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Reframed Initiative: Outcomes and analysis

A study of six best-in-class deep retrofit schematic designs

Betsy Agar, Rajeev Kotha

April 2024

photo: Roberta Franchuk, Pembina Institute

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About the Pembina Institute

The Pembina Institute is a national non-partisan think tank that advocates for strong, effective policies to support Canada's clean energy transition. We employ multi-faceted and highly collaborative approaches to change. Producing credible, evidence-based research and analysis, we consult directly with organizations to design and implement clean energy solutions and convene diverse sets of stakeholders to identify and move toward common solutions.

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These acknowledgments represent the initial steps toward a multi-generational journey of understanding, justice, reconciliation, and commitment to fostering an equitable and inclusive future for all members of society. We share these acknowledgements in the spirit of truth, aiming to contribute positively to the collective pursuit of a more just and inclusive future.

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1. Executive summary

Results from the Reframed Initiative confirm that upgrading Canada's existing buildings with deep retrofits is the best way for buildings to meet the country's net-zero commitments while making homes affordable and protecting Canadians from extreme weather brought on by climate change. The Reframed Lab was a collaborative initiative led by the Pembina Institute in partnership with the City of Vancouver, the BC Non-Profit Housing Association, Metro Vancouver Housing Corporation (MVHC), and the Province of British Columbia (BC Housing).

Reframed brought together more than 70 professionals dedicated to reimagining the retrofits of six low-rise multi-unit residential buildings for low-income households, seniors and people living with disabilities, mental health issues and substance abuse. The retrofits targeted substantial energy and carbon emissions reductions, while prioritizing a range of benefits beyond energy savings, such as climate adaptation and resilience, and occupant health and well-being.

The Lab harnessed strategies and collaborative efforts to transform existing buildings into resilient, energy-efficient, and healthy living spaces for vulnerable communities. The resultant schematic designs formed the basis for deep retrofits on all six buildings to be implemented in 2024 and 2025. This pivotal work not only highlights innovative approaches to building decarbonization and adaptation but also charts a path for nation-wide adoption of retrofit practices to drive down heating and cooling costs for Canadians.

1.1 Key findings

The Reframed design teams estimate deep retrofits can cut energy use by up to 90% and operational carbon emissions reductions up to 99% — further underscoring the comprehensive opportunity deep retrofits present for driving down energy demand, lowering emissions, and cutting utility costs during an affordability crisis.

Our findings underscore the potential for significant impact in:

- **Carbon emissions reduction**: Demonstrating clear pathways to drastically lower the carbon footprint of existing buildings.
- **Increased affordability**: Revealing how energy efficiency retrofits can reduce living costs for occupants, contributing to greater housing affordability.

- **Healthier living spaces**: Highlighting the non-energy benefits of retrofits in improving indoor air quality and overall occupant well-being.
- **Improved resiliency**: Showcasing how retrofitting buildings ensures occupant resilience to withstand climate change impacts, enhancing longevity and safety.

The Reframed Lab fostered a collaborative environment where design team members developed retrofit plans, addressing sustainability challenges through advanced tools encompassing climate adaptation, seismic resilience, occupant health and well-being, and embodied carbon considerations alongside energy and carbon reduction.

With a focus on creating a library of concept designs, the initiative aimed to showcase the technical and financial viability of deep retrofit measures compared to business-as-usual approaches, laying the groundwork for best-in-class retrofits to enhance building resilience, thermal comfort, energy efficiency, and climate impact. Through a detailed cost analysis, the initiative demonstrates the potential financial implications of holistic retrofit strategies, shedding a light on the cost barriers to achieving more impactful, affordable, equitable outcomes.

This report aims to stimulate a constructive dialogue, underpinned by solid evidence and research, about advancing towards a future where deep retrofits are a normative practice, contributing to Canada's 2050 decarbonization targets.

1.2 Recommendations to governments

Send a strong market signal: Introduce standards and regulations that raise the floor of minimum building performance to open markets for industry leaders, paving the way to market transformation and better outcomes for owners and occupants.

Lead through public procurement: All levels of government can help advance and stimulate market uptake of deep retrofits by adopting innovative procurement practices for government-owned buildings that link innovative design, construction, and operations.

Close the deep retrofit cost gap: Invest to help build supply and demand for deep retrofits until the market reaches the economies of scale that lead to cost compression and a self-supporting business case for deep retrofits.

Educate owners on the benefits of deep retrofits: Build demand for deep retrofits by informing owners about the risk of short-sighted investments and the value of implementing holistic, long-term asset management plans that recognize key opportunities in component life cycles.

Invest in workforce development and supply chain growth: Offer opportunities like the Reframed Lab, which unites professionals from the retrofit supply chain, enhancing learning and identifying knowledge and capacity gaps essential for delivering deep retrofits amidst increasing regulations and incentives.

2. About the Reframed Lab

The Reframed Lab was developed and hosted by the Pembina Institute in partnership with the Province of British Columbia (BC Housing), the Metro Vancouver Housing Corporation (MVHC), the City of Vancouver and the BC Non-Profit Housing Association. To facilitate learning, MVHC and BC Housing[1] each identified three multi-unit residential buildings, for a total of six buildings, to be the study subjects of the Lab. The buildings, slated for substantial retrofits, are low-rise multi-unit residential buildings (MURB) serving low-income households, seniors and people living with disabilities, mental health issues and substance abuse.

In this report, we introduce the Reframed Lab and the subject buildings, summarize the schematic designs proposed by the design teams, report the projected energy and carbon reductions the schematic design proposals are expected to achieve, and discuss key takeaways from the lab process and early schematic design development.

2.1 Purpose

The purpose of the Reframed Lab was to:

- Create a collaborative environment where multiple teams can develop comprehensive retrofit plans, supported by a community of practice, all tackling real-world projects simultaneously.
- Develop design tools to aid assessment and design for climate adaptation, seismic resilience, health and wellness, and embodied carbon, in addition to energy and carbon emission reduction.
- Develop a library of concept designs that show the technical and financial feasibility of deep retrofit measures as compared with 'baseline' approaches that meet building code minimums.
- Identify schematic designs that will form the basis for the call for design and construction of best-in-class deep retrofits that will make the buildings more climate and seismic ready, healthier, and more comfortable, more energy efficient and less harmful to the climate.

[1] Owned and operated by Ask Wellness, Tikva Housing Society, and Pacifica and under an operating agreement with BC Housing.

- Estimate the cost difference between baseline retrofits and best-in-class deep retrofits when approached from a whole-building design perspective and capitalizing on synthesis between design objectives.

2.2 Process

The Pembina Institute, BC Housing, and the BC Non-Profit Housing Association selected design teams through a competitive Request for Proposals (RFP), creating teams of three to four professionals including architects, engineers, and potentially construction managers, alongside the building owner. From December 9, 2021, to June 2, 2022, teams took part in the Reframed Initiative's Exploration Lab, a series of workshops that encouraged collaborative design and strategy development for building retrofits. The results, including final designs and cost estimates, were revealed at a symposium on October 6 and 20, 2022. Following this, the Pembina Institute, with the design teams and Reframed partners, conducted the financial and comparative analysis presented in this report. For detailed information on the teams involved, please refer to Appendix A.

Design teams participating in the Reframed Lab were able to work on real-life projects with the support of a network of expert consultants and peers who shared knowledge and provided feedback on their design decisions during a series of workshops (schedule illustrated in Figure 1).

- **Workshop 1**: Design teams introduced the buildings for which they were contracted to design and analyze their existing performance; they worked through an exercise identifying challenges and opportunities in meeting the design objectives.
- **Workshop 2**: Seismic resilience[2] and climate adaptation[3] experts presented tools and strategies to assess risks and to help develop adaptation and resilience design options.
- **Workshop 3**: An expert on indoor environmental quality, inclusion, accessibility, and occupant needs[4] led teams through an analysis and design process. An embodied carbon expert[5] presented and worked with the teams on assessing embodied carbon of design decisions.

[2] Lisa Westerhoff and Robin Hawker, Integral Group

[3] John Sherstobitoff, Ausenco

[4] Joanne Sawatzky and Brenda Martens, Light House Sustainability Society

[5] Anthony Pak, Priopta

- **Workshop 4**: Teams presented carbon and energy modelling based on well-established assessment approaches, as well as preliminary cost estimates and financial analyses for four concept designs.
- **Workshop 5**: Teams presented the feasibility study results for the four concept designs and indicated which pathway they would recommend for developing a full schematic design for feedback from their peers, the experts, and an evaluation committee (made up of Reframed partners).
- **Workshop 6**: In the final Lab workshop, teams presented their preliminary schematic designs with cost estimates and how they met the Reframed design goals.

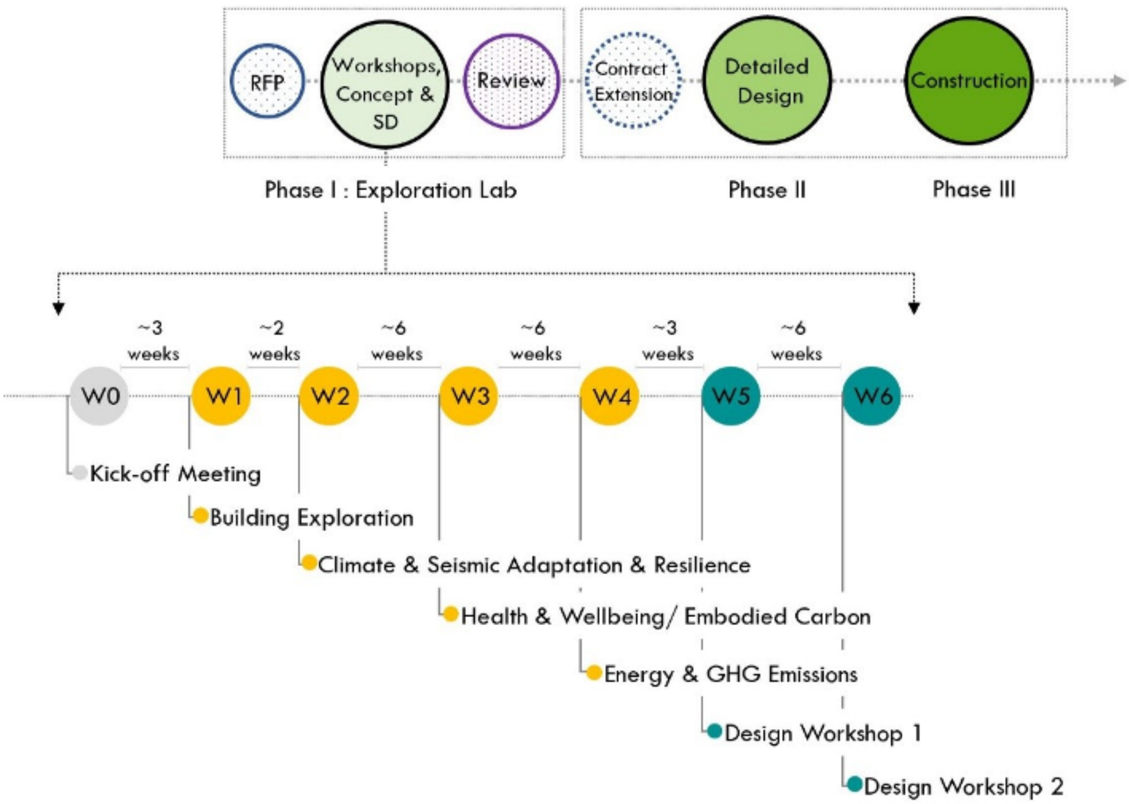

Figure 1. Reframed project phases and phase 1 workshops

2.3 Design objectives

Working on independent projects and deliverables, teams were asked to think beyond their singular project towards solutions more broadly applicable across the low-rise MURB archetype on which they were all working. In addition to ensuring aesthetic and architectural design quality, the primary objectives design teams addressed in in their schematic designs included:

Primary objectives:

- Reducing operational GHG emissions
- Reducing energy consumption
- Maximizing life cycle net present value

Non-energy benefits:

- Enhanced climate adaptation and climate resilience based on local climate risks like extreme heat and cold and forest fire smoke
- Seismic upgrades to meet three performance objectives and roof structural upgrades
- Prioritizing occupant health and well-being
- Minimizing on-site construction and disturbance to occupants
- Enabling the addition of new floor(s) and/or unit(s)
- Minimizing added life cycle embodied carbon associated with the retrofit
- Optimizing on-site PV electricity generation and storage
- Exploring the feasibility of other on-site renewable energy generation technologies

For a detailed understanding of the foundational objectives guiding the retrofit concepts and solutions, please see Appendix B.

Teams were tasked with creating feasibility studies for four distinct concept design bundles primarily aimed at reducing energy consumption and GHG emissions but also to improve building and occupant resilience, among other benefits. The first bundle aimed for a 50% reduction in emissions, while bundles two through four targeted an 80% reduction. These goals align with the Clean BC Road Map's objectives for 2030 and 2050, respectively.

With the goal of selecting the most impactful and sustainable approach for implementation, teams analyzed energy and carbon performance modelling of their design bundles and compared the results to existing conditions and projected performance of a baseline ‘like-for-like’ retrofit baseline.

