door windows. The Google map search of the base house showed 5 northeast windows and 6 southwest windows. Therefore, the main and second floor windows were spread out on the northeast (5), northwest (4), southeast (4), and southwest (6) walls. The window and door area to above grade wall area ratio can not exceed 33% based on 2017 NECB [34]. With the above placements, the wall adjacent to the garage has a ratio of 24%, the second floor wall has a ratio of 17%, the main floor wall has a ratio of 16%, and the entire house has an 18% ratio.

The audit states the type, glazing, coating, and frame type for windows with the corresponding effective thermal resistance. The base house has four types of windows: aluminium sliders with single glazing and no coating/tints (0.13 RSI), aluminium fixed windows with single glazing and no coating/tints (0.15 RSI), vinyl slider windows with double glazing and no coating/tints (0.33 RSI), and vinyl hinged windows with triple glazing and low coating/tints (0.48-0.60 RSI). The specifications for the windows in HOT2000 are shown below aligning with the thermal resistance specified in the audit. The location of the hinged windows with triple glaze ranging between 0.48 and 0.6 RSI was not specified in the audit and the average thermal resistance was used for the windows (0.54 RSI). The closest thermal resistance that could be achieved in HOT2000 was 0.53 RSI and was used for the window modelling.

- Slider windows with sash's (this was chosen as the audit states the windows have vinyl frames and this can only be chosen for slider windows with sash's)
- Coatings/tints are “low - E 0.2 (hard1)”
- Glazing type is “triple/triple with one coat”, “double/double with 1 coat”, or single coating
- Air fill type (HOT2000 default)
- Metal spacer type (HOT2000 default)
- 0 overhang height and header height (HOT2000 default)

- 0 shutter r-value and 1 curtain shading factor (HOT2000 default values that assume the curtains are never closed during the day to allow maximum solar radiation into the house) [65]

- 90° vertical tilt (HOT2000 default)

3.2.6 Exposed Floor

There is one exposed floor in the base house with an area of 0.7 m. The length of the exposed floor was kept at the default value of 3.2 m as the audit did not specify the length.

3.2.7 Temperature

The temperature inputs for the base house are shown in Table 3.6. For proposed house modeling, the temperature setpoints above grade in living spaces are 20°C where a maximum of 5.5°C increase is considered, 15°C for crawl spaces, 25°C for cooling system setpoint and 19°C for basements assuming the basement is not heated with a separate thermostat [33, 35]. The main floor nighttime heating setpoint, main floor nighttime setback duration, and main floor allowable rise were left at default values as there are no requirements within the building codes and was not specified in the audit.

Category	Input	Source
Main Floor Daytime Heating Setpoint	20°C	[35]
Main Floor Nighttime Heating Setpoint	18°C	Default
Main Floor Cooling Setpoint	25°C	Default
Main Floor Nighttime Setback Duration	8 hours	Default
Main Floor Allowable Rise	5.5°C	[35]
Equipment Heating Setpoint	22°C	Default
Equipment Cooling Setpoint	25°C	[35]
Basement Heating Setpoint	19°C	[35]

Table 3.6: Base house HOT2000 temperature inputs

3.2.8 Base Loads

The base loads were left to the default values where it is assumed that 2 adults and 1 child spending 50% of their time indoors and the internal gains applied to the basement was 0.15. Internal gains are defined as "a contribution of heat generated by energy consuming in-house equipment, hot water system(s) and metabolic gains from occupants" [65].

3.2.9 Infiltration

The base house inputs for the infiltration section in HOT2000 are shown in Table 3.7. The house volume was estimated to be 500 m^3 using the following assumptions and values:

- Above grade height of 5.5 m
- Basement slab area of 85.2 m^2 (from audit)

Multiplying the above values gives a house volume of 470 m^3 which was rounded up to 500 m^3 to account for the gable ceiling volume. As well, the model was undefined for house volumes below 500 m^3. For modelling a proposed house, the air change rate and equivalent leakage area of the actual house must be used [33, 35]. The remaining inputs were left to default values.

3.2.10 Ventilation

The actual HVAC system must be modeled for a proposed house [33, 35]. The base house had no ventilation system information in the audit and therefore the ventilation section in HOT2000 was left to the default values. The default values include no specified requirements for the ventilation system, forced air heating duct work for the air distribution/circulation type, and a 480 min/day operation schedule (8 hours a day schedule for proposed house modelling). For the supplemental components, the dryer was left at the default exhaust flow rate of 38 L/s.

Category	Input	Source
House Volume	500 m^3	Calculated
Above Grade Height of Highest Ceiling	5.5 m	Calculated, Default
Building Site Terrain	Suburban, Forest	Default
Air Change Rate	3.18 ACH* at 50 Pa	Audit
Equivalent Leakage Area	496.7 cm^2 at 10 Pa	Audit, [66]
Walls Local Shielding	Heavy	Default
Flue Local Shielding	Light	Default
Weather Station	Open Flat Terrain	Default
Terrain	Grass	Default
Weather Station Anemometer	10 m	Default
Leakage Fractions	Default	Default

*ACH is air changes per hour

Table 3.7: Base house HOT2000 infiltration inputs

3.2.11 Heating/Cooling Systems

The base house contains a furnace and wood fireplace where the fireplace was not included in the house as the usage of the fireplace is not specified in the audit and the HOT2000 default for the fireplace assumes the fireplace is not used. The HOT2000 inputs for the gas furnace are shown in Table 3.8. The pilot light and flue diameter were left to the HOT2000 defaults as they were not specified in the audit. The furnace efficiency was specified by the Annual Fuel Utilization (AFUE) which is the average usage efficiency accounting for the on and off cycling, burner effect, sensible heat, standing pilot losses in cooling months and exhausted latent heat [65]. The cooling months and fan/pump inputs were left to default values as the cooling month's assumption and the fan/pump inputs were not included in the audit.

3.2.12 Domestic Water Heater

The domestic water heating inputs for the base house are shown in Table 3.9. Tank location, insulating blanket thermal resistance, pilot energy, and flue diameter were left to the HOT2000 default values as these values were not included in the audit.

Category	Input	Source
Energy Source	Natural gas	Audit
Type	Condensing	Audit
Output Capacity	23.5 kW	Audit
Efficiency	94% AFUE	Audit
Pilot Light	0 MJ/day	Default
Flue Diameter	0 mm	Default

Table 3.8: Base house HOT2000 space heating system inputs

Category	Input	Source
Energy Source	Natural gas	Audit
Type	conventional tank (pilot)	Audit
Tank Volume	151.4 L	Audit
Energy Factor	0.55	Audit
Tank Location	Basement	Default
Insulating Blanket	0 RSI	Default
Pilot Energy	17.7 MJ/day	Default
Flue Diameter	76.2 mm	Default

Table 3.9: Base house domestic water heating system inputs in HOT2000

3.2.13 Base House Before Retrofit modelling Results

The inputs discussed above yielded an energy consumption of 120 GJ/year which was 3% lower than the energy consumption of the original base house. A 10% difference in energy consumption between the re-created models in the pilot CEIP was deemed acceptable by the CoE. The average energy consumption from the CEIP and EnerGuide data set was 174 GJ/year showing that the base house was consuming less energy than the average. Therefore, to accurately represent the SFHs, the energy consumption of the base house was increased to 174 GJ/year.

The breakdown of energy consumption from space heating, space cooling, water heating, ventilation, lights and appliances, and any other electrical loads from the base house breakdown is shown below. The percentage of energy consumption will affect the energy consumption reduction for retrofits targeting the specified areas. Compared to the original base house, the modeled space heating was 2% lower than the original base house, and the water heating, lights, appliances, and others were 1% lower than the original base house.

- Space heating: 56%
- Space cooling: 0%
- Water heating: 23%
- Ventilation: 0%
- Lights, appliances, and other: 22%

The average breakdown from the CEIP and EnerGuide audit data set is shown below. To ensure that the average energy consumption reduction in the base house is achieved after retrofits are installed, the below percentages will be compared after changes are made to the base house to ensure the average energy consumption breakdown is achieved.

- Space heating: 67%
- Space cooling: 1%
- Water heating: 16%
- Ventilation: 0%
- Lights and Appliances: 7%
- Other: 9%

The below inputs were changed to achieve the average energy consumption. The gaps between the default HOT2000 temperature setpoints were maintained with the below changes.

- Round down the thermal resistance for the roof (2 RSI) and walls (5 RSI)

- Mainfloor daytime heating setpoint is increased to 21°C
- Mainfloor nighttime heating setpoint is increased to 19°C
- Basement heating set point increased to 20°C
- Occupancy increased to 2 adults and 4 children spending 50% of time indoors
- Miscellaneous electrical load decreased to 6.30 kWh/day from the default value of 9.70 kWh/day
- Shower water temperature decreased to 37°C from the default value of 41°C
- Clothes washer water temperature decreased to 37°C from the default value of 45°C
- Furnace was changed to a furnace with continuous pilot with a 80% AFUE. A furnace with continuous pilot was chosen as it had the highest increase in natural gas consumption. 80% AFUE was chosen as this was the lowest furnace efficiency from CEIP participants before retrofits

With the changes in inputs listed above, the base house energy consumption was 174 GJ/year, accurately representing the average pre-2017 SFH in the CoE. The input changes resulted in a 5% difference between the average and base house energy consumption breakdown and is shown below. Table 3.10 compares the heat loss of the base house and the original base house, showing a less than 10% difference.

- Space heating: 64%
- Space cooling: 0%
- Water heating: 21%
- Lights, appliances, and other: 16%

Heat Loss Category	Original Base House	Base House
Attic/Ceiling	6%	6%
Walls	23%	27%
Exposed floors	0%	0%
Windows	37%	30%
Exterior doors	2%	2%
Basement	23%	25%
Air leakage/ventilation	9%	10%

Table 3.10: Heat loss comparison between the base house and the original base house

3.3 HOT2000 Modelling After Retrofit Installation

Homeowners can choose from various retrofits based on price and efficiency. The analyses will have two energy efficiency cases (intermediate efficiency and high efficiency) compared to a baseline case to demonstrate the range of possible energy consumption reductions that SFHs could achieve. The base case assumes that homes do not complete retrofits and maintain the average energy consumption before retrofits. The high efficiency case represents the highest energy reduction using the most efficient systems installed in the pilot CEIP while the intermediate efficiency case represents the lowest energy reduction using the least efficient systems. As the retrofit reaches the end of the useful lifetime, it is assumed that homeowners would replace the systems but maintain the overall average energy consumption as it is unknown how far into the base house lifetime the insulation and equipment are. The retrofit specifications within the intermediate and high efficiency case are discussed below.

3.3.1 Building Envelope and Lighting

The unpublished analysis assumed 370,000 pre-2017 residential buildings would install efficient appliances, improve building envelope insulation, and upgrade lighting. Appliances were not included in the pilot CEIP and were excluded from the analysis with the assumption that appliance upgrades would occur outside of a retrofit program. Lighting retrofits within the pilot CEIP were completed differently between participants. For example, one house upgraded three 300 W light bulbs to 45 W light bulbs along with installing lighting controls to decrease usage by 10 hours/day. Another house upgraded one 100 W light bulb to an 8 W light bulb where usage was not specified. To estimate the energy savings with lighting fixtures within the pilot CEIP analysis, a usage of 2 hours/day was used before and after upgrading lighting fixtures based on a 2012 analysis of residential light usage in the United States [67]. HOT2000 has three default lighting options defined as kWh/day of lighting: less than 25% of compact fluorescent lights (CFL) or light emitting diode (LED) lights (2.6 kWh/day), "25-75% of CFL or LED lights" (1.6 kWh/day), and "more than 75% of CFL or LED" (0.6 kWh/day). Before retrofits, the default lighting option was "less than 25% of CFL or LED" (2.6 kWh/day). Lighting controls could be included in the HOT2000 default options as the options are expressed in kWh/day. To estimate the range of lighting options, the intermediate efficiency efficient case will use the "25-75% of CFL or LED lights" option and the high efficiency case will use the "more than 75% of CFL or LED" option.

At the time this analysis was completed 45% of CEIP participants had installed new windows, 41% increased attic insulation and installed new doors, 18% increased foundation header insulation, 14% increased foundation insulation, and 5% increased wall insulation, completed an exterior home wrap, and other air sealing. Attic insulation, windows, and doors were the three most common building envelope retrofits in the pilot CEIP and was used in the analysis. The range of attic insulation, windows, and door retrofits completed in the pilot CEIP is shown in Table 3.11 within the intermediate and high efficiency case. For windows, all participants upgraded windows to triple glaze, argon or air fill, low emissivity coating, and vinyl, reinforced vinyl, fibreglass, or wood frames. The base house has 14 triple glazed, low emissivity coating, and vinyl framed windows and 9 non-triple glazed, no emissivity windows. The analysis assumed that the 9 windows are upgraded to the same specifications as

Envelope Upgrade	Intermediate Efficiency	High Efficiency
Attic Insulation	8.8 RSI	10.6 RSI
Windows	triple glazed, low emissivity, vinyl frame	
Doors	1.18 RSI	

Table 3.11: Building envelope retrofits used in thesis analysis for all pre-2017 SFH in the CoE

the 14 windows in the base house. For doors, seven out of nine participants upgraded to steel medium density spray foam core (1.14 RSI), which is the same door type used in the base house. 1 house upgraded to a 1.18 RSI door and was used for both energy efficiency cases.

The building envelope and lighting retrofit category also considered space heating transitioning from "86% natural gas, 9% electricity, 4% wood, and 2% heat pumps [in 2021] to 55% air or ground source heat pumps, 14% [hydrogen], 11% [renewable natural gas], 6% natural gas, 10% district energy, and 4% electric" by 2050. The ASHP and GSHP assumption is tied to the heat pump retrofit category where it was assumed that 55% of residential buildings would install an ASHP or GSHP along with building retrofits. Since the focus of the this analysis was pre-2017 SFHs, building retrofits were assumed to be the same retrofits within the building envelope and lighting retrofit category (attic insulation, windows, doors, lighting). Therefore, the heat pump and building and lighting retrofit categories will be combined under the heat pump retrofit category. As the percentage of the SFHs completing the building and lighting category and heat pump category was not specified in the unpublished analysis, the thesis analysis assumes that 55% of pre-2017 SFHs will upgrade attic insulation, lights, and windows along with install an ASHP or GSHP and the remaining 45% would upgrade attic insulation, lights, and windows only.

3.3.2 Air Source Heat Pump

The ASHP efficiency and specification range completed in the pilot CEIP is shown in Table 3.12 between the intermediate and high efficiency case. In the pilot CEIP, 50% of participants who installed an ASHP sized it to 50% of the home's heating and used it for heating and cooling. Additionally, all participants installed the same central single package ASHP where the condenser, compressors, and evaporator are in one package located beside the house's foundation or on the roof [65]. Therefore, a central ASHP covering 50% (intermediate case) or 100% (high case) of the heating load is used for heating and cooling where the efficiency of the system is assumed to be the same between the intermediate and high efficiency case. The base house had a 23.5 kW condensing gas furnace before upgrades, representing 100% of the heating load and so, 50% of the heating load is 11.8 kW. The temperature cutoff and rating type, crankcase heater, sensible heat ratio, and openable window area were left to the HOT2000 default values as these values were unknown.

Category	Input
Function	Heating/cooling
Type	Central single package system
Output Capacity (Inter. Case)	11.8 kW (50% of heating load)
Output Capacity (High Case)	23.5 kW (100% of heating load)
Heating/Cooling Efficiency	11.8 HSPF/22 SEER
Temperature Cutoff	Balance point
Temperature Rating Type	8.3°C
Crankcase Heater	60 W
Sensible Heat Ratio	0.76
Openable Window	0%

Table 3.12: Base house HOT2000 ASHP inputs

3.3.3 Ground Source Heat Pump

The GSHP efficiency and specification range completed in the pilot CEIP is shown in Table 3.12 between the intermediate and high efficiency case. In the pilot CEIP, one house had installed a vertical coil GSHP for heating and cooling. A vertical configuration has the coils in a vertical position 15-150 m below ground [68]. Aligning with the ASHP assumptions, for the intermediate efficiency case, it is assumed that a vertical coil GSHP for 50% (intermediate case) or 100% (high case) of the heating load is used for heating and cooling. As one house in the pilot CEIP has installed a GSHP, the efficiency of the system used in the analysis will be the same between the intermediate and high efficiency case. The temperature cutoff and rating type, crankcase heater, sensible heat ratio, and openable window area were left to the HOT2000 default values as these values were unknown. The depth of the coils was left to default values as there is a 2% difference in electricity consumption and 0% difference in natural gas consumption between coils at 1.5 m and 150 m using the HOT2000 default heating and cooling efficiencies. Vertical coils are meant to be deeper than 1.5 m however, with a difference of 2% in energy consumption between the depths, there will be negligible effect on the cumulative GHG reductions.

Category	Input
Function	Heating/cooling
Output Capacity (Inter/High Case)	11.8 kW/23.5 kW
Heating/Cooling Efficiency	4.2 COP/19.7 SEER
Temperature Cutoff	Balance point
Temperature Rating Type	8.3°C
Crankcase Heater	60 W
Sensible Heat Ratio	0.76
Openable Window Area	0%
Ground Temperature	Default
Average Depth	1.5 m

Table 3.13: Base house HOT2000 GSHP inputs

3.3.4 Natural Gas Condensing Furnace

HOT2000 models the ASHP and GSHP as the primary heating system and a furnace, boiler, or plenum/hydronic/baseboard heater as the backup system. The base house had a natural gas condensing furnace with a 94% AFUE and the assumption is that the house would install a more efficient gas furnace or an electric furnace. Electric furnaces were not offered in the pilot CEIP and were first included in the 2020 NBC with no efficiency specifications [35]. Electric furnaces are currently not in the ABC, indicating that electric furnaces are still relatively new systems [33]. Therefore, a gas furnace will be used as the backup system, understanding that the adoption of electric furnaces could increase in the coming years. Natural gas furnace upgrades ranged between 97-99% AFUE in the pilot CEIP so, the intermediate efficiency case will assume a natural gas condensing furnace with a 97% AFUE and the high efficiency case will a 99% AFUE condensing furnace. Even with a heat pump covering 100% of the heating load, participants within the pilot CEIP installed furnaces that covered 100% of the heating load as a backup so the analysis included furnaces sized to 100% of the heating load.

3.3.5 Water Heater

The potential pathway for water heaters within the ETSAP was 75% of residential and commercial buildings installing heat pumps, electric water heaters, hydrogen water heaters, electric hybrid, or electric on demand heating water heaters (tankless water heaters) between 2023 and 2050. Participants in the pilot CEIP were installing tankless gas water heaters and integrated heat pump water heaters (HPWH). The focus of this category was electric water heaters and, therefore, HPWHs will be used in the analysis for the intermediate and high efficiency case.

Within the unpublished analysis, the assumption was that building retrofits would be completed along with the installation of an electric water heater, however the type of building retrofits was not specified. Since the focus of the analysis was pre-2017 SFHs, building retrofits were assumed to be attic insulation, windows, and door. As well, the unpublished analysis assumed electric space heating (ASHP or GSHP) would be completed along with the installation of an electric water heater. Thus, the heat pump specifications within the heat pump retrofit category will be used within this retrofit category analysis. The analysis will assume that 75% of the SFHs will install an electric water heater, upgrade attic insulation, lights, and windows, and install an ASHP or GSHP while the remaining 25% of the SFHs will upgrade attic insulation, lights, and windows only as the the unpublished analysis did not specify the number of residential buildings completing these retrofit combinations.

The specifications range for HPWHs completed in the pilot CEIP is shown in Table 3.14 between the intermediate and high efficiency case. For HPWHs modeled in HOT2000, the energy factor (EF) must be 0.9 to represent the tank efficiency and the heat pump efficiency is calculated using equation 3.1 and inputted as the HP COP:

$$COP = \frac{EF}{0.9} \tag{3.1}$$

where EF is the heat pump's energy factor, and 0.9 represents the tank's EF [65]. The range of energy factors installed in pilot CEIP is 3.7-3.9 uniform energy factor (UEF). HOT2000 has a UEF mode and assuming the 0.9 tank efficiency is expressed in UEF while in the UEF mode, the HP COP range is 4.1-4.3. The tank size was the same as the base house water heater size before retrofits (151.4L). The tank location, draw pattern, and insulating blanket were left to the HOT2000 default values as these were unknown.

Category	Input
Energy Source	Electricity
Type	Integrated heat pump
Tank Volume	151.4 L
Energy Factor	0.9
Tank Location	Basement
Insulating Blanket	0 RSI
HP COP (Inter./High Case)	4.1/4.3
Draw Pattern	208 L

Table 3.14: Base house HOT2000 HPWH inputs

3.3.6 Solar PV System

The unpublished analysis for rooftop solar PV systems includes 85% of buildings installing rooftop solar PV systems between 2021 and 2041 but does not include specifications for the solar PV. In the pilot CEIP, participants have installed solar PV systems where the average system size was 10,480 kWh/year with an average electricity savings of 7,840 kWh/year. Homes with no exports had an average solar PV size of 6,014 kWh/year, while homes with exports, exported an average of 2,640 kWh/year based on the contractor estimations. Therefore, the analysis will include solar PV with and without exports. The intermediate efficiency case assumes the solar PV system provides 6,014 kWh/year and is utilized in the house throughout the year, and the high efficiency case assumes the solar PV generates enough electricity for the annual electricity consumption to be zero with additional exports of 2,640 kWh/year.

The percentage of residential buildings completing the solar PV category was not specified so the thesis analysis assumes that 85% of the SFHs install a solar PV system. Since the scope is the SFHs where building envelope and lighting retrofits are completed in all pre-2017 residential buildings, the assumption is that attic insulation, windows, doors, and lighting upgrades are done as well. In addition, it was assumed that the remaining 15% of the SFHs will complete attic insulation, windows, doors, and lighting upgrades only.

Degradation is the “reduction in solar panel output over time” [69]. The average maximum annual degradation rate for installed solar PV within the pilot CEIP was 0.5%, where the average first year output was 98% of the maximum expected output. The 98% maximum output in the first year and the 0.5% annual degradation afterwards will be used in the analysis. For the high efficiency case, it is assumed that solar PV will cover 100% of electricity consumption and maintain this coverage throughout the useful lifetime with the degradation. The solar PV exports will have the degradation rate applied.

Chapter 4

Analysis

The electricity emission factor forecasts shown in Figures 2.2 - 2.4 anticipate emission factors heading towards or potentially reaching zero by compared to the 2021 forecast completed by ECCC. In 2040 the electricity emission factor in the 2021 ECCC forecast was 0.2 t_{CO_2}/MWh while the dispatchable dominant forecast within the AESO net zero pathway is 0.05 t_{CO_2}/MWh, showing a potential for different GHG reductions between the two forecasts. For example, if a house were to complete retrofits resulting in 1,000 kWh/year electricity reductions through installing solar PV, upgrading appliances, and/or lighting, the GHG reductions in 2040 would be four times higher on the 2021 forecast completed by ECCC compared to the dispatchable dominant scenario as seen in Table 4.1. The changes in GHG reductions due to the electricity emission factor are worth analyzing to determine how the GHG reductions will change the ETSAP for achieving net zero by 2050.

Electricity Emission Factor Forecast	Electricity Reduced (MWh)	Emission Factor (t_{CO_2}/MWh)	Total GHG Emissions (t_{CO_2}/MWh)
Dispatchable (AESO Net zero Pathway)	1.00	0.05	0.05
2021 ECCC Forecast	1.00	0.20	0.20

Table 4.1: Example of GHG reduction results from different 2040 electricity emission factor forecasts

The GHG reductions within this analysis were calculated by comparing the total GHGs from the two energy efficiency scenarios (referred to as "intermediate case" and "high case") to the base case total GHGs. The GHG reductions on decarbonizing electricity forecasts are compared to the GHG reductions on the 2021 ECCC forecasted electricity forecast (referred to as "2021 ECCC forecast"). The chosen decarbonizing electricity forecasts for the analysis (referred to as "decarbonizing electricity forecasts") were the dispatchable dominant scenario from the AESO net zero pathways report (referred to as "clean electricity forecast") and the 2023 ECCC emission factor forecast (referred to as "2023 ECCC forecast") and are shown in Figure 4.1. The dispatchable dominant scenario was used as the electricity emission factors between 2024 and 2041 have the lowest overall average emission factor out of the three scenarios discussed in the AESO net zero pathway report (Figure 2.2). The dispatchable dominant scenario will show the lowest electricity emission factors forecasted in 2023. The 2023 ECCC forecast was also used as the CoE currently uses this forecast. The TIER emission factors were not used as the emission factors are larger than the 2021 ECCC forecast which is used as the electricity emission factor forecast for comparison. The AESO LTO scenarios were not used as the estimated electricity emission factors are within the bounds of the two chosen emission factor scenarios.

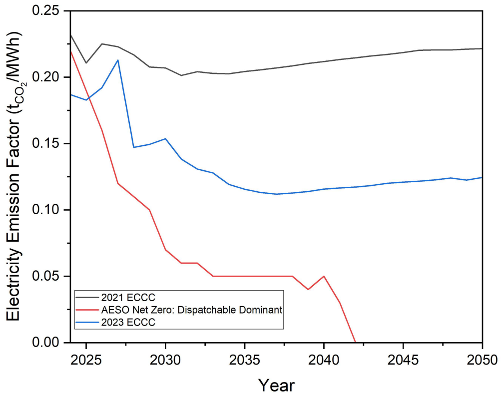

Figure 4.1: Electricity emission factor forecasts used in thesis analysis

A cost analysis was completed where the NPV of energy cost savings was calculated using equation 4.1 [36]. An average interest rate of 3.3% based on the pilot CEIP participant's interest rate for financing retrofits completed in the program was used in the analysis.

$$NPV = \Sigma_{t=0}^{n} \frac{cash_{net}}{(1+i)^t} \tag{4.1}$$

where i is the discount rate, and t is the "number of periods" [36]. The cost analysis will also include the simple payback period (SPP) and discounted payback period (DPP) to determine if homeowners can pay for the retrofits before the useful lifetime is reached. SPP calculates the number of years that a project cost is recouped through cost savings by dividing the project cost by the annual cost savings. DPP is similar to SPP but uses the present value of the annual cost savings shown in equation 4.2.

$$presentvalue = \frac{cash_{net}}{(1+i)^t} \tag{4.2}$$

4.1 Coefficient of Innovation and Imitation for Analysis

The annual adoption of the retrofit combinations was calculated using the mixed influence DOI model theorized by Frank Bass [59]. There are various methods for estimating the coefficient of innovation (p), coefficient of imitation (q), and maximum number of adopters (m) using historical data [23, 60]. Available data sets that could have been used include the Change for Homes Climate Solar Program and HERA program. The Change for Homes Climate Solar Program has data for solar PV installations between 2010 and 2023, while HERA has data for homeowners completing retrofits between 2021 and 2023 [8]. Ideally, the coefficients used in this thesis would represent the adoption of multiple different retrofits or technologies used in the residential buildings where all the SFHs would complete retrofits by 2050 as discussed in Chapter 2. Therefore, literature was used to define a coefficient of innovation and imitation. To determine which coefficients will result in all homes completing retrofits by 2050 from the reports discussed in Chapter 4.6, the cumulative number of adopters was calculated for all the SFHs in Edmonton. The unpublished analysis estimated 370,000 pre-2017 residential buildings in Edmonton. Based on Edmonton's census data between 2016 and 2021, SFHs represent 49.9% and 49.6% of residential buildings, respectively [70, 71].

To determine the percentage of pre-2017 SFHs, LRA was used as the percentages of SFHs decreased linearly between 2016 and 2021. For calculating the percentage of SFHs in 2017, y was the percentage of single family homes and x was the year to get the following equation:

$$\%SFH = 171 - 0.06x \tag{4.3}$$

Using equation 4.3, it is assumed that SFHs in 2017 represented 49.8% of residential buildings or 184,000 homes (rounded up). Using 184,000 homes as the maximum number of adopters and the coefficients of innovations and imitations for each considered report, the cumulative number of adopters in 2050 was calculated and shown in Table 4.2. The average coefficient of innovation and imitation from the data used in the meta-analysis had the most cumulative number of adopters by 2050 and was chosen for this analysis.

Category	p	q	Cumulative number of adopters in 2050	Citation
Climate Action Plan	0.02	0.2	176,000	[60]
Better Energy Homes	0.01	0.06	96,000	[63]
General (Average)*	0.02	0.5	184,000	[64]

*for technologies used in homes only from data set from (Appendix C) [64]

Table 4.2: Cumulative number of pre-2017 SFH in Edmonton for various coefficient of innovations and imitations

4.2 Cost Analysis Assumptions

4.2.1 Electricity Price Scenarios

There are challenges with forecasting electricity prices due to influences like weather, transmission and distribution system costs, and power plant costs [72]. Figure 4.2 shows the average variable retail electricity price in Alberta between 2002 and 2023,

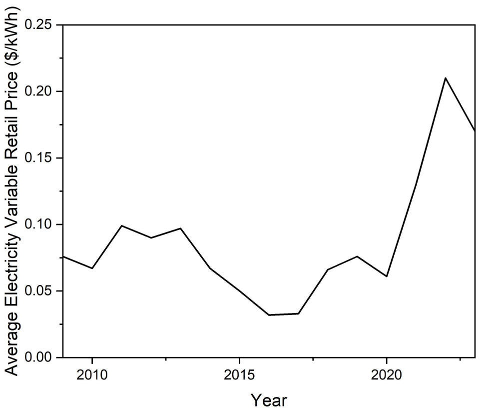

Figure 4.2: Alberta's average annual variable retail electricity price between 2009 and 2023 [74]

showing that electricity pricing is volatile. Therefore, the analysis utilized average historical electricity pricing and assumed that the average stayed consistent between 2024 and 2050.

Alberta Utilities Commission (AUC) "regulates the utilities sector, natural gas and electricity markets to protect Alberta's social, economic and environmental interests where competitive market forces do not" and contains historical values for variable, fixed, and regulated rate pricing in Alberta starting in 2002 [73]. Two energy cost scenarios were used in the analysis where the low energy cost scenario (LECS) used the average variable, fixed, and regulated retail electricity price below the overall average variable, fixed, and regulated rate and the high energy cost scenario (HECS) used the higher average. The cost scenarios will show a range of possible energy cost savings, attempting to factor in the average volatility of electricity pricing using historical data between 2002 and 2023 where the final values are shown in Table 4.3.

The electricity distribution, transmission, and rider costs for residential buildings in Edmonton come from FortisAlberta, ATCO electric, EPCOR, and ENMAX utilities, all regulated under AUC [75]. FortisAlberta provides distribution, transmission, and rider between 2016 and 2023, while EPCOR provides costs between 2010 and 2023 [76, 77]. ENMAX and ATCO have distribution, transmission, and rider between

Scenario	Electricity Price ($/kWh)	Micro-generation ($/kWh)
LECS	$0.05	$0.09
HECS	$0.16	$0.21
Variable Distribution, Transmission, and Rider	$0.06	-

Table 4.3: Electricity retail, distribution, transmission and rider price for analysis [74, 76–79]

2017 and 2023, therefore the 2017-2023 cost data from FortisAlberta and EPCOR were used [78, 79]. The distribution, transmission, and rider cost may not increase or decrease with electricity retail pricing as the distribution, transmission, and rider cost is set for months to years, while the electricity retail pricing can change hourly or daily. In light of this, the average distribution, transmission, and rider cost will be used for the LECS and HECS as shown in Table 4.3.

Homes with solar PVs sell exports at a specified retail electricity price called micro-generation. AUC regulates the micro-generation price with historical prices starting in 2015 [73, 74]. The micro-generation price utilized in the analysis was based on historical data and is shown in Table 4.3. The LECS includes the average micro-generation price below the overall average micro-generation price while the HECS includes the higher average micro generation price.

4.2.2 Natural Gas Price Scenarios

Natural gas costs influence the cost savings of major upgrades such as heat pumps and insulation and has the same volatile nature that electricity cost has as seen in Figure 4.3 with Alberta's average annual variable natural gas price between 2012 and 2023. Therefore, the LECS and HECS scenarios included the lower and higher average variable, fixed, and regulated rate natural gas price in Alberta. Another option considered was the Alberta's energy company or AECO-C price which is Alberta's "gas trading price" that forecasted the yearly natural gas retail price from 2022 to 2032 based on "historical values from the Canadian Gas Retail Reporter" [80, 81]. However,

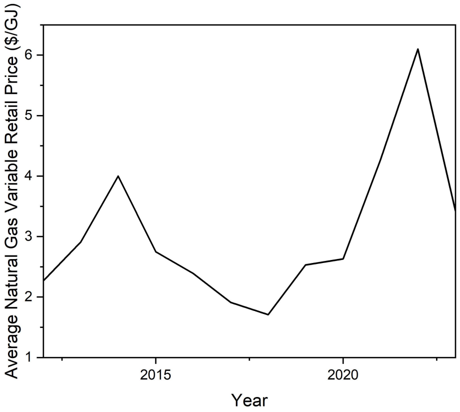

Figure 4.3: Alberta's average annual variable retail natural gas price between 2012 and 2023 [74]

to remain consistent with the electricity pricing, the average AUC historical values were used assuming the average natural gas energy price stays consistent between 2024 and 2050 and is shown in Table 4.4. These natural gas cost scenarios will show a range of possible energy cost savings, attempting to factor in the average volatility of natural gas pricing.

The natural gas variable distribution and rider cost for Edmonton come from ATCO gas and APEX utilities (regulated under the AUC) [75]. ATCO gas provides monthly average variable distribution and rider cost between 2013 and 2023 for buildings that consume 1,200 GJ/year or less of natural gas [82, 83]. APEX Utilities provides monthly average variable distribution and rider cost between 2013 and 2023 "for residences and small businesses who consume up to 8,227 gigajoules (GJ) per year" [84, 85]. The average variable distribution and rider cost will be used for the LECS and HECS as shown in Table 4.4 like the electricity scenarios.

