Research

Decarbonizing Canada's Large Buildings: A Path Forward

January 2022

Acknowledgments

The Canada Green Building Council (CaGBC) acknowledges the contributions of the Government of Canada, the Real Estate Foundation of BC, and the Province of Nova Scotia (represented by the Nova Scotia Department of Energy and Mines) in the preparation of this report. CaGBC also thanks the consultants on this report, RDH Building Science, working in partnership with Dunsky Energy + Climate Advisors.

About the Canada Green Building Council

The Canada Green Building Council (cagbc.org) is a leading national non-partisan not-for-profit organization dedicated to accelerating the transformation to high-performing, healthy green buildings, homes, and communities throughout Canada. CaGBC is a leading green building education provider and conducts extensive research on key environmental and economic issues associated with green building. CaGBC helps governments identify and lower barriers to green building, owners and operators adapt to change, and companies identify and leverage opportunities in the green building marketplace.

About RDH

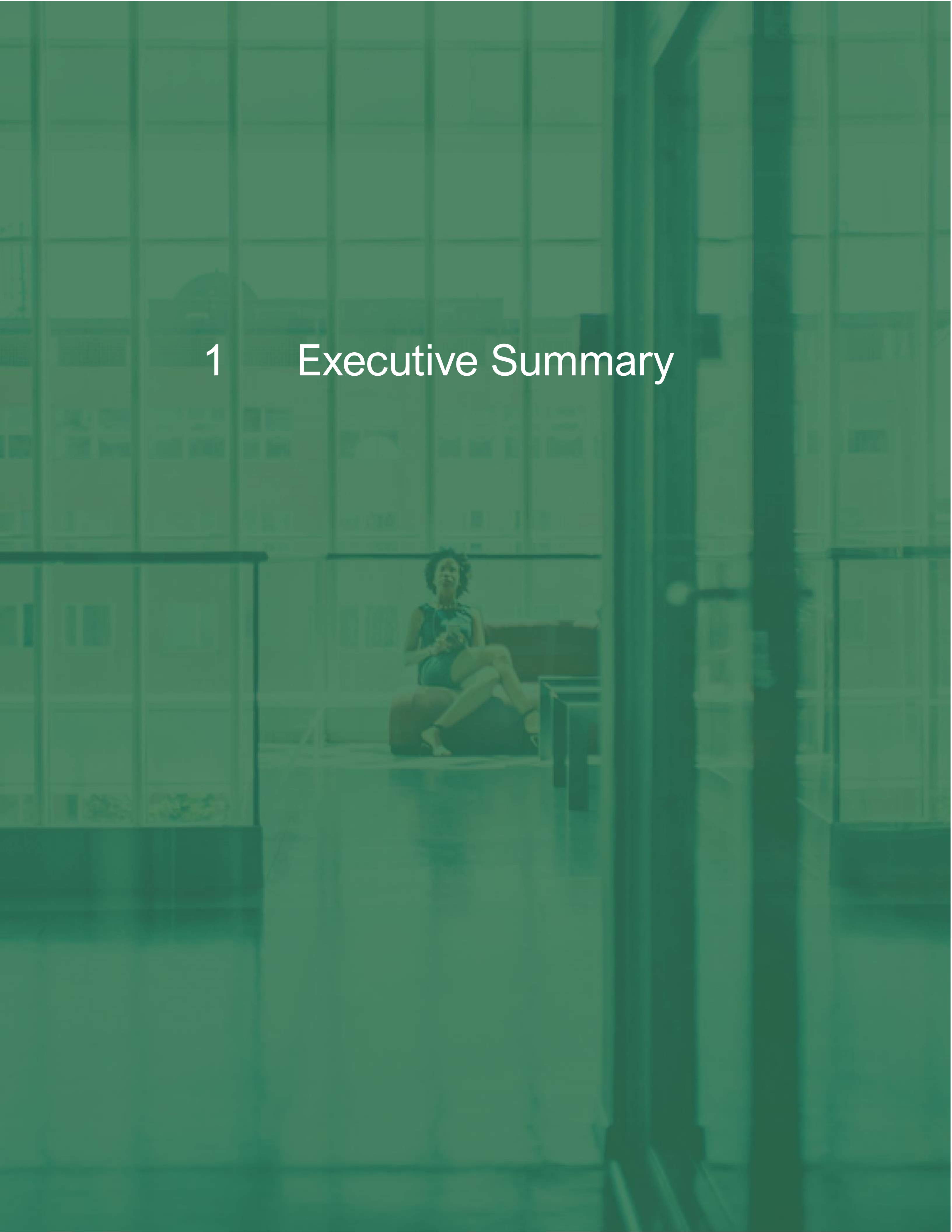
RDH Building Science prides itself on helping clients make informed decisions that lead to durable, efficient and low-carbon buildings. Their expertise and dedicated service area suppports various types of research, energy efficiency, and sustainability projects for all types of organizations, including building designs and retrofits, government policy inititiatives, regulation updates, utility conservation management programs, and building related sustainable leadership measures.

