

Retrofit Costing Study: Decarbonizing Canada's Large Buildings

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ABSTRACT

For Canada to achieve its climate targets, building owners must retrofit and decarbonize hundreds of millions of square meters of space. To get there, strengthened policies and significant investments will be required. While governments and industry leaders understand the importance of deep carbon retrofits, knowledge gaps remain around building-level assessments and implementation. This paper summarizes the findings of a recent study commissioned by CaGBC developed by RDH with Dunsky, which points to the need for market advancement and strategies to overcome financial and market barriers to encourage wider retrofit adoption. The research assessed pathways to decarbonize building energy use, including exploring deep carbon retrofit solutions for 50 large building archetypes.

Our paper demonstrates viable paths to zero emissions for building owners and outlines actions that can be taken to decarbonize. Overall, the modeling results indicated that almost all archetypes could achieve a TEUI threshold of 100 kWh/m²/yr, thereby meeting decarbonization targets. Moreover, 44 of the 50 archetypes were found to offer cost-effective retrofit pathways, using 2022 energy and carbon prices. Considering the improved economics arising from increasing carbon pricing in Canada over the 2022-2030 period, cost-effectiveness of all retrofit packages is expected to continue to improve over time. This suggests that the challenges of achieving deep decarbonization is less related to the technical and financial challenges, but to the market and policy barriers. As such the paper goes on to offer compelling policy options that can be applied by governments and industry as they are moving toward their decarbonization goal.

Introduction

Reducing emissions from existing buildings is critical to achieving a 40-45% cut by 2030 and net-zero emissions by 2050 as per Canada's climate targets (ECCC 2022). The Canada Green Building Council (CaGBC) Roadmap for Retrofits in Canada estimated that large building retrofits could reduce building-sector emissions by up to 51% (21.2 million tons of CO₂e) by 2030 (CaGBC and WSP 2017). While the potential and importance of deep carbon retrofits is generally known, implementation and costs at the building level are not well understood. Policymakers and building owners must fully understand the costs and potential energy and GHG savings of deep carbon retrofits to inform policy development and investment decisions.

To support the decarbonization, the CaGBC, with support from the Government of Canada, the Real-Estate Foundation of British Columbia (BC), and the Province of Nova Scotia commissioned the engineering firm RDH Building Science Inc. (RDH), and the energy and climate consultancy firm Dunsky Energy + Climate Advisors (Dunsky) to carry out a decarbonization retrofit costing study. The analysis focused on identifying viable and most cost-effective deep decarbonizing packages for 50 large building archetypes, covering five typical

building forms in each of five Canadian cities and two construction vintages (building ages). The goal of this study was to provide annualized energy and GHG savings from retrofits, insight into the capital cost requirements and business case for retrofits as well as policy, regulatory, and financial mechanisms that can support additional investment in retrofits.

By understanding the technical pathways to achieving deep retrofits, this analysis aims to support the building industry to move forward with deep carbon retrofits and enable federal, provincial, and local governments to make informed decisions about programs, policies and regulations needed to accelerate the retrofit market in Canada. This paper outlines the main technical findings from the energy modelling, the financial viability of those deep retrofits as well as a discussion of recommended policy and support mechanisms to overcome the remaining barriers slowing down market adoption and the implementation and procurement approaches available to building owners and operators.

Methodology

To assess the technical pathways, whole-building energy modelling was used. As a first step, a total of 50 baseline archetypes were developed, comprising five building types, five locations, and two vintages (construction eras), including:

- Low-rise commercial office building (approx. 2 stories), 3,000 m² (32,292 ft²)
- Mid-rise commercial office building (approx. 13 stories), 21,000 m² (226,042 ft²)
- Low-rise multi-unit residential building (MURB) (approx. 4 stories), 6,000 m² (64,583 ft²)
- Mid-rise multi-unit residential building (approx. 13 stories), 13,000 m² (139,931 ft²)
- Primary school (approx. 2 stories), 6,900 m² (74,271 ft²)

The archetypes were chosen because they are representative of a large portion of Canada's existing building space and approximately 30% of Canada's building-related emissions (Natural Resources Canada 2017). To account for regional differences in building energy and emissions, the archetypes have been modelled in Vancouver, Edmonton, Toronto, Montreal, Halifax. Regional differences include variations in climate, energy supply and carbon intensity of the electricity grid. Also, to align deep retrofits efforts with natural renovation cycles, two vintages were selected: 1970s and 1990s. Indeed, since typical mechanical and envelope upgrades tend to occur in 30- to 50-year cycles, those two sets of buildings are representative of buildings up for major renovations.

For each building archetype, a baseline was developed with a unique set of enclosure and heating, ventilation, and air conditioning (HVAC) system characteristics. Baseline assumptions vary by vintage and location, and are detailed in the full study report (CaGBC, RDH, and Dunskey, 2022).

A business-as-usual (BAU) scenario was also used as a reference point for the incremental costing calculations and carbon reduction analysis. The BAU retrofit measures reflect commonplace renewals that most building owners/operators undertake as equipment needs replacing (e.g., boilers) or as technology makes existing systems obsolete (e.g., lighting), which would not typically lead to deep carbon emission reductions. These renewals were assumed to achieve current federal and provincial code-minimum performance.

Finally, carbon reduction measures (CRMs) include electrical, mechanical, and enclosure improvements as well as on-site solar PV arrays. The CRMs were determined through industry consultation and experience. To align with building renovation cycles, the scope of CRMs varies by vintage. The deep carbon retrofit for the 1970's building archetype includes electrical, enclosure and mechanical upgrades to maximize emissions reductions and support cost-effectiveness. The deep carbon retrofit for the 1990's buildings includes electrical and mechanical upgrades, with the assumption that enclosure upgrades will occur in the future. Solar PV was always included and was sized to the smaller of: available roof area, 100% of the building's annual electricity consumption, and utility net metering limits as defined in each location. It was assumed that all upgrades were undertaken concurrently for time and cost-efficiency. However, the bundles were modelled separately to better understand the impact of the electrical and enclosure measures prior to implementing the mechanical upgrade measures. All the CRMs for the deep retrofit pathway were established based on what is currently feasible with available products and building practices.