Scenario	Natural Gas Price ($/GJ)
LECS	$2.48
HECS	$5.25
Variable Distribution and Rider	$2.69

Table 4.4: Natural gas retail, distribution, and rider price for analysis [74, 82–85]

Canada adopted a carbon pricing policy in 2017 for natural gas emissions from combustion [86]. The carbon price increased from \$20/t_{CO_2} in 2019 to \$50/t_{CO_2} in 2022 and is scheduled to increase by \$15/t_{CO_2}/year until 2030 (\$170/t_{CO_2}) [87]. The carbon tax is the carbon pricing policy expressed in \$/GJ and applied to the natural gas cost. The LECS and HECS scenarios will each include a case with the carbon tax, assuming the carbon price remains at \$15/t_{CO_2} after 2030, and without the carbon tax. The carbon tax (CT) from 2024-2030 is shown in Table 4.5 and was calculated using equation 4.4:

$$CT = \frac{CP}{\rho_{NG} HHV_{NG}} \tag{4.4}$$

where ρ_{NG} is the natural gas density of 0.67 kg/m^3, CP is the annual carbon price (\$/t_{CO_2}) converted to \$/m^3 using a 0.0019 t_{CO_2}/m^3 conversion, and HHV_{NG} is the higher heating value of natural gas which is 0.055 GJ/kg [88]. The 0.0019 t_{CO_2}/m^3 conversion is calculated using equation 4.5:

$$conversion = \frac{CP}{FCR_{NG}} \tag{4.5}$$

where FCR_{NG} (\$/m^3) is the annual natural gas fuel charge rate for the carbon pricing policy between 2023 to 2030 (\$65/t_{CO_2} in 2023 and increasing by \$15/t_{CO_2} to \$170/t_{CO_2} by 2030) where the conversion is a constant 0.0019 t_{CO_2}/m^3 [87, 89]. ρ_{NG} was calculated using equation 4.6 under the ideal gas law:

$$\rho_{NG} = \frac{PM}{RT} \tag{4.6}$$

where P is the pressure of 101 kPa, M is the molar mass of natural gas of 16 g/mol, R is the universal gas constant of 8 J/molK and T is the temperature of natural gas of 293K [88].

Year	2024	2025	2026	2027	2028	2029	2030
Carbon Tax ($/GJ)	$4.14	$4.92	$5.70	$6.48	$7.25	$8.03	$8.80

Table 4.5: Canada's carbon tax from 2024-2030

4.2.3 Retrofit Cost

To calculate the SPP and DPP, the average retrofit costs were determined by averaging the pilot CEIP participant's retrofit costs including a 5% GST. The cost analysis also included the incremental or additional cost of replacing the space heating, water heating, windows, doors, lighting, and attic insulation assuming retrofits are completed at the end of the system's useful life. The incremental cost was determined through a literature review of retrofit cost data for less or equal efficient systems to what is installed in the base house and the considered costs are shown in Table 4.6. For ASHPs and GSHPs, the incremental cost was compared to the cost of installing furnaces using the average project cost for furnace retrofits in the pilot CEIP. The chosen retrofit and increment costs used in the analysis are shown in Table 4.7. The average cost of door within the pilot CEIP was less than the door cost from the literature review of incremental costs and was excluded.

Upgrade	Type	Cost	Year	Citation
Window	Double pane	$8,370	2019, 2021	[90]
		$10,620	2019, 2021	[90]
		$24,450 (with GST)	2019	[91]
Window (/m^2)		$625	2019, 2021	[90]
		$625	2019, 2021	[90]
		$625 (with GST)	2019	[91]
Doors	0.85 RSI	$4,100	2020, 2021	[90]
Gas furnace	92% AFUE	$1,200	2020	[90]
Gas water heater	0.83 EF	$1,400	2019, 2020	[90]
	0.83 EF	$890 (with GST)	2020	[91]

Table 4.6: Canadian retrofit cost data from literature for less efficient systems compared to the base house systems

Retrofit	Average Cost	Replacement Cost	Incremental Cost	Citation
ASHP	\$12,960	\$10,100	\$2,860	
GSHP	\$47,980	\$10,100	\$37,880	
Furnace	\$10,100	\$1,200	\$8,900	[90]
HPWH	\$5,430	\$1,180	\$4,250	[90, 92]
Solar PV (/kWh)	\$2.51	-	\$2.51	
Lighting Fixture	\$250	-	\$250	
Lighting Control	\$310	-	\$310	
Attic Insulation	\$2,190	-	\$2,190	
Attic Insulation (/m^2)	\$16	-	\$16	
Windows	\$19,020	\$14,800	\$4,220	[90, 91]
Windows (/m^2)	\$1,290	\$645	\$642	[90, 91]
Doors (/door)	\$3,520	-	\$3,520	

Table 4.7: Average retrofit costs with GST

4.3 Analysis Results and Discussion

To calculate the cumulative energy consumption within each retrofit category, equation 4.7 and 4.8 were used:

$$E_{ele,n} = \Sigma_{i=1}^{n}(N_{Rhomes,i} * E_{eleR,i}) + (N_{Ohomes,i} * E_{eleO,i}) + (m - \Sigma_{i}^{n} N_{homes,i}) * E_{non,ele,i} \tag{4.7}$$

$$E_{ng,n} = \Sigma_{i=1}^{n}(N_{Rhomes,i} * E_{ngR,i}) + (N_{Ohomes,i} * E_{ngO,i}) + +(m - \Sigma_{i}^{n} N_{homes,i}) * E_{non,ng,i} \tag{4.8}$$

where $E_{ele/ng,n}$ is the cumulative electricity and natural gas consumption, N_{Rhomes} is the number of homes adopting the retrofit combination in that year, N_{Ohomes} is the number of homes adopting the building envelope and lighting retrofits only in that year, $E_{ele/ng,i}$ is the resulting electricity and natural gas consumption after the retrofits are installed in that year, $(m - \Sigma_{i}^{n} N_{homes,i})E_{non,ele/ng,i}$ represents the energy consumption for homes not completing retrofits that year, and n represents the year. The cumulative GHGs were calculated using equation 4.9:

$$Emissions_{ele,n} = E_{ele,n} EF_{ele,n} \tag{4.9}$$

$$Emissions_{ng,n} = E_{ng,n} EF_{ng,n} \tag{4.10}$$

where $EF_{ele/ng,n}$ is the electricity or natural gas emission factor for the specified year (t_{CO_2}/MWh) and $Emissions_{ele/ng,n}$ is the total GHGs (t_{CO_2}).

4.3.1 Retrofit Category Assumptions

The assumptions for each retrofit category are discussed below and the specifications and efficiencies for the retrofits completed in the intermediate and high efficiency cases are shown in Table 4.8. The overall assumptions for the analysis was:

- All houses will remain standing by 2050
- Natural gas emission factor of 0.05 t_{CO_2}/GJ [12]
- Retrofits are all completed in the same year and annual energy patterns are assumed to be unchanged
- Retrofits are completed at the end of the space heating lifetime
- Electric vehicle charging is not considered

The solar PV retrofit category has the following assumptions:

- Building envelope retrofits are completed for all pre-2017 SFHs where attic insulation, windows, doors, and lighting are upgraded
- 85% of the SFHs install a solar PV system

The heat pump retrofit category has the following assumptions:

- Building envelope retrofits are completed for all the SFHs
- 29% of the SFHs install an ASHP and 19% install a GSHP

The water heater retrofit category has the following assumptions:

- Building envelope retrofits are completed for all pre-2017 SFHs
- 75% of the SFHs install a HPWH, 49% install an ASHP, and 26% install a GSHP
- 35% of the 75% of pre-2017 SFHs install a GSHP

Retrofit	Lifetime [93]	Intermediate Efficiency Case	High Efficiency Case
ASHP	16	Single package; 11.8 kW; 11.8 HSPF; 22 SEER	Single package; 23.5 kW; 11.8 HSPF; 22 SEER
GSHP	16	vertical coil; 11.8 kW; 4.2 COP; 19.7 SEER	vertical coil; 23.5 kW; 4.2 COP; 19.7 SEER
Gas Furnace	16	Condensing gas furnace; 23.5 kW; 97% AFUE	Condensing gas furnace; 23.5 kW; 99% AFUE
Water Heater	15	Heat pump; 3.7 UEF; 151.4 L	Heat pump; 3.9 UEF; 151.4 L
Attic Insulation	20	8.8 RSI	10.6 RSI
Windows	15	9 windows; triple/triple with one coat; Low-E 0.2 (hard1); vinyl frame	
Doors	15	1.18 RSI	
Lighting	15	25-50% or more of CFL/LED	75% or more of CFL/LED
Solar PV System	25	6,014 kWh/year	2,460 kWh/year of exports

Table 4.8: Retrofit specifications for base house

4.3.2 Solar PV

The GHG reductions for the solar PV retrofit category are shown in Table 4.9 (under "Results"). The emission factors of the decarbonizing electricity forecasts are lower than the emission factors in the 2021 ECCC forecast as shown in Figure 4.1. Therefore, there are additional GHG reductions based on the grid cleaning itself up and is shown in Table 4.9 (under "Forecast"). The cumulative GHG emissions from the forecasts are calculated using equations 4.7 and 4.8 and the GHG reductions are calculated by subtracting the total GHGs from the 2021 ECCC forecast from the total GHGs for the decarbonizing electricity forecasts.

The results of the solar PV analysis show that for the intermediate case, the GHG reductions using the decarbonizing electricity forecasts were 5-10% less than the GHG reductions using the 2021 ECCC forecast. To achieve the same GHG reductions seen with the 2021 ECCC forecast, natural gas consumption must be reduced by 2-4%. For the high case, the GHG reductions were 18-38% higher using the 2021 ECCC forecast compared to the decarbonizing electricity forecast. Reducing natural gas consumption by 12-24% with the decarbonizing electricity forecasts results in the same GHG reductions using the 2021 ECCC forecast. Focusing on reducing electricity consumption alone is not enough to reduce the same GHG emissions when using the 2021 ECCC forecast for both efficiency cases. Therefore, natural gas consumption must be reduced as well. The heat pump and water heater retrofit categories will focus on reducing natural gas consumption and installing solar PV to discuss the GHG reductions for reducing both electricity and natural gas consumption.

Electricity Emissions	Intermediate Case ($\mathrm{Mt}_{\mathrm{CO}_2}$)			High Case ($\mathrm{Mt}_{\mathrm{CO}_2}$)			
Factor Forecasts	Results	Forecast	Total	Results	Forecast	Exports	Total
Clean Electricity	5.6	2.8	8.4	5.9	1.5	0.27	7.7
2023 ECCC	7.4	1.4	8.8	8.4	0.78	0.99	10.2
2021 ECCC	9.3	-	9.3	10.8	-	1.7	12.5

Table 4.9: GHG reductions for rooftop solar PV retrofit category on decarbonized electricity emission factor forecasts

The cost analysis results are shown in Table 4.10, where the project cost is for the maximum solar PV output and exports. The useful life of the retrofits (solar PV, windows, doors, attic insulation) ranges between 15-25 years. The SPP and DPP were larger than 25 years for the intermediate case showing that the retrofits will be replaced before the project cost could be recouped despite having the lower project cost compared to the high case. For the high case, the SPP with and without the carbon tax was 19 and 20 years, respectively, within the HECS and with exports. The SPP being lower than the useful lifetime of the solar PV system shows that higher electricity costs and exports are necessary for homeowners to recoup the solar PV project cost before the useful life is reached.

Retrofits	Project Cost	Project Cost (Incremental)	Energy Cost Savings with Carbon Tax		Energy Cost Savings without Carbon Tax	
			LECS	HECS	LECS	HECS
BE, Lighting (IE)	\$23,000	\$17,900	\$6,670	\$8,840	\$3,210	\$5,370
BE, Lighting (HE)	\$23,000	\$17,900	\$7,400	\$10,270	\$3,930	\$6,800
Solar PV (IE)	\$38,100	\$33,000	\$17,500	\$30,490	\$14,030	\$27,020
Solar PV (HE)	\$48,860	\$43,760	\$25,500	\$47,780	\$22,030	\$44,310

IE = intermediate efficiency case; HE = high efficiency case

Table 4.10: Project cost and energy cost savings for solar PV category between 2024 and 2050

4.3.3 Heat Pump

Heat pumps increase electricity consumption and decrease natural gas consumption where increasing electricity is not a ideal with high electricity emission factors as seen with the 2021 ECCC forecast. The GHG reductions for the heat pump retrofit category are shown in Table 4.11, where increasing electricity consumption using the decarbonizing electricity forecasts had a 30-47% increase in GHG reductions for the intermediate and high case compared to the GHG reductions using the 2021 ECCC forecast.

Electricity Emissions Factor Forecasts	Intermediate Case (Mt_{CO_2}) Results	Forecast	Total	High Case (Mt_{CO_2})	Forecast	Total
Clean Electricity	12.9	8.2	21.1	14.0	8.5	22.5
2023 ECCC	12.0	4.1	16.1	12.9	4.2	17.1
2021 ECCC	11.1	-	11.1	12.0	-	12.0

Table 4.11: GHG reductions for heat pump retrofit category on decarbonized electricity forecast scenarios

Solar PV reduces more GHG emissions using the 2021 ECCC forecast than the decarbonized electricity forecasts as seen in the solar PV retrofit category results.

Natural gas consumption must be reduced as well to achieve the same GHG reductions using the 2021 ECCC forecast. Table 4.12 shows the GHG reductions combining the assumptions from the heat pump and solar PV retrofit category. Compared to the GHG reductions using the 2021 ECCC forecast, GHG reductions were increased by 18-31% and decreased by 3-8% when using the decarbonizing electricity forecasts within the intermediate and high case, respectively. Within the high case and using a clean electricity forecast, the 55% of homes would need to reduce natural gas consumption by 43% to achieve the same GHG reductions using the 2021 ECCC forecast. Another solution is increasing the percentage of homes completing retrofits to 64% to achieve the same GHG reductions. Using the 2023 ECCC forecasts, the 55% of homes would need to achieve an additional 20% natural gas consumption reduction or increase the percentage of homes to 59% to have the same GHG reductions using the 2021 ECCC forecast.

Electricity Emissions	Intermediate Case (Mt_{CO_2})			High Case (Mt_{CO_2})			
Factor Forecasts	Results	Forecast	Total	Results	Forecast	Exports	Total
Clean Electricity	13.3	6.2	19.5	15.0	3.1	0.27	18.4
2023 ECCC	13.4	3.1	16.5	16.8	1.6	0.99	19.4
2021 ECCC	13.5	-	13.5	18.4	-	1.7	20.1

Table 4.12: GHG reductions for a combination of heat pump and solar PV retrofit categories within decarbonized electricity forecast scenarios

The cost analysis results are shown in Table 4.13. Combining solar PV with the heat pump category within the high case using the HECS with carbon tax and an ASHP, resulted in a SPP of 23 years. All other combinations resulted in payback periods larger than 25 years. Therefore, the retrofits will be replaced before the project cost is recouped except for the solar PV system. Despite the retrofits reducing GHG emissions, the cost of the systems is larger than the energy cost savings throughout the retrofit's useful lifetime. Financial aid in the form of rebates and grants will be necessary to assist homeowners in retrofitting homes to reduce the retrofit project cost. As well, solar PV can assist with paying for retrofit costs.

Retrofits	Project Cost	Project Cost (Incremental)	Energy Cost Savings with Carbon Tax		Energy Cost Savings without Carbon Tax	
			LECS	HECS	LECS	HECS
BE, Lighting (IE)	$23,000	$17,900	$6,670	$8,840	$3,210	$5,370
BE, Lighting (HE)	$23,000	$17,900	$7,400	$10,270	$3,930	$6,800
ASHP (IE)	$46,060	$29,700	$11,040	$5,410	($1,760)	($7,390)
ASHP (HE)	$46,060	$29,700	$11,450	$3,220	($3,670)	($11,900)
GSHP (IE)	$81,100	$64,700	$12,600	$4,420	($3,360)	($11,540)
GSHP (HE)	$81,100	$64,700	$12,830	$4,880	($3,130)	($11,080)
ASHP, Solar (IE)	$61,150	$44,760	$21,860	$27,060	$9,060	$14,260
ASHP, Solar (HE)	$90,540	$74,150	$44,720	$71,060	$29,610	$55,940
GSHP, Solar (IE)	$96,180	$79,780	$23,420	$26,070	$7,460	$10,110
GSHP, Solar (HE)	$125,580	$109,180	$46,110	$72,730	$30,150	$56,780

IE = Intermediate efficiency case; HE = High efficiency case

Table 4.13: Project cost and energy cost analysis for heat pump and solar PV category between 2024-2050 in 2023 CAD

4.3.4 Water Heater

Electric water heaters increase electricity consumption and decrease natural gas consumption while combining electric water and space heating systems can eliminate natural gas consumption assuming appliances are electric and the natural gas furnace is not used. Therefore, electric space and water heating retrofits alone are not an ideal retrofit with higher electricity emission factors. Increasing electricity consumption using the decarbonizing electricity forecasts had higher GHG reductions compared to using the 2021 ECCC forecast GHG reductions as seen in the heat pump retrofit category. Within the water heater retrofit category, GHG reductions were 29-46% higher using the decarbonizing electricity forecasts as shown in Table 4.14, maintaining the conclusion of higher GHG reductions are achieved when electricity consumption is increased using the decarbonizing electricity forecasts.

The results of combining the water heater and solar PV retrofit categories are shown in Table 4.12. The intermediate case shows that GHG reductions increase by

Electricity Emissions	Intermediate Case ($\mathrm{Mt_{CO_2}}$)			High Case ($\mathrm{Mt_{CO_2}}$)		
Factor Forecasts	Results	Forecast	Total		Forecast	Total
Clean Electricity	20.0	10.0	30.0	21.8	10.5	32.3
2023 ECCC	18.2	5.0	23.2	19.7	5.2	24.9
2021 ECCC	16.4	-	16.4	17.6	-	17.6

Table 4.14: GHG reductions for water heater retrofit category on decarbonized electricity forecast scenarios

17-29% usin the decarbonizing electricity forecasts compared to using the 2021 ECCC forecast. For the high case, the GHG reductions using the 2021 ECCC forecast were 6-12% higher in comparison to using the decarbonizing electricity forecasts. Within the high case, natural gas consumption is reduced by 96% and 100% (compared to the base case) when installing as ASHP and GSHP, respectively. The natural gas consumption is not eliminated when using a ASHP due to the house utilizing the natural gas furnace when the outdoor temperature is lower than the operating temperature of the ASHP. With the 75% of homes eliminating energy consumption, the GHG reductions using the 2021 ECCC forecast will not be achieved when using the decarbonizing electricity forecasts. Therefore, on the clean electricity forecast with 75% of homes achieving a total energy consumption of zero, the 25% of homes completing building envelope and lighting retrofits only would need to further reduce energy consumption by an additional 45% to achieve the same GHG reductions when using the 2021 ECCC forecast. Increasing the percentage of homes installing solar PV, heat pumps, and HPWHs to 89% can also achieve the same GHG reductions. On the 2023 ECCC forecast, the 25% of homes upgrading the attic insulation, windows, doors, and lighting would need to achieve an additional 14% natural gas and electricity consumption reduction as well as the 75% of homes achieving zero energy consumption to have the same GHG reductions when using the 2021 ECCC forecast. Increasing the percentage of homes to 81% can also achieve the same GHG reductions.

The results of the cost analysis for the water heater category are shown in Table

Electricity Emissions Factor Forecasts	Intermediate Case ($\mathrm{Mt_{CO_2}}$) Results	Forecast	Total	High Case ($\mathrm{Mt_{CO_2}}$) Results	Forecast	Exports	Total
Clean Electricity	20.5	7.2	27.7	23.3	2.2	0.27	25.8
2023 ECCC	20.1	3.6	23.7	25.4	1.1	0.99	27.5
2021 ECCC	19.7	-	19.7	27.5	-	1.7	29.2

Table 4.15: GHG reductions for a combination of water heater and solar PV retrofit categories within decarbonized electricity forecast scenarios

4.16. Within the high case, the HECS with the carbon tax, ASHP, and a solar PV had a SPP of 22 years. With the useful life of the retrofits ranging between 15-25 years, the retrofits will be replaced before the project cost is recouped except for the solar PV. The conclusion from the heat pump retrofit category can be seen within the water heater retrofit category where financial aid will be necessary to assist homeowners in reducing the burden of retrofit costs along with encouraging solar PV installations to assist with retrofit costs.

	Project Cost	Project Cost (Incremental)	Energy Cost Savings with Carbon Tax LECS	HECS	Energy Cost Savings without Carbon Tax LECS	HECS
BE, Lighting (IE)	$23,000	$17,900	$6,670	$8,840	$3,210	$5,370
BE, Lighting (HE)	$23,000	$17,900	$7,400	$10,270	$3,930	$6,800
HPWH, ASHP (IE)	$50,590	$28,480	$13,940	$6,010	($2,860)	($10,790)
HPWH, ASHP (HE)	$50,590	$28,480	$14,460	$3,630	($4,970)	($15,810)
HPWH, GSHP (IE)	$85,610	$63,510	$15,410	$4,400	($4,880)	($15,880)
HPWH, GSHP (HE)	$85,610	$63,510	$15,670	$4,920	($4,620)	($15,370)
HPWH, ASHP, Solar (IE)	$65,680	$43,580	$24,770	$27,660	$7,970	$10,860
HPWH, ASHP, Solar (HE)	$95,840	$79,440	$47,500	$74,420	$30,700	$57,620
HPWH, GSHP, Solar (IE)	$100,710	$78,600	$26,230	$26,050	$5,940	$5,770
HPWH, GSHP, Solar (HE)	$135,650	$113,550	$53,260	$81,390	$32,970	$61,100

IE = Intermediate efficiency case; HE = High efficiency case

Table 4.16: Project cost and energy cost analysis for water heater and solar PV category between 2024-2050 in 2023 CAD

4.3.5 Discussion

Using the 2021 ECCC forecast as the electricity forecast during the time of the ETSAP release, the priorities for retrofitting buildings was to reduce electricity consumption due to high emission factors. If electricity is increased from installing heat pumps or electric water heaters, solar PV can assist with reducing electricity consumption to avoid increasing GHG emissions. The analysis above shows that increasing electricity consumption and reducing natural gas consumption when using the decarbonizing electricity forecasts resulted in 29-50% higher GHG reductions compared to using the 2021 ECCC forecast. Therefore, reducing electricity consumption could no longer be a priority on decarbonizing electricity forecasts and homeowners could freely increase electricity consumption when natural gas consumption is reduced. Combining solar PV with a heat pump and electric water heater eliminated electricity consumption and further increased GHG reductions. Hence, the CoE should focus on retrofitting the building envelope and lighting along with installing heat pumps, solar PV, and electric water heaters within SFHs. However, when comparing GHG reductions between the three electricity emission factor forecasts, the GHG reductions are 3-12% less when using the decarbonizing electricity forecast. As well, when solar PV was only considered, the GHG reductions were 5-38% less compared to GHG reductions using the 2021 ECCC forecast. Therefore, using the decarbonizing electricity forecasts, the CoE would need to target 4-14% more homes to complete retrofits within the retrofit categories or further reduce energy consumption by 2-45% to achieve the same GHG reductions seen using the 2021 ECCC forecast. The trajectory of future electricity emissions is uncertain and the CoE will need to closely monitor electricity emissions to determine the number of homes completing retrofits and what retrofits to recommend to ensure the highest GHG reductions.

The cost analysis shows that homeowners would recoup project cost before the end of the useful lifetime for solar PV only within the HECS, with carbon tax, solar PV exports, and installing ASHPs. The energy price can not be guaranteed to remain in the higher average range and the carbon tax is not confirmed to remain till 2030 or 2050. Therefore, further financial aid in the form of rebates and grants may be necessary to assist homeowners in completing retrofits and recoup project costs before the retrofits must be replaced. As well, the SPP was less than 25 years when solar PV with exports were installed and should be recommended to homeowners to assist with reducing project costs.

4.4 Additional Points to Consider

Installing heat pumps and decarbonized water heaters will require the electrification of space and water heating systems. Currently, heat pumps use refrigerant to carry heat towards and away from a space [94]. Refrigerants emit emissions which can impact the environment and the CoE's ETSAP goal of achieving net zero by 2050 [95].

The refrigerant emissions in heat pumps can be estimated based on the type of refrigerant, the amount of refrigerant in the heat pump, and the annual leakage percentage [96]. Currently, most residential heat pumps use the refrigerant R-410a, which has a 100 year global warming potential (GWP) of 2,255 [96]. GWP is a metric used to compare the emissions of gases to carbon emissions in a specified time frame [97]. In 2014, the Department of Energy and Climate Change in the United Kingdom concluded that the average leakage percentage of refrigerants in heat pumps was 3.5% annually for residential buildings [98]. The Intergovernmental Panel on Climate Change (IPCC) reported in 2005 that heat pumps in residential buildings leak 4-5% of refrigerants annually where heat pumps usually have 1-5 kg of refrigerant [96, 99]. IPCC is an organization with the United Nations to report and assess climate change [100]. Therefore, on average, a heat pump would emit 200 kg or 0.2 t_{CO_2} annually when using R-410a assuming an annual leakage of 3.5% and 2.6 kg of refrigerant (calculated based on 0.2 t_{CO_2} result) [96].

Based on the heat pump retrofit category, the maximum number of adopters is 101,000 assuming 55% of pre-2017 SFHs install a heat pump between 2024-2050. Given this assumption and the fact that heat pumps after 2023 will use R-454b with a GWP of 531, the minimum average annual emissions in 2050 is 5,050 t_{CO_2} [96]. For the water heaters retrofit category, the maximum number of adopters is 137,600 assuming 75% of pre-2017 SFHs install a heat pump water heater by 2050. Given this assumption, the minimum average annual emissions in 2050 is 6,880 t_{CO_2} using R-454b [96]. In comparison to the GHG reductions seen above, the refrigerant emission increase is less than 1%. As the refrigerant type used in heat pumps is updated and the GWP decreases, emission from heat pumps will only get lower but should be monitored.

Chapter 5

Conclusion

This analysis examined how Alberta's decarbonizing electricity grid will affect the priorities and outcomes for the CoE goals of achieving net zero by 2050 for pre-2017 residential buildings between 2024 and 2050. The focus was on pre-2017 SFHs installing rooftop solar PV systems, heat pumps, and electric water heaters along with building envelope and lighting retrofits as specified within the ETSAP. A model house based on the average energy consumption from SFHs participating in the pilot CEIP and 3,885 Energuide audits completed in the Edmonton between 2017 and 2023 served as a reference in the analysis where the energy consumption was calculated using HOT2000.

The analysis calculated and compared the GHG reductions and energy cost savings for pre-2017 SFHs on the 2021 ECCC electricity emission factor forecast and the 2022-2023 forecast of Alberta electricity grid emission factors using a DOI adoption method. Two energy efficiency cases (intermediate and high efficiency) were included to discuss the range of possible GHG reductions based on installed retrofits within the pilot CEIP, where the intermediate case used the lowest retrofit efficiency while the high case used the highest efficiencies. The two energy efficiency cases were compared to a base case where all pre-2017 SFHs do not complete retrofits and maintain the average energy consumption for pre-2017 SFHs in the Edmonton.

During the release of the ETSAP, reducing electricity consumption was the main focus due to high emission factors. Increasing electricity consumption and decreasing natural gas consumption resulted in a 29-50% higher GHG reductions when using the decarbonizing electricity forecasts. Therefore, with lower electricity emissions, homeowners could freely increase electricity consumption while decreasing natural gas consumption and achieve higher GHG reductions. Combining solar PV with heat pumps and electric water heaters resulted in the highest GHG reduction when using all considered electricity emission factor forecast and should be recommend to ensure the highest GHG reduction is achieved. However, when comparing the GHG reductions between the electricity emission factor forecasts, installing solar PV alone resulted in 5-38% higher GHG reductions while combining solar PV with electric water heaters and/or heat pumps resulted in 3-12% higher GHG reductions when using the 2021 ECCC forecast. The CoE would need to target 2-45% more energy consumption reduction or 4-14% more homes to complete retrofits within the retrofit categories.

Lastly, an energy cost analysis was completed to determine the financial aspect of completing retrofits. Two energy cost scenarios based on the average energy pricing from the AUC and the carbon tax was used. The cost analysis showed that homeowners would recoup project costs before the end of the solar PV useful lifetime within the high energy cost scenario with the carbon tax and exports. Energy pricing is difficult to forecast and can not be expected to remain in the higher average range. As well, the carbon tax could be removed before 2030 or 2050, and therefore, further financial aid in the form of rebates and grants is necessary to recoup project costs before the retrofits must be replaced. Another option is to encourage larger solar PV system installations where solar PV exports could assist with reducing project costs.

In conclusion, with the water heater retrofit category achieving the highest GHG emission reductions on all discussed electricity emission factor forecasts, the CoE should recommend homes target solar PV, electric water heaters, and heat pumps to reach net zero by 2050 with solar PV exports assisting with recouping project costs before the retrofits useful lifetime is reached. However, lower electricity emissions require further energy consumption reduction or targeting more homes to complete retrofits to achieve the same GHG reductions seen when using higher emission factors.

5.1 Limitations and Future Work

Limitations include:

- Actual energy consumption after retrofits were installed to determine the gap between estimated and actual energy consumption;
- Forecasts for future energy prices and Alberta's electricity emission factors between 2024 and 2050;
- Modeling all pre-2017 archetypes to accurately represent buildings in Edmonton; and
- Adoption rates for retrofits in Edmonton.

Future works include:

- The data from before and after retrofit energy consumption as more retrofits are completed in the CoE can be used to determine the difference between actual and modeled energy savings to be used in estimating GHG emission reductions in the CoE; and
- Monitor the increase in emissions from refrigerants in heat pumps.

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Appendix A: CEIP Pilot Program Final Report

University of Alberta's Final Result Report for Clean Energy Improvement Program (CEIP)

April 2024

Final Report

Prepared for City of Edmonton's CEIP Team

By: Elizabeth Lartey, EIT and Tim Weis, PhD, PEng

Executive Summary

This report provides an overview of the energy savings upgrades that were performed as of October 31, 2023 as part of Edmonton's residential Clean Energy Improvement Pilot Program (CEIP). The program was launched on March 29, 2022 and was closed only 3 days later as the value of submissions exceeded the available $9.7 million of available financing. The program was relaunched on August 22, 2023 and closed January 20, 2024 to utilize unused commercial budget and to reach a residential pilot sample file count of up to 100 properties.

Of the 201 applications initially submitted 90 remain open with the top 3 reasons for withdrawal including applicants not having the required 5-year tax history (16%), using other rebate programs or using their own funds (12%), or the applicant not responding (9%). The 3 most common upgrades included 74% of homes upgrading windows and doors, 63% increased insulation, 56% installed solar PV.

An analysis was conducted on the 27 homes in the CEIP pilot program, and includes 91 upgrades (20 upgrade types where 4 upgrade types were not modeled). The analysis was broken into two parts where the first focuses on the 91 upgrades from 2023 to the upgrades' useful life expected under CEIP. Energy savings, GHG emission savings, energy cost savings (two energy cost scenarios), dollar per tonne of CO_{2e} reduced, and simple and discounted payback periods were calculated using the HOT2000 verification models created by the authors. No direct (first hand) analysis of any upgrades were completed by the authors.

Two major areas of uncertainty that could affect some of the metrics listed above were addressed by considering low, medium and high with respect to the pace of decarbonization of Alberta's electricity grid, and the consumer-facing federal carbon tax (which also acts as a proxy for low, medium and high energy prices). While the sample size is small and upgrade metrics can vary significantly from house to house depending on what equipment is assumed in the absence of the upgrade, overall home efficiency, other upgrades concurrently or already in place, etc, the average energy and cost savings of each upgrade type was compiled for the houses that did participate. Air source heat pumps (ASHPs), ground source heat pumps (GSHPs), and solar PV systems were found to have the highest energy savings and GHG emissions savings. GSHP, high efficiency boilers, and foundation insulation upgrades had the highest cost savings. Solar PV, foundation insulation, and attic insulation have the lowest cost per tonne of emissions reduction. Foundation insulation, lighting fixtures, and solar PV had the lowest simple payback period.

Energy, GHG and cost savings of the 27 homes were also considered between 2023 when the upgrades were completed and 2050 assuming that upgrades are replaced once between the time period where homeowners install the same system at the same project cost. Research on efficiency programs has commonly found that actual energy savings tends to be less than expected or modeled savings, although it is not clear why this is the case. A typical home in Edmonton consumes 8000 kWh of electricity and 130 GJ of natural gas annually, which has energy costs around $2,600 in 2023 (excluding fixed costs), and results in close to 7 t_{CO2e}/year. On average the upgrades from the CEIP program reduced energy by around 30%; GHG emissions by 2.4 $t_{CO2e/yr}$, average project costs of $75,000 with average energy cost savings of $22,000 over the 2023-2050 timeframe. Upgrades improved emissions and energy savings, but many were unlikely to pay for themselves during their expected lifetimes, with the notable exception of solar PV.

Solar projects tended to be the most financially lucrative upgrade, the majority of which achieved positive cash flows in the first year of operation as a result of the financing through CEIP. However, while Alberta's electricity system has historically been dominated by coal, it is rapidly decarbonizing, which has a perverse impact of significantly reducing the potential GHG savings that result from solar PV systems. Conversely, a low carbon grid means that fuel switching options to heat pumps (either air source or ground source) have the single largest opportunity for carbon reductions, but tend to have some of the highest costs. This presents an opportunity to encourage the pairing of the two upgrades where revenues from solar systems can help to support higher cost heat pumps. It also improves the greenhouse gas reduction opportunity for PV systems (the same would also be true for electrification of vehicles, although the latter is out of scope of this work).