About Dunsky Energy + Climate Advisors

Founded in 2004, Dunsky Energy + Climate Advisors supports leading governments, utilities, corporations and non-profits across North America in their efforts to accelerate the clean energy transition, effectively and responsibly. Working across buildings, industry, energy and mobility, we support our clients through three key services: we quantify opportunities (technical, economic, market); design go-to-market strategies (plans, programs, policies); and evaluate performance (with a view to continuous improvement).

ISBN: 978-1-7771372-7-4

1 Executive Summary



Executive Summary

Buildings contribute approximately 17 per cent of Canada's greenhouse gas emissions.[1] While governments will tackle emissions from new buildings through increasingly stringent energy codes and regulations, Canada will not meet its climate targets if it does not address existing buildings. The onus is on building owners and operators to upgrade, retrofit, and ultimately decarbonize hundreds of millions of square metres of space.[2] To decarbonize existing buildings, Canada will need new or strengthened regulations and policies, significant investments, innovative financing structures, and building-system advances, as well as a focus on electrical grid decarbonization and a steadily increasing carbon price.

The Canada Green Building Council (CaGBC) *A Roadmap for Retrofits in Canada* report estimates that retrofitting large buildings could reduce greenhouse gas (GHG) emissions by up to 51 per cent or 21.2 million tonnes. Although the potential and importance of deep carbon retrofits[3] is generally known, implementation and costs at the building level are not well understood. Policy-makers and building owners must fully understand the cost of deep carbon retrofits and the potential energy and GHG savings to better inform policy development and investment decisions.

To support the market in advancing decarbonization, CaGBC commissioned RDH Building Science Inc. in partnership with Dunsky Energy + Climate Advisors to evaluate technical pathways for achieving deep carbon retrofits. ***Decarbonizing Canada's Large Building: A Pathway Forward*** is the resulting technical report. A summary of the key findings is also available at cagbc.org/decarbonize.

Whole-building energy modelling was used to evaluate retrofit opportunities across 50 different building archetypes, reflecting a representative range of building types, size, age, and location.[4] Office, multi-unit residential buildings (MURBs), and primary school archetypes were chosen because they constitute a large portion of Canada's existing buildings and associated emissions. In 2018, these typologies represented approximately 31 per cent of Canada's existing building floor space and approximately 30 per cent of its building-related emissions.[5] Vintages (construction eras) were chosen to be reflective of building ages at which major investments in mechanical systems and enclosures are likely. Locations were chosen to represent different climatic regions, utility costs and electrical grids.

For each building archetype, the researchers developed baselines and assessed business-as-usual (BAU) upgrades—that is, those activities routinely undertaken as building systems reach their anticipated service life. The researchers then identified and assessed the performance outcomes resulting from deep carbon retrofits and conducted financial analyses of the retrofit measures for each archetype.

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[1] Canada's Pan Canadian Framework on Clean Growth and Climate Change available at https://publications.gc.ca/collections/collection_2017/eccc/En4-294-2016-eng.pdf

[2] Decarbonization in the built environment is the process of reducing GHG emissions from building operations through energy demand reduction, electrification, renewable energy, and other measures. While decarbonization includes both operational and embodied building emissions, this research only addresses the former of the two.

[3] A deep carbon retrofit is the process of improving and updating a building's systems with the primary goal of minimizing greenhouse gas emissions. It can include reducing building energy demand, replacing and/or electrifying heating and mechanical systems, and/or producing on-site renewable energy.