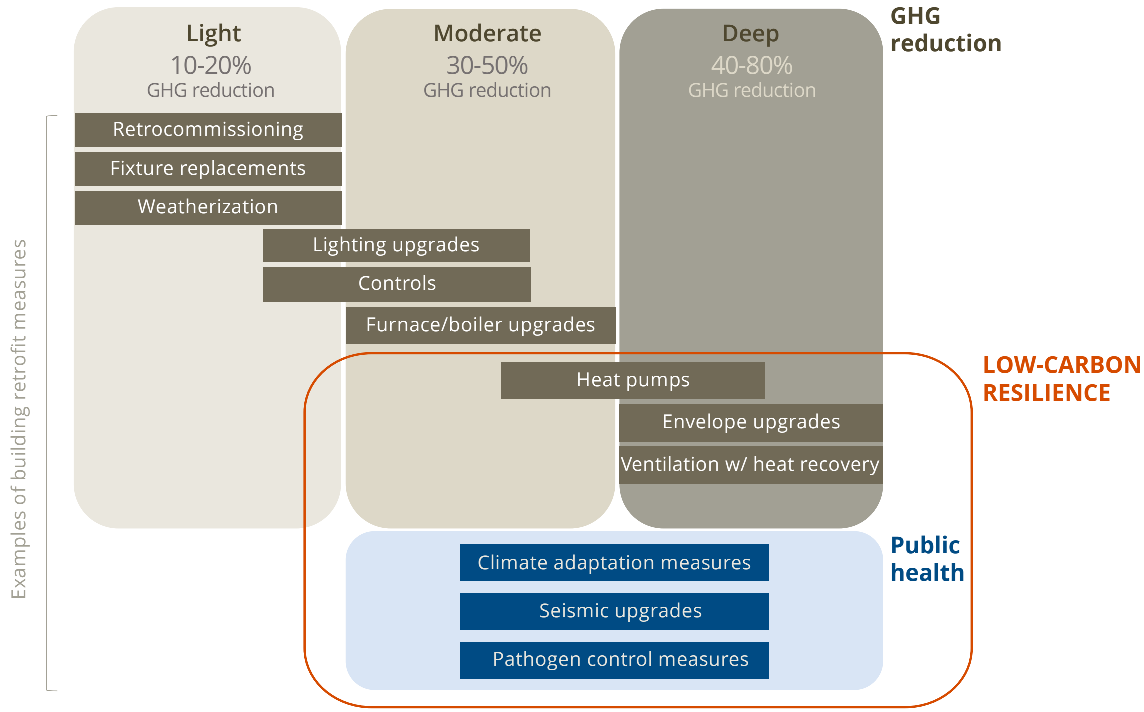

Figure 2. Building retrofit measures for GHG reduction and resilience

Out of this analysis, the building owners and Reframed Initiative partners selected one concept design to move forward to the schematic design and drawings phase. The present analysis compares performance of the final deep retrofit schematic design with existing and baseline modelling. Descriptions of the existing, baseline and deep retrofit bundles are described below:

> **Existing conditions**: Teams modelled existing building performance to understand the impacts of the concept design bundles relative to the building's existing performance. Financial analyses of the preferred design approach were compared to existing performance of the building.
>
> **Like-for-like baseline retrofit**: Teams identified and modelled like-for-like retrofit measures expected to be needed just to keep the facility maintenance and repair up to date. This baseline was used to help isolate the costs and benefits in the analysis of ambitious energy and carbon reduction targeted by the feasibility studies.
>
> **Deep retrofit schematic design**: Teams developed best-in-class concept design bundles that included envelope and mechanical equipment upgrades to maximize GHG emissions reduction (in the range of 80% compared to the

existing building) while balancing performance with other Reframed objectives (described below). The preferred bundle for each building was developed into a full schematic design.

3. Reframed buildings

The selection process for the Reframed buildings began with an initial pre-screening based on criteria such as ownership model, construction year, and heating systems. Following this, detailed surveys assessed characteristics like the building's area, number of units, and structural design. The teams then evaluated performance metrics such as energy consumption and GHG reduction potential. Condition assessments, financial considerations, and potential social benefits played a key role in guiding the final selection.

All the buildings studied in the Reframed Lab are low-rise, multi-unit residential buildings (MURBs). The subject buildings were selected for several reasons:

- Their vintage (age and buildings code in effect at time of construction) offers significant opportunities for carbon emissions reductions as they have high energy demands served by natural gas-based equipment.
- The envelopes are characterized by low R-values and poor airtightness, making them prime candidates for enhancements such as recladding or panelized retrofits.
- With relatively simple architecture, these buildings lend themselves to exterior retrofits, allowing tenants to remain in place during construction.
- A common archetype in B.C., low-rise MURBs represent a large opportunity for scaling up the solutions developed by the design teams.

3.1 Building descriptions

Building descriptions are provided in Table 1 and details are summarized in Table 2.

Table 1. Building descriptions

Medewiwin

Located in Victoria, B.C., Medewiwin houses seniors and is operated by Pacifica Housing with support from BC Housing through an operating agreement. The original three-storey, wood-framed building was built in 1963 and a two-storey addition was built in 2002. The 1,347 m^2 floor area provides 26 housing units for up to 50 residents.

Dany Guincher

Dany Guincher is in Vancouver, B.C., and operated by Tikva Housing Society with support from BC Housing. This three-storey, wood-framed multi-unit residential building was built in 1970 and enables individuals with disabilities to live independently. With a total conditioned floor area of 588 m^2, it comprises 11 units that accommodate up to 15 residents and has underground parking.

Manor House

Manor House is an MVHC building in the City of North Vancouver that provides supportive housing for families, seniors, and individuals living with disabilities. Constructed in 1970, this four-storey wood-framed building has large windows and private balconies. The building has 50 units within a conditioned floor area of 3,865 m^2, houses up to 80 residents and has underground parking.

Crown Manor

Crown Manor provides supportive housing in New Westminster, B.C., under the management of MVHC. This three-storey wood-framed MURB provides 2,468 m^2 of conditioned floor space including 29 living units, providing homes for up to 60 residents, including families, seniors, and those living with disabilities. The facility has balconies and an underground parking garage, topped with a unique concrete slab that extends to create additional surface parking.

Le Chateau

Le Chateau is an MVHC property in Coquitlam, B.C. This wood-framed, low-rise building provides supportive living for families, seniors and individuals living with disabilities. Erected in 1976, this three-storey structure has 24 dwelling units and 2,359 m^2 of conditioned floor area. It accommodates up to 48 residents and offers two levels of underground parking.

Crossroads Inn

Crossroads Inn is a four-storey steel-framed building operated by the Ask Wellness Society and is supported by BC Housing initiative through an operating agreement. A former hotel, this 1,474 m^2 building has 50 residential units and has been adapted to provide homes for up to 75 residents. At the ground level, Ask Wellness also provides support services for residents and members of the broader Kamloops community who are navigating mental health and substance use.

Table 2. Overview of building characteristics for the six MURBs in the Reframed initiative study

Building Name	Location (Climate Zone)	Housing Corporation	Structure Type	No. of Storeys	Year Built	Dwelling Units	Total Conditioned Floor Area (m^2)	Common Space (m^2)	Parking Details
Medewiwin	Victoria (CZ 4)	Pacifica Housing	Hybrid concrete masonry & wood	3 (+2 extension)	1963 (2002)	26	1,347	Not available	No designated parking
Dany Guincher	Vancouver (CZ 4)	Tikva Housing Society	Wood-framed	3	1970	11	588	125	8 parking stalls, 1 parking storey, parking area: 213m²
Manor House	North Vancouver (CZ 4)	MVHC	Wood-framed	3	1970	50	3,865	588	57 parking stalls, 1 underground parking storey
Crown Manor	New Westminster (CZ 4)	MVHC	Wood-framed	3	1966	29	2,468	441	External parking
Le Chateau	Coquitlam (CZ4)	MVHC	Wood-framed	4	1976	24	2,359	669	2 stories of underground parking
Crossroads Inn	Kamloops (CZ 5)	Ask Wellness Society	Steel-framed	4	1994	50	1,474	Not available	No designated parking

3.2 Existing building performance overview

At 309 kWh/m^2/yr, the median energy use intensity for the buildings in this study are 50% higher than the B.C. average for similar buildings with natural gas space and water heating, which is estimated at 200 kWh/m^2/yr.[6]

The six buildings demonstrate a range of energy performance characteristics, reflecting diverse construction periods and building upgrades. Roof insulation values in five of the buildings fall between RSI-1.41 to RSI-2.82 and wall insulation ranges from RSI-1.05 to RSI-1.97, indicating low thermal resistance. At RSI-4.4, Le Chateau's roof has the only insulation value that would meet today's minimum performance threshold of RSI-3.52 as defined by Step 1 in the Energy Step Code. Similarly, with values spanning from USI-2.90 to USI-7.0 the windows in all the Reframed buildings perform poorly, exceeding the thermal loss maximum set by today's code of USI-2.5, pointing to high potential for energy savings through window upgrades.

Modelled estimates of air leakage for all buildings suggest infiltration rates exceeding the typical assumed rate of 0.25 L/s/m^2 at 5 Pa[7], indicating these buildings are very drafty and allow heat to escape through their envelopes. At the same time, ventilation is relatively poor with most buildings dependant on bathroom and kitchen fans to exhaust stale indoor air.

All the building use boilers for space heating; these are considered mid-efficiency ranging between 80-88% efficient except for Crossroads Inn, which has a boiler for hydronic heating that was replaced in 2008 and is rated 92% efficient. The domestic hot water system efficiencies varied; half of the buildings have mid-efficiency hot water heating (DHW), two buildings have DHW systems that are classified as at least 92% efficient and one building has a DHW system operating at only 65% efficiency.

Detailed summaries of the measures across building designs (existing, baseline, and deep) are provided in Table 15 through Table 20, in Appendix C.

[6] RDH Building Science Inc., *Low-Rise Emission Reduction Study- Final Report* (2020).

[7] BC Building Code, A-10.2.3.4. (3) Air Leakage Rates.
https://free.bcpublications.ca/civix/document/id/public/bcbc2012/23094234de2

3.3 Key building manager and tenant concerns

To complement design team building assessments, we engaged a consultant to consult and gather information from managers and tenants from the buildings located in the lower mainland (Medewiwin, Manor House, Crown Manor, and Le Chateau). They were asked how they would rate their overall satisfaction, thermal comfort, air quality, lighting, noise, common space, and energy affordability. The key outcomes are summarized below and in Table 3.

Overall, tenants reported satisfaction with the buildings. The Crown Manor survey had the highest participation rate and raised no significant flags. That said, there is a cluster of “yellow” dots in the thermal comfort and air flow sections for all buildings. The tenants in Manor House were least satisfied with summer temperatures and lack of control over temperature, and they raised concerns about air flow. Similarly, Medewiwin tenants expressed dissatisfaction with having a lack of control in both summer and winter, and many use plug-in heaters. Medewiwin tenants also flagged concerns about noise transmission from neighbouring units.

Table 3. Tenant survey results

Survey Issue		Medewiwin	Manor House	Crown Manor	Le Chateau
Response Rate	No. of responses	13	21	17	14
	No. of units	25	50	22	30
	Response Rate	52%	42%	77%	47%
Overall	Unsatisfied with building overall	23%	24%	13%	7%
	Rate curb appeal of building as unattractive	31%	43%	13%	21%
	Very infrequent interaction with neighbors	23%	29%	7%	21%
Thermal Comfort	Find temp uncomfortable in summer	46%	76%	53%	64%
	Unsatisfied with ability to control temperature in summer	69%	71%	35%	36%
	Have AC	23%	29%	41%	36%
	Find temperature uncomfortable in winter	62%	40%	29%	42%

	Unsatisfied with ability to control temperature in winter	69%	50%	29%	58%
	Have plug-in heater	69%	35%	29%	58%
Air Quality	Find airflow is not 'just right'	38%	70%	50%	38%
	Unsatisfied with freshness of air	54%	43%	38%	36%
Lighting	Unsatisfied with overall lighting	46%	29%	13%	36%
	Describe natural light as too little	54%	29%	0%	14%
	Unsatisfied with electrical lights	38%	33%	13%	29%
Noise	Unsatisfied with overall noise level	18%	29%	19%	57%
	Describe neighbours as 'very loud'	69%	30%	13%	62%
	Describe noise from outside the building as 'very loud'	38%	33%	33%	50%
	Describe noise from appliances as 'very loud'	15%	38%	25%	57%
Common Spaces	Unsatisfied with temperature in common spaces	8%	48%	25%	43%
	Find light in common spaces unacceptable	0%	24%	13%	0%
	Unsatisfied with availability of spaces for socializing	15%	30%	25%	7%
Energy Affordability	Find electricity bills a burden	NA	33%	38%	50%

Dissatisfaction with summer temperatures is consistent with modelling conducted by design teams, which shows overheating as a primary climate risk. Indoor air quality, temperature control, lighting quality, and seismic resilience are additional concerns the design teams raised in their assessments of the buildings.

Legend

- Good outcome
- Middling outcome
- Bad outcome

4. Deep retrofit designs

4.1 Baseline upgrade designs

To help illustrate the benefits of the deep retrofits, design teams developed baseline designs for like-for-like replacements needed for systems reaching end of life. By modelling the performance of more typical interventions, designers could isolate the incremental costs and benefits of carrying out deep retrofits, which facilitated the financial analysis of the deep retrofit designs.

At a high level, baseline upgrades included roof insulation for Crossroads Inn and Medewiwin, and wall insulation was recommended for Crown Manor and Dany Guincher. Window upgrades were recommended for all but Crossroads Inn, and air sealing was recommended for Dany Guincher and Manor House. Space heating upgrades with condensing gas-fired boilers were recommended as baseline replacements for Manor House, Dany Guincher, and Le Chateau. An air handling unit with a heat recovery ventilator (HRV) was also recommended for Dany Guincher.

4.2 Deep retrofit schematic design proposals

Deep retrofit schematic design details are included in Appendix C and a high-level summary of the key measures are provided in Table 4.

To improve the performance of the building envelopes, insulation and air sealing were included in the deep retrofit designs for all six buildings. Recommendations for increasing roof insulation improvements varied, with some buildings opting to maintain existing levels and others stepping up to RSI values above 7.0. The exterior recladding strategy resulted in the recommendations for wall insulation, generally increasing the RSI values to above 4.0. As part of the improvement process, all single-pane windows would be replaced with more efficient double or triple-pane alternatives (selection of window type depended on window-to-wall ratio, comfort objectives and financial impact).

In all cases, additional efficiencies were provided by upgrading conventional boilers and HVAC systems to air-source heat pumps (ASHP) and/or gas engine heat pumps (GEHP). This included replacing the existing makeup air units, which provided ventilation and corridor pressurization, with advanced systems such as HRVs and ERVs. Electrification of space and water heating systems was a key focus, especially for Le Chateau, Medewiwin, and Dany Guincher. Crown Manor and Crossroads Inn design teams recommended partial electrification of space heating systems for various reasons, including recent boiler replacements and the recognition that significant GHG emissions reductions could also be achieved through a diversified natural gas pathway. This approach helps avoid potential challenges such as the need for electrical panel capacity upgrades. Air sealing was recommended for all buildings with some aiming for leakage rates as low as 0.1 $L/s/m^2$. In-suite HRVs or ERVs would be introduced to provide efficient and balanced ventilation. Four of the buildings implemented LED fixtures coupled with occupancy sensors to further optimize energy consumption.