Once the technical pathways were determined, a financial analysis was performed to assess the cost and financial viability of modelled retrofit measures. The analysis took into consideration Canada's carbon pollution pricing implemented in 2019. While any province or territory has the flexibility to design their own pricing system, the federal government imposes minimal pricing standards for all. Following these minimum requirements, retrofits were assumed to be completed in 2022 when the price of carbon is \$50/tonne, rising to \$170 by 2030 (ECCC 2020). After 2030, the price was assumed to rise \$6.50/tonne/year to reach a \$300/tonne/year threshold in 2050¹. Key financial analysis variables are summarized in Table 1.

Table 1: Key Financial Analysis Variables

Variable	Value	Justification
Timeframe for analysis	40 years	This study includes both mechanical and enclosure upgrades. These have significantly different life cycles. Forty years was used as an average. For simplicity and comparability, the same value was used for the 1990s retrofits which did not include enclosure upgrades.
Discount rate	5% / year	Selected to represent a blend of lower nominal discount rates expected by governments and institution buildings and commercial building represented in this study.
Utility escalation rate	2% / year	Reflects the recent last 20 years of consumer price index (CPI) escalator. While over the shorter-term timeframes, utilities can have higher or lower values, over longer terms, such as the 40-year timeframe used in this study, CPI and utilities are similar.

¹ These values follow the Government of Canada's guidelines for investment decisions in order to achieve a net-zero building portfolio (Treasury Board of Canada Secretariat 2021).

Carbon price	\$300/tonne/year in 2050	Based on Canada's carbon pollution pricing. Starting at \$50/tonne/year in 2022 and up to \$300/tonne/year in 2050.
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Key Findings

This section details our findings focusing first on the technical findings from the whole-building energy modelling, then on our financial analysis results highlighting the viability of those pathways and finally we discuss recommended policy mechanisms needed to create actionable decarbonization pathways for building owners, and procurement approaches that can be leveraged to implement those retrofits.

Energy and GHG savings

The technical findings from the energy modelling show that by implementing packages of CRMs on existing buildings in conjunction with their building renovation cycles, deep carbon emission reductions can be achieved (reaching nearly 100% for some archetypes). Depending on the archetype, vintage, and location, there are variations in the extent of total energy use intensity (TEUI) and greenhouse gas intensity (GHGI) reductions achieved, as well as on peak electrical demand.

Energy

Results indicated that almost all archetypes could achieve energy reductions greater than 70% compared with BAU measures. Moreover, for most of the buildings, it appeared that a TEUI reduction below a 100 kWh/m²/yr threshold (31.7 kBtu/ft²/yr) was within reach, indicating that it is technically feasible to adopt performance-based metrics with high performance requirements.

Modelled site TEUIs per archetype are shown in Figure 1. For comparison purposes, one of the most stringent standards adopted in Canada, the BC Energy Step Code, was selected as a point of reference in the figure².

When comparing the two building vintages, it appeared that the deep carbon retrofit of the 1970s archetypes (including electrical, enclosure and mechanical upgrades) achieve higher energy savings, and lower final TEUIs, as compared to the retrofit of the 1990s archetypes (including just electrical and mechanical upgrades). A TEUI of 91 kWh/m²/yr or less was achieved for all 1970s buildings and a TEUI of 156 kWh/m²/yr or less was achieved for all 1990s archetypes. This illustrates the benefit of using a demand-reduction approach to deep retrofits that prioritizes enclosure upgrades that coincide with building renewal cycles.

The potential for energy savings was highest for the office archetypes since the baseline office archetypes have higher TEUIs and thus have more opportunities to reduce energy consumption. For all archetypes in all locations, the largest energy end use was space heating.

² The BC Energy Step Code, developed by the Province of BC, uses a multitiered rollout method where the bottom step reflects the BC Building Minimum, and the top step corresponds to a high-performance building. The minimum performance of the top step is 100 kWh/m²/yr for MURBs and offices and 120 kWh/m²/yr for hotels and other commercial (Government of British Columbia 2022)².