The report also includes comments and recommendations for the full scale clean energy improvement program, discussion on other jurisdictions' analysis of energy efficiency programs from the first and second interim report, and recommendations on upgrades that should be targeted based on future goals be they energy savings, GHG emission reduction, cost savings, or net-zero homes.

Table of Contents

1.0 Background and Objectives

The pilot Clean Energy Improvement Program (CEIP) is a program from the City of Edmonton (CoE) based on the Property Assessed Clean Energy (PACE) model that finances energy efficiency and renewable energy improvements (“upgrades”) in residential and commercial buildings [1]. PACE programs are designed to help property owners implement energy upgrades that they repay through their property taxes as they reap the energy cost savings of these upgrades [1]. By attaching the costs of upgrades to the property, the owner enjoys the benefits (reduced utility bills and improved comfort), during the repayment term. If ownership changes during the life of the repayment, since obligation remains with the property after a sale, the new owner takes over the entire property tax account (including any CEIP balances). This also helps to remove a barrier to upgrades such that an owner need not worry if they may never personally fully recover the cost benefit of an upgrade if they do not intend or know if they will own the property long-term. The CEIP pilot program was designed with the intention of expanding to a full-scale, long-term program. CEIP is a key part of the CoE’s goals to achieve “net zero emissions” by 2050 as outlined in Edmonton’s Community Energy Transition Strategy and Action Plan [2]. The strategy includes targeting residential and commercial buildings to complete deep retrofits to achieve 19% of required GHG reductions by 2050 [3].

The goals of the pilot program are to test interest in the PACE mechanism and identify opportunities and challenges before establishing a full scale program. Goals of the long-term program include economic development and job creation in the retrofit industry; supporting energy management by building owners; incentivizing less common but more impactful technologies (i.e. heat pumps); encouraging deep green retrofits; and ultimately reducing GHG emissions by increasing the number of energy efficient systems in the residential and commercial building sectors [1]. The pilot results are used to test and evaluate GHG emission reductions and identify areas for improvement [1]. The pilot is intended to evaluate outcomes and to determine if CEIP should be limited to a pilot scale program, modified, and/or expanded to a full scale permanent program as outlined in the CoE’s Community Energy Transition Strategy and Action Plan for implementing energy transition programs [4], [5]. These findings and lessons learned will assist in establishing a full scale program should the City Council make that decision.

In September 2022, an interim report was completed 5 months after the pilot’s residential program launch (March 2022) and 2 months after the pilot’s commercial program launch (July 2022). The intent of that report was to review the pilot program design, evaluate the current status of the program and any lessons learned, and compare the program to other PACE programs done in North America. The report listed advice on the future full program and next steps for the research.

In July 2023, a second interim report was completed 15 months after the pilot's residential program launch (March 2022), and 12 months after the pilot's commercial program launch (July 2022). The intent of that report was to provide an update on the pilot program; analyze the cost and expected savings of the 51 completed upgrades in the residential program along with a forecast of future energy and GHG savings over the upgrades' useful life and until 2035. The report ended with further advice for the full program, and next research steps.

This final report was completed 20 months after the pilot's residential program launch, and 17 months after the pilot's commercial program launch. The intent of this report is to provide an update on the pilot program; analyze the cost and expected savings of the 91 completed upgrades in the residential program along with a forecast of future energy and GHG savings over the upgrades' useful lives and until 2050. This report ends with final advice for the full program, and potential next research steps.

2.0 Current Pilot Program Statistics

The pilot CEIP consisted of a residential and commercial program with up to $9.7 million for financing from Federation of Canadian Municipalities (FCM), and applicants were able to stack rebates up to $1.55 million from City of Edmonton's incentive programs. Residential buildings stacked rebates from the Home Energy Retrofit Accelerator (HERA) program and Change Homes for Climate Solar Program while commercial buildings stacked rebates from the Building Energy Retrofit Accelerator (BERA) program. A maximum total of financing and rebates of $11.25 million was made available for CEIP pilot applicants. The residential program was initially designed to accept a maximum of 80 residential applications [2]. To meet the goal of "deep retrofits", each application requires a minimum of three upgrades, with a maximum financing of $50,000 per application before interest and administration fees. Residential upgrade categories include heating, ventilation and air conditioning (HVAC) systems, lighting, water heating, doors and windows, insulation, air sealing, and the installation of solar PV and solar thermal systems. The property owner was responsible for any remaining balance above $50,000 after all successful rebates have been applied. Municipal residential rebates could be obtained from the Home Energy Retrofit Accelerator (HERA) program for windows, space heating, insulation, and water upgrades and the Change Homes for Climate Solar program for solar PV systems [6], [7], and Canada Greener Homes.

The residential program was launched on March 29, 2022 for pre-qualifications, and closed April 1, 2022 as the value of submissions quickly exceeded the available financing. The residential program was reopened on August 22, 2023 and closed January 20, 2024 to take advantage of funds unused for the commercial stream and to reach a pilot sample file count of up to 100 properties. As of December 12, 2023, 201 applications were submitted of which 90 remain open, 6 are wait-listed, 19 were declined by the program, 11 expired, and 68 were canceled by the applicants themselves. There are 75 reasons for applications being canceled by the applicant or the City and are listed below (for commercial and residential CEIP) [8]:

- Not having the required 5-year property tax history (12)
- Using the City of Edmonton's Home Energy Retrofit Accelerator (HERA) program, the Federal Greener homes rebates, own funds, and/or another financing program instead (9)
- Non-responsive applicant (7)
- Upgrade Specific (6)
    - The program not containing homeowners preferred equipment brand (1)
    - For heat pumps, the only eligible option was "Energystar." Homeowner tried to find an energy star heat pump and was out of stock in Canada
    - Heat pump requirement to supply 50% of heating load was not perceived to be feasible in this climate using an air source heat pump (1)
    - Contractor not recommending solar for the home because of shading (1)
    - Not enough options for tankless water heaters (1)
    - Desired retrofit not included in program (waterproof basement) (1)
    - Desired retrofit not eligible for the house (2)
    - Available heat pump options are not feasible in cold climate (1)
- Contractor (6)
    - Unable to find a primary contractor willing to complete all retrofits (3)
    - Limited number of vendors and not feasible for smaller, local vendors to participate in program (1)
    - Quotes did not meet equipment and documentation requirements for the program (1)
- Not meeting program deadlines (5)
- Unwilling to meet 3-upgrade minimum (4)

- Interest rate (3)
    - The Bank of Canada interest rate increases (1)
    - Program interest rate was too high (2)
- No longer needed or wanted retrofits or further retrofits (3)
- Project cost was too high (2)
- The program not covering costs of previously done retrofits and/or planned upgrades outside of the program (2)
- The overall program is complicated/requires too much information/takes too long to complete (2)
- Unexpected circumstances (2)
- Canceled with no reason (2)
- Retrofit cost increasing and grant did not cover enough of the cost (1)
- Thought CEIP was a grant program (1)
- Program did not respond in time so homeowner did upgrades without program (1)
- Homeowner moved and was unable to restart process in new house (1)
- Homeowner moved (1)
- Homeowner lived outside of Edmonton (1)
- Stressed from dealing with Canada Greener Homes and HERA program and therefore did not want to engage in another program (1)
- Pilot program was closed (1)
- Condo board did not approve (1)
- Too many energy auditor options (1)

Applications were spread out throughout Edmonton with 29% of buildings located in Central Edmonton. Appendix A shows a map of the applicants as of June 2023. A summary of the applicants for the residential program as of December 12, 2023 is shown in Table 1. Table 1 shows that 97% of applicants were in fully detached residential buildings with 17% built between 1950-1959, 1980-1989, and 2010-2019. 74% of applicants chose windows and doors, 63% chose insulation, and 56% chose solar PV.

Table 1: Summary of Residential CEIP Metrics as of December 12, 2023

	# (out of 96)	%		# (out of 96)	%
Type of Building			**1980-1989**	**6**	**17%**
Fully Detached	**93**	**97%**	1990-1999	1	3%
Semi-Detached	2	2%	2000-2009	4	11%
Town/Row House	1	1%	**2010-2019**	**6**	**17%**
Location in City			2020-2023	1	3%
North	8	8%	**Upgrade Type**		
Northeast	6	6%	Air Sealing	45	47%
Northwest	4	4%	Alternative Energy	0	0%
South	7	7%	Drain Water Heat Recovery	19	20%
Southeast	10	10%	Heat Pump or A/C	36	38%
Southwest	18	19%	High Eff. Furnace/Boiler	35	36%
West	9	9%	Insulation	60	63%
Central	**28**	**29%**	Lighting	27	28%
East	6	6%	Lighting Controls	21	22%
Year of Construction*			Recovery Ventilation	21	22%
1930-1939	1	3%	Solar PV	54	56%
1940-1949	4	11%	Solar Thermal	9	9%
1950-1959	**6**	**17%**	Water Heating	40	42%
1960-1969	2	6%	**Windows and Doors**	**71**	**74%**
1970-1979	5	14%	*for 36 applicants with pre-audits		

Table 2 and Table 3 shows the metrics of the pilot program from the second (May 1, 2023) and first (August 22, 2022) interim report to show the growth and decline of the pilot program. Solar PV, windows/doors, and insulation remain the three highest chosen retrofits.

Table 2: Summary of Residential CEIP Metrics as of May 1, 2023

	# (out of 43)	%		# (out of 43)	%
Type of Building			**1980-1989**	**9**	**21%**
Fully Detached	**40**	**93%**	1990-1999	1	2%
Semi-Detached	2	5%	2000-2009	4	9%
Town/Row House	1	2%	2010-2019	6	14%
Location in City			2020-2023	1	2%
North	1	2%	**Upgrade Type**		
Northeast	4	9%	Air Sealing	18	42%
Northwest	3	7%	Alternative Energy	0	0%
South	4	9%	Drain Water Heat Recovery	8	19%
Southeast	5	12%	Heat Pump or A/C	15	35%
Southwest	9	21%	High Eff. Furnace/Boiler	11	26%
West	5	12%	Insulation	27	63%
Central	**12**	**28%**	Lighting	13	30%
Year of Construction			Lighting Controls	9	21%
1930-1939	1	2%	Recovery Ventilation	12	28%
1940-1949	4	9%	**Solar PV**	**31**	**72%**
1950-1959	7	16%	Solar Thermal	6	14%
1960-1969	4	9%	Water Heating	16	37%
1970-1979	6	14%	Windows and Doors	30	69%

Table 3: Summary of Residential CEIP Program Metrics as of August 22, 2022

	# (out of 47)	%		# (out of 47)	%
Type of Building			1980-1989	8	17%
Fully Detached	**45**	**96%**	1990-1999	3	6%
Semi-Detached	2	4%	2000-2009	2	4%
Town/Row House	0	0%	2010-2019	7	15%
Location in City			2020-2022	1	2%
North	2	4%	**Upgrade Type**		
Northeast	2	4%	Air Sealing	19	40%
Northwest	8	17%	Alternative Energy	0	0%
East	0	0%	Drain Water Heat Recovery	9	19%
South	3	6%	Heat Pump or AC	15	32%
Southeast	9	19%	High Eff. Furnace/Boiler	11	23%
Southwest	**13**	**28%**	Insulation	30	64%
West	3	6%	Lighting	10	21%
Central	7	15%	Lighting Controls	7	15%
Year of Construction			Recovery Ventilation	12	26%
1940-1949	5	11%	**Solar PV**	**36**	**77%**
1950-1959	**9**	**19%**	Solar Thermal	5	11%
1960-1969	4	9%	Water Heating	14	30%
1970-1979	7	15%	Windows and Doors	29	62%

The commercial program was designed to accept approximately 20 applications [9]. Each application requires a minimum of three upgrades with a maximum total upgrade financing of $1,000,000 per application. Eligible commercial upgrades are doors/windows/insulation, air sealing, commercial kitchen, HVAC, lighting, motors and drives, solar energy, and water heating. Commercial rebates were available from the Building Retrofit Accelerator (BERA) program for HVAC, energy efficiency certification, building envelope, lighting and non lighting controls, hot water, and solar upgrades [10].

The commercial program was launched on June 7, 2022 and closed on August 22, 2023 As of December 12, 2023, the program has eight applicants with a total potential financing valuation of $3.1 million and one applicant has completed upgrades. Of the 8 applicants, 6 applicants have chosen retrofits. A summary of the applicants for the commercial program is shown in Table 4. The commercial CEIP will continue in the full scale program launching in 2024 and will allow more time for commercial building owners to make a decision as it usually takes commercial building owners 2-3 years to do so.

Table 4: Summary of Commercial CEIP Metrics as of December 12, 2023

	# (out of 8)	%
Type of Building		
Corporate Office	**2**	**25%**
Accommodation Property	**2**	**25%**
Manufacturing Facility	1	13%
Warehousing and Distribution	1	13%
Retail Property	1	13%
Other	1	13%
Location in City		
South	**5**	**63%**
North	2	25%
Central	1	13%
	# (out of 6)	%
Upgrade Type		
Heat Pump or A/C	1	13%
Insulation	1	13%
Lighting	1	13%
Lighting Controls	1	13%
Solar PV	**2**	**25%**

Table 5 shows the metrics of the pilot program as of May 1, 2023 which has one less applicant than current at the time of this analysis as seen in Table 6.

Table 5: Summary of Commercial CEIP Program Metrics as of May 1, 2023

	# (out of 7)	%
Type of Building		
Corporate Office	**2**	**29%**
Accommodation Property	**2**	**29%**
Manufacturing Facility	1	14%
Warehousing and Distribution	1	14%
Retail Property	1	14%
Location in City		
South	**4**	**57%**
North	2	29%
Central	1	14%
	# (out of 6)	%
Upgrade Type		
Heat Pump or A/C	1	17%
Insulation	1	17%
Lighting	1	17%
Lighting Controls	1	17%
Solar PV	**2**	**33%**

3.0 Literature Review

3.1 Information Presented in First Interim Report

In 2007-2008, California became the first state to propose and test PACE programs and by 2010, 22 states had adopted PACE programs [11]. These projects include installation and upgrades of insulation, solar PV systems, HVAC, doors, hot water heaters, windows, roofing, and natural disaster protection [12]. From these projects, there has been documented increases in jobs and occupant wellbeing, and a decrease in energy use, emissions, and water use [13].

Despite these benefits, there are some notable issues with the program. In the United States, the residential PACE program financing was a senior lien when a property is foreclosed instead of the mortgage [12]. This resulted in Fannie Mae and Freddie Mac banning mortgages on residential buildings with PACE programs as the senior lien [12]. This caused a ban on residential PACE programs throughout the United States and caused some states and counties to offer alternative financing solutions or offer the PACE program as a secondary lien (which is not common) [11]. As well, difficulties have arised for homeowners trying to sell properties with PACE program financing where homeowners are asked to pay the full PACE financing before selling the property or can not sell the property because customers do not want to contribute to the program [12]. Despite these challenges, the potential benefits have encouraged increased PACE programming across the United States and Canada in recent years.

In Florida, PACE was implemented in 2013 and by 2019 the program has decreased energy consumption and GHG emissions while increasing economic and state product growth [12]. Specifically for reduction in energy consumption and GHG emissions, the cost (funding) to benefits and saving is similar [12]. From August 2018 - November 2019, the program received a large investment from the PACE administrator, Ygrene [12]. Between the two time periods, there was a 7% increase in GHG emission reductions, 8% increase in electricity consumption reductions, 30% decrease in natural gas consumption reduction, and a 14% decrease in the number of jobs created between the two research periods [12]. Between 2018-2019, there was a 150% increase in solar PV system installations, 26% increase in building envelope upgrades, and 106% increase in HVAC system upgrades and installation [12]. Table 6 shows the total program metrics from 2013-2019 with two research periods: 2013-2018 and 2018-2019.

Table 6: Florida's PACE Program Metrics 2013- 2019 [12]

	2013-2018	2018-2019	Total
Ygrene Funding (million USD)	$401	$342	$743
Reduction in Electricity Consumption (GWh)	460	500	960
Reduction in Natural Gas Consumption (Mcf)	280	200	480
Reduction in GHG Emissions (Mt_{CO2e})	0.26	0.28	0.54
Total Number of Person-Year Jobs Created	11,720	10,100	21,820

Energy efficiency programs like PACE promise energy savings, reduction in GHG reductions, and decrease in energy costs using engineering models which have often been found to overestimate the actual savings from retrofits and in up to half the cases, the cost of the retrofits is greater than the energy cost savings [14], [15].

Some solutions to these issues include conducting trial periods to collect real data to use in these engineering models to better predict the savings for these programs and the building retrofits [14], [15]. As well, these trial periods can help with the full program design [14].

In Michigan, an evaluation of the region's largest residential energy efficiency program, Weatherization Assistance Program (WAP), was conducted on 30,000 homes [15]. WAP has assisted with weatherization to 7 million low income residential buildings since 1976 [15]. The intent of the report was to evaluate the actual savings and findings of the program and compare to what was expected from the program [15]. The analysis found that the upfront costs for the retrofits were twice the energy savings [15]. As well, the models used to predict the energy savings were three times more than the actual energy savings [15]. The predicted energy savings for each household was $9,810 while the actual savings per household was around $2,349 [15].

3.2 Information Presented in Second Interim Report

Retrofitting residential buildings is defined as "installing measures or equipment in existing homes in order to increase the energy efficiency of these buildings" [16]. Buildings consume one third of the total final energy consumption globally where residential buildings consume 73% of the total final energy consumption globally [17]. Energy Efficiency (EE) programs for residential buildings aim to assist this goal by reducing GHG emissions in a cost effective way along with creating jobs, increasing economic growth, and increasing health benefits [18]. However, Giandomenico et al., based out of Ottawa, published a systematic review of energy efficiency program evaluations between 1984 and 2021 found that on average these programs did not achieve deep retrofits (retrofits equating to 50% or more energy savings) in buildings [18], although that was not always necessarily the programs' goal. This review found that the average weighted energy savings was 7.2% and the highest reported average savings 26%. Insulation and programs that served low-income, fuel-heated households exclusively tended to have the highest reported energy savings with lowest program costs [18].

Deep retrofit savings could be achieved through the "house as a system approach" which is defined as "a set of retrofits in a logical and integrated manner to maximize benefits and outcomes" [16]. In other words, this approach focuses on the order the retrofits are completed and the number of retrofits completed (in stages) to achieve 50-80% energy savings [16]. Based on "Consumer's Guide: Keeping the Heat In", the following order has the building envelope retrofits completed first to target heat loss problems and mechanical systems installed afterwards at a smaller size [16]:

1. Air sealing
2. Windows/doors, wall/basement/attic insulation
3. Upgrade mechanical systems

The University of Waterloo conducted interviews of energy advisors in Waterloo, Ontario to determine the list of important retrofits to be completed for the house as a system approach listing the importance of different retrofits outlined in Table 7 [16].

Table 7: List of retrofit importance for house as a system approach [16]

Retrofit	Explanation/Rationale
Air Sealing	- High improvement (if not, the largest) of energy performance (mainly in older homes) but can be complex to achieve - Improves insulation and decreases air leakage - "Very important to improve"
Basement Insulation	- High impact on energy performance - Walls and header insulation are a good energy saving retrofit - "Very important to improve"
Wall Insulation	- "Important to improve"
Ceiling Insulation	- Economically sound and increase in comfort - "Important to improve"
Window	- Not enough savings for cost justification - "Less important to improvement", " expensive", "least efficient upgrade"
Heating System	- Building envelope retrofitting must be completed first to determine size - High energy savings and comfort with low energy costs
Hot Water System	- Not a high priority retrofit - "Less important to improvement"
HRV	- Air quality improvement and necessary once air leakage has been reduced

Table 8 shows the energy savings and cost effectiveness of the retrofits shown in Table 7 except for HRV and air sealing (was not part of the analysis) based on an analysis done in Canada on energy consumption in residential buildings between 1993 and 2001 [16], [19]. Based on Table 5 and 6, along with a case study done in Toronto in 2016 for finding deep retrofit strategies in three types of single family homes, windows were determined to be a high cost upgrade compared to energy savings and less suitable to be targeted for achieving deep retrofits [16]. Based on Table 5 and 6, upgrading of heating systems and insulation are shown to be high energy saving, low cost upgrades much better suited for deep retrofits [16]. The systematic review from Giandomenico et al, also concluded that insulation and programmable thermostats were the most cost effective and had the highest savings while storm windows and doors were among the least cost effective [18]. They further found that houses that had natural gas for primary heating had 2% higher savings than houses with electricity for primary heating, and 6.6% higher savings than houses with both natural gas and electricity for heating [18]. Despite these savings, there is a possibility of free-riding where rebates are given to homes "that would have completed the upgrade even" if rebates were not given [20]. It should be noted that financing programs such as CEIP, are less susceptible to free-ridership as they are not direct rebate programs, but it is nonetheless an issue for program designers to keep in mind.

Table 8: List of retrofit energy savings and cost effectiveness [16]

Upgrade	Energy Savings (GJ/year/house)	Cost Effectiveness (MJ/year/$)
Basement Insulation	12.0 - 20.6	7.0 - 18
Wall Insulation	2.0 - 5.4	6.9 - 8.1
Ceiling Insulation	4.6 - 9.6	2.0 - 5.7
Window	3.0 - 13.9	1.1 - 2.8
Heating System	25.5 - 31.6	9.0 - 9.7
Hot Water System	1.6	2.4

In addition to free-ridership, the permanence of savings is often another concern about energy efficiency programs. A study done in the UK examining insulation upgrades found that homes that completed cavity insulation on average experienced energy savings for four years after the upgrades and homes that completed loft insulation for two years, both coinciding with the payback period (3-4 years for cavity insulation and 1.5-3 years for loft insulation) [17]. After these periods, the gas consumption was equal to the gas consumption before the retrofits were completed [17]. This could be due to the rebound effect (where lower energy costs allow for increased consumption) and/or the gap between the expected savings (from models) and actual savings which the study found to be 30% (±51%) for this program [17]. However, a different trend was seen in a study done on post-retrofit energy savings of 1,475 homes participating in the EnerGuide for Houses program in Medicine Hat [21]. The study looked at the house's electricity and natural gas consumption from 2007-2019 while completing upgrades between 2008 and 2012 [21]. It was found that energy consumption after the retrofits were installed remained consistent 10 years after the retrofits were installed [21].

The Giandomenico et al., review of 23 residential programs found that on average actual savings were only 55.6% of the expected savings, with a range from 25%-85% [18]. Behavior of occupants are not included in the models for expected savings but would need to be to determine more accurate expected savings [17]. The Papineau et al., analysis of post upgrade energy consumption and savings in 1,475 homes in Medicine Hat found that on average actual savings were 61% of natural gas expected savings, 56% of electricity expected savings, and 56% of total energy expected savings between energy consumption before and after retrofits [21].

A number of lessons learned from energy efficiency programs have been discussed in literature. The following are lessons learned from two reports. One report listed lessons learned from the operational experiences from the World Bank Group from 2003-2009 [22]. The second report listed lessons learned based on three studies findings of overcoming energy efficiency barriers from 2008-2013 [23].

1. Full market analysis (including planning and assessing the market) to determine/predict future market problems and capabilities is necessary and ensure that the program is always marketed [22].
2. The program needs to be flexible and demand driven to adapt to market shifts, policy changes, and implementations [22].
3. Technical support should be available for any issues that may arise to be used as lessons learned and training [22].
4. Communicate clear incentives for continuous participation in the program (including homeowners, banks, administration support, etc.) [22]. As well, information on technologies is required for homeowners to make choices on which technology to adopt and the benefits and risks for it [23].
5. The program must have a balance between "policy frameworks" and implementation, financial intermediation and technical assessments/information, and market and government participation [22], [23].
6. Marketing plans should be in place and a marketing contractor could be utilized to design and implement the best marketing strategy [22].

With this in mind, the following analysis examines only the reported expected energy savings for the homes in the CEIP program, as actual savings data require years of follow up information. It is important to emphasize that most previous studies suggest these modeled efficiency savings are likely to be higher than those actually realized. However, upgrades where fuel switching is involved from a high emitting fuel to a lower emitting one (such as gas to low-carbon electricity), and/or on-site electricity generations such as solar PV, behavioral change is less important to resulting GHG emissions, although the future emissions savings are dependent on the overall electricity grid's medium term emissions intensity.

3.3 Review of City of Edmonton Historic Energuide Data

A review of the City of Edmonton's mapping tool was done by a student at the University of Alberta in July 2023. The mapping tool is a dataset that includes Energuide reports of homes that completed energy audits in Edmonton. While some of these homes may have subsequently completed energy upgrades, there was no requirement to do so, nonetheless, collectively the audits provide a useful data set for residential energy consumption patterns in Edmonton. The review of the data consisted of analyzing the energy consumption and GHG emissions from the Energuide reports. The Energuide reports were compiled in May 2023 with 4,104 audits completed between 2017 and 2023 for homes built between 1902 and 2021. The number of audits based on the decade of construction is shown in Figure 1.

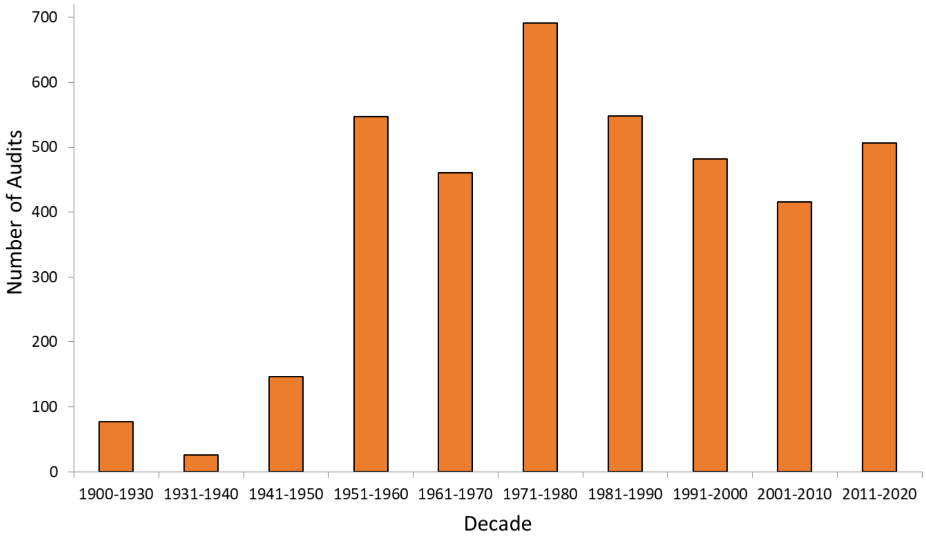

Figure 1: Number of audits completed based on decade of construction

The average energy consumption, GHG emissions, space and water heating consumption, and Energuide rating for homes built between 1900-2020 separated by decade in which homes were built are shown in Figure 2-5. There is a noticeable decrease between homes built in 2001-2010 and 2011-2020 suggesting that focusing on homes built before 2010 will likely have higher energy savings opportunities for future efficiency programs.

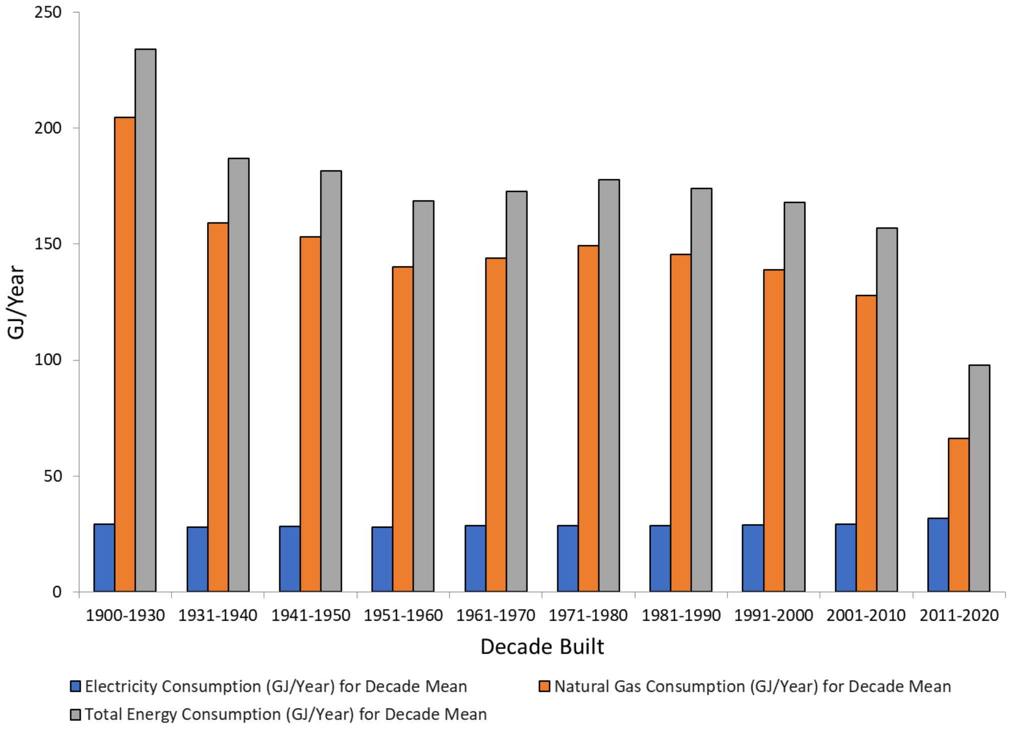

Figure 2: Annual average energy consumption for homes based on decade of construction

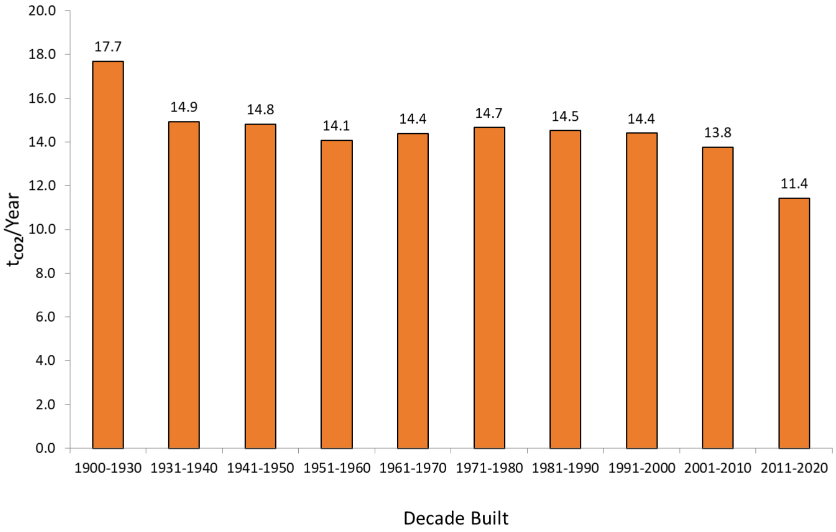

Figure 3: Annual GHG emissions for homes based on decade of construction

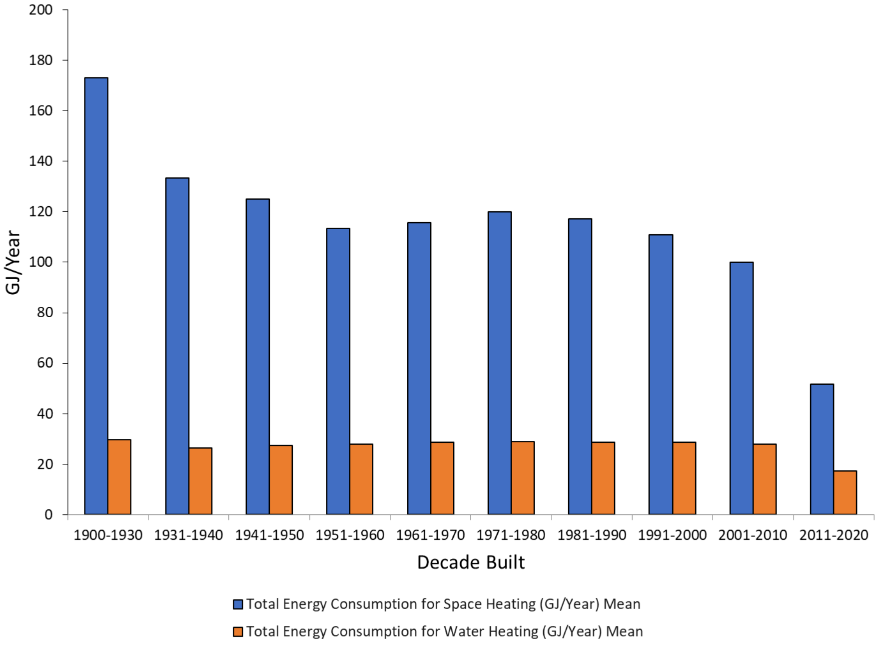

Figure 4: Average annual space and water heating consumption for homes based on decade of construction

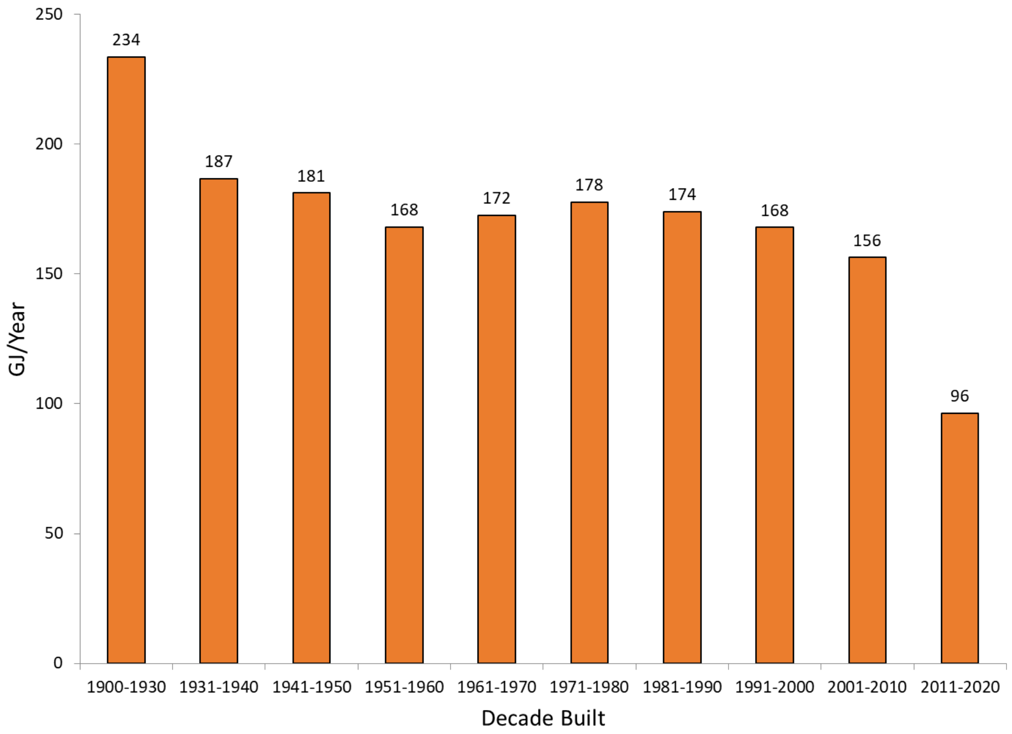

Figure 5: Energuide rating for homes based on decade of construction

4.0 Analysis of CEIP Retrofit Results to Date

This section analyzed the 27 homes that completed upgrades during the CEIP pilot program resulting in 91 individual upgrades as of October 31, 2023 in two parts. The first analysis focuses on the retrofits installed ("upgrades only") from 2023 to upgrades' useful life and the second part focuses on the house as a complete system from 2023-2050. Table 9 shows the 14 types of upgrades completed in the CEIP pilot along with their estimated useful life [24].