Table 4. Key measures for deep retrofit designs across buildings

Measure	Medewiwin	Dany Guincher	Manor House	Crown Manor	Le Chateau	Crossroads Inn
Envelope upgrades	RSI-7.04 roof and RSI-5.28 walls	RSI-7.04 roof and RSI-4.4 walls	RSI-6.9 roof and RSI-2.6 walls	RSI-5.3 roof and RSI-4.2 walls	RSI-4.4 roof and walls	RSI-7.0 roof and RSI-1.76 walls
Window upgrades	Double-glazed windows	Double-glazed windows	Triple-glazed windows	Triple-glazed windows	Double-glazed windows	Double-glazed windows
Ventilation	In-suite ERVs for new portion, 1 corridor AHU	In-suite HRVs, corridor AHU with HRV	In-suite HRVs, roof AHU with hydronic coil	In-suite HRVs, corridor MUA	In-suite HRVs, 2 corridor MUAs w/ electric resistance heating	In-suite HRVs, roof MUA with electric heating coil
Electrification	Full	Full	No	Full	Full	Partial
Renewable generation	Solar PV for energy generation and solar thermal DHW preheating	None	Solar thermal DHW preheating	Solar PV for energy generation	None	None
High-efficiency heating	In-suite ASHPs for new portions, central ASHP for common areas	In-suite mini-split ASHPs	Gas engine heat pumps (GEHP) for heating	Central ASHP	In-suite ASHPs	In-suite ASHPs
Other space heating and cooling measures	Baseboards and in-floor heating for old portions (served by ASHP)	DOAS heating coil for pre-conditioning corridor ventilation air	Heat pump system (hydronic coil heating and water-cooled DX cooling)	In-suite mini-splits, hydronic baseboards served by the heat pump	Electric baseboards for common areas	Hydronic baseboards (served by a gas boiler) for common areas only
Water heating	Air-to-water DHW HP with solar preheat (CO_2 refrigerant)	2 DHW ASHPs (CO_2 refrigerant)	GEHP, drain water heat recovery and solar pre-heating	DHW ASHP	5 DHW HPs (CO_2 refrigerant)	2 electric resistance DHW heaters

Lighting upgrades	LEDs and occupancy sensors	LEDs and occupancy sensors	LEDs	LEDs	LEDs and occupancy sensors	LEDs and occupancy sensors
Backup systems	None	None	Backup condensing boiler for heating	Retain the existing gas boiler as backup to provide redundancy	Backup generator to power lighting, heating, and power for common areas and elevators	Retain the existing hydronic baseboards as backup during peak winter conditions
Seismic upgrades	Full-code seismic upgrade	Shear wall upgrade	No seismic upgrades	No seismic upgrades	Seismic upgrade per 2020 guidelines	No seismic upgrades

Legend	
(green)	Optimal performance
(yellow)	Partially meets expectations
(red)	Opportunity for improvement

4.3 Unique approaches and technologies

In addition to reducing energy demand and carbon emissions, participants in the Reframed Lab workshops were tasked with integrating climate adaptation and seismic resilience, considering health and well-being of occupants, and reducing embodied carbon in their material choices. Teams were asked to consider creative solutions for achieving other non-energy objectives that are hard to account for in financial analyses such as those listed in section 2.3 and categorized below:

- Adaptation measures
  - Enhanced climate adaptation and climate resilience based on local climate risks
  - Seismic upgrades to meet three performance objectives, and roof structural upgrades
- Passive thermal upgrades
  - Comprehensive wall and roof upgrades
  - Triple-pane windows
- Occupant experience enhancements
  - Prioritizing occupant health and well-being
  - Minimizing on-site construction and disturbance to occupants
- Energy and cost-saving features
  - Optimizing on-site solar PV electricity generation and storage
  - Exploring the feasibility of other on-site renewable energy generation technologies
- Additional unique features
  - Enabling the addition of new floor(s) and/or unit(s)
  - Minimizing added life cycle embodied carbon associated with the retrofit

Table 5 summarizes the unique strategies each team developed to help address the needs of building managers and tenants identified through interviews and tenant engagement surveys.

Table 5. Comparative overview of unique schematic design features by building

Project Name	Adaptation Measures	Passive Thermal Upgrades	Occupant Experience Enhancements	Energy & Cost Savings Features	Additional Unique Features
Medewiwin	In-suite cooling, seismic upgrades	Roof and wall insulation	Slip-resistant finishes, localized temperature control	Solar PV panels, solar thermal domestic hot water pre-heating	-
Dany Guincher	Electrification, heat recovery ventilators	-	Fresh air filtration	Reflective roof coating, comprehensive climate resilience plan	Dedicated outdoor air system, flood resistance and waterproofing upgrades
Manor House	Centralized GEHP system, backup boilers	Roof and wall insulation, triple-pane windows	Fresh air filtration, in-suite HRVs	Drain water heat recovery, solar thermal domestic hot water pre-heating	Double-wall hot water tanks, reuse of hydronic piping systems
Crown Manor	Electrification, HRVs, seismic upgrades	Wall insulation, triple-pane windows, exterior overhangs	Fresh air filtration	Solar PV panels	Addition of two dwelling units
Le Chateau	Combined HRV/heat pump units, in-suite cooling, backup generator	Wall insulation	Fresh air filtration, replaces gas fireplaces	-	-
Crossroads Inn	PTHPs, in-suite cooling energy recovery ventilators	Comprehensive roof replacement with additional insulation	Fresh air filtration, moderates indoor humidity	-	Reuse of hydronic baseboards and boiler

5. Deep retrofit performance outcomes

Teams demonstrated the performance of their schematic designs by modelling total energy, heating and cooling energy (section 5.1) and carbon emissions (section 5.2). Section 5.3 describes the non-energy benefits of the proposed designs, while section 5.4. compares the costs of deep retrofit measures against costs of baseline building updates.

5.1 Energy performance

Heating energy consumption

All six deep retrofit schematic designs were projected to achieve significant reductions in the total heating energy consumption (space and water heating combined), ranging from 58% to 93%, compared to baseline designs (Figure 3). (For reference, median value comparisons reveal a 17% reduction in heating energy use per dwelling unit for baseline retrofits and 80% for deep retrofits, along with an 18% decrease per conditioned floor area (CFA) for baseline and 82% for deep retrofits). When compared with the modest reductions modelled for the baseline replacement designs, ranging from 3% to 56%, the deep retrofit schematic designs demonstrate the effectiveness of upgrading building envelopes with insulation, air sealing and high efficiency heating systems to achieve energy savings.

It is worth noting that the Crossroads Inn baseline retrofit design was the only one that did not include window upgrades, and it was projected to make only a 3% efficiency gain. Crossroads Inn is the newest of the six buildings and was built in 1994 under a more stringent code than the other five buildings. It is also in a seismic zone that is a lower risk area than the lower mainland and Vancouver Island where the other five buildings are located.

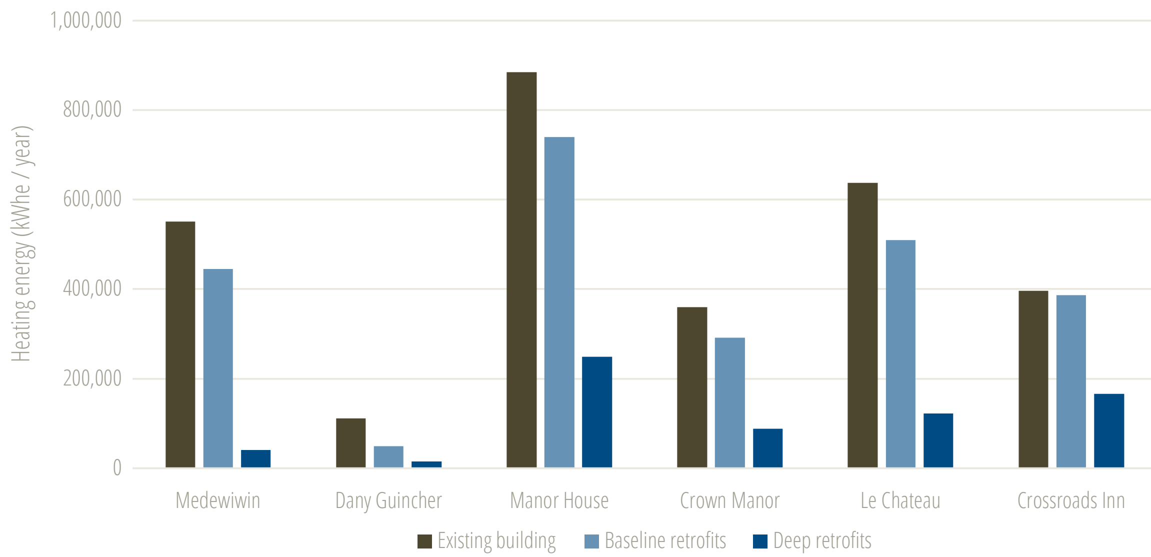

Figure 3. Comparison of heating energy use

The baseline design for Dany Guincher stands out as it includes seismic and insulation upgrades designed to meet 2022 BC Building Code, whereas other teams focused the baseline retrofit designs on more typical like-for-like replacements. This results in steep efficiency gains at the baseline level that the deep retrofit schematic designs achieve in the other buildings. Table 6 illustrates this well; whereas most designs reduce energy by 20% or less at the baseline level retrofit, the baseline design for Dany Guincher is projected to achieve an impressive 56%, highlighting the advancements in code requirements since Dany Guincher was constructed in 1970.

Not including Dany Guincher, the incremental difference between the heating energy consumption savings of the proposed baseline and deep retrofit schematic design retrofits range from 56% to 74%. Even with the more ambitious starting point, the incremental heating energy reductions projected for Dany Guincher's deep retrofit schematic design proposal are expected to achieve an additional 30% reduction.

Table 6. Total heating energy

Building	Heating energy consumption reduction (%)		
	Baseline	Deep retrofit	Incremental difference
Medewiwin	-19%	-93%	-74%
Dany Guincher	-56%	-87%	-30%
Manor House	-16%	-72%	-56%
Crown Manor	-19%	-76%	-57%
Le Chateau	-20%	-81%	-61%
Crossroads Inn	-3%	-58%	-56%

Total energy consumption

All deep retrofit schematic designs are projected to reduce total energy use by at least 44% compared to existing building performance despite additional energy use resulting from adding ventilation and cooling to satisfy climate resilience and health and well-being objectives. (For reference, median value comparisons reveal a 15% reduction in total energy use per dwelling unit for baseline retrofits and 68% for deep retrofits, along with a 16% decrease per CFA for baseline and 71% for deep retrofits).

Figure 4 illustrates the typical baseline retrofit results leading to nominal energy consumption reduction, in stark contrast to what can be achieved through deep retrofit measures.

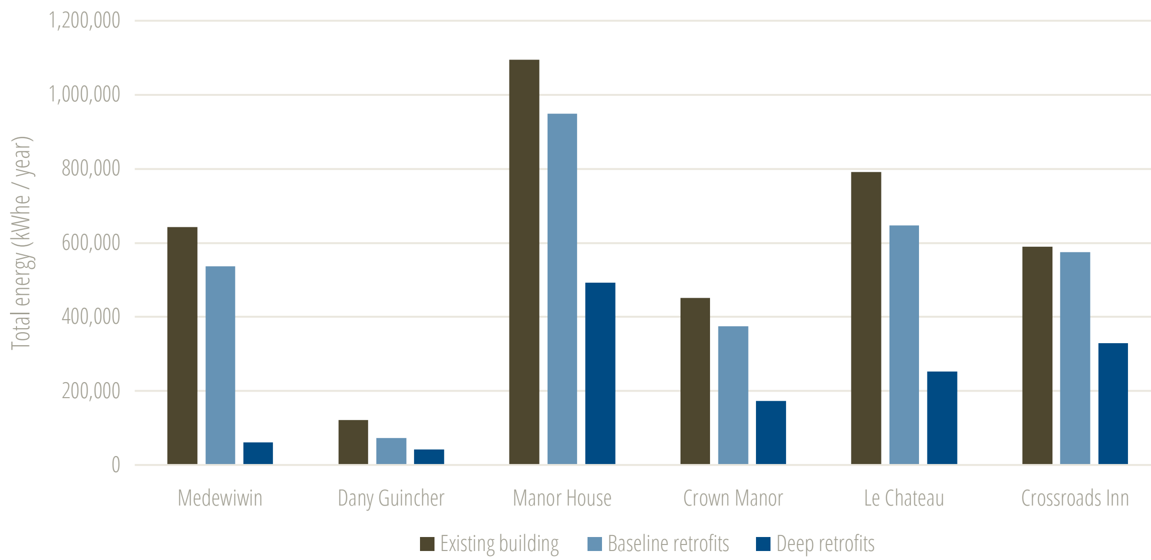

Figure 4. Comparison of total energy use

Although none of the buildings currently have hard-wired cooling systems, window air conditioners have been accounted for in the Le Chateau and Crossroads Inn existing conditions modelling, as illustrated in Figure 5. The deep retrofit schematic design for Manor House consists of central heat pump system and a modular GEHP to cool the zones and the common areas.

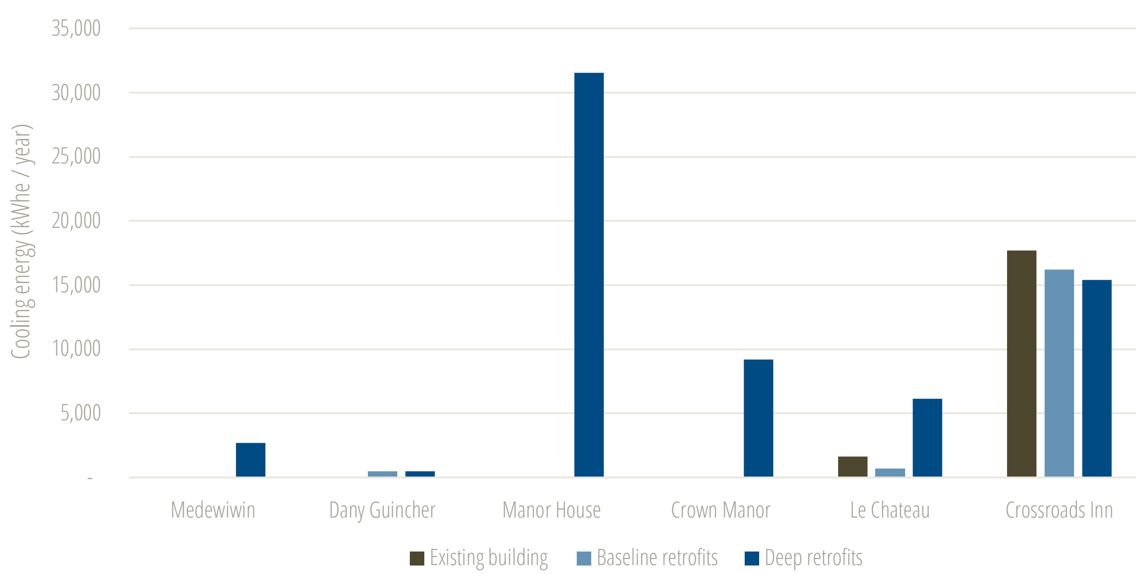

Figure 5. Comparison of cooling energy use

Table 7 shows the projected total energy consumption reduction compared with existing building performance. Total energy includes lighting, appliance and plug loads in addition to heating and cooling. Even with the addition of cooling, energy savings were achieved through passive and mechanical thermal upgrades, LED lighting and control upgrades, advanced ventilation systems with heat recovery, and installation of high-efficiency domestic hot water systems, including drain water heat recovery in one case.