[4] An archetype is a theoretical baseline building that practitioners use to compare the anticipated real-world performance of a group of buildings of similar size, type, and use under different scenarios.

[5] Canada's Comprehensive Energy Use Database (CEUD) available at https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

Finally, the researchers examined procurement approaches and recommended policy and support mechanisms needed to create actionable decarbonization pathways for building owners.

The study's overarching goal is to equip building owners and policy-makers with the tools and information needed to accelerate deep carbon retrofits and put Canada on a path to achieving deep emissions reductions.

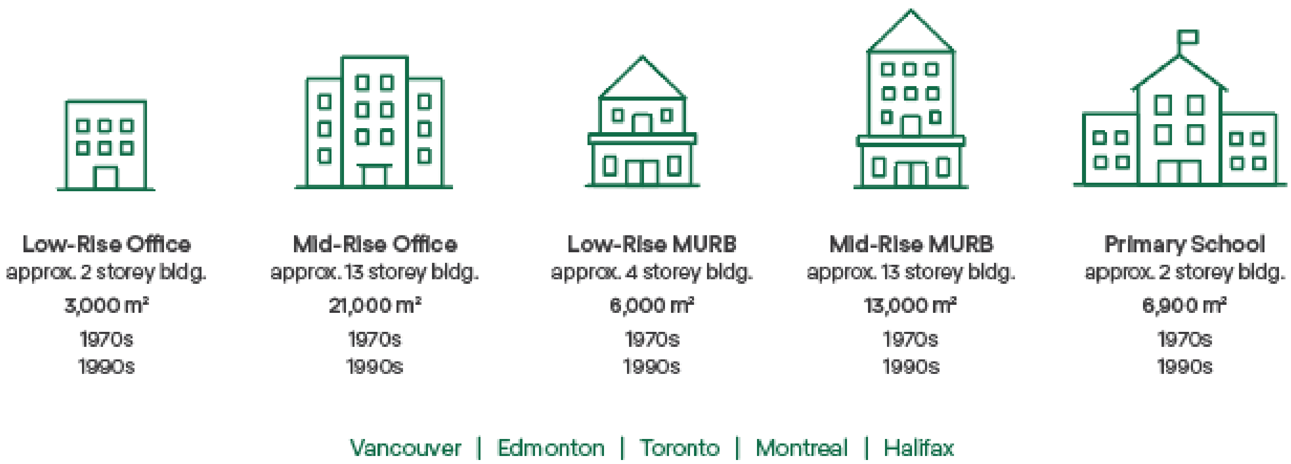


Figure 1. Decarbonizing Canada's Large Buildings – Study Archetypes

The deep retrofit measures in this study represent a pathway to zero carbon for existing buildings. The modelled enclosure and heating, ventilation, and air conditioning systems differed depending on the building age and location and were determined through industry consultation and experience. The study assumes that deep carbon retrofits for the 1970s building archetypes include electrical, enclosure, and mechanical upgrades to maximize emissions reductions and support cost-effectiveness. For the 1990's archetypes, the deep carbon retrofit pathway includes electrical and mechanical upgrades, with the assumption that enclosure upgrades will occur in the future, in line with regular building renewal cycles. On-site solar photovoltaic (PV) is also applied in all the deep carbon retrofit scenarios and retrofits are assumed to be completed in 2022 when the price of carbon will be $50/tonne with future price increases included in the financial analysis.

The study assumes that electrical, enclosure and mechanical upgrades are undertaken concurrently for time and cost-efficiency purposes. However, the measures were modelled separately to reflect potential project phasing and to better understand the impact of the electrical and enclosure upgrade measures prior to adding the mechanical scope of work.