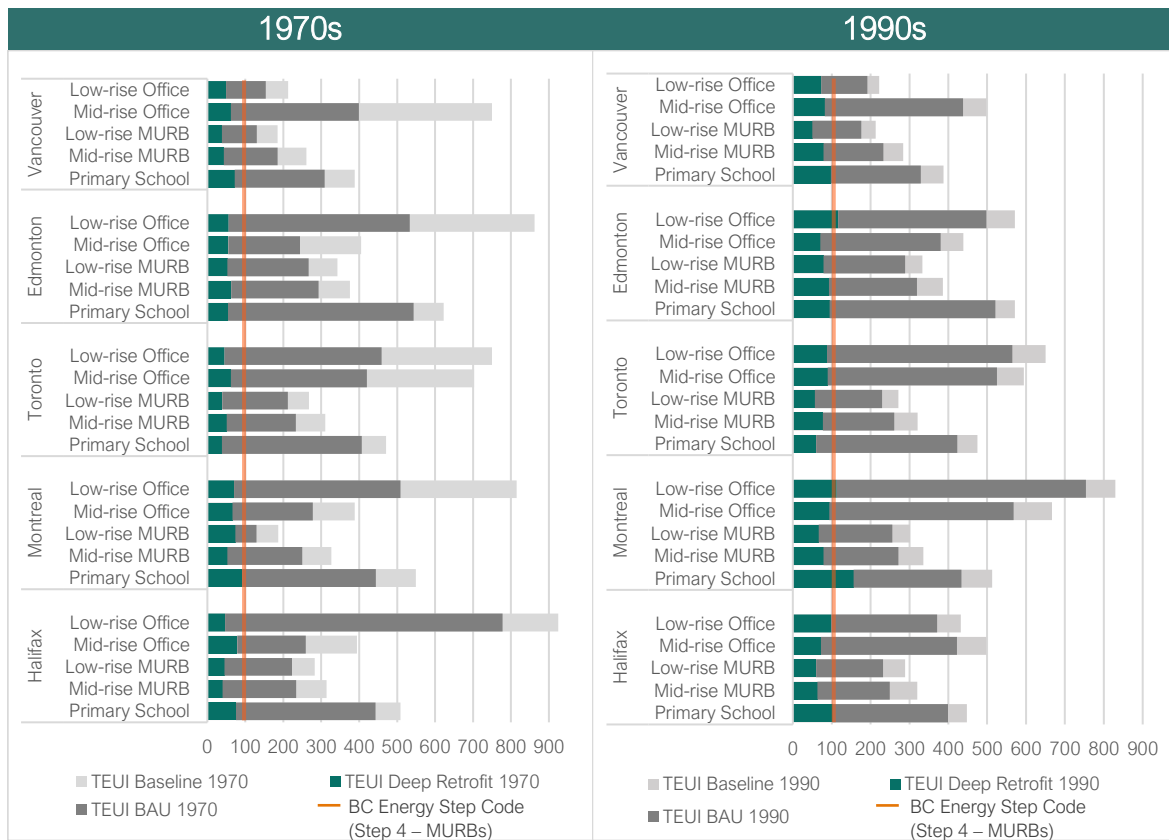
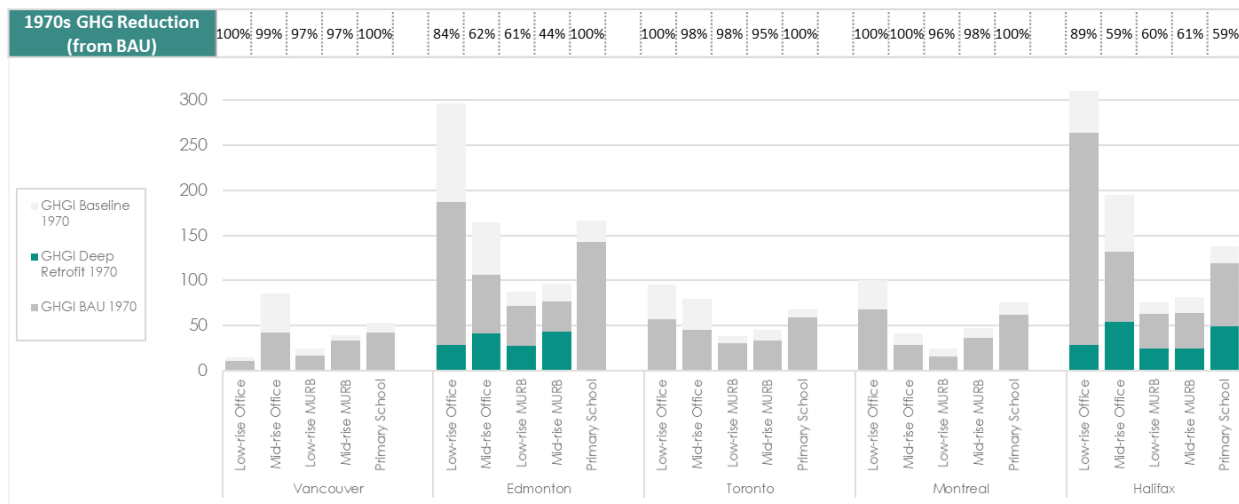


Figure 1: Total energy use intensity per building type by region and by vintage (kWh/m²/yr)

GHG Impacts

Although the deep retrofit packages resulted in similar endpoint TEUIs among the locations studied, the final GHGIs varied significantly between the locations due to differences in the carbon intensity of the grid electricity (ECCC 2019). Figure 2 shows the GHGI the baseline, BAU and deep carbon retrofit of each of the 50 archetypes.



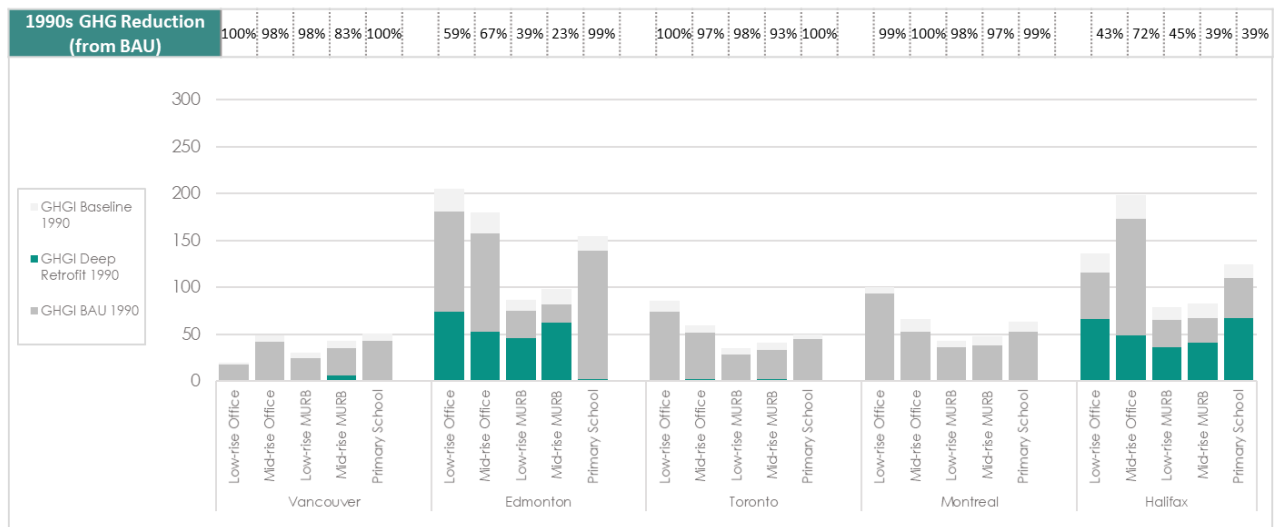


Figure 2: Baseline, BAU and Deep Carbon Retrofit with PV Scenario GHGI per building type by region and by vintage (kgCO_{2eq}/m²/yr)

Results revealed that deep carbon retrofits of buildings located in Montreal, Toronto, and Vancouver are technically ready to achieve net-zero targets. These archetypes achieved the lowest GHGI and the most significant GHG reductions since their electricity grid emission factors are relatively low. The low electrical grid emission factors combined with fuel switching and demand reduction, allowed the deep retrofit packages to deliver GHG reductions in excess of 80% in these cities.