Table 7. Total energy reductions from baseline and deep retrofit model performance estimates

Building	Total energy consumption reduction (%)		
	Baseline	Deep retrofit	Incremental difference
Medewiwin	-16%	-90%	-74%
Dany Guincher	-41%	-66%	-25%
Manor House	-13%	-55%	-42%
Crown Manor	-17%	-62%	-45%
Le Chateau	-18%	-68%	-50%
Crossroads Inn	-3%	-44%	-41%

Except for Medewiwin, the total energy use reductions are lower than the heating energy consumption, which reflects energy end uses that remain unchanged, such as plug loads, which are directly connected to occupant behaviour. The total energy intensities summarized Table 8 illustrate the nominal efficiency gains made through baseline retrofits as compared with the deep energy savings achieved through deep retrofits. As noted above, the Dany Guincher design team proposed a baseline retrofit designed to meet current building code requirements, which imposes stricter energy efficiency requirements than baseline retrofits. This is evidenced by the deeper reduction in energy intensity.

Table 8. Energy use intensity comparison from baseline and deep retrofit model performance estimates

Building	Energy use intensity (kWh/m²/y)		
	Existing building	Baseline retrofit	Deep retrofit
Medewiwin	480	400	50
Dany Guincher	210	120	70
Manor House	280	250	130
Crown Manor	180	150	70
Le Chateau	340	270	110
Crossroads Inn	400	390	220

5.2 Carbon performance

Comparing the baseline to deep retrofit carbon emission projections once again illustrates like-for-like replacement strategies do not achieve the carbon reduction targets needed to decarbonize existing buildings. Figure 6 shows that emissions projected for the baseline design remain close to existing conditions for most buildings. In regions of Canada, such as B.C., where the electrical grids are more decarbonized compared to others, the impact of fuel-switching on carbon reduction, while generally lower compared to regions with higher-carbon grids, can still be profoundly effective when combined with comprehensive energy efficiency measures and deep retrofit designs.

Like energy performance, teams were able to achieve GHG emission reductions of 68% or more with the deep retrofit designs (Table 9). Because of B.C.'s low-carbon electrical grid, fuel-switching all space and water heating systems nearly eliminates carbon emissions, as illustrated by the modelling results for Medewiwin and Dany Guincher. (Median comparisons show annual GHG emissions per dwelling unit decrease by 18% for baseline retrofits and 92% for deep retrofits, and per CFA by 19% for baseline and 92% for deep retrofits.)

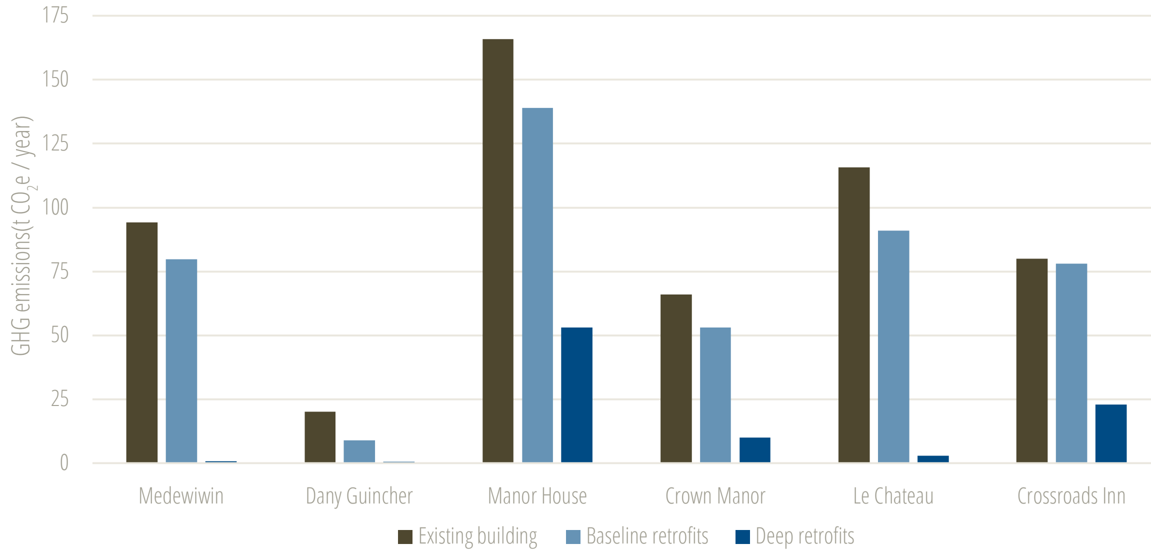

Figure 6. Comparison of annual GHG emissions

Table 9. Total annual GHG emissions reductions from retrofit model performance estimates

Building	Carbon emission reduction		
	Baseline retrofit	Deep retrofit	Incremental difference
Medewiwin	-15%	-99%	-84%
Dany Guincher	-55%	-98%	-42%
Manor House	-16%	-68%	-52%
Crown Manor	-20%	-85%	-65%
Le Chateau	-21%	-97%	-76%
Crossroads Inn	-3%	-71%	-69%

For five of the retrofit designs, modelling of the incremental carbon emissions show greater reductions than the heating energy consumption, largely because of partially or completely fuel-switching to electric space and water heating equipment. The 72% heating energy reduction and 68% carbon emission reduction projected for Manor House best illustrates the emissions reductions that are achievable through energy efficiency without fuel-switching.

5.3 Other non-energy benefits

The energy and carbon analyses tell only one part of the deep retrofit story as they do not capture the value of non-energy benefits, which are discussed below.

Climate adaptation

Canada is already experiencing the effects of climate change, including rising temperatures, increased frequency and intensity of wildfires, changes in precipitation patterns leading to droughts and floods, and in the North, thawing permafrost and diminishing ice and snow. Current construction design standards and practices are based on historic conditions, but the Global Commission for Adaptation estimates investment in infrastructure climate adaptation, including buildings, yields $4 in avoided recovery costs for every $1 spent.[8] Deep retrofits can and should be designed to achieve more than just reducing energy demand and carbon emissions. Done right, they can also make homes safer and better able to withstand extreme weather.

During the Reframed Lab, the teams were led through a resilience risk assessment and adaptation measure design exercise. The primary climate risks surfaced during the Reframed Lab were overheating during extreme heat events and poor indoor air quality due to smoke events. The teams integrated a range of recommendations, including:

- Transitioning from natural gas-powered furnaces and boilers to more efficient heat pumps (variations of these recommended for all buildings) that add space cooling to keep residents safe from extreme temperatures while keeping utility bills affordable. In increasingly hot summer months, opening windows alone does not help people keep their homes cool.
- Improving ventilation with filtration (recommended for all buildings) helps ensure people living in areas with poor outdoor air quality from pollution or forest fires can continue to draw in fresh air at times when opening a window would make indoor air quality worse.
- Increasing insulation (recommended at least double for Dany Guincher, Medewiwin, Le Chateau, Manor House, and Crown Manor), upgrading windows (triple-pane windows recommended for Crown Manor and Manor House) and sealing leaky building enclosures (recommended for all buildings) to reduce heat loss also seals out pollutants. These measures improve resilience because during

[8] Global Commission on Adaptation, *Adapt Now: A Global Call For Leadership On Climate Resilience* (2019). https://gca.org/reports/adapt-now-a-global-call-for-leadership-on-climate-resilience/

power outages, as a well-insulated, sealed building retains its indoor temperature for longer while heating or cooling systems are offline.

- Incorporating passive design features that offer adaptive resilience such as reducing solar gain by installing shading devices (recommended for Crossroads Inn).
- Integrating backup systems such as backup generators (recommended for Le Chateau), condensing boiler (Manor House) or solar PV (recommended for Medewiwin and Crown Manor) with battery backup to ensure primary systems continue to operate during power outages.
- Development of a comprehensive suite of operating and maintenance policies, procedures, and management practices to assist building operators to enable proactive, long-term maintenance and operation of the facility in the face of future climate hazards (recommended for Dany Guincher).

Embodied carbon

We engaged Priopta to work with the design teams on developing strategies to reduce embodied carbon through informed material and component selection. The following outcomes were reported:[9]

- Embodied carbon from the proposed retrofit designs (structure and envelope) ranged from 25 to 125 $kgCO_2e/m^2$, with an average of ~60 $kgCO_2e/m^2$.
- For most of the projects, insulation was the highest impact material, contributing 30-60% of total embodied carbon. Exterior walls and roofs were the highest impact building elements.
- The embodied carbon of mechanical, electrical, and plumbing systems was not included in this study, but based on other studies, is expected in the range of 10 to 50 $kgCO_2e/m^2$, averaging ~30 $kgCO_2e/m^2$ upfront carbon (not including end of life replacements after 10-20 years).
- Refrigerant leakage across all projects was estimated in the range of 0.3 to 1.7 $kgCO_2e/m^2$/year.

By way of comparison, average embodied carbon (structure and envelope) of low-rise wood framed residential buildings from the City of Vancouver Rezoning submissions for new construction range from 150 to 350 $kgCO_2e/m^2$, with an average of ~250 $kgCO_2e/m^2$. Embodied carbon from the proposed Reframed retrofit designs is roughly 25% of the total embodied carbon associated with new construction of similar low-rise wood-

[9] Anthony Pak and Ara Beittoei, *Reframed Lab report: Embodied Carbon Study of Early Design Options for Six Deep Retrofit MURBs in BC* (Priopta, 2023).

framed residential buildings. After learning about embodied carbon of various insulation materials, several teams opted for mineral wool rather than spray foam insulation.

Pak and Beittoei note that while reductions in operational carbon from these retrofits significantly outweigh the additional embodied carbon associated with addition of new materials used in retrofits over the next 10 years, this is influenced by the very high baseline operational greenhouse gas intensity shown on four of the projects. At 35 to 60 $kgCO_2e/m^2$/year, these buildings are emitting much more than typical new construction. For example, the City of Vancouver's rezoning limits greenhouse gas intensity to 3 to 6 $kgCO_2e/m^2$/year.

Seismic updates

British Columbians have been preparing for "the big one" by stocking emergency supplies and making earthquake evacuation plans, but many of our existing buildings are not as well prepared. Decisions to incorporate seismic resilience are based on the functional importance of the building (e.g. a hospital is considered to be critical infrastructure), and the desired seismic performance depends on the owner's tolerance for damage and time the building spends out of service. For example, most buildings are of "normal" importance and seismic performance needs to be enough to resist collapse and minimize loss of life, as illustrated in Figure 7. Seismic upgrade requirements can be triggered by the authority having jurisdiction or by major renovation code requirements but are otherwise voluntary.

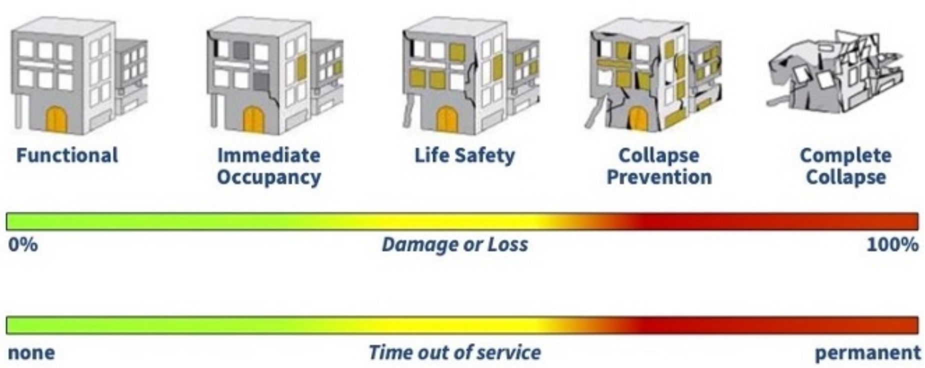

Figure 7. Seismic performance as a function of damage or loss and time out of service

Source: National Research Council[10]

[10] Cited in John Sherstobitoff, *Reframed Lab workshop: Maximizing Synergies between Energy and Seismic Upgrades* (Ausenco, 2022).

Teams evaluated the expected performance of the structures during an earthquake and explored seismic solutions from simple, such as changing the nailing pattern in wall sheathing, to complex structural upgrades such as foundation anchors. Four of the buildings were found to be inadequate in meeting current seismic requirements for structural capacity, posing a risk to life safety during an earthquake. The schematic design recommendations are summarized for the six buildings below:

- Medewiwin
  - Seismic upgrade to meet the highest level defined by B.C. building code
  - Improving connections between structural elements
  - Adding bracing
  - Improve joint between original structure and addition
- Dany Guincher:
  - Seismic upgrade to meet B.C. building code
  - Upgrading, adding, and supporting shear walls
- Manor House:
  - Seismic upgrades not included in the schematic design
- Crown Manor:
  - Removing vulnerability of 'tuck under' parking which creates a weak storey
  - Converting 'tuck under' parking into two additional dwelling units
- Le Chateau:
  - 2020 Seismic Retrofit Guidelines
  - Upgrading shear walls above grade
  - Incorporating foundation wall tie-backs and anchors
- Crossroads Inn:
  - Seismic upgrades included in the schematic design

Seismic upgrades can be approximated based on insurance cost savings, which are estimated to save $4 in recovery costs for every $1 spent on seismic upgrades.[11, 12]

In 2013, the Insurance Bureau of Canada (IBC) estimated the economic losses of major earthquakes affecting B.C. and the Ontario/Québec region based on historical data, including direct property and infrastructure losses and indirect losses from supply chain

[11] National Institute of Building Sciences, *Natural Hazard Mitigation Saves 2019 Report* (2019), 658. https://www.nibs.org/projects/natural-hazard-mitigation-saves-2019-report

[12] Natural Resources Canada, *Earthquake Hazards and Risks*. https://earthquakescanada.nrcan.gc.ca/hazard-alea/earthquake_hazards_risks.pdf

interruptions, infrastructure network disruptions, and other interconnectivity problems between economic sectors.[13]

For the B.C. scenario, IBC modelled a magnitude 9.0 earthquake which estimated $58.6 billion in direct losses from properties and $12.7 billion in indirect infrastructure and asset losses.[14] The Ontario/Quebec scenario was modelled based on a magnitude 7.1 earthquake, which estimated $45.9 billion in direct property losses and $11.3 billion in indirect property, infrastructure, and public asset losses.[15] Understanding the implications of an earthquake in these seismic regions emphasizes the importance of robust building codes, earthquake-resistant construction practices, effective emergency preparedness, and response plans.