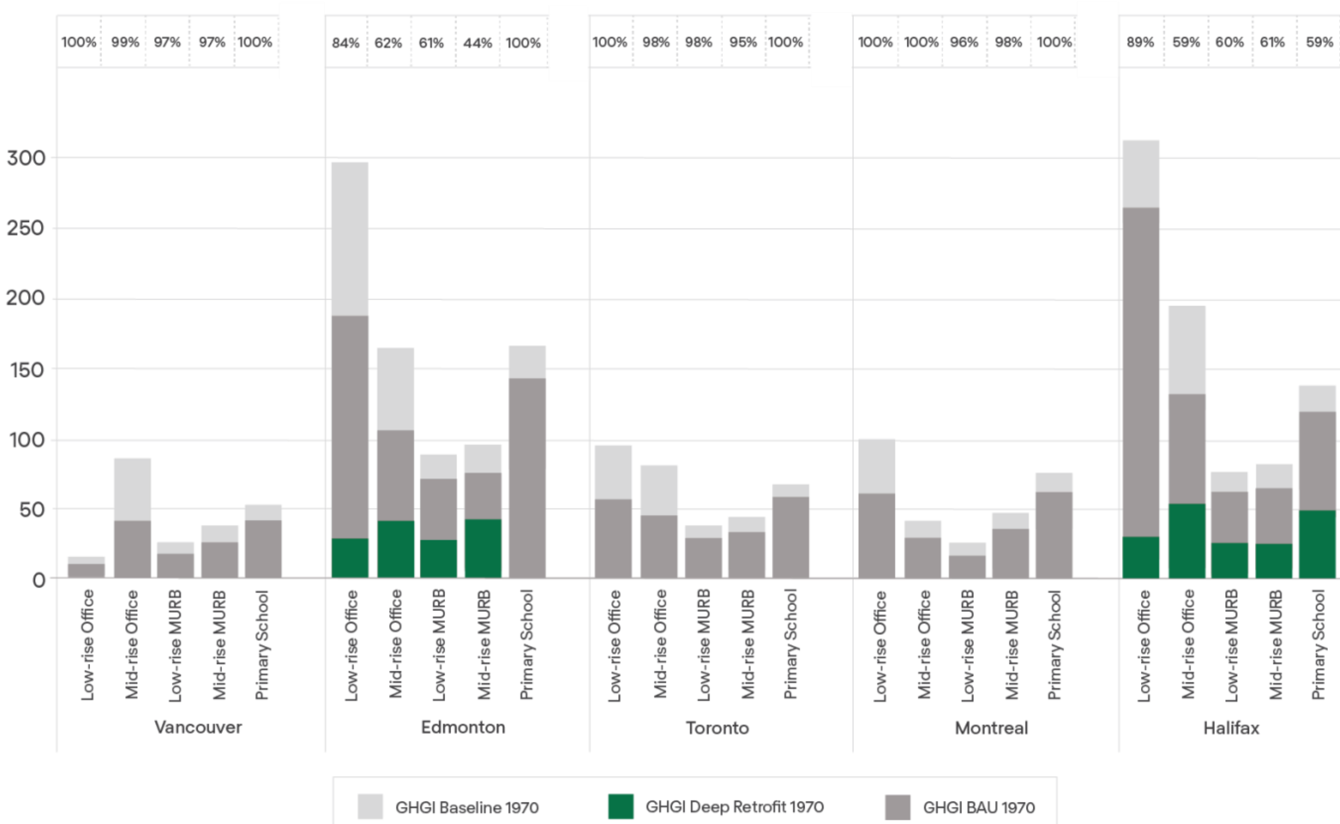
Key findings from the study include:

Canada can decarbonize all existing large buildings by 2050 if we start today.

Every building archetype in the study can achieve deep carbon reductions. All are positioned for the clean electricity grids of the future, and most can achieve zero carbon today. Deep carbon retrofits of building archetypes in Vancouver, Toronto and Montreal achieve emissions reductions of at least 93 per cent due to the low carbon intensity of the electricity grid.[6] In Halifax and Edmonton, greenhouse gas intensities were reduced on average 68% in the 1970s archetypes, and 53% in the 1990s archetypes. Furthermore, fossil fuel use was reduced at least 96% in each archetype, ensuring the retrofitted buildings are well positioned for the clean electrical grids of the future.

The following figure shows the greenhouse gas intensity (GHGI) of the baseline, business-as-usual, and deep carbon retrofit scenarios for all 50 archetypes.

GHG Reduction from BAU - 1970s Vintage Buildings



[6] The exception is mid-rise MURBs in Vancouver, which still achieved reductions of 83 per cent.