Building archetypes in Halifax and Edmonton achieved reductions of greater than 50% in most cases. Even though the percentage of overall emission reductions was lower for those locations, the Edmonton and Halifax archetypes have the potential for the largest absolute carbon reduction. Indeed, as the carbon emission factors associated with electricity are highest in the Edmonton and Halifax regions, electrification of space heating does not result in as significant carbon reductions for buildings in these locations. However, these grids are expected to decarbonize over time³.

While the deep retrofit pathway modelled as part of this study did not achieve complete decarbonization for all locations and archetypes, results demonstrated that the transition to zero carbon by 2050 is still technically possible through three key additional activities:

- Eliminate fossil fuel combustion for all mechanical systems
- Conduct high-performance enclosure upgrades
- Support the complete decarbonization of the regional electricity grid.

Additionally, on-site solar PV can significantly help to reduce emissions for building archetypes with large roof areas that are connected to high-emission electricity grids, and where

³ The impact of grid decarbonization for the Edmonton location was investigated using projected future grid emissions. These projections resulted in a 73% to 76% further decrease in the effective operational emission of buildings after deep retrofits, compared to 2014 levels.

utility net metering policies do not apply size limitations. For example, a solar PV array on roof of an archetypal primary school in Edmonton was shown to virtually eliminate GHG emissions.

Peak Demand Impacts

In a decarbonization approach, peak demand impact of electrification measures is another key component of the technical results. Increases in peak demand can have cost implications for building owners as well as impacting electricity grid stability and capacity.

While results showed peak electrical demand increases for all building archetypes, deep retrofit for 1970s buildings that included demand reduction measures (i.e., enclosure upgrades) as part of the overall package were able to mostly mitigate the associated increase in electricity demand.

For some archetypes, especially the 1990s buildings, the electrification of space heating and service hot water results in an increase in the peak demand, and a shift from summer to winter annual peak. In the absence of demand reduction measures, these new winter peaks were higher than the existing summer peaks. This was more pronounced in buildings with relatively low internal heat gains and summer cooling loads, such as residential buildings and schools.

Findings also showed that archetypes without cooling⁴ experienced the highest increase in annual peak demand. Indeed, for the archetypes with cooling systems, the existing chiller was typically replaced with heat pump(s) that provide both heating and cooling. Since these archetypes already had a higher summer peak demand (associated with the cooling system), the implementation of heat pumps had a lower relative impact on the annual peak demand.

The market maturity of specific systems and equipment may impact the selection of CRMs for retrofit projects in the future. As an example, heat pumps are a continually developing technology and may be implemented differently in the future when capacity and temperature (both supply heating temperature and winter ambient temperature) limitations are improved.

Financial Analysis

After assessing technical pathways to achieve Canada's decarbonization goals, the next steps consisted of assessing the financial feasibility of these retrofits. Indeed, the cost and financial viability of retrofit measures vary substantially depending on the building type, age, location, and carbon intensity of the energy supply. The costing analysis consisted of estimating the incremental capital cost (ICC) for each retrofit bundle relative to regular upgrades occurring during the BAU life of building. ICCs were based on 2020 material and labor costing data estimated from product suppliers, industry reference databases (e.g., R.S. Means) and project experience⁵. The ICCs, along with results from the energy modelling and GHG analysis, were used to determine the cost-effectiveness of the CRMs for each deep retrofit bundle. The section

⁴ Most of the MURB archetypes were not assumed to have central cooling but it was rather assumed that occupants installed their own cooling systems, especially low-rise MURBs. These systems were not replaced in this analysis. Some school archetypes (in particular in Montreal and Halifax) were also not assumed to have cooling.

⁵ While some costs are based on cost data from recent building renewal projects, in some cases where available costing data is for new construction, the cost is increased by a factor of 1.5 to 2.5 to account for the additional cost and complexity typical of retrofit work (such as demolition, managing discovered building problems, and hazardous material remediation)

below highlights the main findings of the financial analysis including cost-effectiveness results, payback period and ICCs.

Cost-effectiveness

To determine the cost-effectiveness of deep carbon retrofits for the chosen archetypes, the study analyzed the net-present value (NPV) by calculating the discounted value of forecasted revenue from energy savings.

Overall, findings revealed that there is positive news for the deep carbon retrofit business case. First, many archetypes (17 of the 50), especially office buildings, proved to be great candidates for starting the decarbonization path since their deep carbon retrofits are already viable today. Those archetypes showed great alignment between carbon savings and energy cost savings. Secondly, most of the remaining archetypes were close to be cost-effective leading to a total of 88% of building archetypes (44 of the 50) able to yield a positive financial return even if it was less than the typically expected annual rate of growth (IRR between 0% and 5%). Since the analysis assumed retrofits completion by 2022 with carbon pricing levels increasing every year, the estimated NPV values for projects implemented after 2022 will be greater, making these decarbonization retrofits financially attractive moving forward. Additionally, while non-energy benefits were not evaluated in this study, accounting for them could further improve cost-effectiveness.

Figure 3 summarizes the findings by archetype but also highlights the challenges that can be encountered by some archetypes. When looking at the differences between the archetypes, a few additional observations can be made.

Firstly, retrofits that start with heating demand reductions are found to generally result in lower ICCs and achieve higher NPVs⁶. Office archetypes with less efficient systems such as dual-duct systems, which typically include cooling systems, have higher baseline electricity usage than other archetypes, resulting in greater electricity savings from a deep retrofit and high NPV. When diving into the differences between the two vintage archetypes, it is clear that 1970s buildings where CRMs include enclosure updates by 2022, were generally more cost-effective than 1990s buildings. Results for the 1970s buildings found that 11 of 25 archetypes had a positive NPV⁷ and all archetypes but the low-rise MURBS located in Montreal had a positive IRR. For the 1990s buildings, 6 out of 25 of the archetypes yielded a positive NPV and in 20 out of 25 instances, the IRR was positive.