5.4 Economic performance

While deep retrofits are more costly than the baseline upgrade bundles, they may also offer greater energy savings and long-term benefits that are not captured in annual net present value (NPV) calculations. The variance across rate scenarios emphasizes the importance of energy price forecasts in financial planning for building retrofits.

Capital cost

Table 10 summarizes the per-unit capital cost projections for the baseline and deep retrofit schematic designs. The median cost for best-in-class retrofits is approximately $138,000 per housing unit, which falls within the grant limit of the Canada Mortgage and Housing Corporation of up to $170,000/unit to cover the full cost of deep retrofits, available through the Canada Greener Affordable Housing – Retrofit Funding program.[16] All of the schematic designs are projected to result in annual energy cost savings. (The median capital cost per dwelling unit is $63,000 for baseline and $138,000 for deep retrofits, while per CFA, it is $1,000 for baseline and $2,000 for deep retrofits.) To put this into perspective, one of the participating social housing operators estimates the

[13] Air Worldwide, *Study of Impact and the Insurance and Economic Cost of a Major Earthquake in British Columbia and Ontario/Québec* (Insurance Bureau of Canada, 2013), 11. http://assets.ibc.ca/Documents/Studies/IBC-EQ-Study-Full.pdf

[14] *Study of Impact*, 13, 17.

[15] *Study of Impact*, 22.

[16] CMHC, "Retrofit Funding for multi-unit residential buildings," 2023. https://www.cmhc-schl.gc.ca/professionals/project-funding-and-mortgage-financing/funding-programs/all-funding-programs/canada-greener-affordable-housing-program/retrofit-funding

cost to construct new buildings ranges from $550,000 t0 $600,000 per unit (including land and soft costs).[17] Total project costs are shown in Table 21 in Appendix D.

Table 10. Retrofit capital cost (by unit) estimates for baseline and deep retrofit schematic designs

Building	Capital cost estimates		
	Baseline retrofit	Deep retrofit	Incremental
Medewiwin (+/-20% cost variance)	$52,000	$113,000	$61,000
Dany Guincher (Class C costing*)	$92,000	$119,000	$27,000
Manor House (As-bid costing**)	$52,000	$147,000	$94,000
Crown Manor (Class C Costing)	$47,000***	$129,000	$83,000
Le Chateau (Class C Costing)	$74,000	$210,000	$136,000
Crossroads Inn (Class C Costing)	$114,000	$150,000	$37,000
Median****	$63,000	$138,000	$75,000

*Class C costing carries a maximum 15% design allowance according to the Royal Architecture Institute of Canada.[18]

**Capital expenses originate from as-bid phase and include materials, labour, and general conditions. It excludes soft construction costs such as contingency, consulting fees, construction management, and building permits.

***Accounts for the two additional living units included in the Crown Manor schematic design.

****Median is used as a measure of central tendency because it is less sensitive to outliers, which can be a problem with small sample sizes.

[17] ZEBx, "Reframed Initiative: Optimizing Deep Building Retrofits," 2024. https://www.zebx.org/mar-2024-decarb-lunch-reframed-initiative-optimizing-deep-building-retrofits/

[18] Royal Architecture Institute of Canada, *Canadian Handbook Of Practice For Architects, Third Edition* (2023), Appendix A: Description of the Classes of Estimates Used by PSPC for Construction Costing of Building Projects. https://chop.raic.ca/appendix-a-description-of-the-classes-of-estimates-used-by-pspc-for-construction-costing-of-building-projects

Net present value

Analysis of the net present value confirms that deep retrofit capital costs are not readily recovered through energy savings alone.[19] For market rental units, government needs to develop a cost-sharing mechanism that allows landlords to recuperate costs without increasing rents. Table 11 compares the NPV of baseline retrofits with the deep retrofit schematic design NPV over a 40-year study period (including one cycle of renewal for components with shortened life cycles). The median incremental NPV is estimated at $68,000, which represents the cost gap that needs to be closed to make the financial case for deep retrofits. Based on median NPV estimates, the deep retrofits add a premium of approximately 60% on top of baseline retrofit costs. Another way to look at this is, baseline renewal costs equate to approximately 66% of deep retrofit costs. Life-cycle cost analysis methodology is described in Appendix E, while assumptions and factors used in the NPV modelling are detailed in Appendix F. (The median NPV per CFA is -$2,000 for baseline retrofits and -$3,000 for deep retrofits.)

Table 11. NPVs by dwelling unit – Reference rate scenario

Building	NPV per unit		
	Baseline retrofit	Deep retrofit	Incremental
Medewiwin	-$103,000	-$139,000	-$36,000
Dany Guincher	-$125,000	-$166,000	-$41,000
Manor House	-$76,000	-$179,000	-$103,000
Crown Manor*	-$69,000	-$165,000	-$95,000
Le Chateau	-$201,000	-$296,000	-$95,000
Crossroads Inn	-$165,000	-$199,000	-$33,000
Median	-$114,000	-$173,000	-$68,000

* Includes additional rental revenue of $37,200 from two new housing units

Recognizing utility escalation rates and variations in rate forecasting, we repeated the NPV analysis using the 2022-2052 rate forecast scenarios developed by BC Hydro and FortisBC and compared them to the reference scenario we developed based on projections by the Canadian Energy Regulator (see Appendix F for details). The box and

[19] The financial analysis tool used for this report is available upon request. Please contact the author or the Buildings team at the Pembina Institute for access.

whisker plot shown in Figure 8 shows the financial outcomes of retrofitting buildings under different energy rate forecasts. Under the BC Hydro energy rate scenario, baseline retrofits are projected to have worse NPVs than under the other rate scenarios, whereas the financial outcomes are very close when using the rate forecasts from FortisBC and CER. During deep retrofitting, these differences in financial outcomes disappear. This highlights an important benefit of deep retrofits: by significantly lowering the need for heating energy, they make the financial returns less affected by changes in energy prices.

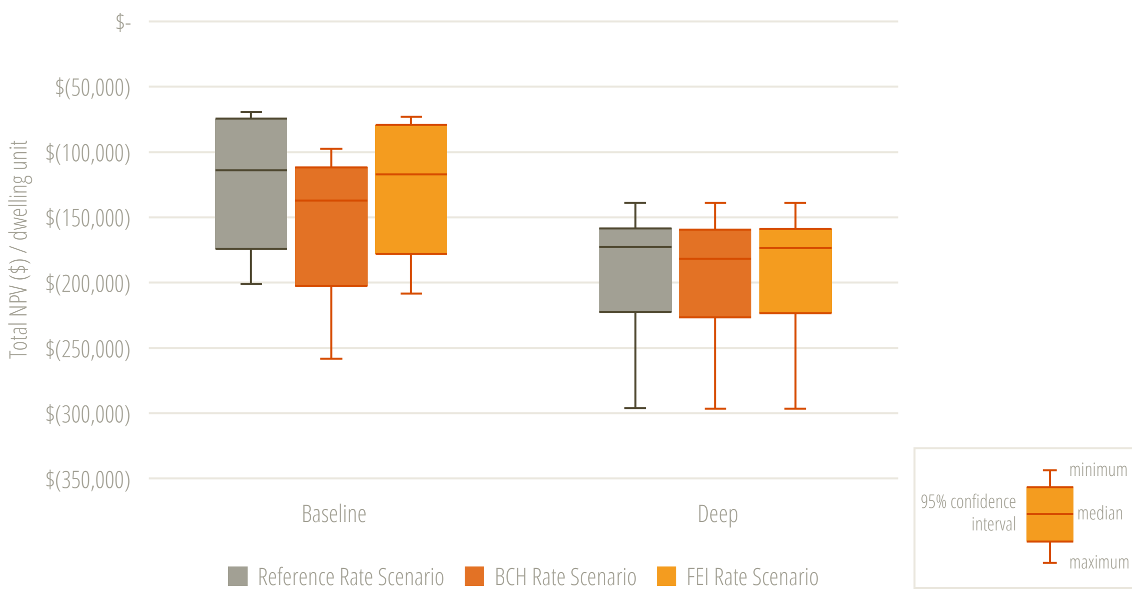

Figure 8. Comparison of NPVs per dwelling unit, across three rate forecast scenarios

Carbon abatement costs

Under the current federal carbon pollution pricing system, the regulatory charge for carbon emissions from fossil fuels is benchmarked at $65/tonne carbon dioxide equivalent (tCO_2e) and is scheduled to climb to $170/tonne by 2030. The proposed deep retrofit schematic designs show deep carbon reduction is feasible, but energy cost savings and the avoided cost of carbon alone cannot recover the full retrofit costs. Furthermore, there is no correlation between net present value and carbon reduction, meaning deep carbon reduction does not necessarily equate to high retrofit costs. For example, Dany Guincher has the lowest NPV but one of the highest estimates costs of carbon abatement, as shown in Table 12 (note, Table 12 is included for illustration only and should not be used as a proxy for the cost of carbon). This could be a result of the baseline proposal being designed to bring the building up to the current building code, which makes the deep retrofit schematic design responsible for only the most expensive and hardest to abate or "last mile" carbon emissions. Also, comparing Le Chateau and Crown Manor, they have similar incremental NPVs but show very different carbon abatement costs.

Table 12. Incremental costs relative to tonnes CO_2e abated

Building	Incremental NPV (by building)	Deep retrofit GHG (tCO_2e/y)	Baseline retrofit GHGs (tCO_2e/y)	Abated (tCO_2e over 40 years)	Cost per tonne of CO_2e abated ($\$/tCO_2e$)
Medewiwin	-$931,000	1	80	3,158	$295
Dany Guincher	-$456,000	0	9	342	$1,334
Manor House	-$4,993,000	53	139	3,440	$1,451
Crown Manor	-$3,098,000	10	53	1,732	$1,789
Le Chateau	-$2,284,000	3	91	3,524	$648
Crossroads Inn	-$1,707,000	23	78	2211	$772
Median	-$1,996,000	6	79	2,684	$743

In short, like energy savings, the returns on reducing carbon emissions are unable to bear the cost of the upgrades proposed through the Reframed Lab. This reinforces the need for building upgrade decisions to include benefits, including health, safety, and resilience, that are difficult to monetize.

Social housing loans and grants

Several of the Reframed Lab demonstration projects have been awarded grants and subsidies through programs offered by the Province of B.C., the Government of Canada, and FortisBC. A list of incentives programs currently available to social housing providers is provided in Appendix G.

As shown in Table 13, the substantial subsidies awarded to the Medewiwin and Manor House deep retrofits pay for 89% and 129% of the incremental capital costs. While both grants are expected to result in a positive financial case for the deep retrofit, the examples for Crown Manor and Le Chateau reinforce that even baseline retrofits are costly but necessary, especially in buildings funded through low rental revenues. To address this challenge, it is important to shift the focus towards the non-energy benefits of retrofits (e.g. enhancing climate adaptation capabilities of the building, reducing embodied carbon, and improving seismic resilience). By recognizing and valuing these broader benefits, a more compelling case for investment in building retrofits can be made.

Table 13. NPVs by dwelling unit – Reference rate scenario, with incentives

Building	Funding programs	Incentive	Incentive proportion of incremental capital (from Table 10)	NPV per unit with incentives	
				Deep retrofit	Incremental
Medewiwin*	CleanBC Communities Fund Investing in Canada Infrastructure Program	$1,410,000	89%	-$85,000	+$18,000
Manor House	FortisBC Deep Energy Retrofit Pilot Program	$6,075,000	129%	-$63,000	+$13,000
Crown Manor**	CleanBC Social Housing Incentive Program (SHIP)	$112,000	4%	-$161,000	-$92,000
Le Chateau	CleanBC Social Housing Incentive Program (SHIP)	$200,000	6%	-$288,000	-$87,000

* Includes solar PV

**Includes additional rental revenue of $37,200 from two new housing units

6. Key takeaways

The Reframed Lab was designed to disrupt traditional ways of procuring, designing, and delivering retrofit projects. We worked closely with building owners to select suitable buildings, define project objectives, foster collaboration, and stimulate creativity. The best-in-class schematic that the designs teams developed are not typical under public procurement and portfolio renewal practices that lean toward short-term financial returns. The request for proposals for these demonstration projects introduced qualitative objectives that do not show up on a balance sheet, and these led to creative, holistic design approaches that balance design goals.

Through participation in the Reframed Lab, six design teams produced best-in-class schematic designs that meet ambitious energy and carbon emissions reduction targets and incorporate a range of non-energy benefits that are difficult to quantify and incorporate into traditional financial analyses. The schematic designs developed through this unique process formed the basis for the design and construction RFPs, aligning with the initiative's goal of transforming multi-unit residential retrofitting. Upgrades to the first building are expected to start in winter 2024, followed by the other buildings later in the year. Three categories of key takeaways have emerged: procurement learnings, design process learnings and design learnings.

6.1 Procurement learnings

The Reframed Lab was designed around integrated project delivery principles to optimize results through all phases and prioritize collaboration around a collective vision. In practice integrated project delivery leads to sharing project risks and rewards; however, due to the public procurement and project tendering practices in place, the Reframed Lab project leads are not expected to execute the projects in most cases. This would result in a change of project leadership. In addition to the re-work and related additional costs associated with changing project teams, this approach risks losing the less tangible, more visionary objectives of the schematic designs for various reasons, such as differences in designer priorities, lack of experience with innovative technologies, or poor understanding of the whole-building design approach.

Some of these more holistic objectives that were considered by the design teams that could be lost through standard project tendering and implementation processes include considerations around electrification plans and component selection. Reframed design teams considered strategies to avoid costly electrical upgrades that can be associated with electrification of space and water heating, balancing the trade-offs of multiple desired outcomes.

Other aspects of how building portfolios undergo renewal cycles and procure upgrades have impacts on the objectives identified in the Reframed Lab design process, including the practice of bulk purchasing of replacement components. Bulk purchase has been an effective means to save on upfront capital costs, but the practice entrenches like-for-like replacements and precludes holistic building upgrades. The common practice of bulk buying could contradict the aims of deep retrofits as capital renewal based on component life cycles can take a building out of the cycle until another system fails. Deep retrofits are most cost-effective if planned and executed in conjunction with major system replacements and as part of a zero-emissions portfolio objective. Building owners could adopt a net-zero-over-time approach, which develops whole building renewal design strategies that include life-cycle trigger events to time deep energy retrofits. BC Housing is showing leadership by balancing extensive whole-building renewal projects with isolated component repairs (when most appropriate), ensuring the building's overall functionality is considered while meeting immediate operational needs.