GHG Reduction from BAU - 1990s Vintage Buildings

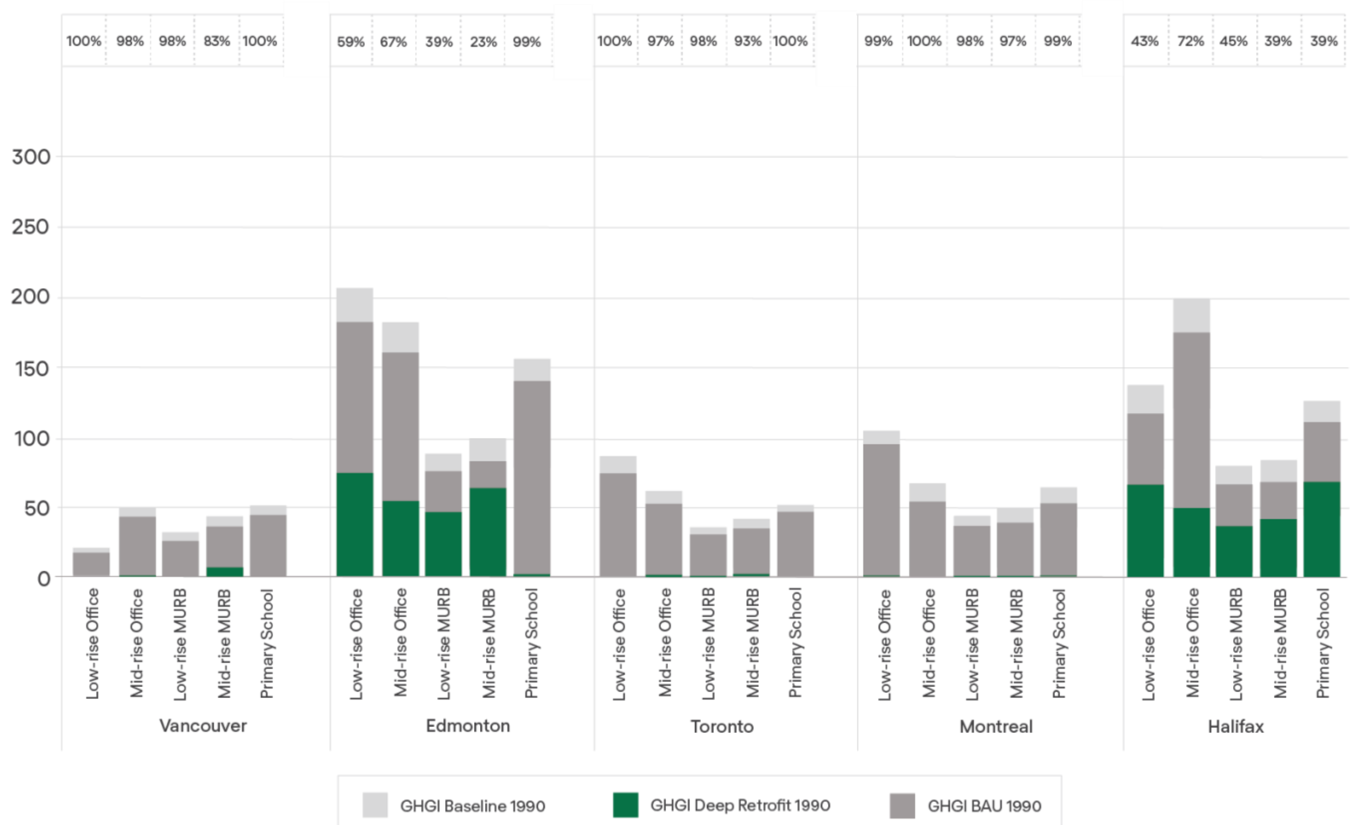


Figure 2. GHGI of the baseline, BAU and deep carbon retrofit scenarios for each archetype (kgCO₂eq /m²/yr)

On-site solar PV can play a key role in reducing emissions in certain locations. Solar PV has the greatest impact on emissions for building archetypes with a large roof area, located in regions with carbon intensive electricity grids and no utility net metering size limitations. For example, the addition of solar PV on the large roof of the Edmonton primary school enabled that archetype to achieve emissions reductions of 99-100 per cent.