Secondly, building location greatly impacted the analysis. Buildings in Halifax and Toronto experienced higher NPV from deep retrofits than in other locations due to above-average natural gas and above-average electricity prices, respectively.

Finally, the decarbonization appears to be financially more challenging for MURB and primary school archetypes given the current divergence of carbon and cost savings for those archetypes. Targeted financial assistance (e.g., low-interest financing) and specific policies (e.g., higher carbon pricing levels) will be essential in those cases to help close the gap and make these retrofits even more attractive as discussed in the next section.

⁶ However, building condition and renewal schedules may dictate which retrofit strategies are most feasible and cost-effective at a given point in time for individual buildings.

⁷ A positive NPV indicates that the internal rate of return (IRR) is higher than the discount rate applied (5%).

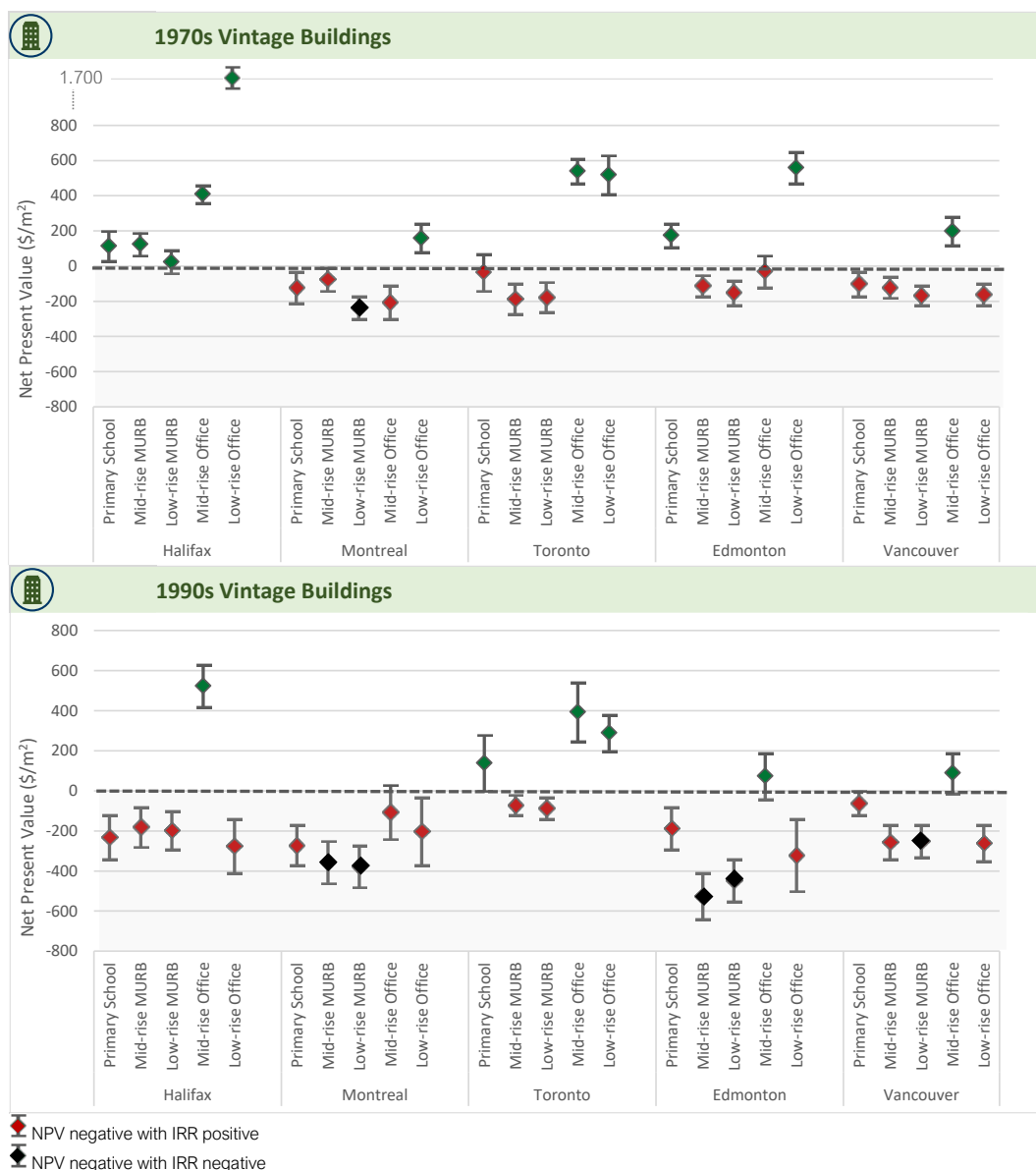


Figure 3: Net Present Value (\$/m²) of the Deep Carbon Retrofit with Solar PV Scenario per building type by region and by vintage (relative to BAU Scenario)

The cost of carbon abatement (\$/tCO₂e) is deemed to be zero in scenarios with positive NPVs, indicating that the deep retrofit is internally cost-effective. Because some archetypes have positive NPVs or minimal negative NPVs, the calculated cost of carbon abatement is in line with industry values for typical internalized carbon abatement costs – 31 out of the 50 archetypes had carbon abatement costs of less than \$100/ton, with only 5 archetypes having a carbon abatement cost of more than \$300/ton.

Discounted Payback Period

Recognizing that building owners use payback period assessment to determine if the investment is worthwhile based on their context, our financial analysis included that metric as

well to determine the probability of natural market transformation. As illustrated in Table 2, this metric proved to be challenging for deep carbon retrofit activity with most archetypes having greater than 15-year paybacks. Only 1970s low-rise offices in Toronto and Halifax and mid-rise offices in Toronto, Halifax and Edmonton presented the discounted payback periods lower than 15 years. Therefore, in general, building owners can expect longer payback period than what they were used to. These results highlight the need for low risk, innovative financing solutions designed to support building owners and encourage them to accept extended payback period.