6.2 Design process learnings

The Reframed Lab featured a collaborative and holistic design approach, and participants noted that the workshop leaders, topics, exercises, and opportunities to engage with and learn from each other were unique and valuable. Participants stated that they valued the exposure to new technologies, ideas, and ways of thinking; opportunities to collaborate with fellow specialists and other professionals; time to explore more options, more deeply and based on data; the chance to validate thinking and mentor others; and generally, the sense of working together on a collective goal. Several mentioned that the workshops brought in the human side of design, and they found the climate resilience and embodied carbon design workshops very useful. This process was very different from traditional design approaches where each team member solves one problem at a time, passing the project along to the next specialist.

The tools to model energy and carbon performance are well established and familiar to most designers, whereas we learned that tools to evaluate climate and seismic risks and select components that minimize embodied carbon are not well developed. There are also few tools that look at upstream emissions for analysis of embodied carbon that can contribute to decisions on renewal or replacement, which could result in materials being sent to landfill. We also found that financial analyses are not formalized, standardized, or even mandated. The teams undertook a wide variation of financial analysis, including how net present value is calculated and what factors, like discount rates, are applied, and there was considerable variation in costing inputs. To facilitate evaluation and comparative analysis of multiple designs, we developed a custom financial analysis tool based on data imported from the teams' schematic designs and costing estimates. The results of that analysis form the basis of section 5.4 of this report and the macro-economic assumptions employed are included in Appendix F.

Standards, practices, and tools also must be developed to evaluate non-energy benefits. Ideally, designers would be able to assign a value to benefits whose costs are traditionally externalized, such as through public health services or disaster recovery.

6.3 Design learnings

The buildings that participated in the Reframed Lab were selected to identify how retrofit designs could be replicated elsewhere. However, the unique features of each building and the need to address multiple design goals, such as energy efficiency and occupant comfort, in varied contexts made replication challenging. That said, the six deep retrofit schematic designs share some common features: they all incorporated some degree of increasing insulation, improving air sealing, and switching from inefficient natural gas heating equipment to a mix of electric and natural gas-fired heat pumps.

While there was some overlap between design approaches, teams also developed creative solutions to improve building and financial performance, such as:

- Adding solar PV to help reduce utility costs (note, solar thermal was proposed for one project, but the savings were incorporated into the total energy savings).
- Adding new dwelling units to increase revenue and improve seismic resistance, by building shear walls to provide lateral resistance that the existing support posts that tuck under parking are unable to achieve.
- Enhancing insulation with overcladding to minimize tenant disruption.
- Adding heat recovery ventilators to reduce heat loss while bringing in fresh, filtered air.

The retrofit design objectives were informed by the primary risks these buildings faced, including overheating, poor air quality, flooding, and seismic damage. Taking a holistic deep retrofit design approach allowed teams to address multiple objectives at once and, in some cases, take advantage of synergies that emerged. Teams also learned that thoughtful design decisions can reduce the need for costlier and more complex actions, such as electrical upgrades, if prioritized at the outset of the design process.

Passive measures such as well-sealed building envelopes and improved insulation can help reduce utility costs, exposure to utility rate volatility and carbon emissions. In Medewiwin, passive measures alone were able to achieve a 34% reduction in overheating hours. It is also worth noting that the renewal cycle is longer for passive measures (assumed 40 years for this study) which means replacement costs occur less frequently.

In addressing mechanical systems, the design teams balanced cost, equipment life cycle and feasibility, so the resulting deep retrofit schematic designs include a range of solutions from retaining natural gas heating through partial fuel-switching to full electrification. One participant noted that electrification is the most straightforward approach to reducing GHGs but when selecting equipment setup, consideration of functionality (e.g., refinement of zone control) should be balanced against burden of maintenance (e.g., many units mean many units to service). Fuel-switching in a province with clean electricity, like B.C., can result in increased efficiencies and deeper carbon emission reductions. In addition to increasing efficiency significantly, heat pumps provide the added benefit of cooling, which is increasingly being added as a requirement in building codes. Most critically, the envelope-first approach of these schematic designs demonstrates there are multiple pathways to deep decarbonization, spanning from full to partial electrification.

Through the financial analysis of the proposed designs, the Reframed projects confirmed that energy savings alone cannot pay for the costs of deep retrofits and most occupant benefits do not show up on the balance sheet. The preliminary costs of the proposed deep retrofit schematic designs range between $113,000 and $210,000 per unit,[20] which falls within the grant limit of CMHC's Canada Greener Affordable Housing funding of up to $170,000 per unit. For comparison, the new construction cost of adding units to Crown Manor are estimated at $228,000 per unit. When the cost of baseline like-for-like retrofits are recognized, the incremental NPV of deep retrofits or cost gap is reduced to -$68,000 per home. Based on median NPV estimates, the deep retrofits add a premium of approximately 60% on top of baseline retrofit costs. Another way to look

[20] Estimates for the deep retrofit schematic designs are Class C or D costing, which means they can carry as much as a 25% allowance.

at this is that undergoing the baseline renewal costs equate to approximately 66% of deep retrofit costs.

In the cases where substantial grants have been awarded for the incremental costs of the deep retrofit measures, both projects (Medewiwin and Manor House) are projected to have a positive NPV. It is worth noting that the proposed like-for-like baseline retrofits also result in negative NPVs, meaning even baseline retrofits present a challenging financial case. A preliminary review of grants and loans currently available suggests that there is a focus on heating equipment instead of on deep efficiency upgrades for envelope components. FortisBC offers the most significant rebates for envelope upgrades, such as through its Deep Energy Retrofit Pilot Program, which is supporting the Manor House deep retrofit (see Appendix G).

As described in section 5.3, deep retrofits have many non-energy benefits that remain challenging to monetize and are often only realized by those who have the financial means to undergo upgrades. To ensure equitable access to these benefits, low-income Canadians and non-market housing projects require longer-term asset management planning and access to different financing mechanisms. We need to socialize the costs of the community health, safety, and resilience benefits even while monetizing them remains challenging.

With advances in technology, increased market competition, and greater economies of scale, we expect cost compression to help improve the financial case for carrying out deep retrofits over time. Meanwhile, strategic design can help narrow the cost gap, such as planning phased deep retrofits to align with component replacement schedules and optimize the financial case for deep retrofits. Other revenue streams could be integrated into a deep retrofit, such as the addition of dwelling units or leasing land for electric vehicle charging, which could generate revenue and improve access to vehicle charging for renters.[21]

[21] Steven Han and Jason Wang, *A Guide to Installing EV Infrastructure in Alberta's Multi-Unit Residential Buildings: How to prepare for an electric vehicle future* (Pembina Institute, 2023). https://www.pembina.org/pub/guide-installing-ev-infrastructure-albertas-multi-unit-residential-buildings

7. Recommendations

The Reframed Initiative takes a whole-market approach to scaling up deep retrofits by advancing conditions critical for success, including stimulating beachhead markets, securing partnerships with trusted solution providers, removing energy, financial, regulatory and policy system barriers, and optimizing subsidy pools. The Reframed Lab surfaced specific opportunities that government bodies at various levels can take to help advance deep retrofits to reach market scale by addressing market, financial, regulatory, and policy barriers, outlined below.

7.1 Regulations and standards

Send a strong market signal

- Introduce standards and regulations that raise minimum building performance to open markets for industry leaders, paving the way to market transformation and better outcomes for owners and occupants.
  - Set mandatory building performance standards, such as the benchmarking and disclosure programs implemented by the Province of Ontario and the City of Vancouver (through its Charter City rights). These can be enforced through financial mechanisms like tax penalties or fines.
  - Update the national model codes (and alterations to existing buildings codes in development by B.C. and Canada) with health, resilience, and low embodied carbon and support provincial and local adoption and industry compliance.
- Streamline regulatory processes to expedite certification of advanced technologies produced domestically as well as those available outside but not certified for use in Canada, such as heat pumps that use refrigerants with low global warming potential.

7.2 Programs and policies

Lead through public procurement

All levels of government can help advance and stimulate market uptake of deep retrofits by adopting innovative procurement practices for government-owned buildings.

- Define and prioritize project outcomes focused on occupant benefits, such as health, safety, and resilience, and minimize embodied carbon emissions, such as through procurement of components that are constructed from locally manufactured, low-carbon materials.
- Schedule portfolio renewal through bulk purchasing of retrofit bundles for groups of public buildings to ensure holistic system upgrades that align with 2050 net zero emission targets, versus bulk purchasing components, such as boilers, which perpetuates incremental upgrades.
- Revise public procurement policies and practices to foster innovation, ensuring a fair distribution of risks and benefits among all involved stakeholders, leading to better outcomes and capacity building among project partners, such as through Integrated Project Delivery. The goal here is to involve all participants (designers, builders, etc.) through all phases of a project, from design to construction, to enhance efficiency and innovation.
- Require embodied carbon reporting and phase in requirements for using low-embodied carbon materials over time, such as City of Vancouver is implementing and is planned for Canada's Greening Government strategy and Buy Clean policy.

Close the deep retrofit cost gap

Help build supply and demand for deep retrofits until the market reaches the economies of scale that lead to cost compression and a self-supporting business case for deep retrofits.

- Increase government and utility subsidies, grants, and tax incentive programs to support early adopters of deep retrofit capital projects.
- Focus subsidy and grant programs on providing home retrofits and low-carbon, high efficiency heating equipment for low-income and social housing providers at zero cost. These programs should include assurances that protect renters and alleviate energy poverty.

- Design grants and other incentive programs to prioritize deep retrofits and pivot away from supporting incremental upgrades that counter the objective of ultimately reaching net-zero emissions.
- Ensure long-term incentive program stability that allows for phased deep retrofits that align with component life cycles, such as outlined by RMI's zero-over-time model,[22] thereby optimizing the upgrades with scheduled replacement costs.
- Streamline owner access to incentives and subsidies, such as through point-of-sale discounts delivered through trusted solution providers who can automatically apply them to eligible projects; this both reduces complication for the consumers and gives suppliers confidence in steady market demand.

7.3 Capacity-building

Educate owners on the benefits of deep retrofits

Build support for deep retrofits by helping owners understand the risk of short-sighted investments and the value of implementing holistic, long-term asset management plans that recognize key opportunities in component life cycles.

- Develop shared messaging with various sectors of the retrofit industry, utilities, and other levels of government to communicate the feasibility and benefits of deep retrofitting with technologies like heat pumps along with passive interventions and clarify the interactions and complementarity of combined actions.
- Leverage common touchpoints industry, utilities and public-facing municipal departments have with consumers, such as equipment service appointments, roof, or window replacements, or through tax or utility bills, to communicate the value of deep retrofits and clarify available incentives and rebates and how to access them.

Invest in workforce development and supply chain growth

Provide opportunities like the Reframed Lab for learning and revealing gaps in supply chain knowledge and capacity to deliver deep retrofits.

[22] RMI, *Best Practices for Achieving Zero Over Time for Building Portfolios* (2018). https://rmi.org/insight/zero-over-time-for-building-portfolios

- Support industry associations, academia, and other levels of government in upgrading; develop high performance construction training and certification programs to include additional knowledge and skills needed to deliver deep retrofit informed by principles of building science.
- Support industry associations, academia, and other levels of government in attracting workers to the field, such as by removing access barriers to increase equity and diversity, promoting the range of professions and trades needed from high tech design through manufacturing to hands-on installation, and providing training grants and bursaries for upskilling current practitioners and attracting new workers.
- Develop national standardized methods for carrying out financial and climate risk analyses that all levels of government could use when procuring projects, but also to help develop industry capacity and facilitate comparison between projects and design selection.
- Reward companies that show leadership in decarbonizing buildings. For example, governments could provide tax incentives to companies that complete an annual minimum number of projects that meet near-net-zero emissions.

7.4 Further research

Ongoing research is needed to remove systemic barriers to building decarbonization and build the business case for deep retrofits by quantifying and valuating non-energy benefits and unlocking private investments needed for market transformation.

Identifying and removing systemic barriers to deep retrofits

While helping the solution providers in the new construction and retrofit industry advance skills and adopt new technologies and approaches, governments and utilities need to remove external barriers to building decarbonization. More research is needed to:

- Clarify the energy mix that will be available to building owners to help realistic decarbonization planning. Utilities and governments need to develop integrated energy plans that place building decarbonization within the context of economy-wide energy requirements, for building owners and solution providers to work toward and local governments to plan around.
- Better understand the conditions that make decarbonization of buildings possible not only in urban, but also rural and remote regions of Canada. What

external conditions and contexts makes projects successful and how can we create those conditions elsewhere?

Building the business case for deep retrofits

Further research is needed to clarify and quantify the value of non-energy benefits. Health care, energy poverty relief, and recovery from extreme weather events all impose costs on governments. Research is needed to help understand the value of non-energy benefits and opportunity costs:

- Calculate the opportunity cost of doing nothing to adapt buildings to future climate extremes and risks, to reduce energy demand for heating and cooling energy costs, and to incorporate preventative health measures.
- Gather data on incremental cost difference between baseline retrofits and deep retrofits that put our buildings on a path to net zero emissions. Reframed provides six examples of a small subset of the building stock. Developing a case study template would help standardize data collection of case studies and demonstration projects and the impacts of factors such as rising inflation, carbon tax increases, and utility rate escalation.
- Support early market innovation by providing last-mile funding for best-in-class projects identified by trusted third-party deep retrofit accelerators such as those participating in the Greener Neighbourhood Pilot Program and the Deep Retrofit Accelerator Initiative.
- Explore alternative cost-recovery mechanisms that protect tenants from rent hikes. For example, time-limited carbon cap-and-trade or carbon offset purchasing systems (with transparent accounting) could allow owners to satisfy building performance regulations while they implement zero-over-time deep retrofits.
- Investigate the opportunities to incorporate revenue generation from retrofit add-ons such as on-site renewable generation, leasing space for electric vehicle charging, and adding rental units.
- Work with financial institutions to value reduced operating costs and lower risks in underwriting, reducing financing costs.
- Work with the insurance industry on regulatory changes and products that support building owners who undertake deep retrofits to reduce vulnerability to climate risks, such as retrofits that include adaptation measures, especially in regions that are vulnerable to extreme climate-related risks.

Appendix A. Design teams

Reframed partners

The Reframed partners launched the Reframed Lab, uniting architects, contractors, engineers, and manufacturers to innovate MURB retrofits.

- Pembina Institute
- Metro Vancouver
- City of Vancouver
- BC Non-Profit Housing Association
- BC Housing

Selection criteria for design teams

In selecting the design team for the Reframed Initiative, BC Housing focused on ensuring the teams were capable and experienced. The chosen team had to be ready to take on the challenges of sustainable and resilient design with innovation and expertise.