Energy use reductions of more than 70 per cent yield significant cost savings.

Almost all archetypes could realize energy reductions greater than 70 per cent compared with business-as-usual measures. These reductions would yield significant energy cost savings for building owners and tenants.

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

The deep carbon retrofit of the 1970s archetypes (including electrical, enclosure and mechanical upgrades) achieved higher energy savings and lower final TEUIs as compared to the retrofit of the 1990s archetypes (including electrical and mechanical). This illustrates the benefit of using a demand-reduction approach to deep retrofits and prioritizing enclosure upgrades at the time of regular renewals.

The TEUI per archetype is shown in the following figure.

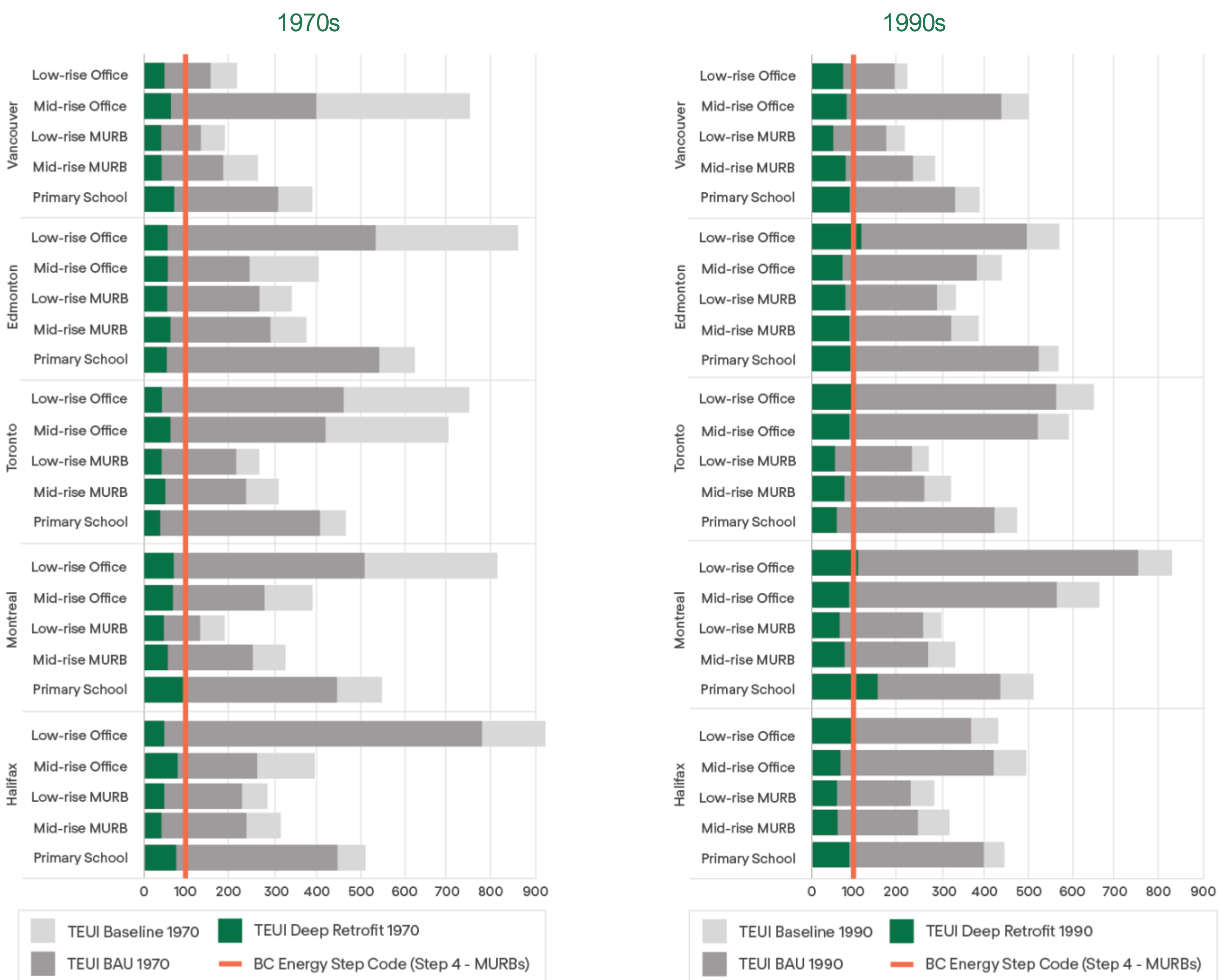


Figure 3. Total energy use intensity (TEUI) per archetype (kWh/m2/yr)