Table 2: Discounted Payback Period per building type by region and by vintage

	Vancouver	Edmonton	Toronto	Montréal	Halifax
Low-rise Office 1970	●	●	●	●	●
Low-rise Office 1990	●	●	●	●	●
Mid-rise Office 1970	●	●	●	●	●
Mid-rise Office 1990	●	●	●	●	●
Low-rise MURB 1970	●	●	●	●	●
Low-rise MURB 1990	●	●	●	●	●
Mid-rise MURB 1970	●	●	●	●	●
Mid-rise MURB 1990	●	●	●	●	●
Primary School 1970	●	●	●	●	●
Primary School 1990	●	●	●	●	●

- Between 0-5 years
- Between 5-15 years
- > 15 years

Incremental Capital Costs

Understanding the level of investment required to get to our climate targets is also essential to fully comprehend the financial feasibility of CRMs. Indeed, to undertake deep carbon retrofits building owners must manage and secure the capital needed to cover the incremental costs as compared to BAU. Based on results, incremental costs for completing the deep retrofit package varies between \$210/m² and \$1,060/m² as displayed in Figure 4. The ICC can therefore be a major barrier for some building owners despite a good return on investment in some instances.

Mechanical upgrades were the largest driver for most archetypes, representing over 75% of the total ICC for retrofits to 1970s buildings and over 90% for retrofits to 1990s buildings. These findings highlight the need to mitigate these costs through effective decarbonization strategies. For example, results showed that in many cases, the ICC of a deep retrofit that includes enclosure upgrades is actually lower than the ICC without enclosure upgrades because enclosure upgrades minimize the size and cost of mechanical systems upgrades. In this study, enclosure CRMs included the upgrade of the thermal performance of the windows (to triple

glazed), of the roofs and walls (exterior insulation), as well as reducing infiltration by upgrading enclosure components and re-detailing air barriers.

Diving deeper, for some archetypes, it was found that one of the largest contributors to ICCs when replacing boilers with air to water heat pumps (AWHPs) was upgrading the capacity of the hydronic terminal units. However, these costly upgrades of the terminal heating system can be avoided, if an enclosure deep retrofit is pursued or if the existing terminal heating system and heating distribution is sized to work with lower temperature water (such as when fan-coils are already sized for cooling).

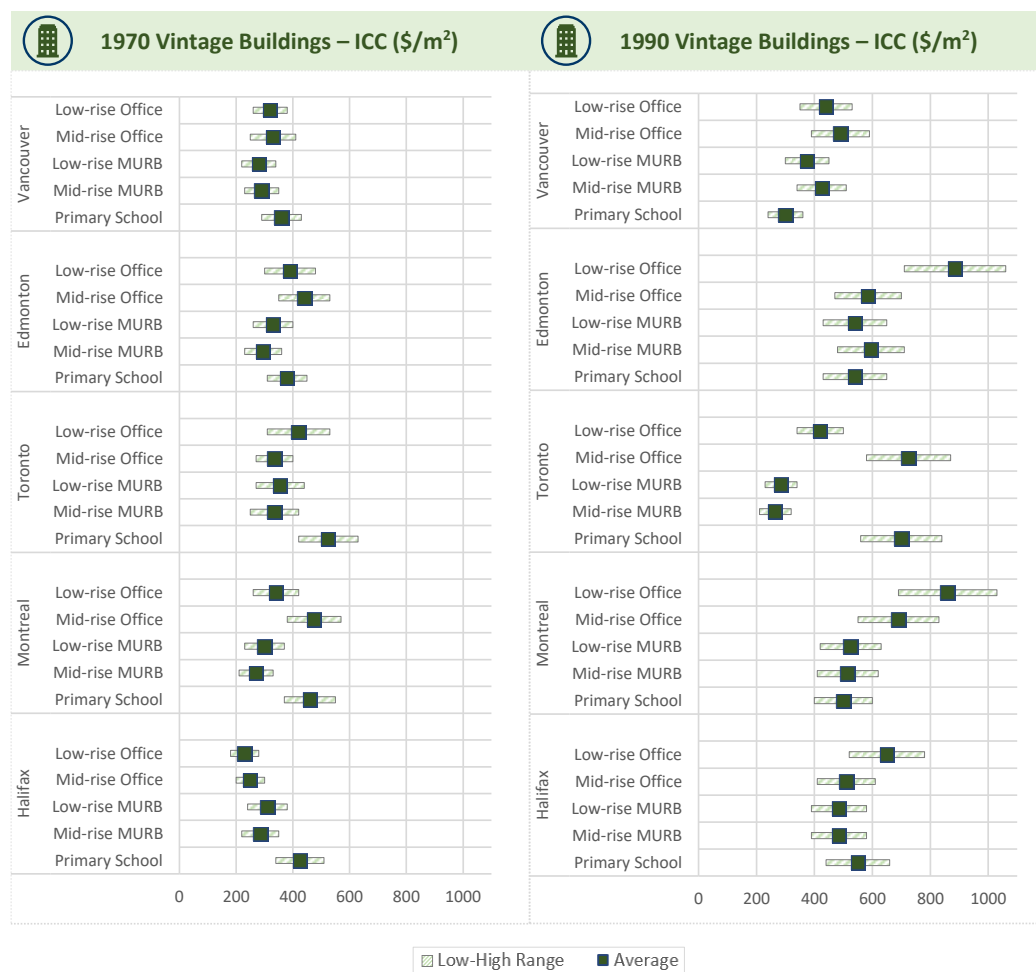


Figure 4: Incremental Capital Cost per building type by region and by vintage (\$/m²)

Policy Tools to Support Retrofits

In light of the findings from the energy modelling and the financial analysis, it is undeniable that retrofits are unlikely to accelerate at the pace needed to meet climate targets without significant policy support to address economic, market and financing barriers. While findings proved that technical and sometimes financial pathways exist for large building decarbonization, the case for deep carbon retrofits will stay a challenge for most building

owners. Policy and other government support initiatives will play an key role in improving the business case and overcoming additional barriers to retrofits spanning from lack of carbon awareness to split incentives issues. Fortunately, there are many policy tools available, including financing mechanisms, regulatory mechanisms and other supporting strategies such as education and capacity building (Table 3).