Topics of discussion include:

- Energy savings resulting from retrofits
- GHG emission savings
- Lifetime dollar savings (energy cost savings only)
- CO_2 abatement cost
- Simple Payback Period (SPP) and DIscounted Payback Period (DPP)

Table 9: Residential upgrades performed in pilot CEIP as of October 31, 2023 [24]

Upgrade	Useful Life (years)	Upgrade	Useful Life (years)
Air Source Heat Pump	16	Tankless Gas Water Heater	13
Ground Source Heat Pump	16	Attic Insulation	20
Boiler	25	Foundation Insulation	20
Furnace	16	Rim Joist Insulation	20
Solar PV System	25	Windows	15
Lighting Fixture	15	Doors	15
Lighting Controls	10	HRV	18
Drain Water Heat Recovery	20	Other Air Sealing	3
Heat Pump Water Heater	15	Battery Storage	10
Smart Thermostat	11	Pipe Insulation	Not specified

Note: the following upgrades were available, but not adopted in the CEIP pilot program: wall insulation, ECM motor for furnaces, solar thermal water heating, storage water heater, exterior home wrap, high efficiency air conditioner, and exposed floor insulation

4.1 Emission Factors and Their Importance on GHG Results

A typical home in Edmonton consumes around 130 GJ of natural gas annually, and 8000 kWh of electricity (using the results of from the review of EnerGuide audits completed in Edmonton between 2017-2023). The resulting GHG emissions depend on the emissions intensity of each of these fuels. GHG emissions from the combustion of natural gas emissions depend slightly on the regional gas composition but are relatively straightforward and are typically around 0.052 t_{CO2e}/GJ in Alberta (or 1962 g_{CO2e}/m^3 as reported by Environment and Climate Change Canada) [25]. This results in about 6.8 t_{CO2e} per year for a typical home (upstream emissions are not included as they are the responsibility of the upstream industries).

On the other hand, Alberta's electricity system is undergoing a rapid change in emissions intensity as coal is phased out. Historically Alberta's electricity emissions have been as high as 0.85 t_{CO2e}/MWh (0.25 t_{CO2e}/GJ) in 2015 which be the equivalent of an additional 6.8 t_{CO2e} per year resulting from electricity consumption of a typical home in Edmonton, almost identical to emissions from natural gas consumption. Environment and Climate Change Canada (ECCC) reported Alberta's electricity emissions intensity as 0.64 t_{CO2e}/MWh for 2020, while the Market Surveillance Administrator reported emissions below 0.5 t_{CO2e}/MWh by the beginning of 2022, meaning the total GHG emissions resulting from energy consumption in a typical home in Edmonton will have dropped by almost 20%; from 13.6 t_{CO2e}/yr in 2015 to 10.8 t_{CO2e}/yr in 2022 [26].

By the end of 2024 Alberta will have completely phased out its coal fleet, and new proposed federal regulations aimed at achieving 'net zero' electricity by 2035. While the federal regulations have not been published at the time of this study, early indications suggest that grandfathering, flexibility measures and carbon capture and storage's actual effectiveness may mean an emissions intensity of 0.0 t_{CO2e}/MWh is unlikely by 2035, the decarbonizing electricity sector trend is clear. This change in electricity emissions factor has a significant impact on emissions resulting from energy consumption in buildings in Alberta as well as the savings potential resulting from efficiency upgrades. For example, a solar PV system that displaces 100% of the electricity for a home in Edmonton would have reduced 6.8 t_{CO2e} per year for a typical home in 2015, but might not save any GHG emissions by 2035 if the bulk system has achieved net zero. On the other hand, an electric heat pump that replaced a high efficiency natural gas furnace in 2004 would have resulted in an emissions increase, but could result in a 6 t_{CO2e} per year reduction by 2035. It is worth noting that this change has happened so quickly that previous GHG savings models need to be revisited and in some cases expected savings from retrofits may not be estimated correctly by contractors.

The pace of Alberta's electricity decarbonization is uncertain, but given its importance to GHG savings, this report considers several different plausible scenarios for the emissions intensities as outlined in Table 10 below. Details of the electricity emissions factors are found in Appendix C. The natural gas emissions factor used in the analysis is 1962 g_{CO2e}/m^3 or 0.001962 kg_{CO2e}/m^3 [25].

Table 10: Electricity Emissions Factor Scenarios

Scenario	2035 GHG Intensity (t_{CO2e}/MWh)	Notes
Net Zero by 2035 [27]	~0	AESO Net-Zero Emissions Pathway Report (2022) details several scenarios, none of which quite reach zero by 2035, but all resemble a near linear reduction between now and then. The net zero by 2035 scenario assumes zero emissions are achieved in a linear reduction starting in 2023 aligning with the electricity GHG emissions benchmark.
2022 ECCC forecast [28]	0.17	ECCC forecast which is currently used by the City of Edmonton for emissions calculations.
TIER benchmark [29]	0.27	Uses the TIER high performance benchmark that starts at 0.37 t/MWh in 2022 and decreases by 2% per year. Generators performing below this benchmark can sell credits, while those performing above it must pay a penalty associated with the difference.

4.2 Upgrade Energy Savings

This section estimates the energy savings resulting from upgrades completed in the CEIP pilot as of October 31, 2023. The savings were modeled using HOT2000 v11.10 from Natural Resource Canada (NRCan). The details of savings resulting from the retrofits and the methodology for the analysis are shown in Appendix C. Actual performance data can take years to collect and is outside the scope of this work, and so the following analysis uses modeled results in order to estimate the savings resulting from the current pilot. The estimated energy and GHG emission savings may differ from the second interim report as new information on upgrades was provided.

The energy, GHG emissions, and cost savings is a comparison between what the house had before and after the upgrades except for water and space heating systems. The cost savings for the space and water heating systems, and the systems' replacement values of existing equipment are considered with two scenarios:
Full cost replacement ("Replacement"): Attributes the entire cost of the upgrade to the upgrade cost. This assumes the upgrade was replacing functioning existing equipment with significant working life remaining. For simplicity no salvage value is attributed to existing equipment.
Incremental cost ("Incremental"): The upgrade replaces a system that was at the end or near the end of its useful life and the upgrade was chosen instead of a low efficiency alternative. This scenario assumes new equipment would need to be purchased regardless, and as a result energy, emissions, and cost savings are incremental between the low efficiency alternative and the actual upgrade.

4.3 Electricity, Natural Gas, and Carbon Pricing

Future energy costs can be difficult to predict as they have both increased and decreased over the past several decades in Alberta. Two electricity and natural gas price scenarios were used to determine future cost savings and are shown in Table 11. The electricity price scenario is the average retail prices based on the variable retail price, fixed retail price, and regulated rate option (RRO) between October 2003-2023 [30]. The natural gas scenario is the average retail prices of the low and high natural gas retail prices from 2023-2032 forecasted by AECO-C [31]. Encore by EPCOR's five year fixed electricity and natural gas plans were chosen as representative numbers for all variable costs. Details of the electricity and natural gas cost breakdown are shown in Appendix C.

Table 11: Natural Gas and Electricity Unit Price Scenarios

Energy Price Scenario	Natural Gas ($/GJ)	Electricity ($/kWh)
Low	1.66	0.07
High	5.60	0.13

The federal government has implemented a consumer facing carbon price which is currently $65/t$_{CO2e}$ and expected to increase to $170/t$_{CO2e}$ by 2030. The carbon price and carbon cost is shown in Table 12.

Table 12: Carbon Pricing Schedule and Cost for Natural Gas from 2023-2030

Year	2023	2024	2025	2026	2027	2028	2029	2030
Carbon Price ($/t$_{CO2e}$)	$65	$80	$95	$110	$125	$140	$155	$170
Carbon Cost ($/GJ)	$3.36	$4.14	$4.92	$5.69	$6.47	$7.25	$8.02	$8.80

It should be emphasized that both gas and electricity prices can be volatile, and long-term cost savings will vary as a result. Alberta's electricity prices are currently near all-time highs, and if these costs fall in the coming year it would notably improve the cost savings of heat pumps, while decreasing the savings for solar PV systems. Given the challenges associated with forecasting energy prices, dollar savings estimates should be considered with requisite caution, but provide a reasonable approximation based on current, and reasonable forecast prices.

4.4 Isolated Upgrades

For this section, the energy savings are modeled for each retrofit done independently, answering the question: *what would the savings be if the house only completed one upgrade?* For example, if a house installed an ASHP as well as insulated the walls, the modeled savings examines if only the ASHP were installed, and then if only the insulation was installed. Sometimes multiple upgrades can be reinforcing (as would be the case with an ASHP and solar PV for example), while in other cases, the combined savings might be less than the sum of the individual savings (as would be the case with an ASHP combined with wall insulation). The purpose of examining each upgrade is to give a sense of the order of magnitude of savings potential for each technology, recognizing the aforementioned caveats which are particularly important when fuel switching is involved in one of the upgrades. For context, as stated earlier, a typical home in Edmonton consumes about 130 GJ of natural gas per year and 8000 kWh of electricity. At current grid emissions intensity, the energy consumption in a typical home in Edmonton results in 6.8 t_{CO2e}/yr from natural gas, 3.0 t_{CO2e}/yr from electricity for a total of around 10 t_{CO2e}/yr.

4.4.1 Air Source Heat Pump (ASHP)

ASHPs reduce energy used for heating, but require anywhere between one-third to one-half as much additional electrical energy to do so, therefore the net savings resulting from a heat pump depend not only on the relative differences in natural gas savings and increase in electricity consumption, but also in the expected difference in the energy sources' prices and associated emissions. Four participants added ASHPs as part of the CEIP program, which resulted in approximately a 50% reduction in natural gas consumption, as well as almost a doubling in electricity consumption compared to typical levels of consumption (130 GJ/yr and 8,000 kWh/yr respectively) as can be seen in Table 13 below which shows the energy savings estimates for installed four ASHP in the CEIP pilot. Table 14 shows the ASHP GHG emissions savings based on the energy savings for the equipment specifications that were installed in the CEIP homes as well the three electricity emissions factor scenarios during the useful lifetime. Annual emissions savings can be as much as double if the grid reaches net-zero by 2035 compared to if it follows the emissions limit laid out in TIER.

Table 13: HOT2000 modeled energy savings for ASHP

House	Electricity Savings		Natural Gas Savings (GJ/yr)	Net Energy Savings (GJ/yr)	Installed ASHP Specifications
	(kWh/yr)	(GJ/yr)			
1110 (Replacement)	(6,540)	(23.5)	76.5	53.0	10.6 HSPF, 17.9 SEER 34,000 Btu/hr capacity
1118 (Replacement)	(5,984)	(21.5)	51.2	29.7	10 HSPF, 18 SEER 38,000 Btu/hr capacity
1131 (Replacement)	(5,831)	(21.0)	53.3	32.3	11.8 HSPF, 22 SEER 48,000 Btu/hr
1165 (Replacement)	(6,931)	(25.0)	69.1	44.1	3.22 COP (heating), 3.66 COP (cooling) 24.06 kW capacity

Table 14: Total HOT2000 modeled GHG emissions savings for ASHP

House	Lifetime (t_{CO2e})			Annual (t_{CO2e}/year)		
	Net Zero	2022 ECCC	TIER	Net Zero	2022 ECCC	TIER
1110	49.9	42.0	32.2	3.1	2.6	2.0
1118	29.8	22.6	13.7	1.9	1.4	0.9
1131	31.0	24.9	16.2	2.0	1.6	1.0
1165	37.3	26.1	12.0	2.3	1.6	0.8

The cost analysis for the ASHP are shown in Table 15-16. For the incremental scenario, the cost of the ASHP was compared to the cost of the furnace before retrofits except for 1165 where the cost of the ASHP was compared to the cost of the upgraded furnace. The assumed cost for the furnaces are shown in Table 15. Table 16 shows the summary of the lifetime dollar savings analysis (assuming the useful life is 16 years), and details can be found in Appendix D1. At current energy prices, it is more expensive to run an ASHP than operate a furnace. At lower carbon prices, the ASHP is unlikely to recoup its investment cost as the SPP and DPP would be larger than 50 years with and without the carbon price therefore, the house will not recoup the project cost before the ASHP must be replaced.

Table 15: Furnace cost and specifications for incremental scenario

House	Cost [32]	Specifications
1110	$1,000	80-89% AFUE
1118	$1,000	80-89% AFUE
1131	$2,000	90-95% AFUE
1165	$8,925	98.2% AFUE

Table 16: Summary of lifetime dollar savings analysis for ASHP for 2022 ECCC Grid

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*		
1110 (Replacement)	($241) ($1,700)	$241 $276	($5,235) ($6,695)	$360 $395	($9,348) ($10,807)	$458 $493	50+	
1110 (Incremental)		$217 $252		$336 $371		$434 $469	-	
1118 (Replacement)	($3,597) ($6,116)	$1,122 $1,233	($6,941) ($6,695)	$1,269 $1,381	($9,694) ($12,213)	$1,391 $1,502	50+	
1118 (Incremental)		$1,078 $1,189		$1,225 $1,337		$1,347 $1,458	-	
1131 (Replacement)	($2,890) ($5,128)	$621 $711	($6,371) ($8,610)	$761 $851	($9,238) ($11,476)	$876 $966	50+	
1131 (Incremental)		$541 $631		$681 $770		$796 $885	-	
1165 (Replacement)	($7,631) ($12,275)	$803 $981	($12,140) ($16,784)	$976 $1,154	($15,853) ($20,497)	$1,118 $1,296	50+	
1165 (Incremental)		$461 $639		$634 $812		$776 $954	-	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.2 Ground Source Heat Pump (GSHP)

GSHPs reduce energy used for heating, but require anywhere between one-third to one-half as much additional electrical energy to do so, therefore the net savings resulting from a heat pump depend not only on the relative differences in natural gas savings and increase in electricity consumption, but also in the expected difference in the energy sources' prices and associated emissions. One participant added GSHPs as part of the CEIP program, which resulted in approximately a 55% reduction in natural gas consumption, as well as almost a doubling in electricity consumption compared to typical levels of consumption (130 GJ/yr and 8,000 kWh/yr respectively) as can be seen in Table 17 below which shows the energy savings estimates for the only GSHP installed in the CEIP pilot. Table 18 shows the GSHP GHG emissions savings based on the energy savings for the actual installed specifications and the three electricity emissions factor scenarios. GSHP reduces natural gas consumption and increases electricity consumption, and therefore the net emissions savings is dependent on the electricity emissions factor. The table shows that in all electricity emissions factor scenarios, a GSHP will result in an average 3.0 t_{CO2e}/year GHG emission reduction over its useful lifetime.

Table 17: HOT2000 modeled energy savings for GSHP

House	Model Energy Savings*		Model Natural Gas Savings (GJ/yr)	Net Model Savings (GJ/yr)	Installed GSHP Specifications
	(kWh/yr)	(GJ/yr)			
1115	4,225	15.2	73.8	58.6	19.7 SEER, 4.2 COP 46,500 Btu/hr

*default depth of 1.5 m

Table 18: Total HOT2000 modeled GHG emissions savings for GSHP

House	Lifetime (t_{CO2e})			Annual (t_{CO2e}/year)		
	Net Zero	2022 ECCC	TIER	Net Zero	2022 ECCC	TIER
1115	52.8	48.4	42.4	3.3	3.0	2.7

The cost analysis for GSHPs are shown in Table 19-20. For the incremental scenario, the cost of the GSHP was compared to the cost of the furnace before retrofits and is shown in Table 19. Table 20 shows the summary of the lifetime dollar savings analysis (useful life assumed to be 16 years based on CEIP guidelines, although GSHPs are often considered to have working lives from 20-40 years) presented in Appendix D2 with and without carbon prices. The house achieved net zero after these installations. The table shows that GSHPs have cost savings with carbon prices and the carbon abatement cost is positive indicating that houses will pay to decrease GHG emissions. The SPP and DPP would be larger than 50 years with and without the carbon price therefore, the house will not recoup the project cost before the GSHP is likely to exceed its useful life. It should be noted that while a GSHP is not likely to operate for 50 years, it does become increasingly cost effective in the later years with a higher carbon price on natural gas. Furthermore, GHG emission savings increase in later years as the electricity grid decarbonizes, and so the modeled savings underestimate GHG savings for GSHPs that begin operating with a less carbon intensive grid.

Table 19: Furnace cost and specifications for incremental scenario

House	Cost [32]	Specifications
1115	$1,000	80-89% AFUE

Table 20: Summary of lifetime dollar savings analysis for GSHP for 2022 ECCC Grid

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*		
1115 (Replacement)	$4,232 $4,827	$930 $917	($589) $7	$1,029 $1,017	($4,558) ($3,963)	$1,111 $1,099	50+	
1115 (Incremental)		$909 $897		$1,008 $996		$1,090 $1,078	-	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.3 High Efficiency Boiler

Table 21 shows the energy savings for the installed boiler based on the modeled savings from the HOT2000 model for the replacement scenario (discussed in section 4.2) only as this particular home undertook numerous upgrades in order to work towards a net-zero energy consumption home some of which were outside of the CEIP program. Table 22 shows the boiler GHG emissions savings based on the energy savings.

Table 21: HOT2000 modeled energy savings for boilers

House	Natural Gas Savings (GJ/yr)	Installed Boiler Specifications
1119	23.0	Condensing boiler with AFUE of 95% and 11.5 kW capacity

Table 22: Total HOT2000 modeled GHG emissions savings for boiler

House	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
1119	30.3	1.2

The cost analysis for the boilers are shown in Table 23-24. For the incremental scenario, the cost of the installed boiler was compared to the cost of the boiler before retrofits and is shown in Table 23. Table 24 shows the summary of the lifetime dollar savings analysis (useful life of 25 years) presented in Appendix D3 with and without carbon prices. Table 23 shows that boilers have cost savings with and without carbon prices ranging between $2,000 and $9,000 but have a payback period larger than 50 years with and without the carbon price, in part due to the relatively high efficiency of the home's building envelope which lowers overall heating demand.

Table 23: Boiler cost and specifications for incremental scenario

House	Cost [33]	Specifications
1119	$2,200	77% AFUE (low standard boiler)

Table 24: Summary of lifetime dollar savings analysis for boilers

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$/$t_{CO2e}$*	Net Lifetime Dollar Savings*	$/$t_{CO2e}$*	Net Lifetime Dollar Savings*	$/$t_{CO2e}$*		
1119 (Replacement)	$6,743 $9,008	$407 $332	$4,114 $6,379	$494 $419	$2,181 $4,446	$558 $483	50+	
1119 (Incremental)		$334 $260		$421 $346		$485 $410	-	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.4 High Efficiency Furnace

High efficiency furnaces, specifically condensing furnaces, further reduce energy consumption used for heating with the second heat exchanger for more heat output [34]. Eight participants upgraded to a condensing furnace as part of the CEIP program. The estimated energy savings and GHG emission reductions are shown Table 25 and 26, respectively.

Table 25: HOT2000 modeled energy savings for furnace

House	Natural Gas Savings (GJ/yr)	Installed Furnace Specifications
1078	10.9	Condensing furnace with 98.1% AFUE and 24.6 kW capacity
1089	25.7	Condensing furnace with 97% AFUE and 97,000 Btu/hr capacity
1098	24.8	Two condensing furnace with 99% AFUE and 17.5 kW capacity
1131	2.8	Condensing furnace with 98.2% AFUE and 85,00 Btu/hr capacity
1140	31.9	Condensing furnace with 97% AFUE and 64,000 Btu/hr capacity
1141	13.7	Condensing furnace with 99% AFUE and 88,000 Btu/hr capacity
1159	16.5	Condensing furnace with 97% AFUE and 15 kW capacity
1165	2.2*	Condensing furnace with 98.2% AFUE and 85,000 Btu/hr

*Savings are low due to this house upgrading a 95% AFUE furnace to a 98% AFUE furnace.

Table 26: Total HOT2000 modeled GHG emissions savings for furnace

House	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
1078	9.2	0.57
1089	21.6	1.4
1098	20.9	1.3
1131	2.3	0.15
1140	26.9	1.7
1141	11.6	0.72
1159	13.9	0.87
1165	1.9	0.12

The cost analysis for the high efficiency furnaces are shown in Table 27-28. Table 27 shows the cost for the incremental scenario to compare to the cost of the furnace before retrofits. Table 28 shows the summary of the lifetime dollar savings analysis (useful life of 16 years) presented in Appendix D4 with and without carbon prices. The table shows that furnaces have cost savings with and without carbon prices throughout the useful life ranging between $100 and $8,000. The payback period ranges between 20-50+ indicating that homeowners will not recoup the project cost before the furnace is likely to exceed its useful life. The abatement cost is positive for all homes except one (1140) under a high energy cost scenario with the carbon price increasing to $170/GJ. Note that 1140 had the highest estimated energy savings and GHG emission reductions however, would not recoup the project cost before the furnace exceeds its useful life.

Table 27: High efficiency furnace cost and specifications for incremental scenario

House	Cost	Specifications	Source
1078	$4,000	90-95% AFUE	[32]
1089	$1,000	80-89% AFUE	
1098	$1,000	80-89% AFUE	
1131	$2,000	90-95% AFUE	
1140	$1,000	80-89% AFUE	
1141	$1,000	80-89% AFUE	
1159	$1,000	80-89% AFUE	
1165	$2,000	90-95% AFUE	

Table 28: Summary of lifetime dollar savings analysis for furnaces

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*		
1078 (Replacement)	$1,958 $2,644	$693 $618	$1,247 $1,933	$770 $696	$661 $1,347	$834 $759	50+	
1078 (Incremental)		$257 $182		$334 $259		$398 $323	-	
1089 (Replacement)	$4,613 $6,230	$156 $81	$2,937 $4,554	$234 $159	$1,557 $3,174	$298 $223	26 50+	32 50+
1089 (Incremental)		$110 $35		$188 $113		$251 $177	-	
1098 (Replacement)	$4,465 $6,029	$470 $395	$2,843 $4,408	$547 $472	$1,507 $3,072	$611 $536	46 50+	50+
1098 (Incremental)		$374 $299		$451 $377		$515 $441	-	
1131 (Replacement)	$499 $674	$4,815 $4,740	$318 $493	$4,892 $4,818	$169 $344	$4,956 $4,881	50+	
1131 (Incremental)		$3,960 $3,885		$4,037 $3,962		$4,101 $4,026	-	
1140 (Replacement)	$5,740 $7,752	$68 ($7)	$3,655 $5,667	$145 $70	$1,938 $3,950	$209 $134	20 50+	23 50+
1140 (Incremental)		$30 ($44)		$108 $33		$172 $97	-	
1141 (Replacement)	$2,470 $3,336	$633 $558	$1,573 $2,439	$710 $636	$834 $1,700	$774 $699	-	
1141 (Incremental)		$546 $472		$624 $549		$688 $613	-	
1159 (Replacement)	$2,968 $4,009	$642 $567	$1,890 $2,930	$719 $644	$1,002 $2,042	$783 $708	50+	
1159 (Incremental)		$570 $495		$647 $572		$711 $636	-	
1165 (Replacement)	$401 $541	$4,541 $4,466	$255 $396	$4,618 $4,544	$135 $276	$4,682 $4,607	50+	
1165 (Incremental)		$3,475 $3,401		$3,527 $3,617		$3,617 $3,542	-	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.5 Solar PV System

Solar PV systems reduce electricity consumption and if large enough, give homeowners the possibility to earn extra money by exporting excess electricity to the grid. Fifteen applicants have installed a solar PV system and the electricity savings with exports based on the contractors estimated solar productions are shown in Table 29. Table 30 and 31 shows the solar PV and exports GHG emissions savings on the three electricity emissions factor scenarios, respectively.

Table 29: HOT2000 modeled energy savings for solar PV system

House	Electricity Savings (kWh/year)	Contractor Exported Electricity Estimate (kWh/year)
1074	8,400	10,380
1075	8,239	2,551
1078	8,532	4,566
1082	5,825	0
1086*	3,541	0
1088	10,262	3,282
1089	7,833	682
1090	7,872	1,075
1094	8,245	433
1104	6,263	0
1112	9,286	2,450
1113	7,618	2,526
1115	7,506	2,871
1131	1,321	0
1141	7,594	2,405

*export estimation made within HOT2000 as contractor does not provide export estimations

Table 30: Total HOT2000 modeled GHG emissions savings for solar PV system

House	Lifetime (t_{CO2e})			Annual (t_{CO2e}/year)		
	Net Zero	2022 ECCC	TIER	Net Zero	2022 ECCC	TIER
1074	18.3	39.6	54.6	0.73	1.6	2.2
1075	18.0	38.9	53.5	0.72	1.6	2.1
1078	18.6	40.3	55.4	0.74	1.6	2.2
1082	12.7	27.5	37.8	0.51	1.1	1.5
1086*	7.7	16.7	23.0	0.31	0.7	0.9
1088	22.4	48.4	66.7	0.89	1.9	2.7
1089	17.1	37.0	50.9	0.68	1.5	2.0
1090	17.2	37.1	51.1	0.69	1.5	2.0
1094	18.0	38.9	53.6	0.72	1.6	2.1
1104	13.7	29.5	40.7	0.55	1.2	1.6
1112	20.2	43.8	60.3	0.81	1.8	2.4
1113	16.6	35.9	49.5	0.66	1.4	2.0
1115	16.4	35.4	48.8	0.65	1.4	2.0
1131	2.9	6.2	8.6	0.12	0.2	0.3
1141	16.6	35.8	49.3	0.66	1.4	2.0

*export estimation made within HOT2000 as contractor does not provide export estimations

Table 31: Total HOT2000 modeled exports GHG emissions savings for solar PV system

House	Lifetime (t_{CO2e})			Annual (t_{CO2e}/year)		
	Net Zero	2022 ECCC	TIER	Net Zero	2022 ECCC	TIER
1074	22.6	49.0	67.4	0.9	2.0	2.7
1075	5.6	12.0	16.6	0.2	0.5	0.7
1078	10.0	21.5	29.7	0.4	0.9	1.2
1082	0.0	0.0	0.0	0.0	0.0	0.0
1086*	0.0	0.0	0.0	0.0	0.0	0.0
1088	7.2	15.5	21.3	0.3	0.6	0.9
1089	1.5	3.2	4.4	0.1	0.1	0.2
1090	2.3	5.1	7.0	0.1	0.2	0.3
1094	0.9	2.0	2.8	0.0	0.1	0.1
1104	0.0	0.0	0.0	0.0	0.0	0.0
1112	5.3	11.6	15.9	0.2	0.5	0.6
1113	5.5	11.9	16.4	0.2	0.5	0.7
1115	6.3	13.5	18.6	0.3	0.5	0.7
1131	0.0	0.0	0.0	0.0	0.0	0.0
1141	5.2	11.3	15.6	0.2	0.5	0.6

*export estimation made within HOT2000 as contractor does not provide export estimations

The summary of the lifetime dollar savings for solar PVs are shown in Table 32 (useful life of 25 years) and the full analysis is presented in Appendix D5 for the three electricity emission factor scenarios. It should be noted that this analysis does not consider the “solar club” where micro generators in Alberta switch their retail rates in the summer to receive a higher rate for energy exported to the grid. Instead, the exports used the retail rates shown in Table 11. Even without this assumption, solar PV systems that are financed through CEIP have positive cash flows immediately from on-site savings as well as electricity exported. 13 out of 15 houses had a negative \$/t_{CO2e} saved, indicating that they would have a net financial benefit from decreasing GHG emissions.

Table 32: Summary of lifetime dollar savings analysis for solar PV systems

House	Lifetime Dollar Savings*	Lifetime Export*	Net Zero	2022 ECCC	TIER	SPP~ (yr)	DPP~ (yr)
			$/t_{CO2e}$*	$/t_{CO2e}$*	$/t_{CO2e}$*		
1074	$26,455 $38,327	$32,691 $47,362	($315) ($963)	($145) ($445)	($106) ($323)	0 27	0 32
1075**	$23,751 $34,409	$7,354 $10,654	($162) ($755)	($75) ($349)	($54) ($253)	0 23	
1078	$24,595 $35,633	$13,162 $19,069	($384) ($977)	($77) ($452)	($129) ($328)	0 22	
1082	$16,792 $24,327	$0	$169 ($424)	$78 ($196)	$57 ($142)	24 36	26 50+
1086	$10,208 $14,788	$0	$1,103 $510	$510 $235	$370 $171	50+	
1088	$29,582 $42,858	$9,461 $13,707	($320) ($914)	($148) ($422)	($107) ($307)	0 23	0 25
1089**	$22,580 $32,713	$1,966 $2,848	($35) ($629)	($16) ($291)	($12) ($211)	0 25	0 27
1090	$22,693 $32,876	$3,099 $4,490	($93) ($686)	($43) ($317)	($31) ($230)	0 30	0 39
1094	$23,768 $34,434	$1,248 $1,808	($307) ($900)	($142) ($416)	($103) ($302)	0 24	0 25
1104	$18,054 $26,157	$0	($43) ($637)	($20) ($294)	($14) ($214)	0 31	0 43
1112**	$26,769 $38,782	$7,063 $10,232	($303) ($897)	($140) ($414)	($102) ($301)	0	
1113**	$21,960 $31,815	$7,282 $10,549	($221) ($815)	($102) ($376)	($74) ($273)		
1115	$21,638 $31,348	$8,276 $11,990	$579 ($14)	$268 ($7)	$194 ($5)	24 35	34 50+
1131	$3,809 $5,518	$0	($211) ($805)	($98) ($372)	($71) ($270)	40 50+	50+
1141**	$21,891 $31,715	$6,933 $10,044	$23 ($570)	$11 ($263)	$8 ($191)	0 31	0 40

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario
**SPP/DPP for project cost - rebates
~SPP and DPP assume a 0.5% decrease in electricity production

4.4.6 Lighting Fixtures

Lighting fixtures and control upgrades are one of many ways to decrease electricity consumption by decreasing the light bulb wattage and lighting usage. Four applicants have upgraded the exterior lighting fixtures and controls with the estimated energy savings shown in Table 33. Table 34 shows the lighting fixtures GHG emissions savings for the three electricity emissions factor scenarios in kg_{CO2e} due to how small the GHG emission savings are.

Table 33: HOT2000 modeled energy savings for lighting fixtures

House	Electricity Savings (kWh/yr)	Specifications	Electricity Savings Assumptions*
1074	559	Three, 300 W outdoor light bulbs were replaced with 45 W light bulbs.	Before/After upgrade: 2 hr/day usage
1088	29.2	One motion detector light bulb (12 W) was replaced with a 34 W lightbulb	Before upgrade: 12 hr/day usage After upgrade: 2 hr/day usage
1090	108.1	Four light fixtures (60 W) were replaced with 24 W light bulb	Before/After upgrade: 2 hr/day usage
1104	58.4	One, 100 W security light bulb was replaced with a 21.3 W lightbulb	Before/After upgrade: 2 hr/day usage

*Before upgrading, 1088 had the light on all night, therefore assumed 12 hours/day. For the rest, the quotes did not specify a usage/day. A 2 hr/day usage was chosen based on the Department of Energy's residential lighting usage study for homes in the US completed in 2012 [35]. The study concluded an average usage between 1.4-1.7 hrs/day. 2 hrs/day was used in estimating the energy savings for lighting fixtures to show the higher end of usage.