The TEUI results for the deep retrofit MURB archetypes are in line with the requirements for the upper steps/tiers of the BC Energy Step Code (ESC) and Toronto Green Standard, which guide new construction. All MURB archetypes result in lower TEUI than required for the highest step (Step 4) of the BC ESC, which is 100 kWh/m^2/yr. Similarly, all the office buildings achieve the upper step of the BC ESC, which is also 100kWh/m^2/yr. This indicates that adopting performance-based metrics is feasible for existing buildings, though additional support mechanisms, such as energy modelling guidelines, would need to be developed.

There is good news for the deep carbon retrofit business case.

The study evaluates key financial metrics for retrofit measures, including net present value (NPV),[7] internal rate of return (IRR),[8] incremental capital cost (ICC),[9] and the cost of carbon abatement (CCA)[10] – assessed over a 40-year time horizon, using a five per cent discount rate for the cost of capital, and accounting for planned increases to carbon prices ($170 a tonne by 2030 and $300 a tonne by 2050).

While the study noted that the modelled business cases are not yet conventionally attractive for some archetypes, there is positive news – and as the cost of carbon increases and technologies advance the business case for retrofits will improve over time.

It pays to reduce carbon today for many building archetypes.

Given the significant potential for energy-cost savings, deep carbon retrofits are viable right now for many low- and mid-rise office archetypes, as well as a few MURBs and primary school archetypes (17 of the 50 archetypes). This highlights how "quick wins" could kickstart the decarbonization retrofit market.

Even for archetypes with negative NPVs, the capital needed to address the investment gap is generally aligned with industry values for typical internalized carbon abatement costs. As shown in the table below, of the 50 archetypes studied, 45 had CCA values below $300 per tonne of carbon. Note that a CCA of $0 per tonne indicates a positive NPV, requiring no additional abatement costs.

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[7] Investors calculate net present value (NPV) to evaluate and compare capital projects or financial products with cash flows spread over time. It allows them to understand the "time value" of money.

[8] The internal rate of return on an investment is the rate of return that will be earned from implementing a retrofit or the rate of return that sets the net present value of all cash flows (both positive and negative) from the investment equal to zero.

[9] The incremental capital cost is the estimated additional capital investment required for each retrofit measure relative to the corresponding business as usual upgrade investments needed.

[10] The cost of carbon abatement represents the dollars of funding that is required for some archetypes and bundles to off-set the additional life cycle costs of the measures and achieve the GHG emissions savings.

	Low-rise Office	Mid-rise Office	Low-rise MURB	Mid-rise MURB	Primary School
1970					
Vancouver	$374	$0	$252	$109	$52
Edmonton	$0	$2	$78	$74	$0
Toronto	$0	$0	$140	$136	$6
Montreal	$0	$169	$378	$45	$41
Halifax	$0	$0	$0	$0	$0
1990					
Vancouver	$377	$0	$248	$211	$29
Edmonton	$63	$0	$371	>$500	$29
Toronto	$0	$0	$68	$48	$0
Montreal	$45	$41	$260	$230	$120
Halifax	$116	$0	$156	$166	$48

Table 1: Cost of Carbon Abatement per Archetype ($/t$CO_2$e)

Of the archetypes studied, office buildings are the "low-hanging". Nearly all office building archetypes can reach net zero carbon operations, while at the same time achieving a positive NPV. This suggests that deep carbon retrofits make sense for these buildings today, especially for the 1970s archetypes, which included enclosure upgrades.