The selection criteria were as follows:

- Diverse professional expertise: Teams needed to include architects, engineers, and environmental consultants.
- Record of experience: We looked for teams with a history of successful projects in sustainable design.
- Ability to collaborate: The capability to work effectively as a team during workshops was essential.

Moreover, teams were assessed on:

- Contractual understanding: Teams had to demonstrate the ability to adhere to BC Housing's contractual requirements.
- High-quality deliverables: We reviewed the teams' previous work to ensure they met standards for energy efficiency and sustainability.
- Contract extension readiness: Teams needed to show they were open to extending their involvement for the project's continuity.

The selection was conducted with a commitment to fairness, focusing solely on meeting the Initiative's comprehensive needs. The final decision was based on the team's potential to create and execute a transformative design in alignment with BC Housing's sustainability objectives.

Design teams

The multi-disciplinary teams collaboratively crafted deep retrofit solutions for the low-rise MURBs, focusing on carbon reduction, energy efficiency, seismic resilience, and occupant health.

Table 14. Reframed design teams by building

Building	Design Teams
Medewiwin	Low Hammond Rowe Architects, ReNü Engineering, RJC Engineers, RDH Building Science, Hanscomb Ltd.
Dany Guincher	Entuitive, Martin Pykalo Architecture, AME Group, Advicas Group Consulting Inc.
Manor House	RDH Building Science, FRESco, SES Consulting, AES Engineering
Crown Manor	Williams Engineering, Integra Architecture, TLSE Engineering, Advicas Group Consulting
Le Chateau	Evoke Buildings, Monstera Projects, Impact Engineering, Bush, Bohlman & Partners LLP, Station One Architects, O'M Engineering, BELi, Hanscomb Inc.
Crossroads Inn	RJC Engineers, Cover Architectural Collaborative, AME Group, Projects with Grace Inc., O'M Engineering, LTA Consultants Inc.

Reframed Lab consultants

The Reframed Lab consultants offered expertise in regenerative design, climate risk, health, embodied carbon, and seismic mitigation for retrofit guidance.

- Jennifer Cutbill – Lateral Agency
- Lisa Westerhoff – Introba (Integral Group)
- Robin Hawker – Introba (Integral Group)
- John Sherstobitoff – Ausenco
- Joanne Sawatzky – Light House
- Anthony Pak – Priopta
- Ilana Judah – ACORN Resilience & Sustainability
- Ghazal Ebrahimi – Provincial Health Services Authority
- Maryam Rezaei – Tenant engagement consultant

Appendix B. Reframed objectives

The objectives outlined in this section form the cornerstone of the Reframed Initiative and formed Schedule B of the RFP issued by BC Housing and Metro Vancouver Housing Corporation. Proponents were expected to align their retrofit concepts, solutions, and deliverables with these objectives to ensure a consistent approach towards collective goals.

Primary objectives/goals (to be addressed in all retrofit concepts):

- Reduction of GHG emissions and energy consumption.
- Enhancement of climate adaptation and resilience.
- Exploration of seismic upgrades, performance objectives, and roof structural upgrades.
- Minimization of on-site construction impacts and occupant disturbance.
- Promotion of occupant health and well-being.
- Maximization of the life cycle net present value.
- Minimization of added life cycle embodied carbon.
- Optimization of on-site PV electricity generation and storage solutions.
- Maintenance of aesthetic and architectural design quality.

Secondary objectives/goals (optional and concept-specific):

- Enabling the addition of new floors or units if feasible.
- Assessing the feasibility of other on-site renewable energy generation technologies.

Considerations for proponents:

- Assess market maturity of proposed solutions, focusing on innovation and readiness within the next two years.
- Include a comprehensive evaluation of costs, savings, lifespan, and financial incentives of proposed measures.
- Ensure the incorporation of measures to adapt to current and future climatic conditions, referencing relevant climate data.
- Consider the wider community impacts and benefits, aiming for a balance between individual building performance and broader environmental and societal gains.

Appendix C. Deep retrofit schematic design summaries

Table 15 summarizes the schematic designs proposed for deep retrofitting the six buildings and compares them to existing conditions and baseline design proposals.

Table 15. Retrofit bundle comparison – Medewiwin

Area	Feature	Existing Building	Baseline	Deep Retrofit
Envelope	Roof Insulation	RSI-1.41 (average 1963 + 2002)	RSI-5.28 (1963 portion only)	RSI-7.04
	Wall Insulation	RSI-1.54 (average)	Same as existing building	RSI-5.28
	Windows	USI-4.06 (average), SHGC 0.35-0.7	USI-1.48 (1963 portion only), SHGC 0.27-0.35	Same as baseline
Systems	HVAC (Central)	Gas-fired boiler (82.7% efficiency)	Gas-fired boiler (84% efficiency)	Central ASHP + 2 MUAs for common areas
	HVAC (Zones)	Hydronic radiators	Same as existing building	Ceiling ducted ASHPs (Ephoca) (COP_h 3.78 @16°C to 2.27 @-15°C, COP_c 3.65), electric resistance heating below -15°C
	Water Heating	Gas-fired tank heater (80% efficiency)	Gas-fired tank heaters (95% efficiency)	Air-to-water DHW heat pump (COP 2.5 @20°C to 1.5 @-10°C)
Airtightness	Infiltration Rate	0.5 L/s*m² at 5 Pa	0.4 L/s*m² at 5 Pa	0.06 L/s*m² at 5 Pa
Ventilation	Ventilation Type	Gas-fired rooftop unit (2002 portion only, 80% efficiency); Exhaust per suite	Rooftop MUAs (91% efficiency)	ERV (85% sensible/70% latent effective)

Table 16. Retrofit bundle comparison – Dany Guincher

Area	Feature	Existing Building	Baseline	Deep Retrofit
Envelope	Roof Insulation	RSI-2.46	RSI-5.2	RSI-7.04
	Wall Insulation	RSI-1.97	RSI-3.45	RSI-4.4
	Windows	USI-6.13, SHGC 0.8	USI-1.55, SHGC 0.38	Same as baseline
Systems	HVAC (Central)	Gas-fired boiler (83% efficiency)	Gas-fired boiler (90% efficiency)	MUA and electric resistance heating coil in corridor, electric baseboards in other common areas
	HVAC (Zones)	Hydronic baseboards	Same as existing building	Daikin mini-split ASHP (COP_h = 4.06, SEER = 19), 1 per suite
	Water Heating	2 gas DHW tanks (65% efficiency)	Condensing DHW tanks (90% efficiency)	2 x Sanden DHW ASHPs (COP 2.8)
Airtightness	Infiltration Rate	0.5 L/s*m² at 5 Pa	0.2 L/s*m² at 5 Pa	Same as baseline
Ventilation	Ventilation Type	Kitchen exhaust fans	Kitchen exhaust fans; electric resistance heating coil, corridor AHU with HRV (65% efficiency)	DOAS heating coil for corridors; HRVs for suites

Table 17. Retrofit bundle comparison – Manor House

Area	Feature	Existing Building	Baseline	Deep Retrofit
Envelope	Roof Insulation	RSI-1.8	Same as existing building	RSI-6.9
	Wall Insulation	RSI-1.06	Same as existing building	RSI-2.6
	Windows	USI-6.7, SHGC 0.82	USI-1.53, SHGC 0.27	USI-0.97, SHGC 0.19
Systems	HVAC (Central)	3 gas-fired boilers (2 in service, 1 decommissioned) (79% and 85% efficiencies)	Condensing gas-fired boiler (90% efficiency)	Gas engine heat pump (COP_h 1.5/COP_c 1.3) with backup condensing gas-fired boiler (90% efficiency)
	HVAC (Zones)	Hydronic baseboards or in-floor heating	Same as existing building	Heat pump system (Bulldog) (hydronic coil heating and water-cooled DX cooling)
	Water Heating	Gas-fired condensing boiler (95% efficiency)	Same as existing building	Gas engine heat pump (COP 1.4) with backup condensing gas-fired boiler (90% efficiency); Solar water heaters and drain water heat recovery for pre-heating
Airtightness	Infiltration Rate	0.5 L/s*m² at 5 Pa	0.4 L/s*m² at 5 Pa	0.3 L/s*m² at 5 Pa
Ventilation	Ventilation Type	2 MUAs for corridors; Kitchen & bathroom exhaust fans in suites	Same as existing building	In-suite HRVs with bypass (89% sensible heat recovery efficiency); Rooftop MUA unit heated and cooled with hydronic coils; air flow reduced by 75%

Table 18. Retrofit bundle comparison – Crown Manor

Area	Feature	Existing Building	Baseline	Deep Retrofit
Envelope	Roof Insulation	RSI-2.6	Same as existing building	RSI-5.3
	Wall Insulation	RSI-1.1	RSI-1.6	RSI-4.2
	Windows	USI-3.4, SHGC 0.5	USI-1.61, SHGC 0.5	USI-1.02, SHGC 0.3
Systems	HVAC (Central)	Non-condensing gas-fired boiler (87% efficiency), hot water baseboard heating	Same as existing building	ASHP
	HVAC (Zones)	Hydronic baseboards	Same as existing building	Hydronic baseboards and mini-split ASHPs for suites
	Water Heating	Gas-fired boiler (82% efficiency)	Gas-fired boiler (ASHRAE 90.1 2016, 80% efficiency)	ASHP DHW system
Airtightness	Infiltration Rate	0.3 L/s*m² at 5 Pa	Same as existing building	0.2 L/s*m² @ 5 Pa
Ventilation	Ventilation Type	Washroom exhausts only	Same as existing building	Suite HRVs, Corridor MUA

Table 19. Retrofit bundle comparison – Le Chateau

Area	Feature	Existing Building	Baseline	Deep Retrofit
Envelope	Roof Insulation	RSI-4.4	Same as existing building	Same as existing building
	Wall Insulation	RSI-1.5	Same as existing building	RSI-4.4 using high density mineral wool
	Windows	USI-7.0; SHGC 0.8	USI-1.56-1.59; SHGC 0.27-0.34	Same as baseline
Systems	HVAC (Central)	Non-condensing gas boiler (80% efficiency)	Gas-fired condensing boiler (95% efficiency) with outdoor air reset	Electric baseboards for common areas
	HVAC (Zones)	Hydronic baseboards. Gas fireplaces in suites. ~40% suites have portable AC units (modelled as PTAC units with COP 3.5)	Same as existing building	Suite ASHPs with integrated HRVs (Innova) for heating & cooling (COP_c 3.4 and COP_h 3.5)
	Water Heating	Gas-fired boiler (82% efficiency)	Gas-fired DHW heater (95% efficiency)	5 DHW heat pumps (Sanden) (annual COP 3.5, CO_2 refrigerant), electric resistance heating elements for backup
Airtightness	Infiltration Rate	1.06 L/s*m² at 5 Pa, constant	0.2 L/s*m² at 5 Pa for walls, Roof stays as is	Same as baseline
Ventilation	Ventilation Type	2 corridor MUAs with no electric resistance heating (1 turned off); Kitchen and washroom exhausts in suites, no direct ventilation to all suites	2 corridor MUAs with electric resistance heating (both running); Kitchen & washroom exhaust fans in suites	2 corridor MUAs with electric resistance heating (both running); Suite HRVs, kitchen & washroom exhaust fans in suites

Table 20. Retrofit bundle comparison – Crossroads Inn

Area	Feature	Existing Building	Baseline	Deep Retrofit
Envelope	Roof Insulation	RSI-2.82	RSI-7.044	Same as baseline
	Wall Insulation	RSI-1.05	Same as existing building	RSI-1.76
	Windows	USI-2.90 (average), SHGC 0.71 (average)	Same as existing building	Same as existing building
Systems	HVAC (Central)	Gas-fired boiler (92% efficiency), hydronic baseboards	Same as existing building	Same as existing building
	HVAC (Zones)	Hydronic baseboards, 1 window AC per suite	Same as existing building	1 PTAC ASHP (seasonal COP_h = 3, COP_c = 4) per suite (Ephoca AIO: Fan coil + bathroom exhaust + ERV + outdoor unit); Hydronic baseboard heaters in common areas
	Water Heating	Gas-fired water heater (80% efficiency)	Same as existing building	2 electric resistance DHW heaters (90% efficiency)
Airtightness	Infiltration Rate	0.2 L/s*m² at 5 Pa	Same as existing building	0.1 L/s*m² at 5 Pa
Ventilation	Ventilation Type	Gas rooftop MUA unit (80% efficiency), Suite washroom exhausts	Same as existing building	Gas-fired MUA unit (80% efficiency); PTAC with built-in HRV (75% SRE) in suites

Appendix D. Total project capital costs

Table 21 summarizes the capital costs estimated for the baseline and deep retrofits, as well as the energy costs the deep retrofits are projected to save.

Table 21. Retrofit capital cost estimates (by building) for baseline and deep retrofit schematic designs

Building	Capital cost estimates			Annual energy costs the deep retrofit designs are projected to save
	Baseline retrofit	Deep retrofit	Incremental	
Medewiwin (+/-20% cost variance)	$1,359,000	$2,949,000	$1,590,000	$27,000 (Solar PV: $7,000)
Dany Guincher (Class C costing*)	$1,015,000	$1,310,000	$295,000	$350
Manor House (As-bid costing**)	$2,620,000	$7,334,000	$4,714,000	$29,000
Crown Manor (Class C Costing)	$1,353,000***	$4,013,000	$2,659,000	$11,000 (Solar PV: $3,357)
Le Chateau (Class C Costing)	$1,785,000	$5,040,000	$3,256,000	$20,000
Crossroads Inn (Class C Costing)	$5,698,000	$7,525,000	$1,828,000	$5,000
Median****	$1,572,000	$4,527,000	$2,244,000	$16,000

*Class C costing carries a maximum 15% design allowance according to the Royal Architecture Institute of Canada.[23]

[23] Royal Architecture Institute of Canada, *Canadian Handbook Of Practice For Architects, Third Edition* (2023), Appendix A: Description of the Classes of Estimates Used by PSPC for Construction Costing of Building Projects. https://chop.raic.ca/appendix-a-description-of-the-classes-of-estimates-used-by-pspc-for-construction-costing-of-building-projects

**Capital expenses originate from as-bid phase and include materials, labour, and general conditions. It excludes soft construction costs such as contingency, consulting fees, construction management, and building permits.

***Accounts for the two additional living units included in the Crown Manor schematic design.

****Median is used as a measure of central tendency because it is less sensitive to outliers, which can be a problem with small sample sizes.