Table 34: Total HOT2000 modeled GHG emissions savings for lighting fixture

House	Net Zero (kg_{CO2e})	2022 ECCC (kg_{CO2e})	TIER (kg_{CO2e})	Net Zero (kg_{CO2e}/year)	2022 ECCC (kg_{CO2e}/year)	TIER (kg_{CO2e}/year)
1074	1240	1814	2604	83	121	174
1088	65	95	136	4	6	9
1090	240	351	504	16	23	34
1104	130	190	272	9	13	18

The summary of the lifetime dollar savings for lighting fixtures are shown in Table 35 (useful life of 15 years) and the full cost analysis is presented in Appendix D6. Table 35 shows that lights have the potential for high cost savings shown in 1074 where 300 W light bulbs were replaced with 45 W light bulbs where the payback period was 0 years and the abatement cost was negative indicating that there is a net financial benefit from decreasing GHG emissions. The cost savings for the other homes throughout the lifetime ranged between $50 and $150 with payback periods ranging from 18 to 50+ years indicating that homes will not recoup the project cost before the lights are likely to exceed its useful life.

Table 35: Summary of lifetime dollar savings analysis for lighting fixtures

House	Net Lifetime Dollar Savings*	Net Zero	2022 ECCC	TIER	SPP (yr)	DPP (yr)
		$\$/t_{CO2e}$*	$\$/t_{CO2e}$*	$\$/t_{CO2e}$*		
1074	$1,120 $1,623	($570) ($976)	($390) ($667)	($272) ($465)	0	
1088	$51 $74	$6,567 $6,215	$3,819 $3,579	$2,660 $2,493	50+	
1090	$188 $272	$3,220 $2,869	$641 $401	$447 $279	50+	
1104	$102 $147	$432 $81	$1,642 $1,402	$1,144 $976	18 26	19 32

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.7 Drain Water Heat Recovery (DWHR)

DWHR is used to transfer "heat from the shower drain water to pre-warm the cold supply water before it goes into the water heater" [40]. Two applicants installed DWHR achieving the same natural gas and GHG emission savings as seen in Table 36 and Table 37, respectively.

Table 36: HOT2000 modeled energy savings for DWHR

House	Natural Gas Savings (GJ/yr)	Installed DWHR Specifications
1094	2.9	Heat recovery rate of 9.3/kW and 50.1% rated efficiency
1118		Heat recovery rate of 7.7/kW and 41.0% rated efficiency

Table 37: Total HOT2000 modeled GHG emissions savings for DWHR

House	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
1094	3.0	0.15
1118		

The summary of lifetime dollar savings for DWHRs are shown in Table 38 (useful life is 20 years) and the full cost analysis is presented in Appendix D7 with and without carbon prices. Table 38 shows that DWHRs have cost savings with and without carbon prices running between $200 and $800 throughout the useful life. The dollars per tonne is positive indicating that houses will pay to decrease GHG emissions. The payback period ranges between 42-50+ years therefore, the house will not recoup the project cost before the DWHR is likely to exceed its useful life.

Table 38: Summary of lifetime dollar savings analysis for DWHR

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*		
1094	$659 $895	$773 $698	$410 $635	$856 $781	$217 $443	$919 $845	50+	
1118	$667 $895	$259 $184	$415 $643	$342 $267	$220 $448	$406 $331	42 50+	50+

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.8 Heat Pump Water Heater (HPWH)

HPWHs reduce energy used for heating water, but require electrical energy to do so, therefore the net savings resulting from a heat pump depend not only on the relative differences in natural gas savings and increase in electricity consumption, but also in the expected difference in the energy sources' prices and associated emissions. Five participants upgraded to HPWHs as part of the CEIP program. The energy savings and GHG emission reductions can be seen in Table 39 and Table 40, respectively for the three electricity emissions factors scenarios.

Table 39: HOT2000 modeled energy savings for HPWH

House	Model Energy Savings		Model Natural Gas Savings (GJ/yr)	Net Model Savings (GJ/yr)	Installed HPWH Specifications
	(kWh/yr)	(GJ/yr)			
1078	1,160	4.2	18.8	14.7	Electric integrated HPWH with 3.85 UEF and 65 US gal
1110	1,164	4.2	17.4	13.3	Electric integrated HPWH with 3.75 UEF and 50 US gal
1115	1,171	4.2	16.0	11.8	Electric integrated HPWH with 3.75 UEF and 50 US gal
1131	1,186	4.3	18.5	14.2	Electric integrated HPWH with 3.70 UEF and 80 US gal
1159	1,116	4.0	15.0	11.0	Electric integrated HPWH with 3.85 UEF and 65 US gal

Table 40: Total HOT2000 modeled GHG emissions savings for HPWH

House	Lifetime (t_{CO2e})			Annual (t_{CO2e}/year)		
	Net Zero	2022 ECCC	TIER	Net Zero	2022 ECCC	TIER
1078	12.3	11.2	9.6	0.82	0.75	0.64
1110	11.2	10.1	8.5	0.75	0.67	0.57
1115	10.1	8.9	7.3	0.67	0.59	0.49
1131	12.0	10.9	9.3	0.80	0.73	0.62
1159	9.4	8.3	6.8	0.63	0.55	0.45

The cost analysis for the HPWhs are shown in Table 41-42. Table 41 shows the cost for the incremental scenario to compare to the cost of the water heater before retrofits. Table 42 shows the summary of the lifetime dollar savings analysis (useful life of 15 years) presented in Appendix D8 with and without carbon prices. Table 42 shows that HPWHs do not have cost savings due to fuel switching for a constant $65/GJ carbon price and without the carbon price. The abatement cost is positive indicating that houses will pay to decrease GHG emissions. The payback period exceeded 50 years for all homes as the increase in electricity dollars outweighs the natural gas savings, even after the payment period ends.

Table 41: Water heater cost and specifications for incremental scenario

House	Cost [36]	Specifications
1078	$750	Direct vented storage tank
1110/1115/1131/1159	$1,700	Storage tank

Table 42: Summary of lifetime dollar savings analysis for HPWH for 2022 ECCC Grid

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*		
1078 (Replacement)	$824 $894	$385 $379	($304) ($234)	$487 $481	($1,254) ($1,184)	$573 $566	50+	
1078 (Incremental)		$318 $312		$419 $413		$505 $499	-	
1110 (Replacement)	$892 $1,015	$679 $666	($152) ($30)	$783 $771	($1,031) ($909)	$871 $859	50+	
1110 (Incremental)		$508 $496		$622 $701		$701 $689	-	
1115 (Replacement)**	$642 $674	$395 $392	($317) ($285)	$504 $500	($1,124) ($1,092)	$595 $591	50+	
1115 (Incremental)**		$203 $199		$311 $308		$403 $399	-	
1131 (Replacement)	$1,034 $1,203	$308 $293	($74) $95	$411 $396	($1,007) ($839)	$498 $482	50+	
1131 (Incremental)		$150 $135		$253 $238		$340 $324	-	
1159 (Replacement)	$568 $583	$813 $811	($330) ($315)	$923 $921	($1,086) ($1,071)	$1,015 $1,013	50+	
1159 (Incremental)		$606 $604		$716 $714		$808 $806	-	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

**SPP/DPP for project costs-rebates

4.4.9 Tankless Gas Water Heater

Tankless gas water heaters (TGWH) reduce heat loss by eliminating water tanks and in turn reduce natural gas consumption and GHG emissions. Six applicants installed TGWHs and the energy savings and GHG emission reductions are shown in Table 43 and 44, respectively.

Table 43: HOT2000 modeled energy savings for TGWH

House	Natural Gas Savings (GJ/yr)	Installed TGWH Specifications
1075	8.9	Condensing TGWH with 0.96 EF
1098	9.0	Condensing TGWH with 0.96 EF
1107	8.7	Condensing TGWH with 0.96 EF
1130	8.2	Condensing TGWH with 0.95 UEF
1135	7.4	Condensing TGWH with 0.96 EF
1141	6.7	Condensing TGWH with 0.96 EF

Table 44: Total HOT2000 modeled GHG emissions savings for TGWH

House	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
1075	6.1	0.47
1098	6.2	0.48
1107	5.9	0.46
1130	5.6	0.43
1135	5.1	0.39
1141	4.6	0.35

Table 45 shows the cost for the incremental scenario to compare to the cost of the water heater before retrofits. Table 46 shows the summary of the lifetime dollar savings analysis (useful life is 13 years) presented in Appendix D9 with and without carbon prices. TGWHs have cost savings with and without the carbon price ranging between $300 and $1,800 throughout the lifetime. The dollars per tonne is positive indicating that houses will pay to decrease GHG emissions. The payback period would be larger than 35 years with and without the carbon price therefore, the house will not recoup the project cost before the TGWH is likely to exceed its useful life.

Table 45: Water heater cost and specifications for incremental scenario

House	Cost [36]	Specifications
1078	$750	Direct vented storage tank
1098/1107/1130/1135/1142	$1,700	Storage tank

Table 46: Summary of lifetime dollar savings analysis for TGWH for 2022 ECCC Grid

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*		
1075 (Replacement)	$1,259 $1,713	$522 $447	$825 $1,279	$593 $518	$437 $891	$657 $582	39 50+	50+
1075 (Incremental)		$398 $323		$470 $395		$533 $459	-	
1098 (Replacement)	$1,283 $1,746	$676 $601	$841 $1,303	$747 $672	$446 $908	$811 $736	46 50+	50+
1098 (Incremental)		$401 $326		$472 $536		$536 $461	-	
1107 (Replacement)	$1,230 $1,673	$1,064 $989	$806 $1,249	$1,136 $1,061	$427 $871	$1,199 $1,125	45 50+	50+
1107 (Incremental)		$777 $702		$849 $913		$913 $838	-	
1130 (Replacement)	$1,160 $1,578	$638 $563	$760 $1,178	$710 $635	$403 $821	$773 $699	50+	
1130 (Incremental)		$334 $259		$405 $330		$469 $394	-	
1135 (Replacement)	$1,053 $1,432	$859 $784	$689 $1,069	$930 $856	$366 $745	$994 $920	50+	
1135 (Incremental)		$524 $449		$595 $520		$659 $584	-	
1141 (Replacement)	$952 $1,296	$928 $853	$624 $967	$999 $924	$331 $674	$1,063 $988	50+	
1141 (Incremental)		$557 $482		$629 $554		$693 $618	-	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.10 Attic Insulation

Attic insulation reduces heat loss and is the top three building envelope upgrade completed in pilot CEIP. Ten applicants increased the attic insulation and Table 47 and 48 shows the energy and GHG emission savings, respectively.

Table 47: HOT2000 modeled energy savings for attic insulation

House	Natural Gas Savings (GJ/yr)	Attic Insulation Specifications
1078	1.8	Increase 648 sq ft of attic space to 8.8 RSI
1082	6.1	Increase all attic space to 8.8 RSI
1088	1.8	Increase all attic space to 8.8 RSI
1094	2.4	Increase all attic space to 8.8 RSI
1112	9.9	Increase 2050 sq ft of attic space to 8.8 RSI
1113	2.1	Increase 850 sq ft of attic space to 8.8 RSI
1119	4.2	Increase 1293 sq ft of attic space to 8.8 RSI
1135	5.0	Increase 832 sq ft of attic space to 8.8 RSI
1159	2.5	Increase all attic space to 8.8 RSI
1165	2.9	Increase all attic space to 8.8 RSI

Table 48: Total HOT2000 modeled GHG emissions savings for attic insulation

House	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
1078	1.8	0.09
1082	6.4	0.32
1088	1.9	0.10
1094	2.5	0.13
1112	10.5	0.52
1113	2.2	0.11
1119	4.4	0.22
1135	5.2	0.26
1159	2.6	0.13
1165	3.0	0.15

The lifetime dollar savings for the attic insulation upgrades is shown in Table 49 (useful life of 20 years) with the full cost analysis presented in Appendix D10 with and without carbon prices. Table 49 shows that attic insulation has a cost savings ranging between $100 and $5,500. The abatement cost was negative for three homes (out of ten homes upgrading insulation) where two homes had negative abatement costs for all energy cost and carbon price scenarios while one has had negative abatement costs for the high energy cost scenario with a carbon price increasing to $170/GJ. The payback period would be larger than 30 years with and without the carbon price therefore, the house will not recoup the project cost before the attic insulation needs to be upgraded.

Table 49: Summary of lifetime dollar savings analysis for attic insulation

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*		
1078	$404 $543	$477 $402	$251 $390	$560 $485	$133 $272	$624 $549	50+	
1082	$1,404 $1,885	$138 $63	$873 $1,353	$221 $146	$463 $943	$285 $210	32 50+	43 50+
1088	$416 $559	$911 $836	$259 $401	$993 $919	$137 $280	$1,057 $982	50+	
1094	$553 $742	$522 $447	$344 $533	$605 $530	$182 $371	$669 $594	47 50+	50+
1112	$2,287 $3,070	$53 ($22)	$1,422 $2,205	$135 $61	$754 $1,537	$199 $124	25 50+	29 50+
1113	$488 $655	$659 $584	$304 $471	$741 $666	$161 $328	$805 $730	50+	
1119	$968 $1,299	$149 $75	$602 $933	$232 $157	$319 $650	$296 $221	33 50+	46 50+
1135	$1,146 $1,538	$48 ($27)	$712 $1,104	$131 $56	$378 $770	$195 $120	24 50+	27 50+
1159	$3,446 $4,625	($915) ($1,372)	$2,142 $3,322	($410) ($867)	$1,136 $2,315	($20) ($477)	37 50+	50+
1165	$4,027 $5,406	($569) ($1,026)	$2,504 $3,882	($64) ($521)	$1,327 $2,706	$326 ($131)	50+	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.11 Rim Joist Insulation

Rim joist insulation reduces heat loss and three applicants increased the rim joist insulation. Table 50 and 51 shows the energy and GHG emission savings, respectively.

Table 50: HOT2000 modeled energy savings for rim joist insulation

House	Natural Gas Savings (GJ/yr)	Rim Joist Insulation Specifications
1082	0.3	Rim joist insulation increased to 3.17 RSI (100% of area)
1101	2.7	Rim joist insulation increased to 10.78 RSI (100% of area)
1113	0.5	Rim joist insulation increased to 4.22 RSI (100% of area)

Table 51: Total HOT2000 modeled GHG emissions savings for rim joist insulation

House	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
1082	0.3	0.01
1101	2.8	0.14
1113	0.5	0.03

Table 52 shows the summary of the lifetime dollar savings analysis (useful life of 20 years) and the full cost analysis is presented in Appendix D11 with and without carbon prices. Table 52 shows that rim joist insulation has cost savings ranging between $20 and $650. The abatement cost is positive indicating that houses will pay to decrease GHG emissions. The payback periods would be larger than 50 years with and without the carbon price therefore, the house will not recoup the project cost before the insulation must be upgraded.

Table 52: Summary of lifetime dollar savings analysis for rim joist insulation for 2022 ECCC grid

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*		
1082	$64 $85	$3,216 $3,190	$39 $61	$3,299 $3,224	$21 $43	$3,363 $3,288	50+	
1101	$615 $826	$551 $476	$383 $593	$634 $559	$203 $413	$698 $623		
1113	$118 $159	$2,690 $2,615	$74 $114	$2,773 $2,698	$39 $80	$2,836 $2,762		

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.12 Foundation Insulation

Foundation insulation reduces heat loss and two applicants increased the foundation insulation. Table 53 and 54 shows the energy and GHG emission savings, respectively.

Table 53: HOT2000 modeled energy savings for foundation insulation

House	Natural Gas Savings (GJ/yr)	Foundation Insulation Specifications
1100	9.5	17% of foundation insulation was increased to 3.52 RSI
1101	20	100% of foundation insulation was increased to 1.93 RSI

Table 54: Total HOT2000 modeled GHG emissions savings for foundation insulation

House	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
1100	10.0	0.50
1101	21.0	1.1

The lifetime dollar savings for foundation insulation is shown in Table 55 (useful life of 20 years) and the full cost analysis is presented in Appendix D12 with and without carbon prices. Table 55 shows that foundation insulation has cost savings ranging between $700 and $7,200 throughout the useful lifetime. The abatement cost is negative only for the energy cost scenario where the carbon price increases to $170/GJ and the high energy cost scenario where the carbon price stays at $65/GJ. The payback periods range between 0 and 50+ years with and without the carbon price therefore, the house has the possibility to recoup the project cost before the insulation must be upgraded.

Table 55: Summary of lifetime dollar savings analysis for foundation insulation for 2022 ECCC grid

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*		
1100	$2,180 $2,926	($61) ($136)	$1,355 $2,101	$22 ($53)	$719 $1,465	$85 $11	18 50+	21 50+
1101	$4,600 $6,174	$24 ($50)	$2,860 $4,434	$107 $32	$1,516 $3,090	$171 $96	0 40	0 50+

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.13 Windows

Windows reduces heat loss and is the top three building envelope upgrade completed in pilot CEIP. Ten applicants upgraded windows and Table 54 and 55 shows the energy and GHG emission savings, respectively.

Table 54: HOT2000 modeled energy savings for windows

House	Natural Gas Savings (GJ/yr)	Windows Specifications
1086	6.3	Upgrade 8 windows; wood/vinyl frame, triple, low-e 0.04 tint/coating, air/argon spacing
1089	3.7	Upgrade 14 windows; fiberglass frame, triple, low-e 0.04 tint/coating, argon spacing
1098	12.3	Upgrade 12 windows; reinforced vinyl frame, triple, low-e 0.04 tint/coating, air spacing
1100	28.2	Upgrade 20 windows; reinforced vinyl frame, triple, low-e 0.04 tint/coating, air spacing
1101	3.5	Upgrade 6 windows; vinyl frame, triple, low-e 0.04 tint/coating, argon spacing
1107	33.6	Upgrade 17 windows; reinforced vinyl/vinyl frame, triple, low-e 0.04 tint/coating, argon spacing
1110	57.8	Upgrade 20 windows; vinyl frame, triple, low-e 0.04 tint/coating, argon spacing
1119	1.9	Upgrade 8 windows; vinyl frame, triple, low-e 0.04 tint/coating, argon spacing
1135	1.7	Upgrade 8 windows; vinyl frame, triple, low-e 0.04 tint/coating, argon spacing
1140	1.4	Upgrade 15 windows; vinyl frame, triple, low-e 0.04 tint/coating, argon spacing

Table 55: Total HOT2000 modeled GHG emissions savings for windows

House	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
1086	5.0	0.33
1089	2.9	0.20
1098	9.7	0.65
1100	22.2	1.5
1101	2.8	0.18
1107	26.5	1.8
1110	45.6	3.0
1119	1.5	0.10
1135	1.4	0.09
1140	1.1	0.07

The lifetime dollar savings for windows are shown in Table 56 (useful life of 15 years) and the full cost analysis is presented in Appendix D13 with and without carbon prices. Table 56 shows that windows have cost savings ranging between $100 to $13,000 throughout the useful life.The abatement cost is positive indicating that houses will pay to decrease GHG emissions. The large dollar per tonne shows that windows have higher project costs, lower cost savings, and lower GHG emission reductions. Therefore, window retrofits require rebates to decrease project cost to decrease the dollar per tonne. The payback period would be larger than 50 years with and without the carbon price and therefore, the house will not recoup the project cost before the windows are likely to be replaced.

Table 56: Summary of lifetime dollar savings analysis for window

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$/$t_{CO2e}$*	Net Lifetime Dollar Savings*	$/$t_{CO2e}$*	Net Lifetime Dollar Savings*	$/$t_{CO2e}$*		
1086	$1,059 $1,433	$6,555 $6,480	$680 $1,054	$6,631 $6,556	$360 $735	$6,695 $6,620	50+	
1089	$623 $844	$5,752 $5,677	$400 $620	$5,828 $5,753	$212 $432	$5,892 $5,817		
1098	$2,051 $2,776	$1,485 $1,410	$1,317 $2,041	$1,561 $1,486	$698 $1,423	$1,625 $1,550		
1100	$4,709 $6,372	$1,102 $1,027	$3,022 $4,686	$1,177 $1,103	$1,602 $3,266	$1,241 $1,166		
1101	$583 $790	$1,132 $1,057	$375 $581	$1,208 $1,133	$199 $405	$1,272 $1,197		
1107	$5,614 $7,597	$811 $736	$3,603 $5,587	$887 $812	$1,911 $3,894	$950 $876		
1110	$9,656 $13,068	$538 $463	$6,198 $9,610	$614 $539	$3,286 $6,698	$677 $603		
1119	$315 $426	$6,818 $6,744	$202 $313	$6,894 $6,819	$107 $218	$6,958 $6,883		
1135	$1,074 $1,454	$7,966 $7,687	$690 $1,069	$8,249 $7,970	$366 $745	$8,487 $8,208		
1140	$858 $1,161	$13,452 $13,173	$551 $854	$13,735 $13,456	$292 $595	$13,974 $13,694		

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.14 Doors

Doors reduces heat loss and is the top three building envelope upgrade completed in pilot CEIP. Nine applicants upgraded doors and Table 57 and 58 shows the energy and GHG emission savings, respectively.

Table 57: HOT2000 modeled energy savings for doors

House	Natural Gas Savings (GJ/yr)	Doors Specifications
1082	0.4	Replaced 3 doors with steel medium density spray foam core
1086	4.4	Replaced 4 doors with steel medium density spray foam core
1089	0.01	Replaced patio door with steel medium density spray foam core
1098	0.4	Replaced 3 doors with steel medium density spray foam core
1100	0.03	Replaced side door: 1.18 RSI
1101	1.8	Replaced 2 doors: 0.98 RSI (1), 1.14 RSI (1)
1107	4.9	Replaced 4 doors: 1.08 RSI (1), 1.14 RSI (3)
1130	0.1	Replaced 1 door with steel medium density spray foam core
1140	2.4	Replaced 1 door with steel polystyrene core

Table 58: Total HOT2000 modeled GHG emissions savings for doors

House	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
1082	0.5	0.02
1086	4.6	0.23
1089	0.0	0.00
1098	0.4	0.02
1100	0.0	0.00
1101	1.9	0.09
1107	5.1	0.26
1130	0.1	0.01
1140	2.5	0.13

The lifetime dollar savings for doors is shown in Table 59 (useful life of 15 years) and the full cost analysis is presented in Appendix D14 with and without carbon prices. Table 59 shows that doors have cost savings ranging between $1 and $1,500. The abatement cost is positive indicating that houses will pay to decrease GHG emissions. The large dollar per tonne shows that doors need rebates to decrease the dollar per tonne. The payback period would be larger than 50 years with and without the carbon price and therefore, the house will not recoup the project cost before the doors are likely to be replaced.

Table 59: Summary of lifetime dollar savings analysis for door for 2022 ECCC grid

House	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
	$170 by 2030		$65					
	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*		
1082	$100 $134	$26,679 $26,604	$62 $96	$26,762 $26,687	$33 $67	$26,826 $26,751	50+	
1086	$1,007 $1,351	$1,153 $1,078	$626 $970	$1,235 $1,161	$332 $676	$1,299 $1,224		
1089	$2	$745,025 $744,950	$1 $2	$745,107 $745,033	$1	$745,171 $745,096		
1098	$82 $109	$25,618 $25,543	$51 $79	$25,700 $25,625	$27 $55	$25,764 $25,689		
1100	$7 $9	$141,384 $141,309	$4 $7	$141,466 $141,392	$2 $5	$141,530 $141,455		
1101	$409 $549	$2,250 $2,175	$254 $395	$2,332 $2,257	$135 $275	$2,396 $2,321		
1107	$1,120 $1,503	$3,173 $3,098	$696 $1,080	$3,256 $3,181	$369 $752	$3,320 $3,245		
1130	$29 $39	$16,090 $16,015	$18 $28	$16,173 $16,098	$10 $20	$16,237 $16,162		
1140	$548 $735	$906 $831	$340 $528	$989 $914	$180 $368	$1,053 $978		

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.15 Heat Recovery Ventilators (HRV)

Modern houses are relatively air tight and often need forced air exchange to ensure enough fresh air enters an occupied house. A heat recovery ventilator is an air-to-air heat exchanger that pre-warms inlet fresh air with air that is being exhausted. Purely from an energy point of view an HRV in isolation requires electricity to operate to exhausts warm air despite being necessary to enable air tight homes. HRVs are often combined with an improvement in leakage, so combined with air sealing and insulation they are a net energy savings, however when considered in isolation, they are energy consuming devices. Table 60 and 61 shows the energy and GHG emission impacts of an HRV that was added as part of the CEIP pilot.

Table 60: HOT2000 modeled energy savings for HRV

House	Electricity Savings (kWh/yr)	HRV Specifications
1078	(256)	28 L/s with 82% efficiency

Table 61: Total HOT2000 modeled GHG emissions savings for HRV

House	Lifetime (t_{CO2e})			Annual (t_{CO2e}/year)		
	Net Zero	2022 ECCC	TIER	Net Zero	2022 ECCC	TIER
1078	(0.6)	(0.8)	(1.2)	0.0	(0.1)	(0.1)

The increase in lifetime dollars for HRVs are shown in Table 62 (useful life of 18 years) with the full cost analysis presented in Appendix D15 with and without carbon prices. As discussed above, HRVs increase electricity consumption and therefore the table shows that there are no cost savings. The abatement cost is positive indicating that houses will pay to decrease GHG emissions, and there is no payback period as there is no cost savings.

Table 62: Summary of lifetime dollar savings analysis for solar PV systems

House	Net Lifetime Dollar Savings*	$/$t_{CO2}$ Net Zero	$/$t_{CO2}$ 2022 ECCC	$/$t_{CO2}$TIER	SPP (yr)	DPP (yr)
1078	($513) ($744)	$4,276 $3,871	$2,924 $2,646	$2,036 $1,843	n/a	n/a

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

4.4.16 Upgrades Not Modeled

Smart thermostats, other air sealing, lighting controls, pipe insulation, and battery storage energy savings were completed but not included in the above analysis as the energy savings for the upgrades are smaller in comparison to the upgrades discussed above or depend on homeowners behavior where the assumptions were not given by contractors. Instead, the energy savings for the upgrades not modeled were estimated through literature review and assumptions and are discussed below.

4.4.16.1 Thermostats

Two houses (1118 and 1119) have installed Google Nest smart thermostats and Ecobee thermostats. Thermostats or thermostat settings can not be modeled in HOT2000, and are very dependent on the occupants' personal settings. Google Nest has completed an analysis of the Google Nest programmable thermostat to determine the energy decrease of a house after the thermostat was installed, looking at the homes utility bills before and after the installation [37]. There were three studies done to determine the energy savings associated with installing a Google Nest [37]. One study was done in Oregon for 185 homes that had the Google Nest thermostat and heat pumps for space heating in 2014 [37]. The study found that there was a 12% or 781 kWh/year average electricity consumption decrease [37]. Another study was done in Indiana in 2015 where 300 homes installed a Google Nest thermostat and 300 homes installed a Honeywell programmable thermostat [37]. The study found that the homes that installed a Google Nest thermostat saw a 12.5% (±1.5%) average natural gas decrease and a 13.9% (±5%) or 429 kWh/year average electricity decrease [37]. The third study was done by Google Nest with 735 homes in 36 states used for the natural gas savings and 624 homes in 39 states for the electricity savings [37]. All houses have an installed central A/C and gas heating [37]. The study found that for houses that had one thermostat there was a 11% average natural gas decrease and a 15.5% HVAC electricity decrease [37]. For the entire sample size where 25% of homes for the electricity analysis and 19% of homes for the natural gas analysis had two or more thermostats, there was a 9.6% (±2.1%) average natural gas decrease and a 17.5% (±2.9%) average HVAC electricity decrease [37]. While it is not clear if these savings would translate directly to Edmonton they give an estimate that savings could be on the order of 10%, but will vary based on occupants behavior and the house and the systems in it [37].

4.4.16.2 Other Air Sealing

One house (1112) has done "other air sealing" where they have installed adhesive weather stripping to the attic hatch. The decrease in heat loss can be calculated using the assumptions below and the heat loss equation specified in Appendix C. With this, the estimated decrease in heat loss is 46 btu/hr (4.9×10^{-5} GJ/hr).

1. The attic hatch is a solid wood door with a thermal resistance of 0.39 RSI (this is the thermal resistance for a solid wood door in HOT2000). The door was insulated with R-40 (or 7.04 RSI) for a change in thermal resistance of 6.65 RSI;
2. The attic hatch has an area of 3 m^2 based on the 2019 Alberta Building Code stating that attic access areas must be 3 m^2 or larger [38]; and

3. Heat moves from the room that the attic hatch (t_i) is located into the attic (t_a). The room that the attic hatch is located in is assumed to have a constant temperature of 20℃ (68℉). This is based on the models created by the authors daytime heating setpoint for the main floor and assuming that temperature is maintained on the second floor. Usually, attic spaces are 20℃ (68℉) for colder climates and was assumed to be temperature during winter (Nov-Mar), resulting in no heat loss [39]. Attic spaces are usually 10-20℉ higher than outdoor temperatures in warmer climates and therefore during Apr-Nov, the assumption is that the attic space is an average of 15℉ higher than outdoor temperatures used in HOT2000 resulting in temperatures ranging between 8-26℃ [39].

4.4.16.3 Battery Storage

Two houses (1075 and 1088) have installed a 13.5 kWh Tesla powerwall and backup gateway system (battery storage) used to store excess solar energy from its newly installed solar PV system. Any change to energy consumption would be highly dependent on whether the homeowner chose to operate their battery simply as a backup system or more actively to store solar energy. In either case, batteries have relatively high round-trip efficiencies, and would have a small change in net electricity consumption. There would be no emissions savings associated with a battery, as any solar electricity that is generated is fully credited with grid emissions savings, and the RUR does not recommend this upgrade, so it was excluded in the above analysis.

4.4.16.4 Pipe Insulation

Seven houses have completed pipe insulation for hot water heaters, boilers, and furnaces to reduce heat loss and can be calculated using the heat loss equation shown in Appendix C. Pipe insulation savings is very small, as half of the year, any energy that is lost from hot water pipes is radiated into the home that is otherwise being warmed and therefore was negligible and excluded from the analysis.

4.4.16.5 Lighting Controls

Three houses (1074, 1090 and 1104) have installed lighting controls which are based on occupant behavior. The estimated energy savings for lighting controls estimated by AM for CEIP is 0.11 GJ/year/lighting control [40].

4.4.17 Average Savings

To compare the energy, GHG emission, and cost savings for all modeled upgrades, Tables 63-66 shows the average GHG emission reduction for natural gas and electric upgrades, energy savings, and cost savings, respectively.

Table 63: GHG emission reductions for natural gas upgrades

Upgrade	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
Furnace	11.2	0.7
Drain Water Heat Recovery	3.0	0.2
Boiler*	30.3	1.2
Tankless Gas Water Heater	5.6	0.4
Attic Insulation	4.1	0.2
Rim Joist Insulation	1.7	0.1
Foundation Insulation	15.5	0.8
Windows	11.9	0.8
Doors	1.7	0.1

*Savings based on one house

Table 64: GHG emission reductions for electric upgrades

Upgrades	Net Zero (t_{CO2e})		2022 ECCC Forecast (t_{CO2e})		TIER (t_{CO2e})	
	Lifetime	Annual	Lifetime	Annual	Lifetime	Annual
Air Source Heat Pump	37.0	2.3	28.9	2.6	18.5	1.2
Ground Source Heat Pump*	52.8	3.3	48.4	3.0	42.4	2.7
Solar PV System	16.5	0.66	35.6	1.4	49.0	2.0
Solar PV System (exports)	4.8	0.2	10.4	0.4	14.4	0.6
Lighting	0.4	0.0	0.6	0.0	0.9	0.1
Heat Pump Water Heater	11.0	0.7	9.9	0.7	8.3	0.6
HRV*	(0.6)	0.0	(0.8)	(0.1)	(1.2)	(0.1)

*Savings based on one house

The average energy savings for upgrades shown in Table 65 was compared to the March 2023 CEIP target energy savings per household for the modeled upgrades with different energy savings specifications resulting in different energy savings per year. It is a very small sample of upgrades that were completed in the pilot and as a result is difficult to extrapolate too far, nonetheless ASHPs, GSHPs, and attic insulation upgrades were notably below CEIP targets, while most of the other upgrades were close.