Table 3: Key Policy Mechanisms

Financing Mechanisms	Regulatory Mechanisms	Other Supporting Measures
- Repayment mechanisms (e.g., C-PACE and Utility On-Bill Financing) - Credit enhancements (loan loss reserve, loan guarantee and interest rate buy-downs)	- Incentives and Rebates - Carbon Pricing - Local Requirements and Incentives - Energy Rating & Disclosure - Retrofit Codes and Performance Requirements - Net-metering and Other Distributed Energy Policies	- Public Procurement - Demonstration Projects - Retrofit Support Services - Education & Training

Although several policy tools have slowly started to emerge across Canada, it is important to note that there are significant gaps and most initiatives to date have focused on energy savings rather than GHGs. The number and variation of barriers to implementing these deep carbon retrofits means that no single strategy will be able to address them all. Instead, a mix of strategies is required, some focused on individual barriers and others that may address multiple barriers.

Financing initiatives - At provincial level, British Columbia, Ontario, Quebec, and Nova Scotia are the regions with the most developed financing mechanisms in place (Efficiency Canada 2021; Natural Resources Canada 2021). Several financing tools are already available in these provinces, including Property Assessed Clean Energy (PACE) and On-Bill Financing (OBF). It should be noted however, that even in provinces with PACE enabling legislation or OBF, most programs are focused on residential markets: only the City of Toronto has introduced PACE for commercial buildings (Kennedy, Frappé-Sénéclauze, and Agar 2020). However, at the federal level, the CIB's Building Retrofit Initiative has the potential to transform the retrofit market by providing large-scale financing for the studied archetypes, encouraging new innovative business models, crowding in private capital, and helping to establish retrofits as a distinct asset class.

Incentives - In addition to financing mechanisms, incentives are definitely required to help close the gap and create a positive business case for low and mid-rise MURBs, which proved to be less cost-effective than the other modelled archetypes. With current carbon pricing levels, financial incentives are needed to support the transition of this market and help them achieve a positive return of investment, especially for newer buildings in Montreal, Edmonton, and Vancouver. The focus of incentive programs should be expanded to include carbon reduction

measures. Alternatively, higher carbon prices could also better align the industry with Canada's climate targets.

Performance targets - Instituting mandatory performance targets for existing buildings will be critical for driving demand for and implementation of retrofits to help meet climate targets. While most provinces have adopted at least one voluntary mechanism to advance retrofits, mandatory mechanisms or requirements for existing buildings remain rare in Canada. Only Ontario requires building energy rating and disclosure, while all other provincial disclosure initiatives are voluntary. However, retrofit codes and performance requirements are under development in BC, Quebec and at the national level (Lockhart 2021). It is also worth noting that most of the deployed provincial policies are still primarily focused on energy efficiency measures rather than specifically targeting carbon emissions.

Finally, to scale up retrofit market activity, it will also be important to effectively integrate, coordinate and align the various policies and initiatives. Figure 5 highlights the strategies and mechanisms fundamental to success. Many policies are complementary: for example, performance requirements can be integrated with building rating and disclosure policies and financing and incentives can be bundled together to offer a seamless experience for building owners pursuing deep carbon retrofits.

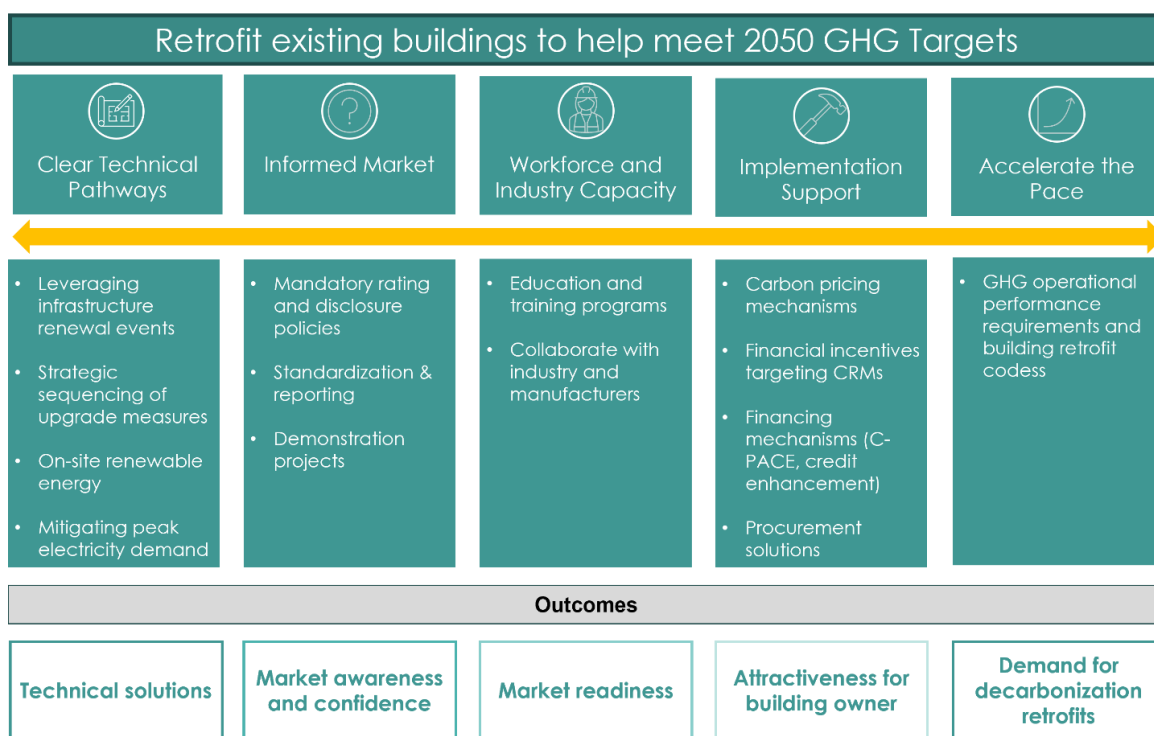


Figure 5: Steps towards Zero Carbon

Procurement and Delivery Options

While our energy and financial analysis highlights the need to significantly scale up support for policy makers, building owners and operators also have a key role to play in the transition. Building owners can choose an appropriate implementation pathway and turn to

innovative procurement and delivery options to help improve their project business case. The study aimed at providing an overview of available options for building owners.