Appendix E. Life-cycle cost analysis methodology

Life-cycle cost calculations were carried out using a tool developed by the Pembina Institute based on the Metro Vancouver Housing Corporation methodology for assessing energy efficiency investments, with explicit expense time series over the study period and guidance provided in the U.S. National Institute of Standards and Technology's Handbook 135. The calculations were carried out using the following conditions:

- Simulations of the existing buildings were calibrated using energy data and rates from 2021/2022 utility bills, energy, and historical weather data.
- All expenses and costs are presented in 2022 dollars, consistent with cost estimate and BCUC energy rate scenario datasets.
- Hourly building performance simulations and Class C capital cost estimates were performed.
- Existing building performance assessments for each building is based on the building performance prior to any retrofit work.
- Baseline retrofit performance and capital cost estimates are based on needed updates identified in Building Condition Assessment reports provided by the building owners and typically affected elements in poor condition and/or exceeding expected service lives.
- Schematic design capital cost estimates and performance are based on design elements and cost estimates provided by the design teams.
- Initial retrofit capital expenses were deemed to be incurred in 2022, supplemented by future capital expenses incurred at the end of the service lives of new assemblies and equipment.

Appendix F. Macroeconomic model assumptions

Energy rate and GHG content scenarios

Three forecasts[24] for future energy rate and energy supply GHG content were used in the LCCA analysis: a reference scenario and future scenarios provided by BC Hydro and FortisBC as part of the Integrated Resource Plans the two utilities submitted to BCUC in 2022. The scenarios incorporate gas and electricity consumption and demand patterns in their projections and factor in the influence of carbon taxes on the overall energy cost, as do the BCUC / CER energy cost forecasts. The rates are assumed to remain constant beyond 2041/2042, the forecast period of each scenario.

Table 22. Comparison of projected impacts on electricity and gas rates, and gas GHG content across three energy scenarios by 2042

	Reference Load Forecast (BCH reference)	BC Hydro Accelerated Electrification (BCH)	FortisBC Diversified Energy (FEI)
Description	Baseline for future energy demands and usage without significant policy or technology changes.	Projects an aggressive shift towards electrification due to policy and technological advancements.	Promotes diversified energy use in buildings, including renewable resources, electrification, and conventional heating energy sources.
Cumulative Electricity Rate Forecast (by 2042) (Figure 9)	Data not publicly available; uses CER Existing Policies Scenario as proxy as it closely matches BC Hydro's Reference Load Forecast of demand graph in the	8.50% increase relative to BCH reference	5.20% increase compared to BCH reference

[24] For the underlying data on the energy rate forecasts presented, please refer to:

BC Hydro, *BC Hydro's Submission: Stage Two* (2022). https://docs.bcuc.com/Documents/Proceedings/2022/DOC_67462_B-14-BCH-Stage2-Submission.pdf

FortisBC, *FEI Stage Two Submission* (2022).

Canada Energy Regulator, *Canada's Energy Future 2023*, "Macro Indicators." https://apps.cer-rec.gc.ca/ftrppndc/dflt.aspx?GoCTemplateCulture=en-CA

	2021 BCH Integrated Resource Plan (Phase 2) submitted to the BCUC		
Cumulative Gas Rate Forecast (by 2042) (Figure 10)	Cumulative rate increase stabilizes at 38% from 2028 onwards	747% increase relative to BCH reference	102% increase compared to BCH reference
Cumulative Change in Natural Gas GHG Content (Figure 11)	0.63% increase relative to 2022, stabilizing from 2041 onwards	61.64% decrease compared to 2022 levels	53.56% decrease by 2052 compared to 2022

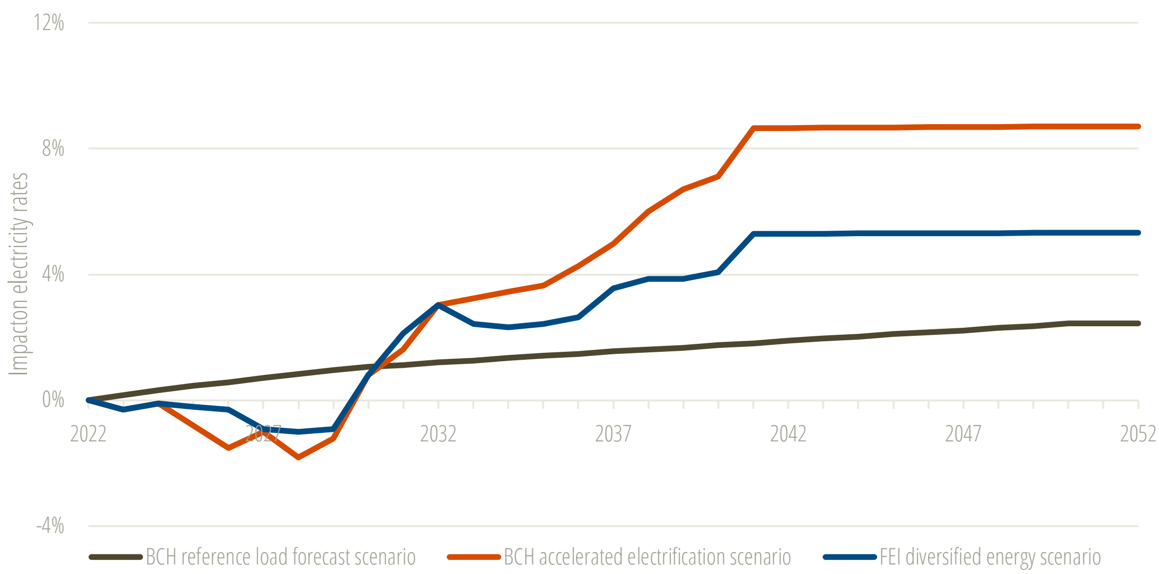

Figure 9. Cumulative impacts on electricity rates projected by each scenario

Rates calculated for 2022 – 2042 and then held constant through to 2052

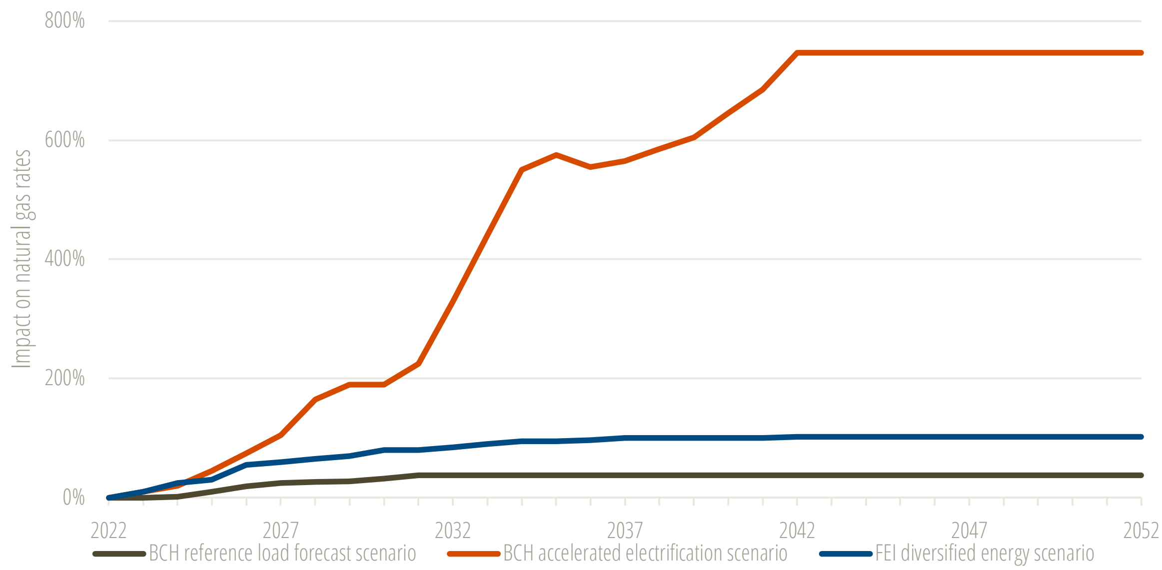

Figure 10. Cumulative impact on natural gas rates projected by each scenario

Rates calculated for 2022 – 2042 and then held constant through to 2052

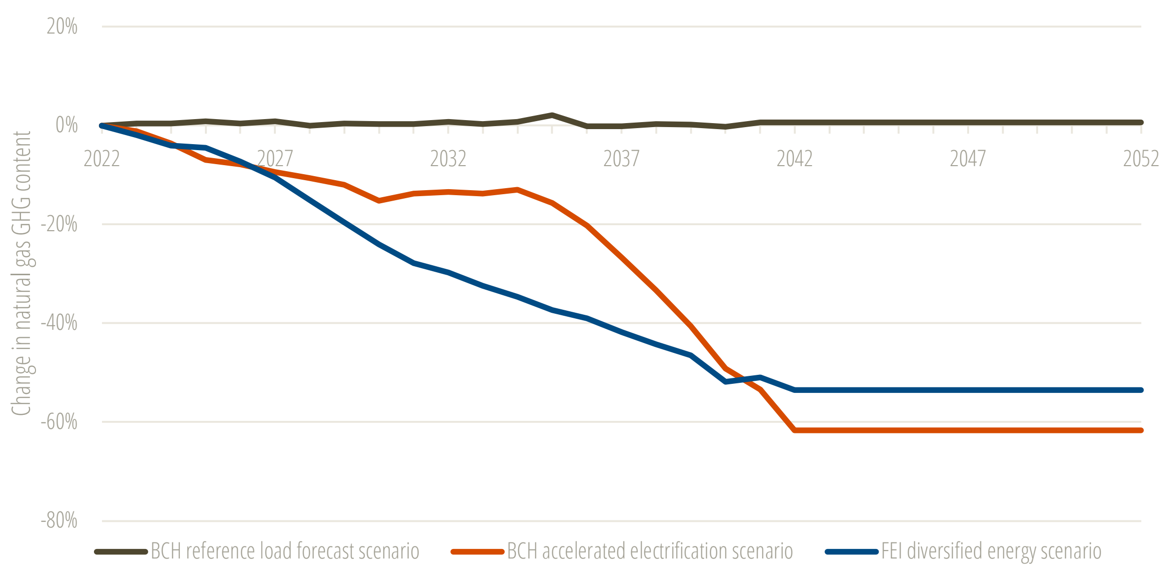

Figure 11. Cumulative change in natural gas GHG content projected by each scenario

Rates calculated for 2022 – 2042 and held then constant through to 2052

Net present value assumptions

- All monetary values are in 2022/2023 dollars
- Nominal discount rate: 5.57% per year
- Real discount rate: 5.00% per year
- General inflation rate is assumed (2%)
- Carbon tax escalation is accounted for in utility rate forecasts
- Blended rates for gas and electricity were used as indicated in Table 23.
- Current cost of water: $2.88/m3 (converted from $8.14 per 100 cubic feet)
- Water utility cost escalation rate: 1.50% per year
- The capex amounts for current and deferred capital expenses depend on the assembly or equipment service life:[25]
    - Short-life assemblies such as electrical and mechanical upgrades: 15 years
    - Long-life assemblies such as the envelope: 40 years
- An escalation rate (2%) is applied for calculating the revenue from new dwelling units across the years (2022 – 2062)
- The sum of discounted net cash flows (in 2022 $) across the years (2022 – 2052) amounts to a building's life-cycle cost NPV
- Discounted net cash flow is obtained by dividing the total annual net cash flow (future $) by a real discount rate (5%)
- The total annual net cash flow is the sum of the following value series:
    - Total energy & GHG tax costs
    - Total operations and maintenance (O&M) expenses
    - Total capital expenses
    - Revenue from new dwelling units
- Projections include forecasts of GHG content and rate impacts of climate policies
- NPV calculations for Crown Manor and Medewiwin consider the reduction in electricity consumption due to generation from installed solar PV. Savings incurred by the solar thermal preheating and wastewater recovery in the Manor House schematic design are captured in the total energy savings.

[25] In instances where teams did not provide specific timeframes for capital expenses, we have applied these default periods.

Table 23. Blended rates for gas and electricity across buildings

	LCC Gas Blended Rate ($/GJ)	LCC Electricity Blended Rate ($/kWh)
Medewiwin	$11.01	$0.11
Dany Guincher	$11.69	$0.14
Manor House	$13.96	$0.12
Crown Manor	$14.30	$0.15
Le Chateau	$14.13	$0.13
Crossroads Inn	$11.04	$0.13
Average	$12.87	$0.13

Appendix G. Financial incentives available for deep retrofitting

Several funding and incentive programs have been launched to support MURB retrofit projects. While many of the MURB projects in the Reframed Initiative would have been eligible for financial incentives, it's important to note that applications for several of these programs were closed at the time of submission. The essence here is not the availability but the considerable level of support that has been made accessible for MURB retrofit projects.

- The **CleanBC Building Innovation Fund** offered a maximum incentive amount of $1,000,000 per project.
- Another significant program from CleanBC is the **Communities Fund - Investing in Canada Infrastructure Program**, which provided funding for up to 65% of the eligible project costs.
- The **Social Housing Incentive Program (SHIP)** by CleanBC provided a variety of incentives based on fuel-switching, building envelope enhancements, and specific GHG savings criteria.
- BC Hydro's initiatives, such as the **CleanBC SHIP Electrical System Upgrade**, covered 100% of building electrical system upgrade costs.
- FortisBC also had a wide range of incentives, from boiler rebates to insulation, with the **Deep Energy Retrofit Pilot Program** emerging as a highlight, potentially covering 60%-80% of total project costs.
- The **National Housing Co-Investment Fund: Renovation** by CMHC is especially noteworthy, offering loans below market rates with favorable conditions for non-profits and Indigenous groups.

Appendix H. Glossary of acronyms

AHU	Air handling unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASHP	Air source heat pump
BCUC	British Columbia Utilities Commission
BCH	BC Hydro
CER	Canada Energy Regulator
CFA	Conditioned floor area
CMHC	Canada Mortgage and Housing Corporation
CO_2	Carbon dioxide
COP	Coefficient of performance
CZ	Climate zone
DHW	Domestic hot water
DOAS	Dedicated outdoor air system
DX	Direct expansion (cooling system)
ERV	Energy recovery ventilator
Et	Efficiency (thermal)
FEI	Fortis Energy Inc.
GEHP	Gas-engine heat pump
GHG	Greenhouse gas
GJ	Gigajoule
HRV	Heat recovery ventilator
HVAC	Heating, ventilation, and air conditioning
LCC	Life-cycle cost
LED	Light emitting diode
MUA	Make-up air (unit)
MVHC	Metro Vancouver Housing Corporation
MURB	Multi-unit residential building
NPV	Net present value

PTAC	Packaged terminal air conditioner
PV	Photovoltaic (solar panels)
RSI	R-Value System International (thermal resistance)
SHGC	Solar heat gain coefficient
tCO_2e	Tonnes of carbon dioxide equivalent
USI	U-Value System International (thermal transmittance)