Table 65: Average total energy savings for installed upgrades

Upgrade	Pilot Energy Savings (GJ/yr)	CEIP Target Savings (GJ/yr) [40]	Specifications
Air Source Heat Pump	37.6	68.2	- 3.47 GJ/kBTU/hr of natural gas consumption and 323.19 kWh/kBTU/hr of electricity consumption - Replacing gas furnace to cover 100% of heat load
Ground Source Heat Pump	58.6*	74.6	- 3.69 GJ/kBTU/hr of natural gas consumption and 323.19 kWh/kBTU/hr of electricity consumption - Replacing gas furnace to cover 100% of heat load
High Efficiency Boiler	23.0*	9.5	- Heating savings of 0.32 GJ/kBTU/hr
High Efficiency Furnace	13.3	10.3	- Heating savings of 0.35 GJ/kBTU/hr
Solar PV System	35.1 (8.0 GJ is from exports)	4.6	- System produces 1276 kWh/kW of solar panels - Savings is the amount of electricity consumption covered by panels
Lighting Fixtures	0.68	0.1 GJ/control 0.06 GJ/ fixture	
Drain Water Heat Recovery	2.9	1.6/DWHR pipe	- Based on ThermoDrain TD338B specifications
Heat Pump Water Heater	17.2	4.7/heat pump	- Average household of 2.4 people
Tankless Gas Water Heater	8.1	2.7/heater	- Average household of 2.4 people
Attic Insulation	3.9	7.6	- 0.01 GJ/sq ft of insulation - Existing insulation is R10 - 1,500 sq ft home
Rim Joist Insulation	1.2	1.5	- 0.01 GJ/sq ft of insulation - Existing insulation is R8 - 1,500 sq ft home
Foundation Insulation	14.7	14.3	- 0.02 GJ/sq ft of insulation - Existing insulation is R5 - 1,500 sq ft home
Windows	15.0	0.06 GJ/ft^2 of window	
Doors	1.6	0.4	- 0.02 GJ/ sq ft of door - Existing door U value of 2.8 - New door U value of 1.6
HRV	(0.9)*	2.3	- Installed with system to improve airtightness

*Savings based on one house

Table 66: Installed and abatement costs for upgrades on 2022 ECCC grid

Upgrade	Project Cost	Including Carbon Price				Without Carbon Price		SPP‡ (yr)	DPP‡ (yr)
		$170 by 2030		$65					
		Net Lifetime Dollar Savings	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings	$\$/t_{CO2e}$*		
Air Source Heat Pump (Replacement)	$14,401	($3,590) ($6,305)	$697 $800	($7,672) ($10,387)	$842 $945	($11,033) ($13,748)	$961 $1,064	50+	
Air Source Heat Pump (Incremental)	$11,170		$574 $678		$719 $822		$838 $942	-	
Ground Source Heat Pump ** (Replacement)	$49,242	$4,232 $4,827	$930 $917	($589) $7	$1,029 $1,017	($4,558) ($3,963)	$1,111 $1,099	50+	
Ground Source Heat Pump (Incremental)	$48,242		$909 $897		$1,008 $996		$1,090 $1,078	-	
Boiler (Replacement)**	$19,062	$6,743 $9,008	$407 $332	$4,114 $6,379	$494 $419	$2,181 $4,446	$558 $483	50+	
Boiler (Incremental)	$16,862		$334 $260		$421 $346		$485 $410	-	
Furnace (Replacement)	$10,063	$2,385 $3,221	$1,825 $1,751	$1,519 $2,354	$1,903 $1,828	$805 $1,641	$1,967 $1,892	20 50+	23 50+
Furnace (Incremental)	$8,313		$1,448 $1,373		$1,526 $1,451		$1,590 $1,515	-	
Drain Water Heat Recovery	$2,222	$663 $890	$516 $441	$412 $639	$599 $524	$219 $445	$663 $588	42 50+	50+
Heat Pump Water Heater (Replacement)	$5,699	$792 $874	$516 $508	($235) ($154)	$622 $614	($1,100) ($1,019)	$710 $702	50+	
Heat Pump Water Heater (Incremental)	$4,189		$357 $349		$462 $455		$551 $543	-	
Tankless Gas Water Heater	$5,460	$1,156 $1,573	$781 $706	$757 $1,174	$853 $778	$402 $818	$916 $842	39 50+	50+

(Replacement)									
Tankless Gas Water Heater (Incremental Cost)	$3,918		$498 $423		$570 $495		$634 $559	-	
Attic Insulation	$1,882	$1,514 $2,032	$147 ($4)	$941 $1,459	$314 $163	$499 $1,017	$444 $292	24 50+	27 50+
Rim Joist Insulation	$1,579	$199 $268	$2,152 $2,078	$124 $192	$2,235 $2,160	$66 $134	$2,160 $2,299	50+	
Foundation Insulation	$3,342	$3,390 $4,550	($18) ($93)	$2,107 $3,268	$64 ($10)	$1,117 $2,278	$128 $53	1 50+	
Windows	$19,979	$2,654 $3,592	$4,561 $4,445	$1,704 $2,642	$4,678 $4,563	$903 $1,841	$4,777 $4,661	50+	
Doors	$7,273	$367 $493	$106,920 $106,845	$228 $354	$107,002 $106,928	$121 $247	$107,066 $106,991	50+	

Upgrade	**Project Cost**	**Net Zero Scenario**		**2022 ECCC Scenario**		**TIER Scenario**		**SPP (yr)‡**	
		Net Lifetime Dollar Savings	**$/t$_{CO2e}$***	**Net Lifetime Dollar Savings**	**$/t$_{CO2e}$***	**Net Lifetime Dollar Savings**	**$/t$_{CO2e}$ ***		
Solar PV (self-consumption)	$25,997	$28,477 $41,256	($35) ($632)	$28,477 $41,256	($16) ($292)	$28,477 $41,256	($12) ($212)	0 50+	
Lighting Fixtures	$502	$365 $529	$2,412 $2,407	$365 $529	$1,428 $1,179	$365 $529	$1,144 $976	0 50+	
HRV**	$2,943	($513) ($744)	$4,276 $3,871	($513) ($744)	$2,924 $2,646	($513) ($744)	$2,036 $1,843	-	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario
**Savings based on one house
‡ SPP and DPP is the range of payback periods for all scenarios

4.5 Houses as a Whole Analysis 2023-2050

This section examines energy, GHG emissions, and dollar savings for the 27 houses with completed upgrades for the 2023-2050 timeframe where the homes were modeled with all completed retrofits done in CEIP. For houses that have installed solar PV systems, the contractor's solar production value was used. Table 67 shows the percent energy decrease for the houses where 3 houses reached deep retrofits equating to 50% or more total energy decrease. Table 68-72 shows the GHG emissions, project costs (excluding rebates and energy cost savings), lifetime dollar savings (excluding project costs and rebates), and dollar per tonnes for each house assuming the full project cost for the space heating and water systems and that retrofits are replaced once during the timeframe and excluding rebates.

Table 67: Energy consumption reductions for participating houses

House	Electricity Savings	Natural Gas Savings	Energy Savings	House	Electricity Savings	Natural Gas Savings	Energy Savings
1074	230%	0%	44%	**1110**	-89%	77%	56%
1075	131%	10%	40%	**1112**	126%	7%	28%
1078	140%	23%	45%	**1113**	133%	2%	26%
1082	81%	5%	17%	**1115**	100%	100%	100%
1086	46%	7%	13%	**1118**	-80%	58%	27%
1088	132%	2%	35%	**1119**	-1%	34%	19%
1089	109%	4%	18%	**1130**	0%	8%	6%
1090	115%	0%	34%	**1131**	-14%	80%	59%
1094	105%	7%	34%	**1135**	0%	13%	11%
1098	0%	31%	27%	**1140**	0%	18%	15%
1100	3%	19%	17%	**1141**	132%	18%	39%
1101	2%	21%	18%	**1159**	-11%	28%	21%
1104	84%	0%	23%	**1165**	-106%	77%	31%
1107	2%	17%	15%	**Average**	**51%**	**25%**	**30%**

Table 68: GHG emission reductions for participating houses on 2022 ECCC electricity grid

House	Lifetime (t_{CO2e})	Annual (t_{CO2e})	Lifetime (% decrease)	House	Lifetime (t_{CO2e})	Annual (t_{CO2e})	Lifetime (% decrease)
1074	106.2	3.8	45%	**1110**	174.0	6.2	55%
1075	73.0	2.6	41%	**1112**	79.8	2.9	28%
1078	111.8	4.0	46%	**1113**	60.2	2.2	27%
1082	42.4	1.5	17%	**1115**	203.9	7.3	100%
1086	36.0	1.3	13%	**1118**	46.8	1.7	26%
1088	78.1	2.8	36%	**1119**	34.0	1.2	19%
1089	58.3	2.1	18%	**1130**	12.2	0.4	6%
1090	49.9	1.8	35%	**1131**	108.1	3.9	59%
1094	56.0	2.0	35%	**1135**	21.1	0.8	10%
1098	75.0	2.7	27%	**1140**	39.7	1.4	15%
1100	58.4	2.1	17%	**1141**	86.5	3.1	40%
1101	44.1	1.6	18%	**1159**	47.1	1.7	20%
1104	34.7	1.2	24%	**1165**	52.4	1.9	45%
1107	58.7	2.1	15%	**Average**	**68.5**	**2.4**	**31%**

Table 69: Energy cost savings for low energy cost scenario

House	Project Cost	$170 by 2030	$65	No carbon price	House	Project Cost	$170 by 2030	$65	No carbon price
1074	$93,367	$70,303	$70,303	$70,304	**1110**	$103,445	$21,629	$2,852	($10,712)
1075	$108,889	$43,503	$42,277	$41,391	**1112**	$57,873	$47,391	$46,029	$45,045
1078	$88,624	$60,462	$56,383	$53,437	**1113**	$55,766	$38,983	$38,587	$38,301
1082	$68,949	$24,153	$23,227	$22,558	**1115**	$192,783	$75,388	$60,979	$50,571
1086	$126,556	$17,117	$15,677	$14,636	**1118**	$47,653	($4,505)	($11,562)	($16,660)
1088	$100,000	$51,543	$51,216	$50,979	**1119**	$63,665	$7,269	$4,184	$1,956
1089	$110,559	$34,405	$33,406	$32,685	**1130**	$17,057	$2,676	$1,588	$802
1090	$51,811	$33,542	$33,522	$33,507	**1131**	$87,465	$21,579	$11,486	$4,196
1094	$48,138	$34,366	$33,625	$33,089	**1135**	$37,421	$4,746	$2,873	$1,520
1098	$91,605	$16,943	$10,317	$5,530	**1140**	$51,686	$8,913	$5,399	$2,861
1100	$70,421	$13,617	$8,547	$4,885	**1141**	$88,658	$44,532	$41,732	$39,710
1101	$34,083	$10,278	$6,440	$3,668	**1159**	$40,428	$8,243	$3,622	$283
1104	$35,249	$23,522	$23,492	$23,471	**1165**	$49,098	($10,960)	($20,001)	($26,532)
1107	$104,000	$13,614	$8,499	$4,804	**Average**	**$75,009**	**$26,417**	**$22,396**	**$19,492**

Table 70: Dollar per tonnes on 2022 ECCC electricity grid for low energy cost scenario

House	$170 by 2030	$65	No carbon price	House	$170 by 2030	$65	No carbon price
1074	$217	$217	$217	**1110**	$470	$578	$656
1075	$895	$912	$924	**1112**	$131	$148	$161
1078	$252	$288	$315	**1113**	$279	$285	$290
1082	$1,056	$1,078	$1,093	**1115**	$576	$646	$697
1086	$3,039	$3,079	$3,108	**1118**	$1,113	$1,264	$1,373
1088	$621	$625	$628	**1119**	$1,657	$1,748	$1,814
1089	$1,306	$1,323	$1,335	**1130**	$1,182	$1,272	$1,336
1090	$366	$366	$367	**1131**	$610	$703	$770
1094	$246	$259	$269	**1135**	$1,545	$1,634	$1,698
1098	$995	$1,083	$1,147	**1140**	$1,078	$1,166	$1,230
1100	$973	$1,060	$1,123	**1141**	$510	$543	$566
1101	$539	$626	$689	**1159**	$683	$782	$852
1104	$338	$339	$339	**1165**	$1,146	$1,319	$1,443
1107	$1,539	$1,627	$1,690	**Average**	**$828**	**$887**	**$930**

Table 71: Energy cost savings for high energy cost scenario

House	Project Cost	$170 by 2030 ($\$/t_{CO2e}$)	$65 ($\$/t_{CO2e}$)	No carbon price ($\$/t_{CO2e}$)	House	Project Cost	$170 by 2030 ($\$/t_{CO2e}$)	$65 ($\$/t_{CO2e}$)	No carbon price ($\$/t_{CO2e}$)
1074	$93,367	$101,852	$101,853	$101,853	**1110**	$103,445	$25,850	$7,072	($6,492)
1075	$108,889	$62,668	$61,442	$60,556	**1112**	$57,873	$68,261	$66,898	$65,914
1078	$88,624	$86,403	$82,325	$79,378	**1113**	$55,766	$56,361	$55,966	$55,680
1082	$68,949	$34,721	$33,795	$33,127	**1115**	$192,783	$105,010	$90,601	$80,192
1086	$126,556	$24,378	$22,937	$21,897	**1118**	$47,653	($8,589)	($15,646)	($20,744)
1088	$100,000	$74,579	$74,251	$74,014	**1119**	$63,665	$9,630	$6,545	$4,317
1089	$110,559	$49,553	$48,554	$47,833	**1130**	$17,057	$3,559	$2,471	$1,685
1090	$51,811	$48,589	$48,568	$48,553	**1131**	$87,465	$28,315	$18,222	$10,931
1094	$48,138	$49,572	$48,831	$48,295	**1135**	$37,421	$6,328	$4,456	$3,103
1098	$91,605	$22,611	$15,984	$11,198	**1140**	$51,686	$11,887	$8,373	$5,834
1100	$70,421	$18,246	$13,177	$9,515	**1141**	$88,658	$63,698	$60,899	$58,877
1101	$34,083	$13,770	$9,932	$7,159	**1159**	$40,428	$10,592	$5,971	$2,632
1104	$35,249	$34,069	$34,040	$34,018	**1165**	$49,098	($18,520)	($27,561)	($34,092)
1107	$104,000	$18,230	$8,499	$9,419	**Average**	**$75,009**	**$37,097**	**$33,077**	**$30,172**

Table 72: Abatement costs assuming the 2022 ECCC electricity grid for high energy cost scenario

House	$170 by 2030	$65	No carbon price	House	$170 by 2030	$65	No carbon price
1074	($80)	($80)	($80)	**1110**	$446	$554	$632
1075	$633	$650	$662	**1112**	($130)	($113)	($101)
1078	$20	$56	$83	**1113**	($10)	($3)	$1
1082	$807	$828	$844	**1115**	$430	$501	$552
1086	$2,837	$2,877	$2,906	**1118**	$1,201	$1,351	$1,460
1088	$326	$330	$333	**1119**	$1,588	$1,679	$1,744
1089	$1,046	$1,063	$1,076	**1130**	$1,110	$1,199	$1,264
1090	$65	$65	$65	**1131**	$547	$641	$708
1094	($26)	($12)	($3)	**1135**	$1,470	$1,559	$1,623
1098	$919	$1,008	$1,071	**1140**	$1,003	$1,091	$1,155
1100	$894	$981	$1,043	**1141**	$289	$321	$344
1101	$460	$547	$610	**1159**	$634	$732	$803
1104	$34	$35	$35	**1165**	$1,290	$1,463	$1,587
1107	$1,461	$1,548	$1,611	**Average**	**$660**	**$719**	**$762**

Figure 8-9 shows the average abatement cost based on the decade of construction for the low and high energy cost scenarios, respectively. In the literature review, it was concluded that 2011-2020 homes had the lowest energy consumption however, homes built between 1991 and 2000 had the lowest abatement cost. Homes built between 1931 and 1940 had the highest energy consumption and abatement cost.

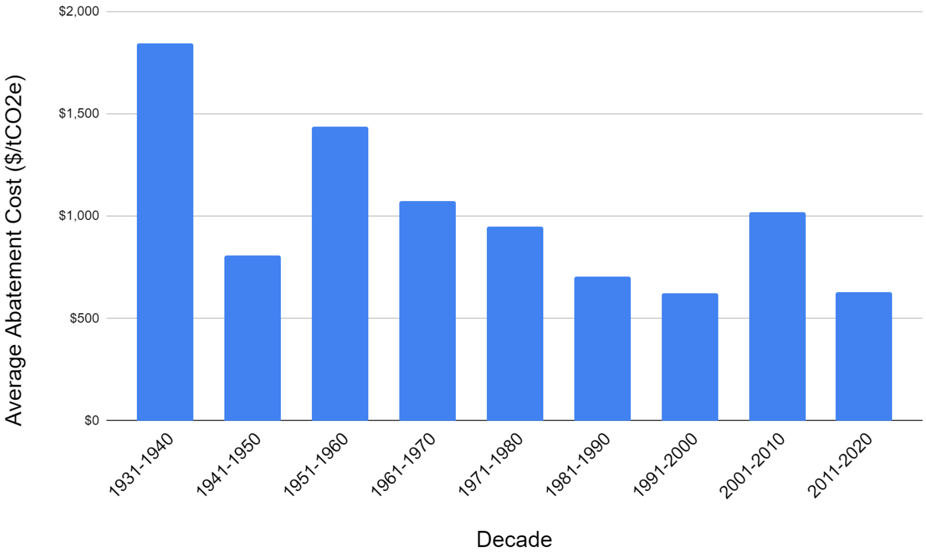

Figure 8: Average abatement cost for low energy cost scenario and three carbon price scenarios within "House as a Whole" analysis based on decade of construction

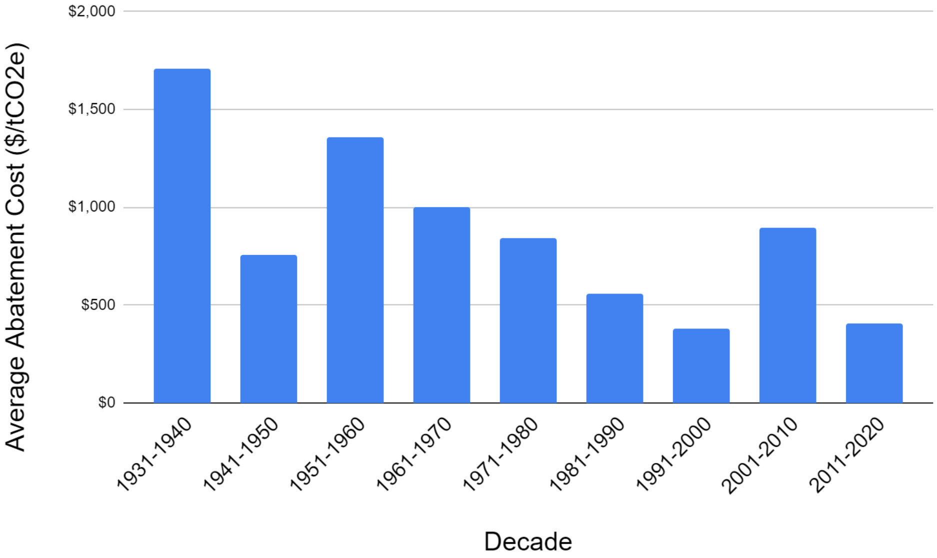

Figure 9: Average abatement cost for high energy cost scenario and three carbon price scenarios within "House as a Whole" analysis based on decade of construction

5.0 Advice, Recommendations, and Risks

This report considers upgrades from a fairly small sample size of 27 houses. It is also a reasonable inference that those participating in the CEIP pilot program are likely skewed towards “early adopters” and their results may not be fully representative of the broader community. Nonetheless, on average the homes who took part in the CEIP program consumed on average within 5% of both average electricity and natural gas for houses in Edmonton (based on the review of 4,104 EnerGuide audits completed in the City) prior to any CEIP upgrades as illustrated below (where 0,0 represents 8,000 kWh of annual electricity consumption 130 GJ of natural gas.

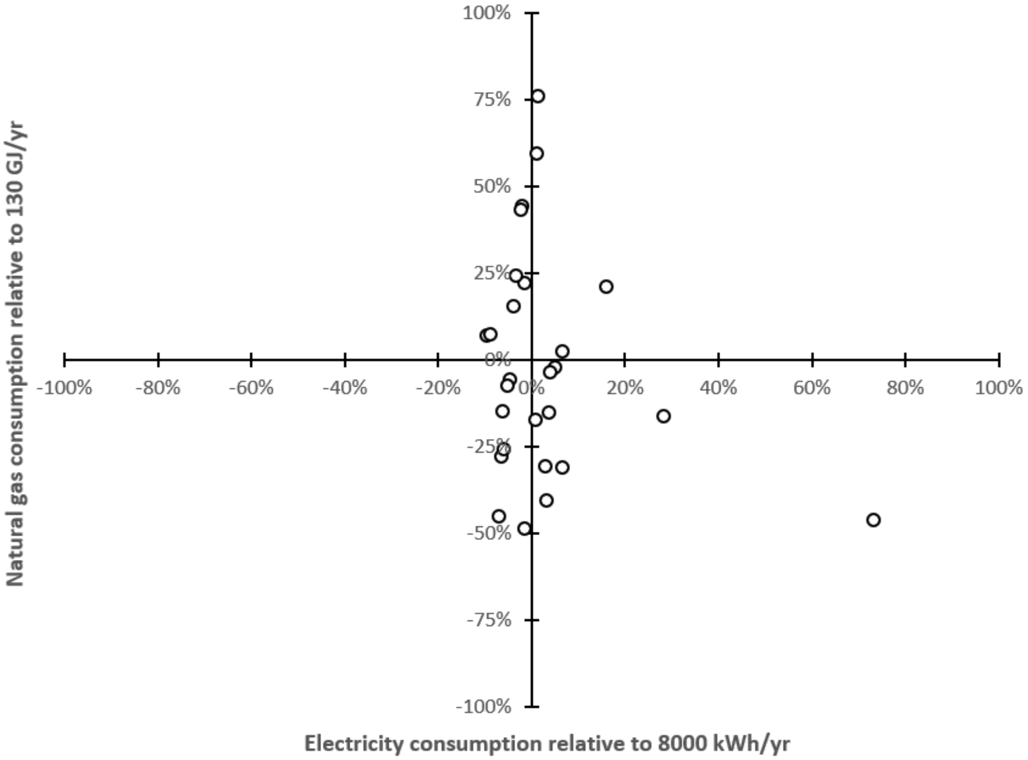

Figure 1: Energy consumption of participating homes prior to CEIP upgrades relative to typical levels of residential electricity (8,000 kWh/yr) and natural gas (130 GJ/yr) consumption in Edmonton

On average, completed upgrades are expected to reduce houses energy consumption by an average of 30% (note this includes exported solar, which counts as negative consumption), reducing typical GHG emissions by 31% (from 8 tCO2e/yr before the upgrades to 6 t_{CO2e}/yr after) as seen in Table 69 and 70.

Some important areas to consider for future programs include the high likelihood that Alberta's electricity system will continue to decarbonize, uncertain future of the federal carbon price, as well as recognizing the energy gap, or models' tendency to overestimate actual long-term energy savings (possibly due in part to what is known as the 'rebound effect'). Some considerations for next steps are discussed below.

1. If 30% energy savings were maintained into a full program, it would put the CEIP program among the more aggressive savings targeted by government programs. While deep retrofits (resulting in energy consumption decreases of more than 50%) were not always achieved, the results indicate it is possible to achieve with export from solar PV systems and electrifying space heating. Houses that aimed to achieve a 50% or more energy savings had project costs (excluding energy cost savings and rebates) of more than $100,000 by 2050. Furthermore, fuel switching devices such as heat pumps and/or electrification of water heating may not have as large energy savings but can result in emissions reductions as the electricity grid's emissions intensity improves.
2. Part of the CoE's plans to decrease GHG emissions in residential buildings by 2050 assumes that homes will decrease electricity consumption by means other than lighting or solar PV systems [41]. The current upgrades eligible in CEIP are largely unlikely to facilitate this assumption. In fact the majority of upgrades targeted natural gas consumption, however, given the likely decarbonization of Alberta's grid, the emphasis on gas is appropriate.
3. The energy gap between estimated and actual energy savings should be monitored accounting for major energy consumption changes like occupancy changes, weather, and occupant behaviours. Many studies suggest the gap could be due to overestimating energy savings and/or changes to behavioral patterns of homeowners after upgrades have been completed [15], [17], [42]. As well, cost of retrofits completed in the full program along with estimated energy use and energy cost savings should be collected and shared publicly, providing additional information to homeowners deciding to complete retrofits. There is no publicly available data specific to Edmonton however, the ongoing relationship with homeowners through CEIP repayments presents an opportunity for long-term data gathering to help future programs and policies both inside Edmonton, and Alberta more broadly. Further, actively reporting energy consumption can keep home owners engaged in their energy patterns.

4. The changing nature of both the grid emissions intensity and the carbon price means that future upgrades may have notably different results. The results presented in this work consider average savings starting in 2023, however, an upgrade that is undertaken starting in 2026 is more likely to experience a higher cost of carbon, and therefore have improved financial viability. In fact, some upgrades began to show positive cash flows in later years even though their averages were still low. On the other hand, solar PV systems are likely to displace fewer and fewer emissions in the future as the electricity grid decarbonizes. Most solar systems were found to be larger than historic levels of electricity consumption, meaning that homeowners might have intentionally planned on further electrification potentially considering electric vehicles. This would increase GHG emission savings. For example, 1074 installed a solar PV system and lighting where it reduced 44% of energy consumption , cost around $93,000, reducing 106 t_{CO2e} and saving $70,000-$102,000 depending on the energy cost and carbon price scenario between 2023 and 2050 assuming the retrofits were replaced once. 1115 achieved net zero where a heat pump water heater, ground source heat pump, and solar PV were installed in the program costing $200,000, reducing 204 t_{CO2e} and saving $50,000-$105,000 depending on the energy cost and carbon price scenario between 2023 and 2050 assuming the retrofits were replaced once. Between the two homes, the energy consumption reduction was 56% higher in 1115 and the GHG emission reduction was 48% higher in 1115.
5. On average the cost of emissions reductions was found to be relatively high (over $1,000/$t_{CO2e}$ over and above the $170/$t_{CO2e}$ carbon price excluding doors). This should not necessarily be surprising as the program targeted more aggressive retrofits, and in several cases, homeowners had already performed other efficiency upgrades either prior to, or in conjunction with CEIP. Many highly cost effective upgrades should be expected to be made without any governmental support. Upgrades' cost effectiveness can be impacted by the spread between energy costs (i.e. currently relatively high electricity prices), the assumed system lifetimes as well as the interaction of upgrades reducing marginal savings. As a result, the relatively high cost per tonne of emissions savings for a small sample size should not be over-interpreted, although it should be monitored as CEIP evolves. Early adopters' willingness to undertake higher relative cost upgrades may help reduce labor and other 'soft costs' lowering future prices, although it is unlikely the majority of homeowners want (or be able) to undertake upgrades that are not cost effective. Additional scenarios should be considered when evaluating emissions reduction costs in the future including different relative and absolute energy costs, learning curves and useful working lives for technologies as the program evolves, and what future energy costs homeowners are anticipating.

6. Adoption rates for the full program should not be expected to be linear. A study on outreach for home energy assessments in Maine found that 45% of participants heard about the program through word of mouth and only 13% through advertisement [43]. It is likely that uptake of a full CEIP program will diffuse more through existing participants than advertising. This may mean slower uptake in the near term, but could accelerate quickly as critical mass is achieved. Rates of uptake should be monitored in the future and be wary of linear projections when forecasting budgets.
7. Explore increasing participation of low income homeowners (single family homes) to the program. It has been noted that low income homeowners spend more of their income on energy costs and have a higher cost of energy per square footage of home [44]. Focusing on installing energy efficient appliances (if offered by the full-scale program); decreasing the up front costs of the upgrades; advertising the program to low income homeowners (explaining how they can participate); and providing coaching assistance for the application and finding contractors, could increase participation [44]. One option to attract low income homeowners is adopting a more strict interpretation of "pay as you save" strategy where upgrades are prioritized to be net financial savings such that amortized costs are lower than the savings [45]. A contract for differences type approach could be taken for low income homes to ensure this is the case rather than direct rebates. Based on this final report results, solar PV, lighting fixtures, and foundation insulation are cost effective and cost saving upgrades while GSHPs, ASHPs, and solar PV are energy and GHG emission saving upgrades that could be recommended to low income homeowners. Solar PV systems should be the top recommendation as homeowners can profit on exporting electricity. This could motivate homeowners to spend more on upgrades and install expensive upgrades (like heat pumps) to further decrease energy costs and emissions while using the exported earnings to pay for the upgrades. Another option for attracting low income homeowners is to eliminate the interest rate on the project costs as Calgary CEIP intends to do.
8. Low and non-low income Multi Unit Residential Buildings (MURB) homeowners should be included in the program and require further investigation on how these buildings can be included. There is a possibility to identify MURBs as commercial buildings instead of residential buildings [46]. An example of MURBs completing energy efficiency retrofits are shown in a case study done on four MURB's in Toronto including two rentals and two freehold condos [47].
9. Diffusion of Innovation Model

a. One can assume that the CEIP pilot is currently filled with applicants in the “innovators” section of the Diffusion of Innovation Model seen in Figure 6 [48], [49]. Innovators are individuals who try new programs and take risks.
b. As the full scale program is established and launched, applicants will be from the early adopters - late majority section of this model. Early adopters are individuals who like to try new things while the early majority are individuals who make a way for the new program to become a part of society [48]. Late majority are individuals who follow the path of the early majority [48]. This means applicants to the pilot program were more likely to have been aware of efficiency benefits and CoE programs and have been willing to accept more perceived risk than later program adopters.
c. As the full scale program becomes more established, applicants will be laggards who are individuals who will be forced to use the program due to them trying to avoid risk [48].
d. A full-scale program will need to consider adaptive measures in later years to reach later adopters, this may include collecting and publishing success stories, more active advertising and adapting to implementation challenges experienced by those already in the program.

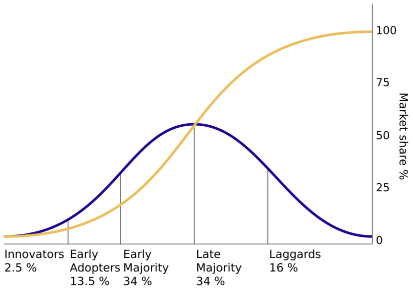

Figure 10: Diffusion of Innovation Model [49]

5.1 Full Scale Program Focus and Design

Future natural gas and electricity prices including carbon prices are hard to predict due to changing political policies and targets for climate change. Depending on the focus of the program, the recommended upgrades within the program will need to change with the changing electricity grid scenarios and carbon prices in order to meet program targets. This may result in the program ensuring that most applicants complete the recommended upgrades to meet program targets. This section will discuss how the full scale CEIP launching in 2024 could be redesigned for a focus on energy efficiency, GHG emission reductions, and cost savings for homeowners, or net zero for a 2022 ECCC electricity grid and the two energy cost scenarios including carbon price:

- Energy efficiency: the focus is reducing energy consumption and increasing energy efficiency of the home
- GHG emission reductions: the focus is to reduce annual GHG emissions of the home using the forecasted decarbonizing electricity grids
- Cost savings: the focus is to install retrofits that will pay for itself before the useful life
- Net-zero: the focus is to achieve net zero where homes "produce as much clean energy as they consume" [50]

5.1.1 Design a Program for Energy Efficiency

The upgrades that reduced the most energy consumption in the pilot program to date were ASHPs, GSHPs, solar PV systems, HPWHs, and boilers (based on one house). The average energy savings, GHG emission reductions, project cost, cost savings, dollar per tonnes, and payback periods is shown in Table 73-74.

Table 73: Average energy and GHG emission savings for energy efficiency focus program on 2022 ECCC grid

Upgrade	Net energy savings (GJ/year)	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
GSHP	58.6	47.9	3.0
ASHP	37.6	28.1	1.8
Solar PV	35.1	46	1.8
Boiler	23.0	30.3	1.2
HPWH	17.2	9.7	1.0

Table 74: Average project cost and cost savings for energy efficiency focus program on 2022 ECCC grid

Upgrade	Project Cost	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
		$170 by 2030		$65					
		Net Lifetime Dollar Savings*	$/$t_{CO2e}$*	Net Lifetime Dollar Savings*	$/$t_{CO2e}$*	Net Lifetime Dollar Savings*	$/$t_{CO2e}$*		
GSHP (Replacement)	$49,242	$6,743 $9,008	$930 $917	$4,114 $6,379	$1,029 $1,017	$2,181 $4,446	$1,111 $1,099	50+	
GSHP (Incremental)	$48,242		$909 $897		$1,008 $996		$1,090 $1,078	-	
ASHP (Replacement)	$14,401	($3,590) ($6,305)	$697 $800	($7,672) ($10,387)	$842 $945	($11,033) ($13,748)	$961 $1,064	50+	
ASHP (Incremental)	$11,170		$574 $678		$719 $822		$838 $942	-	
Solar PV	$25,997	$28,477 $41,256	($16) ($292)	$28,477 $41,256	($16) ($292)	$28,477 $41,256	($16) ($292)	0 50+	
Boiler (Replacement)	$19,062	$6,743 $9,008	$407 $332	$4,114 $6,379	$494 $419	$2,181 $4,446	$558 $483	50+	
Boiler (Incremental)	$16,862		$334 $260		$421 $346		$485 $410	-	
HPWH (Replacement)	$5,699	$792 $874	$516 $508	($235) ($154)	$622 $614	($1,100) ($1,019)	$710 $702	50+	
HPWH (Incremental)	$4,189		$357 $349		$462 $455		$551 $543	-	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

Space heating supply upgrades (GHSP and ASHP), solar PV systems and water heating supply upgrades all result in the most significant energy savings. The three upgrades minimum does not necessarily ensure any of these upgrades would be undertaken, on the other hand, one of these upgrades could have a much more significant energy reduction than three smaller upgrades. Therefore, a program focused on energy savings should target at least one of the space heating, solar PV and/or water heating upgrades as a minimum requirement, exceptions for housing where two of these pre-exist could be made. Given the capital intensive nature of heat pumps, and their associated energy savings, the minimum three up upgrades could be relaxed if one of these were undertaken.

5.1.2 Design a Program for GHG Emissions

The upgrades that reduced the most GHG emissions from the pilot program to date were ASHPs, GSHPs, solar PV systems, foundation insulation, and boilers (based on one house) as shown in Tables 75-77. Note that GHG emission reductions due to solar PV will decrease as the electricity grid decarbonizes in the future and therefore will need to be paired with fuel switching to see high GHG emission reductions.