To deliver these projects, a traditional method is the Design-Bid-Build (DBB) method where owners first hire a design firm to create project designs and then bid out the work for a contractor to implement the design. This method along with innovative financing can be well suited for a lot of projects. For larger projects, Design-Build methods can accelerate the process and remove some financial risks. These are turnkey projects combining traditionally separated services under one, fixed-fee contract. A single entity is responsible for project design and construction and in some cases subsequently operates and maintains the building systems (Design-Build-Operate-Maintain or DBOM). When combined with an energy performance guarantee, they become Energy Performance Contracts.

In short, each method combined with strategic financing will provide a different level of flexibility, capital requirement, risk, benefit, and contract duration (Table 4). The benefits of these approaches can include no up-front payments, less administrative burden, off-balance sheet debt treatment, passing along some of the costs to tenants, and guaranteed performance.

Table 4: Comparison of Project Financing and Project Delivery Combinations

	Characteristic	Traditional owner financing	Innovative owner financing		Pay for performance		Other ⁸
		Out of pocket or borrowing	Property assessed clean energy (C-PACE)	Property on-bill financing / repayment	Energy services agreement	Managed energy services agreement	Energy performance contract (EPC)
Core Attributes	Project delivery method	Typically DBB			DBOM	DBOM	EPC
	Performance risk	Borne by owner			Borne by provider		
	Usual project size	Any	Small to large	Small/medium	Large to very large		
	Transferability to new owners	Does not transfer	Automatically transfers	Potential to transfer	Complicated to transfer	Complicated to transfer	Complicated to transfer
	Key constraints		Challenging in MURBs	Not suited for large projects	Typically, only viable in leased space if contract term does not exceed the lease term		
Contract Structure	Repayment type & form	Depends on type of financing	Fixed via property assessments	Fixed via utility bill	Variable according to energy savings	Fixed payments	Typically fixed payments
	Collateral	Building	Tax assessment lien	Equipment; service termination	Equipment	Equipment	Depends on financing
	Typical balance sheet treatment	On	Inconclusive; potentially some off-balance sheet treatment		Off	Off	On
	Typical duration	Varies	10-20 years	2-15 years	5-15 years	5-15 years	5-20 years
Admin.	Administrative complexity (contract closing time)	Medium (3-9 months)	Medium (3-9 months)	Low (1-3 months)	Medium-High (9-12 months)	Medium-High (9-12 months)	High (12 months or more)

⁸ While Energy Performance Contract is a project delivery mechanism, occasionally ESCOs facilitate financing if required by the client. The provider may directly fund the project or offer support in accessing other funds/subsidies.

Up to now the retrofit industry has been focused mostly on achieving energy cost savings, with project financing methods predicated on a stream of financial savings from energy efficiency. As the retrofit industry's focus shifts to carbon reductions and other co-benefits such as health in the coming years (because of increased public demand and targeted policies), the industry and its financing methods must innovate and streamline new offerings to achieve retrofits at the level of depth and scale needed to reach Canada's climate targets. In addition, traditional energy efficiency service providers such as Energy Service Companies (ESCOs) typically only target public sector markets. New and innovative financing solutions that can support turnkey retrofit providers such as Super ESCOs and Special Purpose Vehicles, and Energy as a Service providers that can identify opportunities, design, implement and finance deep carbon retrofits are needed to scale up retrofit activity.

Conclusion

This analysis demonstrates that deep carbon retrofits can technically be achieved across all building archetypes and in some cases cost-effectively. The transition to zero carbon buildings can be achieved by pursuing a full range of CRMs, with (1) additional mechanical replacements to eliminate all fossil fuel use in some cases, (2) upgrade of enclosures not yet slated for renewals, (3) further decarbonization of grid electricity, and (4) strategic investments of varied levels for all archetypes. In general, the modeling results indicated that almost all archetypes could achieve a TEUI threshold of 100 kWh/m²/yr or lower, thereby meeting the decarbonization target and supporting full electrification of all building services. Moreover, 44 of the 50 archetypes were found to offer cost-effective decarbonization retrofit pathways, using 2022 energy and carbon prices. Considering the improved economics arising from increasing carbon pricing in Canada over the 2022-2030 period, as per the Federal Government's policy, it is expected that the cost-effectiveness of all retrofit packages will continue to improve in the coming years.

However, while the deep decarbonization retrofits modeled in this paper are shown to be technically feasible, and for the most part cost-effective, the returns may not be sufficient or reliable enough to encourage building owners to pursue these on their own merits. Thus, few decarbonization retrofits currently take place, and those that do typically pursue modest savings. With less than a decade left to cut emissions by 40-45%, further action is needed to accelerate the pace of deep carbon retrofits. Policy and other support mechanisms are therefore critical to encouraging building owners to pursue these technically feasible and economically viable deep retrofits in order to reach Canada's climate change goals.

Key policy options include building energy reporting, retrofit energy codes, low-interest and easy to access financing to support building owners to meet evolving requirements, communicating the technical pathways to building owners and the retrofit industry, workforce and industry capacity building, and carbon pricing mechanisms. Collectively, these can require, enable and motivate building owners to pursue decarbonization retrofits in their buildings.

Furthermore, the retrofit market challenge today has grown beyond energy efficiency or even deep energy efficiency improvements. Today's challenge is how best to advance deep carbon retrofit projects that achieve deep carbon emissions reductions. Doing so must overcome all the barriers for energy retrofits – but with the additional challenge that maximizing carbon savings may not always align with maximizing financial savings.

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