Table 75: Average energy and GHG emission savings for "reducing GHG emissions" focus program

Upgrade	Net energy savings (GJ/year)	Lifetime (t_{CO2e})		Annual (t_{CO2e}/year)	
		Net Zero by 2035	**2022 ECCC**	**Net Zero by 2035**	**2022 ECCC**
GSHP	58.6	62.1	47.9	3.9	3.0
ASHP	37.6	37.2	28.1	2.3	1.8
Solar PV	34.1	21.3	42.2	0.86	1.7
Boiler	23.0	30.3		1.2	
Foundation Insulation	14.7	15.5		0.8	

Table 76: Average project cost and cost savings for "reducing GHG emissions" focus program on net zero by 2035 grid

Upgrade	Project Cost	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
		$170 by 2030		$65					
		Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*		
GSHP (Replacement)	$49,242	$6,743 $9,008	$853 $842	$4,114 $6,379	$944 $933	$2,181 $4,446	$1,020 $1,008	50+	
GSHP (Incremental)	$48,242		$834 $823		$926 $914		$1,001 $989	-	
ASHP (Replacement)	$14,401	($3,590) ($6,305)	$525 $602	($7,672) ($10,387)	$636 $713	($11,033) ($13,748)	$727 $804	50+	
ASHP (Incremental)	$11,170		$436 $514		$547 $624		$638 $715	-	
Solar PV	$25,997	$28,477 $41,256	($35) ($632)	$28,477 $41,256	($35) ($632)	$28,477 $41,256	($35) ($632)	0-50+	
Boiler (Replacement)	$19,062	$6,743 $9,008	$407 $332	$4,114 $6,379	$494 $419	$2,181 $4,446	$558 $483	50+	
Boiler (Incremental)	$16,862		$334 $260		$421 $346		$485 $410	-	
Foundation Insulation	$3,342	$3,390 $4,550	($18) ($93)	$2,107 $3,268	$64 ($10)	$1,117 $2,278	$128 $53	1-50+	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

Table 77: Average project cost and cost savings for “reducing GHG emissions” focus program on 2022 ECCC grid

Upgrade	Project Cost	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
		$170 by 2030		$65					
		Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*	Net Lifetime Dollar Savings*	$/t$_{CO2e}$*		
GSHP (Replacement)	$49,242	$6,743 $9,008	$930 $917	$4,114 $6,379	$1,029 $1,017	$2,181 $4,446	$1,111 $1,099	50+	
GSHP (Incremental)	$48,242		$909 $897		$1,008 $996		$1,090 $1,078	-	
ASHP (Replacement)	$14,401	($3,590) ($6,305)	$697 $800	($7,672) ($10,387)	$842 $945	($11,033) ($13,748)	$961 $1,064	50+	
ASHP (Incremental)	$11,170		$574 $678		$719 $822		$838 $942	-	
Solar PV	$25,997	$28,477 $41,256	($16) ($292)	$28,477 $41,256	($16) ($292)	$28,477 $41,256	($16) ($292)	0-50+	
Boiler (Replacement)	$19,062	$6,743 $9,008	$407 $332	$4,114 $6,379	$494 $419	$2,181 $4,446	$558 $483	50+	
Boiler (Incremental)	$16,862		$334 $260		$421 $346		$485 $410	-	
Foundation Insulation	$3,342	$3,390 $4,550	($18) ($93)	$2,107 $3,268	$64 ($10)	$1,117 $2,278	$128 $53	1-50+	

*Top values are the low energy pricing scenario and bottom values are the high energy pricing scenario

For a program focused on GHG emission reductions, the following are suggestions for program design:

- The minimum three upgrade requirement remains to ensure deep energy savings
- Pair solar PV with fuel switching to ensure high GHG emission reductions

5.1.3 Design a Program for Cost Savings

The upgrades that have the possibility of paying for themself before the useful life from the pilot program to date were solar PV, foundation insulation, and lighting fixtures. The average energy savings, GHG emission reductions, project cost, cost savings, dollar per tonnes, and payback periods is shown in Table 78-79.

Table 78: Average energy and GHG emission savings for cost saving focus program on 2022 ECCC grid

Upgrade	Net energy savings (GJ/year)	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
Foundation Insulation	14.7	15.5	0.8
Lighting Fixtures	0.68	0.6	0.03
Solar PV	34.1	42.2	1.7

Table 79: Average project cost and cost savings for cost saving focus program on 2022 ECCC grid

Upgrade	Project Cost	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
		$170 by 2030		$65					
		Net Lifetime Dollar Savings*	$/$t_{CO2e}$*	Net Lifetime Dollar Savings*	$/$t_{CO2e}$*	Net Lifetime Dollar Savings*	$/$t_{CO2e}$*		
Foundation Insulation	$3,342	$3,390 $4,550	($18) ($93)	$2,107 $3,268	$64 ($10)	$1,117 $2,278	$128 $53	1 50+	
Lighting Fixtures	$502	$365 $529	$2,412 $2,407	$365 $529	$1,428 $1,179	$365 $529	$1,144 $976	0 50+	
Solar PV	$25,997	$28,477 $41,256	($16) ($292)	$28,477 $41,256	($16) ($292)	$28,477 $41,256	($16) ($292)	0 50+	

For a program focused on cost savings, the following are suggestions for program design:

- Require applicants to install solar PV, lighting, and/or foundation insulation

5.1.4 Design a Program for Net Zero

The upgrades that will eliminate natural gas consumption and supply required electricity consumption amount from the completed upgrades in the pilot program to date were ASHPs, GSHPs, solar PV systems, and HPWHs. The average energy savings, GHG emission reductions, project cost, cost savings, dollar per tonnes, and payback periods is shown in Table 80-81.

Table 80: Average energy and GHG emission savings for net zero focus program on 2022 ECCC grid

Upgrade	Net energy savings (GJ/year)	Lifetime (t_{CO2e})	Annual (t_{CO2e}/year)
GSHP	58.6	47.9	3.0
ASHP	37.6	28.1	1.8
Solar PV	34.1	42.2	1.7
HPWH (Replacement)	17.2	9.9	0.7
HPWH (Incremental)			

Table 81: Average project cost and cost savings for net zero focus program on 2022 ECCC grid

Upgrade	Project Cost	Including Carbon Price				Without Carbon Price		SPP (yr)	DPP (yr)
		$170 by 2030		$65					
		Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*	Net Lifetime Dollar Savings*	$\$/t_{CO2e}$*		
GSHP (Replacement)	$49,242	$6,743 $9,008	$930 $917	$4,114 $6,379	$1,029 $1,017	$2,181 $4,446	$1,111 $1,099	50+	
GSHP (Incremental)	$48,242		$909 $897		$1,008 $996		$1,090 $1,078	-	
ASHP (Replacement)	$14,401	($3,590) ($6,305)	$697 $800	($7,672) ($10,387)	$842 $945	($11,033) ($13,748)	$961 $1,064	50+	
ASHP (Incremental)	$11,170		$574 $678		$719 $822		$838 $942	-	
Solar PV	$25,997	$28,477 $41,256	($16) ($292)	$28,477 $41,256	($16) ($292)	$28,477 $41,256	($16) ($292)	0-50+	
HPWH (Replacement)	$5,699	$792 $874	$516 $508	($235) ($154)	$622 $614	($1,100) ($1,019)	$710 $702	50+	
HPWH (Incremental)	$4,189		$357 $349		$462 $455		$551 $543	-	

For a program focused on net zero homes, the following are suggestions for program design:

- Applicants must electrify space heating and water heating and install a solar PV that is large enough to cover the new electricity consumption where these do not need to be completed in the same year but a plan for installing retrofits is defined
- Complete a Energuide audit before and after retrofits are installed with suggestions on which retrofit combinations will result in achieving net zero (or a net zero pathway analysis explained below)
- Increase the financing amount per applicant to ensure all retrofits can be completed
- To align with the “retrofit residential” section of Edmonton’s Transition Strategy and Action Plan, the program could be offered to pre-2017 residential buildings only to support the initiative of emission neutral buildings in the city by 2050

- “An emission neutral building is one 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” [5]

The development of a “roadmap to net zero” could be done for homeowners based on the results of initial audits, including laying out a recommended ordering of upgrades based on the “house as a system” approach, as well as estimated costs and savings. With this roadmap to net zero report, homeowners have the tools to ask questions and to fully understand their home's potential while achieving program targets. The changing nature of the electricity system needs to be part of this communication both to home owners and auditors, as it can influence which technologies may have short-term gains (like high efficiency furnaces), vs. long-term ones (like heat pumps). As part of the roadmap a myHEAT analysis and rating could also be completed to help homeowners understand their home’s energy flows. A study was done on 12,500 single family homes in Medicine Hat where the homes were divided into two groups where the first group had a typical energy assessment done on the homes while the second group had a myHeat analysis conducted as well [51]. It was found that houses in the second group with low myHeat ratings completed more energy retrofits [51].

5.2 Research Next Steps

The research next steps could include:

- Verification and estimation of energy savings, GHG emissions, and cost savings for residential and commercial buildings in the full program on Alberta's grid decarbonization scenarios
- Collect and share retrofit cost data, estimated and develop methods to collect actual energy use and savings for residential and commercial buildings within the program to assist in the preparation of completing retrofits and publish results
- Create an Marginal Abatement Cost Curve (MACC) based on applicants within the full program

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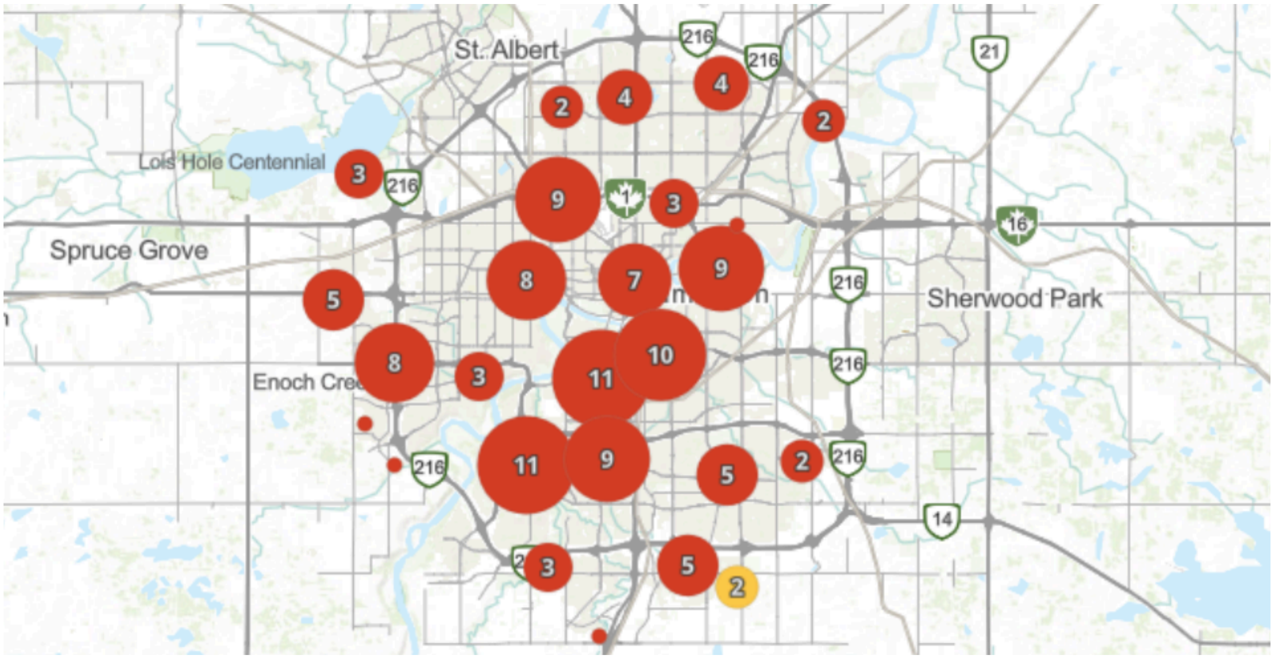
Appendix A: Map of CEIP Applicants' Locations as of June 2023



Appendix B: Electricity Emission Factor Scenarios

Year	Net Zero Scenario (t_{CO2e}/MWh)	2022 ECCC Scenario (t_{CO2e}/MWh)	TIER (t_{CO2e}/MWh)
2022	0.37	0.44	0.37
2023	0.34	0.38	0.36
2024	0.31	0.27	0.36
2025	0.28	0.24	0.35
2026	0.26	0.25	0.34
2027	0.23	0.23	0.33
2028	0.20	0.21	0.33
2029	0.17	0.21	0.32
2030	0.14	0.21	0.31
2031	0.11	0.19	0.30
2032	0.09	0.19	0.30
2033	0.06	0.18	0.29
2034	0.03	0.18	0.28
2035	0.00	0.17	0.27
2036	0.00	0.17	0.27
2037	0.00	0.17	0.26
2038	0.00	0.17	0.25
2039	0.00	0.17	0.24
2040	0.00	0.17	0.24
2041	0.00	0.17	0.23
2042	0.00	0.17	0.22
2043	0.00	0.17	0.21
2044	0.00	0.17	0.21
2045	0.00	0.17	0.20
2046	0.00	0.18	0.19
2047	0.00	0.18	0.19
2048	0.00	0.18	0.18
2049	0.00	0.17	0.17
2050	0.00	0.17	0.16

Appendix C: Calculations

The following are equations used in the energy analysis (from second interim report):

Electricity Yearly and Lifetime GHG Emissions Savings:

$$tCO2e_{elec,\,lifetime} = \sum_{i}^{useful\,life} (energy\ saved\ [MWh])(emissions\ factor\ in\ year\ i\ [tonnes/MWh])$$

The yearly GHG emissions savings is found the following way: $\frac{tCO2e_{elec}}{year} = \frac{tCO2e_{elec,lifetime}}{useful\,life}$

Natural Gas Yearly and Lifetime GHG Emissions Savings:

$tCO2e_{NG,lifetime} = \sum_{i}^{useful\,life} (energy\ saved\ [GJ])(0.051\ [tCO2e/GJ])$ where 0.051 t_{CO2e}/GJ is the natural gas emissions factor.

The yearly GHG emissions savings is found the following way: $\frac{tCO2e_{NG}}{year} = \frac{tCO2e_{NG,lifetime}}{useful\,life}$

Electricity and Natural Gas Lifetime Dollar Savings:

$$Lifetime\ dollars\ saved_{electricity} = (unit\ price\ [\$/kWh])(kWh\ saved)(\ useful\ lifetime\ of\ retrofit)$$

$$Lifetime\ dollars\ saved_{natural\ gas} = (unit\ price\ [\$/GJ])(GJ\ saved)(useful\ lifetime\ of\ retrofit)$$

The electricity and natural gas lifetime and yearly cost savings were calculated for the two energy cost scenarios using the following distribution, transmission, and rider breakdown as of June 19, 2023, from Encore by EPCOR. It was assumed these values do not change and GST was not included in the analysis:

Table C1: Electricity and Natural Gas Distribution, Transmission, and Rider Breakdown

Energy	Variable Distribution	Variable Transmission	Riders
Electricity (¢/kWh) [52]	1.64	3.83	0.90
Natural Gas ($/GJ) [53]	0.93	n/a	1.2

The natural gas lifetime dollar savings will be shown with and without the carbon price. The carbon cost is calculated using the following equation:

$carbon\ cost = \frac{carbon\ price\ x\ NG\ emissions\ factor\ [tonnes/m^3]}{natural\ gas\ density\ x\ HHV_{NG}}$ where the carbon price is specified in Table 9, the natural gas emissions factor is 0.001906 t_{CO2e}/m^3 (based on the fuel charge rates), and the HHV_{NG} is 0.05535 GJ/kg [54].

The natural gas density was calculated the following way:

$$natural\ gas\ density\ =\ \frac{101.3\ [kPa]\ x\ 16\ [kg/kmol]}{8.314[J/mol*K\}\ x\ 293\ K} = 0.6653\ kg/m^3$$

Dollars per tonne CO2 abated with and without rebates:

$$\$/t_{CO2e} = \frac{Project\ cost - lifetime\ dollars\ saved}{lifetime\ tonnes\ of\ emissions\ saved}$$

Simple Payback Period (SPP):

SPP is the year that the cumulative cash flow of a project is positive. The cash flow was calculated the following way:

$$cashflow\ (t)\ =\ rebates(t)\ \pm\ electricity\ cost\ savings\ (t)\ \pm\ natural\ gas\ cost\ savings\ (t)\ -\ yearly\ payment(t)$$

where the electricity and natural gas dollar savings/increase are based on the unit price shown in Table C1, and the yearly payment was applicants specific yearly payment plan which is the principal payment plus the interest.

Discounted Payback Period (DPP):

DPP is the year that the present value cumulative cash flow of a project is positive. The cash flow is calculated the following way:

$$cashflow\ (t)\ = present\ value_{ele}(t)\ \pm present\ value_{NG}(t)\ -\ yearly\ payment(t)$$

where the cash flow per year (bringing the value to the PV) was calculated the following way:

$$present\ value_{ele}(t)\ =\ \frac{electricity\ dollar\ (t)}{(1+interest\ rate)^t}$$

$$present\ value_{NG}(t)\ =\ \frac{natural\ gas\ dollar\ (t)}{(1+interest\ rate)^t}$$

where the interest rate is the fixed interest rate for the payment plan specific to each applicant.

Heat Loss:

The heat loss for upgrades that could not be modeled in HOT2000 was calculated to estimate the energy savings of the upgrades. This was calculated the following way:

$$Q\ = \frac{A\Delta T}{R}$$

where Q is the heat loss (btu/hr), A is the area of the wall (ft^2), ΔT is the change in temperature (℉), and R is the thermal resistance of the wall.

Conversions:

Table C2 shows the energy conversions used in the analysis:

Table C2: Energy Conversions

Conversion	Equation	Note
m^3 to GJ of natural gas [55]	1 m^3 = 0.0373 GJ	Assumes average gas temperature of 15℃ and higher heating value
kWh to GJ of electricity	1 kWh = 277.8 GJ	

Appendix D: Dollar Savings Results

Appendix D1: ASHP Dollar Savings Results

Table D1.1: Cost, cost savings, and dollar per tonnes for ASHP with and without carbon price on a 2022 ECCC grid for low energy price scenario

House	Project Cost	Lifetime Dollar Savings				Net Lifetime Dollar Savings			$\$/t_{CO2}$ 2022 ECCC Grid		
		170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	Electricity Cost	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$
1110 (Replacement)	\$9,893	\$13,748	\$8,754	\$4,641	\$13,989	(\$241)	(\$5,235)	(\$9,348)	\$241	\$360	\$458
1110 (Incremental)	\$8,893								\$217	\$336	\$434
1118 (Replacement)	\$21,798	\$9,205	\$5,861	\$3,107	\$12,802	(\$3,597)	(\$6,941)	(\$9,694)	\$1,122	\$1,269	\$1,391
1118 (Incremental)	\$20,798								\$1,078	\$1,225	\$1,347
1131 (Replacement)	\$12,600	\$9,583	\$6,102	\$3,235	\$12,473	(\$2,890)	(\$6,371)	(\$9,238)	\$621	\$761	\$876
1131 (Incremental)	\$10,600								\$541	\$681	\$796
1165 (Replacement)	\$13,314	\$12,412	\$7,903	\$4,190	\$20,043	(\$7,631)	(\$12,140)	(\$15,853)	\$803	\$976	\$1,118
1165 (Incremental)	\$4,389								\$461	\$634	\$776

Table D1.2: Cost, cost savings, and dollar per tonnes for ASHP with and without carbon price on a 2022 ECCC grid for high energy price scenario

House	Project Cost	Lifetime Dollar Savings				Net Lifetime Dollar Savings			$\$/t_{CO_2}$ 2022 ECCC Grid		
		170 $\$/t_{CO_2}$ (by 2030)	65 $\$/t_{CO_2}$	0 $\$/t_{CO_2}$	Electricity Cost	170 $\$/t_{CO_2}$ (by 2030)	65 $\$/t_{CO_2}$	0 $\$/t_{CO_2}$	170 $\$/t_{CO_2}$ (by 2030)	65 $\$/t_{CO_2}$	0 $\$/t_{CO_2}$
1110 (Replacement)	\$9,893	\$18,567	\$13,573	\$9,460	\$20,267	(\$1,700)	(\$6,695)	(\$10,807)	\$276	\$395	\$493
1110 (Incremental)	\$8,893								\$252	\$371	\$469
1118 (Replacement)	\$21,798	\$12,431	\$9,087	\$6,334	\$18,547	(\$6,116)	(\$9,459)	(\$12,213)	\$1,233	\$1,381	\$1,502
1118 (Incremental)	\$20,798								\$1,189	\$1,337	\$1,458
1131 (Replacement)	\$12,600	\$12,942	\$9,460	\$6,594	\$18,070	(\$5,128)	(\$8,610)	(\$11,476)	\$711	\$851	\$966
1131 (Incremental)	\$10,600								\$631	\$770	\$885
1165 (Replacement)	\$13,314	\$16,763	\$12,254	\$8,541	\$29,038	(\$12,275)	(\$16,784)	(\$20,497)	\$981	\$1,154	\$1,296
1165 (Incremental)	\$4,389								\$639	\$812	\$954

Table D1.3: SPP/DPP for ASHP with and without carbon price for energy price scenarios

<table>
<tr><th rowspan="2">House</th><th colspan="2">$170 (by 2030)</th><th colspan="2">$65</th><th colspan="2">Without carbon price</th></tr>
<tr><th>Low</th><th>High</th><th>Low</th><th>High</th><th>Low</th><th>High</th></tr>
<tr><td>1110/1118/
1131/1165</td><td colspan="6">50+</td></tr>
</table>

Appendix D2: GSHP Dollar Savings Results

Table D2.1: Cost, cost savings, and dollar per tonnes for GSHP with and without carbon price on a 2022 ECCC grid for low energy price scenario

House	Project Cost	Lifetime Dollar Savings				Net Lifetime Dollar Savings			$\$/t_{CO2}$ 2022 ECCC Grid		
		170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	Electricity Cost	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$
1115 (Replacement)	$49,242	$13,269	$8,449	$4,480	$9,037	$4,232	($589)	($4,558)	$930	$1,029	$1,111
1115 (Incremental)	$48,242								$909	$1,008	$1,090

Table D2.2: Cost, cost savings, and dollar per tonnes for GSHP with and without carbon price on a 2022 ECCC grid for high energy price scenario

House	Project Cost	Lifetime Dollar Savings				Net Lifetime Dollar Savings			$\$/t_{CO2}$ 2022 ECCC Grid		
		170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	Electricity Cost	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$
1115 (Replacement)	$49,242	$17,920	$13,100	$9,130	$13,093	$4,827	$7	($3,963)	$917	$1,017	$1,099
1115 (Incremental)	$48,242								$897	$996	$1,078

Table D2.3: SPP/DPP for GSHP with and without carbon price for energy price scenarios

House	$170 (by 2030)			$65			Without carbon price		
	Low	Intermediate	High	Low	Intermediate	High	Low	Intermediate	High
1115	50+								

Appendix D3: High Efficiency Boiler Dollar Savings Results

Table D3.1: Cost and cost savings for boiler with and without carbon price

House	Project Cost	Lifetime Dollar Savings - Low Energy Cost Scenario			Lifetime Dollar Savings - High Energy Cost Scenario		
		170 \$/t$_{CO2}$ (by 2030)	65 \$/t$_{CO2}$	0 \$/t$_{CO2}$	170 \$/t$_{CO2}$ (by 2030)	\$65	0 \$/t$_{CO2}$
1119 (Replacement)	\$19,062	\$6,743	\$4,114	\$2,181	\$9,008	\$6,379	\$4,446
1119 (Incremental)	\$16,862						

Table D3.2: Dollar per tonnes for boiler with and without carbon price

House	\$/t$_{CO2}$ Low Energy Cost Scenario			\$/t$_{CO2}$ High Energy Cost Scenario		
	170 \$/t$_{CO2}$ (by 2030)	65 \$/t$_{CO2}$	0 \$/t$_{CO2}$	170 \$/t$_{CO2}$ (by 2030)	\$65	0 \$/t$_{CO2}$
1119 (Replacement)	\$407	\$494	\$558	\$332	\$419	\$483
1119 (Incremental)	\$334	\$421	\$485	\$260	\$346	\$410

Table D3.3: SPP/DPP for boiler with and without carbon price for energy price scenarios

House	170 \$/t$_{CO2}$ (by 2030)		65 \$/t$_{CO}$		0 \$/t$_{CO2}$	
	Low	High	Low	High	Low	High
1119	50+					

Appendix D4: High Efficiency Furnace Dollar Savings Results

Table D4.1: Cost and cost savings for high efficiency furnace with and without carbon price

House	Project Cost	Lifetime Dollar Savings - Low Energy Cost Scenario			Lifetime Dollar Savings - High Energy Cost Scenario		
		170 $/t_{CO2}$ (by 2030)	65 $/t_{CO2}$	0 $/t_{CO2}$	170 $/t_{CO2}$ (by 2030)	$65	0 $/t_{CO2}$
1078	$8,311	$1,958	$1,247	$661	$2,644	$1,933	$1,347
1089	$7,991	$4,613	$2,937	$1,557	$6,230	$4,554	$3,174
1098	$14,282	$4,465	$2,843	$1,507	$6,029	$4,408	$3,072
1131	$11,760	$499	$318	$169	$674	$493	$344
1140	$7,560	$5,740	$3,655	$1,938	$7,752	$5,667	$3,950
1141	$9,791	$2,470	$1,573	$834	$3,336	$2,439	$1,700
1159	$11,886	$2,968	$1,890	$1,002	$4,009	$2,930	$2,042
1165	$8,925	$401	$255	$135	$541	$396	$276

Table D4.2: Dollar per tonnes for high efficiency furnace with and without carbon price

House	**$\$/t_{CO_2}$ Low Energy Cost Scenario**			**$\$/t_{CO_2}$ High Energy Cost Scenario**		
	170 $\$/t_{CO_2}$ (by 2030)	**65 $\$/t_{CO_2}$**	**0 $\$/t_{CO_2}$**	**170 $\$/t_{CO_2}$ (by 2030)**	**\$65**	**0 $\$/t_{CO_2}$**
1078 (Replacement)	\$693	\$770	\$834	\$618	\$696	\$759
1078 (Incremental)	\$257	\$334	\$398	\$182	\$259	\$323
1089 (Replacement)	\$156	\$234	\$298	\$81	\$159	\$223
1089 (Incremental)	\$110	\$188	\$251	\$35	\$113	\$177
1098 (Replacement)	\$470	\$547	\$611	\$395	\$472	\$536
1098 (Incremental)	\$374	\$451	\$515	\$299	\$377	\$441
1131 (Replacement)	\$4,815	\$4,892	\$4,956	\$4,740	\$4,818	\$4,881
1131 (Incremental)	\$3,960	\$4,037	\$4,101	\$3,885	\$3,962	\$4,026
1140 (Replacement)	\$68	\$145	\$209	(\$7)	\$70	\$134
1140 (Incremental)	\$30	\$108	\$172	(\$44)	\$33	\$97
1141 (Replacement)	\$633	\$710	\$774	\$558	\$636	\$699
1141 (Incremental)	\$546	\$624	\$688	\$472	\$549	\$613
1159 (Replacement)	\$642	\$719	\$783	\$567	\$644	\$708
1159 (Incremental)	\$570	\$647	\$711	\$495	\$572	\$636
1165 (Replacement)	\$4,541	\$4,618	\$4,682	\$4,466	\$4,544	\$4,607
1165 (Incremental)	\$3,475	\$3,553	\$3,617	\$3,401	\$3,478	\$3,542

Table D4.3: SPP for high efficiency furnace with and without carbon price for energy price scenarios

House	170 $/t$_{CO2}$ (by 2030)		65 $/t$_{CO2}$		0 $/t$_{CO2}$	
	Low	High	Low	High	Low	High
1078	50+	50+	50+	50+	50+	50+
1089	33	26	50+	36	50+	50+
1098	50+	46	50+	50+	50+	50+
1131	50+	50+	50+	50+	50+	50+
1140	27	20	43	28	50+	40
1141	50+	50+	50+	50+	50+	50+
1159	50+	50+	50+	50+	50+	50+
1165	50+	50+	50+	50+	50+	50+

Table D4.4: DPP for high efficiency furnace with and without carbon price for energy price scenarios

House	170 $/t$_{CO2}$ (by 2030)		65 $/t$_{CO2}$		0 $/t$_{CO2}$	
	Low	High	Low	High	Low	High
1078	50+	50+	50+	50+	50+	50+
1089	50+	32	50+	50+	50+	50+
1098	50+	50+	50+	50+	50+	50+
1131	50+	50+	50+	50+	50+	50+
1140	35	23	50+	39	50+	50+
1141	50+	50+	50+	50+	50+	50+
1159	50+	50+	50+	50+	50+	50+
1165	50+	50+	50+	50+	50+	50+

Appendix D5: Solar PV System Dollar Savings Results

Table D5.1: Cost and cost savings for solar PV for three electricity grid scenarios

House	Project Cost	Lifetime Dollar Savings - Low Energy Cost Scenario			Lifetime Dollar Savings - High Energy Cost Scenario		
		Electricity	Exports	Total	Electricity	Exports	Total
1074	$46,271	$26,455	$32,691	$59,146	$38,327	$47,362	$85,689
1075	$27,300	$23,751	$7,354	$31,104	$34,409	$10,654	$45,063
1078	$26,800	$24,595	$13,162	$37,758	$35,633	$19,069	$54,702
1082	$18,942	$16,792	$0	$16,792	$24,327	$0	$24,327
1086	$23,132	$10,208	$0	$10,208	$14,788	$0	$14,788
1088	$29,587	$29,582	$9,461	$39,043	$42,858	$13,707	$56,565
1089	$23,888	$22,580	$1,966	$24,546	$32,713	$2,848	$35,562
1090	$23,984	$22,693	$3,099	$25,792	$32,876	$4,490	$37,366
1094	$19,209	$23,768	$1,248	$25,016	$34,434	$1,808	$36,242
1104	$17,467	$18,054	$0	$18,054	$26,157	$0	$26,157
1112	$26,075	$26,769	$7,063	$33,831	$38,782	$10,232	$49,014
1113	$24,349	$21,960	$7,282	$29,242	$31,815	$10,549	$42,365
1115	$43,018	$21,638	$8,276	$29,914	$31,348	$11,990	$43,338
1131	$15,022	$17,881	$0	$17,881	$25,906	$0	$25,906
1141	$29,330	$21,891	$6,933	$28,824	$31,715	$10,044	$41,759

Table D5.2: Dollar per tonnes for solar PV on three electricity grid scenarios

House	**$\$/t_{CO2}$ Net zero**		**$\$/t_{CO2}$ (exports) 2022 ECCC**		**$\$/t_{CO2}$ (total) TIER**	
	Low	**High**	**Low**	**High**	**Low**	**High**
1074	(\$315)	(\$963)	(\$145)	(\$445)	(\$106)	(\$323)
1075	(\$162)	(\$755)	(\$75)	(\$349)	(\$54)	(\$253)
1078	(\$384)	(\$977)	(\$177)	(\$452)	(\$129)	(\$328)
1082	\$169	(\$424)	\$78	(\$196)	\$57	(\$142)
1086	\$1,103	\$510	\$510	\$235	\$370	\$171
1088	(\$320)	(\$914)	(\$148)	(\$422)	(\$107)	(\$307)
1089	(\$35)	(\$629)	(\$16)	(\$291)	(\$12)	(\$211)
1090	(\$93)	(\$686)	(\$43)	(\$317)	(\$31)	(\$230)
1094	(\$307)	(\$900)	(\$142)	(\$416)	(\$103)	(\$302)
1104	(\$43)	(\$637)	(\$20)	(\$294)	(\$14)	(\$214)
1112	(\$303)	(\$897)	(\$140)	(\$414)	(\$102)	(\$301)
1113	(\$221)	(\$815)	(\$102)	(\$376)	(\$74)	(\$273)
1115	\$579	(\$14)	\$268	(\$7)	\$194	(\$5)
1131	(\$211)	(\$805)	(\$98)	(\$372)	(\$71)	(\$270)
1141	\$23	(\$570)	\$11	(\$263)	\$8	(\$191)

Table D4.5: SPP/DPP for solar PV for energy price scenarios

House	SPP		DPP	
	Low	High	Low	High
1074	27	0	32	0
1075*	23	0	23	0
1078	22	0	22	0
1082	36	24	50+	26
1086	50+	50+	50+	50+
1088	23	0	25	0
1089*	25	0	27	0
1090	30	0	39	0
1094	24	0	25	0
1104	31	0	43	0
1112*	0	0	0	00
1113*	0	0	0	0
1115	35	24	50+	34
1131	50+	40	50+	50+
1141*	31	0	40	0

*includes rebates
Note: 0 indicates the payback is less than 1 year

Appendix D6: Lighting Dollar Savings Results

Table D6.1: Cost and cost savings for lighting fixtures

House	Project Cost	Lifetime Dollar Savings	
		Low	High
1074	$413	$1,120	$1,623
1088	$476	$51	$74
1090	$961	$188	$272
1104	$158	$102	$147

Table D6.2: Dollar per tonnes for lighting fixtures on electricity grid scenarios

House	Clean Electricity Grid		2022 ECCC		TIER	
	Low	High	Low	High	Low	High
1074	($570)	($976)	($390)	($667)	($272)	($465)
1088	$6,567	$6,215	$3,819	$3,579	$2,660	$2,493
1090	$3,220	$2,869	$641	$401	$447	$279
1104	$432	$81	$1,642	$1,402	$1,144	$976

Table D4.3: SPP/DPP for lighting fixtures for energy price scenarios

House	SPP		DPP	
	Low	High	Low	High
1074	0			
1088	50+			
1090				
1104	26	18	32	19

Appendix D7: Drain Water Heat Recovery Dollar Savings Results

Table D7.1: Cost and cost savings for DWHR with and without carbon price

House	Project Cost	Lifetime Dollar Savings - Low Energy Cost Scenario			Lifetime Dollar Savings - High Energy Cost Scenario		
		170 \$/$\mathrm{t}_{\mathrm{CO2}}$ (by 2030)	65 \$/$\mathrm{t}_{\mathrm{CO2}}$	0 \$/$\mathrm{t}_{\mathrm{CO2}}$	170 \$/$\mathrm{t}_{\mathrm{CO2}}$ (by 2030)	\$65	0 \$/$\mathrm{t}_{\mathrm{CO2}}$
1094	\$2,988	\$659	\$410	\$217	\$885	\$635	\$443
1118	\$1,456	\$667	\$415	\$220	\$895	\$643	\$448

Table D7.2: Dollar per tonnes for DWHR with and without carbon price

House	Dollar per tonnes Low Energy Cost Scenario			Dollar per tonnes High Energy Cost Scenario		
	\$170 (by 2030)	\$65		\$170 (by 2030)	\$65	
1094	\$773	\$856	\$919	\$698	\$781	\$845
1118	\$259	\$342	\$406	\$184	\$267	\$331

Table D7.3: SPP for high efficiency furnace with and without carbon price for energy price scenarios

House	\$170 (by 2030)		\$65		Without carbon price	
	Low	High	Low	High	Low	High
1078	50+					
1089	50+	42	50+			

Table D7.4: DPP for high efficiency furnace with and without carbon price for energy price scenarios

House	$170 (by 2030)		$65		Without carbon price	
	Low	High	Low	High	Low	High
1078/1089						50+

Appendix D8: Heat Pump Water Heater Dollar Savings Results

Table D8.1: Cost, cost savings, and dollar per tonnes for HPWH with and without carbon price on a 2022 ECCC grid for low energy price scenario

House	Project Cost	Lifetime Dollar Savings				Net Lifetime Dollar Savings			$\$/t_{CO_2}$ on 2022 ECCC Grid		
		170 $\$/t_{CO_2}$ (by 2030)	65 $\$/t_{CO_2}$	0 $\$/t_{CO_2}$	Electricity Cost	170 $\$/t_{CO_2}$ (by 2030)	65 $\$/t_{CO_2}$	0 $\$/t_{CO_2}$	170 $\$/t_{CO_2}$ (by 2030)	65 $\$/t_{CO_2}$	0 $\$/t_{CO_2}$
1078 (Replacement)	$5,103	$3,150	$2,022	$1,072	$2,326	$824	($304)	($1,254)	$385	$487	$573
1078 (Incremental)	$4,353								$318	$419	$505
1110 (Replacement)	$7,665	$2,916	$1,872	$992	$2,023	$892	($152)	($1,031)	$679	$783	$871
1110 (Incremental)	$5,965								$508	$613	$701
1115 (Replacement)	$4,132	$2,677	$1,718	$911	$2,035	$642	($317)	($1,124)	$395	$504	$595
1115 (Incremental)	$2,432								$203	$311	$403
1131 (Replacement)	$4,350	$3,095	$1,986	$1,053	$2,061	$1,034	($74)	($1,007)	$308	$411	$498
1131 (Incremental)	$2,650								$150	$253	$340
1159 (Replacement)	$7,245	$2,507	$1,609	$853	$1,940	$568	($330)	($1,086)	$813	$923	$1,015
1159 (Incremental)	$5,545								$606	$716	$808

Table D8.2: Cost, cost savings, and dollar per tonnes for HPWH with and without carbon price on a 2022 ECCC grid for high energy price scenario

House	Project Cost	Lifetime Dollar Savings				Net Lifetime Dollar Savings			$\$/t_{CO2}$ on 2022 ECCC Grid		
		170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	Electricity Cost	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$
1078 (Replacement)	$5,103	$4,263	$3,135	$2,185	$3,369	$894	($234)	($1,184)	$379	$481	$566
1078 (Incremental)	$4,353								$312	$413	$499
1110 (Replacement)	$7,665	$3,946	$3,946	$2,023	$2,931	$1,015	($30)	($909)	$666	$771	$859
1110 (Incremental)	$5,965								$496	$601	$689
1115 (Replacement)	$4,132	$3,623	$3,623	$1,857	$2,949	$674	($285)	($1,092)	$392	$500	$591
1115 (Incremental)	$2,432								$199	$308	$399
1131 (Replacement)	$4,350	$4,188	$4,188	$2,147	$2,985	$1,203	$95	($839)	$293	$396	$482
1131 (Incremental)	$2,650								$135	$238	$324
1159 (Replacement)	$7,245	$3,393	$3,393	$1,739	$2,810	$583	($315)	($1,071)	$811	$921	$1,013
1159 (Incremental)	$5,545								$604	$714	$806

Table D8.3: SPP/DPP for HPWH with and without carbon price for energy price scenarios

House	$170 (by 2030)		$65		Without carbon price	
	Low	High	Low	High	Low	High
1078/1110	50+					
1115*						
1131/1159						

*for financing project cost of $3,581

Appendix D9: Tankless Gas Water Heater Dollar Savings Results

Table D9.1: Cost and cost savings for TGWH with and without carbon price

House	Project Cost	Lifetime Dollar Savings - Low Energy Cost Scenario			Lifetime Dollar Savings - High Energy Cost Scenario		
		170 $/t$_{CO2}$ (by 2030)	65 $/t$_{CO2}$	0 $/t$_{CO2}$	170 $/t$_{CO2}$ (by 2030)	$65	0 $/t$_{CO2}$
1075 (Replacement)	$4,422	$1,259	$825	$437	$1,713	$1,279	$891
1075 (Incremental)	$3,672						
1098 (Replacement)	$5,460	$1,283	$841	$446	$1,746	$1,303	$908
1098 (Incremental)	$3.760						
1107 (Replacement)	$7,534	$1,230	$806	$427	$1,673	$1,249	$871
1107 (Incremental)	$5,834						
1130 (Replacement)	$4,725	$1,160	$760	$403	$1,578	$1,178	$821
1130 (Incremental)	$3,025						
1135 (Replacement)	$5,408	$1,053	$689	$366	$1,432	$1,069	$745
1135 (Incremental)	$3,708						
1141 (Replacement)	$5,208	$952	$624	$331	$1,296	$967	$674
1141 (Incremental)	$3,508						

Table D9.2: Dollar per tonnes for TGWH with and without carbon price

House	**$\$/t_{CO_2}$ Low Energy Cost Scenario**			**$\$/t_{CO_2}$ High Energy Cost Scenario**		
	170 $\$/t_{CO_2}$ (by 2030)	**65 $\$/t_{CO_2}$**	**0 $\$/t_{CO_2}$**	**170 $\$/t_{CO_2}$ (by 2030)**	**$65**	**0 $\$/t_{CO_2}$**
1075 (Replacement)	$522	$593	$657	$447	$518	$582
1075 (Incremental)	$398	$470	$533	$343	$395	$459
1098 (Replacement)	$676	$747	$811	$601	$672	$736
1098 (Incremental)	$401	$472	$536	$326	$397	$461
1107 (Replacement)	$1,064	$1,136	$1,199	$989	$1,061	$1,125
1107 (Incremental)	$777	$849	$913	$702	$774	$838
1130 (Replacement)	$638	$710	$773	$563	$635	$699
1130 (Incremental)	$334	$405	$469	$259	$330	$394
1135 (Replacement)	$859	$930	$994	$784	$856	$920
1135 (Incremental)	$524	$595	$659	$449	$520	$584
1141 (Replacement)	$928	$999	$1,063	$853	$924	$988
1141 (Incremental)	$557	$629	$693	$482	$554	$618

Table D9.3: SPP for TGWH with and without carbon price for energy price scenarios

House	170 $/t$_{CO2}$ (by 2030)		65 $/t$_{CO2}$		0 $/t$_{CO2}$	
	Low	High	Low	High	Low	High
1075	50+	39	50+			
1098		46				
1107		46				
1130		45				
1135		50+				
1141						

Table D9.4: DPP for TGWH with and without carbon price for energy price scenarios

House	170 $/t$_{CO2}$ (by 2030)		65 $/t$_{CO2}$		0 $/t$_{CO2}$	
	Low	High	Low	High	Low	High
1075/1098/1107/ 1130/1135/1141	50+					

Appendix D10: Attic Insulation Dollar Savings Results

Table D10.1: Cost and cost savings for attic insulation with and without carbon price

House	Project Cost	Lifetime Dollar Savings - Low Energy Cost Scenario			Lifetime Dollar Savings - High Energy Cost Scenario		
		170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	170 $\$/t_{CO2}$ (by 2030)	$65	0 $\$/t_{CO2}$
1078	$1,286	$404	$251	$133	$543	$390	$272
1082	$2,292	$1,404	$873	$463	$1,885	$1,353	$943
1088	$2,149	$416	$259	$137	$559	$401	$280
1094	$1,872	$553	$344	$182	$742	$533	$371
1112	$2,837	$2,287	$1,422	$754	$3,070	$2,205	$1,537
1113	$1,959	$488	$304	$161	$655	$471	$328
1119	$1,629	$968	$602	$319	$1,299	$933	$650
1135	$1,398	$1,146	$712	$378	$1,538	$1,104	$770
1159	$1,083	$3,446	$2,142	$1,136	$4,625	$3,322	$2,315
1165	$2,310	$4,027	$2,504	$1,327	$5,406	$3,882	$2,706

Table D10.2: Dollar per tonnes for attic insulation with and without carbon price

House	$\$/t_{CO2}$ Low Energy Cost Scenario			$\$/t_{CO2}$ High Energy Cost Scenario		
	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	170 $\$/t_{CO2}$ (by 2030)	$65	0 $\$/t_{CO2}$
1078	$477	$560	$624	$402	$485	$549
1082	$138	$221	$285	$63	$146	$210
1088	$911	$993	$1,057	$836	$919	$982
1094	$522	$605	$669	$447	$530	$594
1112	$53	$135	$199	($22)	$61	$124
1113	$659	$741	$805	$584	$666	$730
1119	$149	$232	$296	$75	$157	$221
1135	$48	$131	$195	($27)	$56	$120
1159	($915)	($410)	($20)	($1,372)	($867)	($477)
1165	($569)	($64)	$326	($1,026)	($521)	($131)

Table D10.3: SPP for attic insulation with and without carbon price for energy price scenarios

House	170 $\$/\mathrm{t}_{\mathrm{CO2}}$ (by 2030)		65 $\$/\mathrm{t}_{\mathrm{CO2}}$		0 $\$/\mathrm{t}_{\mathrm{CO2}}$	
	Low	High	Low	High	Low	High
1078	50+	50+	50+	50+	50+	50+
1082	42	32		46		50+
1088	50+	50+		50+		50+
1094	50+	47		50+		50+
1112	33	25		36		50+
1113	50+	50+		50+		50+
1119	43	33		47		50+
1135	32	24		34		49
1159	49	37		50+		50+
1165	50+	50+		50+		50+

Table D10.4: DPP for attic insulation with and without carbon price for energy price scenarios

House	170 $\$/t_{CO_2}$ (by 2030)		65 $\$/t_{CO_2}$		0 $\$/t_{CO_2}$	
	Low	High	Low	High	Low	High
1078	50+	50+	50+	50+	50+	
1082	50+	43		50+		
1088	50+	50+		50+		
1094	50+	50+		50+		
1112	50+	29		50+		
1113	50+	50+		50+		
1119	50+	46		50+		
1135	43	27		49		
1159	50+	50+		50+		
1165	50+	50+		50+		

Appendix D11: Rim Joist Insulation Dollar Savings Results

Table D11.1: Cost and cost savings for rim joist insulation with and without carbon price

House	Project Cost	Lifetime Dollar Savings - Low Energy Cost Scenario			Lifetime Dollar Savings - High Energy Cost Scenario		
		170 \$/t_{CO_2} (by 2030)	65 \$/t_{CO_2}	0 \$/t_{CO_2}	170 \$/t_{CO_2} (by 2030)	\$65	0 \$/t_{CO_2}
1082	\$998	\$64	\$39	\$21	\$85	\$61	\$43
1101	\$2,166	\$615	\$383	\$203	\$826	\$593	\$413
1113	\$1,575	\$118	\$74	\$39	\$159	\$114	\$80

Table D11.2: Dollar per tonnes for rim joist insulation with and without carbon price

House	\$/t_{CO_2} Low Energy Cost Scenario			\$/t_{CO_2} High Energy Cost Scenario		
	170 \$/t_{CO_2} (by 2030)	65 \$/t_{CO_2}	0 \$/t_{CO_2}	170 \$/t_{CO_2} (by 2030)	\$65	0 \$/t_{CO_2}
1082	\$3,216	\$3,299	\$3,363	\$3,142	\$3,224	\$3,288
1101	\$551	\$634	\$698	\$476	\$559	\$623
1113	\$2,690	\$2,773	\$2,836	\$2,615	\$2,698	\$2,762

Table D11.3: SPP/DPP for rim joist insulation with and without carbon price for energy price scenarios

House	170 \$/t_{CO_2} (by 2030)		65 \$/t_{CO_2}		0 \$/t_{CO_2}	
	Low	High	Low	High	Low	High
1082/1101/1113	50+					

Appendix D12: Foundation Insulation Dollar Savings Results

Table D12.1: Cost and cost savings for foundation insulation with and without carbon price

House	Project Cost	Lifetime Dollar Savings - Low Energy Cost Scenario			Lifetime Dollar Savings - High Energy Cost Scenario		
		170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	170 $\$/t_{CO2}$ (by 2030)	$65	0 $\$/t_{CO2}$
1100	$1,571	$2,180	$1,355	$719	$2,926	$2,101	$1,465
1101	$5,114	$4,600	$2,860	$1,516	$6,174	$4,434	$3,090

Table D12.2: Dollar per tonnes for foundation insulation with and without carbon price

House	$\$/t_{CO2}$ Low Energy Cost Scenario			$\$/t_{CO2}$ High Energy Cost Scenario		
	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	170 $\$/t_{CO2}$ (by 2030)	$65	0 $\$/t_{CO2}$
1100	($61)	$22	$85	($136)	($53)	$11
1101	$24	$107	$171	($50)	$32	$96

Table D12.3: SPP for foundation insulation with and without carbon price for energy price scenarios

House	170 $\$/t_{CO2}$ (by 2030)		65 $\$/t_{CO2}$		0 $\$/t_{CO2}$	
	Low	High	Low	High	Low	High
1100	18	1	32	21	50+	30
1101	22	14	28	23		33

Table D12.3: DPP for foundation insulation with and without carbon price for energy price scenarios

House	170 $\$/t_{CO2}$ (by 2030)		65 $\$/t_{CO2}$		0 $\$/t_{CO2}$	
	Low	High	Low	High	Low	High
1100	21	1	46	21	50+	38
1101	28	18	50+	30		50+

Appendix D13: Windows Dollar Savings Results

Table D13.1: Cost and cost savings for foundation insulation with and without carbon price

House	Project Cost	Lifetime Dollar Savings - Low Energy Cost Scenario			Lifetime Dollar Savings - High Energy Cost Scenario		
		170 \$/t_{CO2} (by 2030)	65 \$/t_{CO2}	0 \$/t_{CO2}	170 \$/t_{CO2} (by 2030)	\$65	0 \$/t_{CO2}
1086	\$33,835	\$1,059	\$680	\$360	\$1,433	\$1,054	\$735
1089	\$17,552	\$623	\$400	\$212	\$844	\$620	\$432
1098	\$16,429	\$2,051	\$1,317	\$698	\$2,776	\$2,041	\$1,423
1100	\$29,195	\$4,709	\$3,022	\$1,602	\$6,372	\$4,686	\$3,266
1101	\$3,701	\$583	\$375	\$199	\$790	\$581	\$405
1107	\$27,098	\$5,614	\$3,603	\$1,911	\$7,597	\$5,587	\$3,894
1110	\$34,164	\$9,656	\$6,198	\$3,286	\$13,068	\$9,610	\$6,698
1119	\$10,448	\$315	\$202	\$107	\$426	\$313	\$218
1135	\$11,905	\$1,074	\$690	\$366	\$1,454	\$1,069	\$745
1140	\$15,467	\$858	\$551	\$292	\$1,161	\$854	\$595

Table D13.2: Dollar per tonnes for foundation insulation with and without carbon price

House	$\$/t_{CO2}$ Low Energy Cost Scenario			$\$/t_{CO2}$ High Energy Cost Scenario		
	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	170 $\$/t_{CO2}$ (by 2030)	\$65	0 $\$/t_{CO2}$
1086	\$6,555	\$6,631	\$6,695	\$6,480	\$6,556	\$6,620
1089	\$5,752	\$5,828	\$5,892	\$5,677	\$5,753	\$5,817
1098	\$1,485	\$1,561	\$1,625	\$1,410	\$1,486	\$1,550
1100	\$1,102	\$1,177	\$1,241	\$1,027	\$1,103	\$1,166
1101	\$1,132	\$1,208	\$1,272	\$1,057	\$1,133	\$1,197
1107	\$811	\$887	\$950	\$736	\$812	\$876
1110	\$538	\$614	\$677	\$463	\$539	\$603
1119	\$6,818	\$6,894	\$6,958	\$6,744	\$6,819	\$6,883
1135	\$7,966	\$8,249	\$8,487	\$7,687	\$7,970	\$8,208
1140	\$13,452	\$13,735	\$13,974	\$13,173	\$13,456	\$13,694

Table D13.3: SPP/DPP for foundation insulation with and without carbon price for energy price scenarios

House	170 $/t$_{CO2}$ (by 2030)		65 $/t$_{CO2}$		0 $/t$_{CO2}$	
	Low	High	Low	High	Low	High
1086/1089/1098/ 1100/1101/1107/ 1110/1119/1135/ 1140	50+					

Appendix D14: Doors Dollar Savings Results

Table D14.1: Cost and cost savings for doors with and without carbon price

House	Project Cost	Lifetime Dollar Savings - Low Energy Cost Scenario			Lifetime Dollar Savings - High Energy Cost Scenario		
		$170\ \$/t_{CO2}$ (by 2030)	$65\ \$/t_{CO2}$	$0\ \$/t_{CO2}$	$170\ \$/t_{CO2}$ (by 2030)	$65	$0\ \$/t_{CO2}$
1082	$12,244	$100	$62	$33	$134	$96	$67
1086	$6,312	$1,007	$626	$332	$1,351	$970	$676
1089	$5,849	$2	$1	$1	$2	$2	$1
1098	$9,631	$82	$51	$27	$109	$79	$55
1100	$4,445	$7	$4	$2	$9	$7	$5
1101	$4,620	$409	$254	$135	$549	$395	$275
1107	$17,368	$1,120	$696	$369	$1,503	$1,080	$752
1130	$2,176	$29	$18	$10	$39	$28	$20
1140	$2,816	$548	$340	$180	$735	$528	$368

Table D14.2: Dollar per tonnes for doors with and without carbon price

House	$\$/t_{CO2}$ Low Energy Cost Scenario			$\$/t_{CO2}$ High Energy Cost Scenario		
	170 $\$/t_{CO2}$ (by 2030)	65 $\$/t_{CO2}$	0 $\$/t_{CO2}$	170 $\$/t_{CO2}$ (by 2030)	$65	0 $\$/t_{CO2}$
1082	$26,679	$26,762	$26,826	$26,604	$26,687	$26,751
1086	$1,153	$1,235	$1,299	$1,078	$1,161	$1,224
1089	$745,025	$745,107	$745,171	$744,950	$745,033	$745,096
1098	$25,618	$25,700	$25,764	$25,543	$25,625	$25,689
1100	$141,384	$141,466	$141,530	$141,309	$141,392	$141,455
1101	$2,250	$2,332	$2,396	$2,175	$2,257	$2,321
1107	$3,173	$3,256	$3,320	$3,098	$3,181	$3,245
1130	$16,090	$16,173	$16,237	$16,015	$16,098	$16,162
1140	$906	$989	$1,053	$831	$914	$978

Table D14.3: SPP/DPP for doors with and without carbon price for energy price scenarios

<table>
<tr><th rowspan="2">House</th><th colspan="2">170 $\$/t_{CO2}$ (by 2030)</th><th colspan="2">65 $\$/t_{CO2}$</th><th colspan="2">0 $\$/t_{CO2}$</th></tr>
<tr><th>Low</th><th>High</th><th>Low</th><th>High</th><th>Low</th><th>High</th></tr>
<tr><td>1082/1086/1089/
1098/1100/1101/
1107/1130/1140</td><td colspan="6">50+</td></tr>
</table>

Appendix D15: HRV Dollar Increase Results

Table D5.1: Cost and cost savings for HRV for low energy cost scenario on the three electricity grid scenarios

House	Project Cost	Low Energy Cost Scenario			
		Electricity Cost	$/t_{CO2}$ Clean Electricity Grid	$/t_{CO2}$ 2022 ECCC	$/t_{CO2}$ TIER
1078	$2,943	($513)	$4,276	$2,924	$2,036

Table D5.2: Cost and cost savings for HRV for high energy cost scenario on the three electricity grid scenarios

House	Project Cost	High Energy Cost Scenario			
		Electricity Cost	$/t_{CO2}$ Clean Electricity Grid	$/t_{CO2}$ 2022 ECCC	$/t_{CO2}$ TIER
1078	$2,943	($513)	$3,871	$2,646	$1,843

Appendix D16: Range of SPP and DPP for installed upgrades

Table D16.1: Average SPP for estimated savings for installed upgrades

Upgrade	SPP Range (Low Energy Cost Scenario)			SPP (High Energy Cost Scenario)		
	Gas With Carbon Price		Gas Without Carbon Price	Gas With Carbon Price		Gas Without Carbon Price
	$170 by 2030	$65		$170 by 2030	$65	
Air Source Heat Pump	50+					
Ground Source Heat Pump*	50+					
Boiler*	50+					
Furnace	27-50+	43-50+	50+	20-50+	28-50+	40-50+
Solar PV System	0-50+					
Light Fixtures	0-50+					
Drain Water Heat Recovery	50+			50-50+	50+	
Heat Pump Water Heater (Replacement)	50+					
Heat Pump Water Heater (Incremental)	-					
Tankless Gas Water Heater (Replacement)	50+			39-50+	50+	
Tankless Gas Water Heater (Incremental)	-					
Attic Insulation	32-50+	50+		24-50+	34-50+	49-50+
Rim Joist Insulation	50+					
Foundation Insulation	18-22	32-36	50+	1-14	21-23	30-33
Windows	50+					
Doors	50+					
HRV*	-					

Table D16.2: Average DPP for estimated savings for installed upgrades

<table>
<tr><th rowspan="3">Upgrade</th><th colspan="3">DPP Range
(Low Energy Cost Scenario)</th><th colspan="3">DPP
(High Energy Cost Scenario)</th></tr>
<tr><th colspan="2">Gas With Carbon Price</th><th rowspan="2">Gas Without Carbon Price</th><th colspan="2">Gas With Carbon Price</th><th rowspan="2">Gas Without Carbon Price</th></tr>
<tr><th>$170 by 2030</th><th>$65</th><th>$170 by 2030</th><th>$65</th></tr>
<tr><td>Air Source Heat Pump</td><td colspan="6">50+</td></tr>
<tr><td>Ground Source Heat Pump*</td><td colspan="6">50+</td></tr>
<tr><td>Boiler*</td><td colspan="6">50+</td></tr>
<tr><td>Furnace</td><td>35-50+</td><td colspan="2">50+</td><td>23-50+</td><td>39-50+</td><td>50+</td></tr>
<tr><td>Solar PV System</td><td colspan="6">0-50+</td></tr>
<tr><td>Light Fixtures</td><td colspan="6">0-50+</td></tr>
<tr><td>Drain Water Heat Recovery</td><td colspan="6">50+</td></tr>
<tr><td>Heat Pump Water Heater (Replacement)</td><td colspan="6">50+</td></tr>
<tr><td>Heat Pump Water Heater (Incremental)</td><td colspan="6">-</td></tr>
<tr><td>Tankless Gas Water Heater (Replacement)</td><td colspan="6">50+</td></tr>
<tr><td>Tankless Gas Water Heater (Incremental)</td><td colspan="6">-</td></tr>
<tr><td>Attic Insulation</td><td>43-50+</td><td colspan="2">50+</td><td>27-50+</td><td>49-50+</td><td>50+</td></tr>
<tr><td>Rim Joist Insulation</td><td colspan="6">50+</td></tr>
<tr><td>Foundation Insulation</td><td>21-28</td><td>46-50+</td><td>50+</td><td>1-18</td><td>21-30</td><td>38-50+</td></tr>
<tr><td>Windows</td><td colspan="6">50+</td></tr>
<tr><td>Doors</td><td colspan="6">50+</td></tr>
<tr><td>HRV*</td><td colspan="6">-</td></tr>
</table>

Appendix E: House as a Whole Analysis Results

Table E1: Energy consumption before and after upgrades

House	Consumption Before Upgrades				Consumption After Upgrades				Savings	
	Elec. (kWh)	Elec. (GJ)	Natural Gas (GJ)	Total (GJ)	Elec. (kWh)	Elec. (GJ)	Natural Gas (GJ)	Total (GJ)	GJ	%
1074	8,400	30.2	127.3	157.6	(10,944)	(39)	127	88	70	44%
1075	8,239	29.7	90.0	119.7	2,542)	(9)	81	71	48	40%
1078	8,532	30.7	133.2	163.9	(3,447)	(12)	102	90	74	45%
1082	7,224	26.0	138.9	164.9	1,399	5	132	137	28	17%
1086	7,886	28.4	158.8	187.2	4,289	15	148	163	24	13%
1088	10,262	36.9	108.6	145.6	(3,285)	(12)	106	94	51	35%
1089	7,833	28.2	187.8	216.0	(735)	(3)	180	177	39	18%
1090	7,872	28.3	66.7	95.0	(1,182)	(4)	67	62	33	34%
1094	8,245	29.7	77.3	107.0	(425)	(2)	72	70	37	34%
1098	7,725	27.8	161.5	189.3	7,688	28	111	138	51	27%
1100	8,093	29.1	207.1	236.2	7,890	28	168	197	40	17%
1101	7,295	26.3	139.3	165.6	7,149	26	110	136	30	18%
1104	7,437	26.8	71.4	98.2	1,174	4	71	75	23	23%
1107	8,097	29.1	228.7	257.8	7,926	29	189	218	40	15%
1110	7,812	28.1	186.3	214.4	14,755	53	42	95	119	56%
1112	9,286	33.4	157.3	190.7	(2,450)	(9)	147	138	53	28%
1113	7,618	27.4	122.6	150.0	(2,543)	(9)	120	110	40	26%
1115	7,507	27.0	110.6	137.7	0	0	0	0	138	100%
1118	7,469	26.9	93.7	120.6	13,454	48	40	88	33	27%
1119	13,843	49.8	70.1	119.9	13,991	50	46	97	23	19%
1130	8,296	29.9	110.4	140.2	8,318	30	102	132	8	6%
1131	7,524	27.1	96.6	123.7	8,597	31	19	50	74	59%
1135	8,061	29.0	107.3	136.3	8,062	29	93	122	14	11%
1140	7,695	27.7	150.3	178.0	7,695	28	123	151	27	15%
1141	7,594	27.3	120.2	147.6	(2,396)	(9)	99	90	57	39%
1159	8,317	29.9	125.2	155.1	9,246	33	90	123	32	21%
1165	8,520	30.7	89.7	120.4	17,573	63	20	84	37	31%
Ave.	**8,247**	**29.7**	**127.3**	**157.0**	**4,047**	**15**	**96**	**111**	**46**	**30%**

Table E2: **GHG emissions based 2022 ECCC electricity grid scenario**

House	Natural Gas (t_{CO2e})	Electricity (t_{CO2e})	Natural Gas (t_{CO2e}/yr)	Electricity (t_{CO2e}/yr)	Total (t_{CO2e})	Total (t_{CO2e}/yr)
1074	0.0	106.2	0.0	3.8	106.2	3.8
1075	13.8	59.2	0.5	2.1	73.0	2.6
1078	46.1	65.8	1.6	2.3	111.8	4.0
1082	10.5	32.0	0.4	1.1	42.4	1.5
1086	16.3	19.7	0.6	0.7	36.0	1.3
1088	3.7	74.4	0.1	2.7	78.1	2.8
1089	11.3	47.0	0.4	1.7	58.3	2.1
1090	0.2	49.7	0.0	1.8	49.9	1.8
1094	8.4	47.6	0.3	1.7	56.0	2.0
1098	74.8	0.2	2.7	0.0	75.0	2.7
1100	57.3	1.1	2.0	0.0	58.4	2.1
1101	43.3	0.8	1.5	0.0	44.1	1.6
1104	0.3	34.4	0.0	1.2	34.7	1.2
1107	57.8	0.9	2.1	0.0	58.7	2.1
1110	212.1	(38.1)	7.6	(1.4)	174.0	6.2
1112	15.4	64.4	0.5	2.3	79.8	2.9
1113	4.5	55.8	0.2	2.0	60.2	2.2
1115	162.7	41.2	5.8	1.5	203.9	7.3
1118	79.7	(32.9)	2.8	(1.2)	46.8	1.7
1119	34.8	(0.8)	1.2	0.0	34.0	1.2
1130	12.3	(0.1)	0.4	0.0	12.2	0.4
1131	114.0	(5.9)	4.1	(0.2)	108.1	3.9
1135	21.2	0.0	0.8	0.0	21.1	0.8
1140	39.7	0.0	1.4	0.0	39.7	1.4
1141	31.6	54.8	1.1	2.0	86.5	3.1
1159	52.2	(5.1)	1.9	(0.2)	47.1	1.7
1165	102.1	(49.7)	3.6	(1.8)	52.4	1.9
Average	**45.4**	**23.1**	**1.6**	**0.8**	**68.5**	**2.4**

Appendix B: Decarbonization Scenario Background Information

B.1 AESO Long Term Outlook Scenarios

The reference scenario is the base scenario that represents Alberta's ”current view on the future of the energy market” and is based on Alberta's Technology Innovation and Emissions Reduction (TIER) regulation [45]. TIER is an emission factor benchmarking tool that industrial plants must comply with to help them ”find innovative ways to reduce emissions and invest in clean technology to stay competitive and save money” [51]. TIER is specific for plants that emit more than 2,000 tonnes of carbon dioxide, if the plant is in an ”emissions-intensive, trade-exposed sector”, if the plant has emitted more than 100,000 tonnes of carbon dioxide in 2016, and/or if a plant is in competition with a regulated plant [51]. If plants are above the emissions factor specified in the TIER for that year, they must pay a penalty, otherwise they can receive credits [51]. The clean-tech case is defined as the ”scenario that tests an upside to trends in decarbonization, electrification and cost reductions in renewables that accelerate grid changes toward low emissions and greater Distributed Energy Resources (DER) technologies ” [45]. The robust global oil and gas demand case is the ”scenario that tests the impact of an aggressive growth outlook for Alberta's energy sector” [45]. The stagnant global oil and gas demand case is the ”scenario that tests the impact of economic stagnation in Alberta due to muted investment in the oil and gas sector” [45].

B.2 AESO Net Zero Emissions Pathway Emission Reduction Scenarios

The dispatchable dominant scenario is summarized as "a scenario where thermal units with low carbon emissions, resulting from carbon capture or hydrogen combustion technologies, continue to form a significant portion of Alberta's supply mix" and focuses on the usage of "blue hydrogen-fired simple cycle (SC) generation" and combined-cycle (CC) generation with carbon capture and storage (CCS) [48]. CC generation would replace coal to gas systems weree CCS is introduced in 2026 and and starting in 2030, blue hydrogen-fired SC is used [48]. The first mover advantage scenario is summarized as "a scenario with continued high growth in renewables and moderate energy storage additions which displace dispatchable thermal units" [48]. Wind installation increases from 2022-2041, solar installation stops by 2030, and hydrogen-fired SC and CC with CCS is used as the renewables backup systems [48]. The renewables and storage rush scenario is summarized as "the highest renewables-addition scenario coupled with high volumes of energy storage and the lowest amount of low carbon thermal-based supply additions", steping up from the first mover advantage scenario [48].

Appendix C: Coefficient of Innovation and Imitation from Meta-Analysis

The summary of reports within the meta-analysis for the coefficient of innovation and imitation for household technologies in the United states only are shown in Table C.1.

Technology	Year	p	q	Source	Technology	Year	p	q	Source
Electric Fridge	1920-1940	0.003	0.2	[59]	Clothes Dryer	1949-1961	0.02	0.3	[101]
Freezers	1946-1961	0.02	0.2		Air Conditioners	1949-1961	0.02	0.4	
Black and White Television	1946-1961	0.03	0.3		Color Televisions	1963-1970	0.04	0.6	
Air Conditioners	1946-1961	0.01	0.4		Dishwasher	1949-1961	0.0035	0.1	
Dryers	1948-1961	0.02	0.4		Clothes Dryer	1949-1961	0.01	0.4	
Water softeners	1949-1961	0.02	0.3		Air Conditioners	1949-1961	0.007	0.4	
Lawn mowers	1948-1961	0.009	0.3		Color Televisions	1963-1970	0.02	0.7	
Electric bed coverings	1949-1961	0.006	0.2		Black and White Television	1947-1953	0.03	0.6	[102]
Coffee Maker	1948-1961	0.02	0.3				0.00002	0.3	
Steam Irons	1949-1960	0.03	0.3					1.7	
Recover Player*	1952-1961	0.02	0.7		Color Television	1963-1970	0.03	0.6	
Color Television (retail)**	1959-1969	0.005	0.8	[103]			0.01	0.4	
Color Television (Manu.)	1959-1969	0.007	0.8					1.2	
Color Television	1963-1966	0.005	0.8	[104]	Clothes Dryer	1949-1961	0.02	0.3	
	1963-1972	0.005	0.8				0.009	0.2	
Cable Television	1963-1966	0.008	0.4					0.8	
	1963-1972	0.009	0.4		Air Conditioners	1949-1961	0.01	0.4	
Electric Refrigerators	1922-1940	0.02	0.06	[105]			0.0002	0.2	
Air conditioner	1946-1961	0.05	0.2					0.8	
Dishwasher	1947-1968	0.0004	0.2		Dishwasher	1949-1961	0.01	0.2	
Black and White Television	1948-1960	0.06	0.1				0.02	0.4	
Clothes Dryer	1950-1961	0.07	0.2					0.4	
Color Television	1961-1970	0.01	0.5						

*assumed to be record players; **retail sales; manufacturer sales

Table C.1: Average coefficient of imitation and innovation for technologies used in homes from data set used in meta analysis [64]