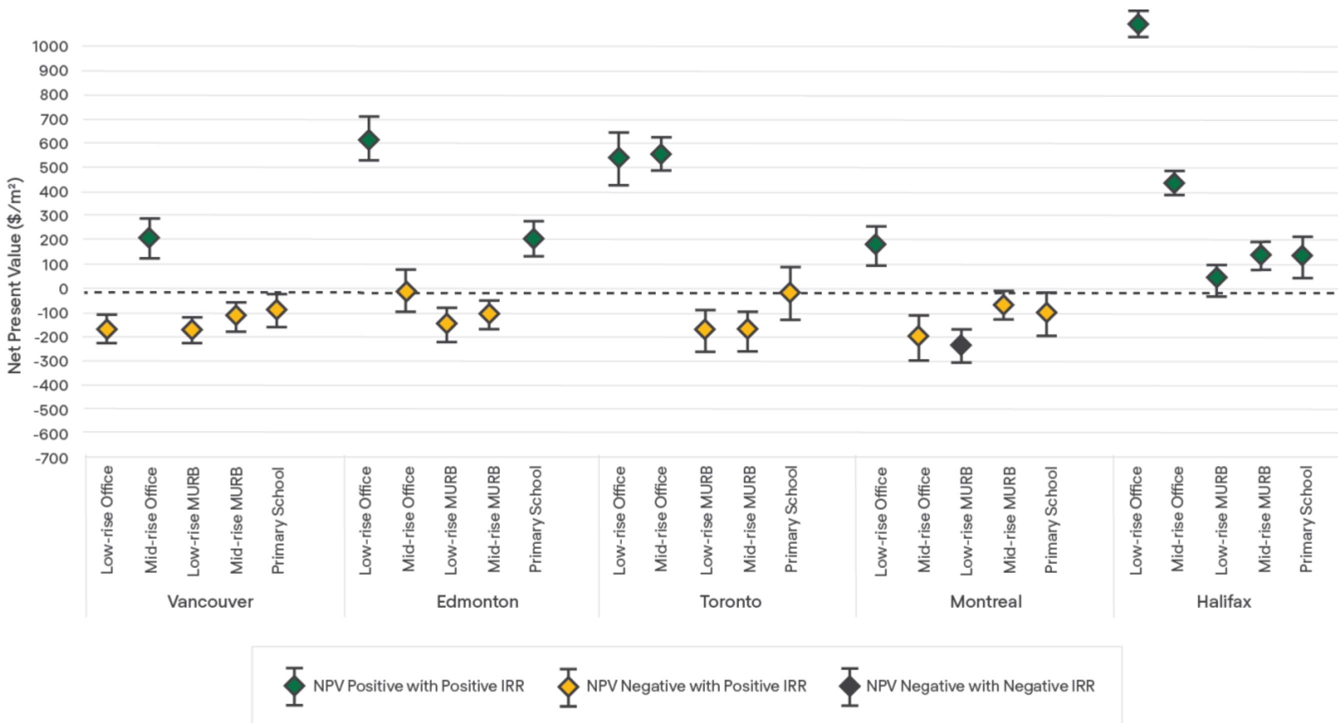
Financially, implementing deep decarbonization retrofits is most challenging for MURB archetypes: MURB retrofits realize less favourable NPVs than retrofits of office archetypes, despite similar or lower ICCs, because they do not reduce electricity use to the same degree.

In most cases where the models returned a negative NPV, the IRR was positive (i.e., between 0% and 5%). In other words, owners would see a positive financial return, but less than the estimated cost of capital or borrowing rate. Positive internal rates of return were achieved for 45 archetypes (see Figure 4). While deep carbon retrofits for some specific archetypes might not be financially attractive today, owners should not rule them out. Instead, they should consider a life-cycle-cost analysis on a building-by-building basis, to optimize the timing of improvements as the cost and risk of carbon escalate.

Building owners must cover the additional cost of deep retrofits compared to BAU maintenance and upgrades. Based on the financial analysis, the ICC for completing the deep retrofits varies between $210/m^2 and $1,060/m^2. This can be a barrier for some building owners, even in situations where there is a good return on investment. Mechanical upgrades are the largest incremental capital cost driver for most archetypes, typically representing over 75 per cent of the total incremental capital cost for retrofits to 1970s buildings and over 90 per cent for retrofits to 1990s buildings.

The figure below presents the net present value ($/m^2) of the deep carbon retrofit scenario by archetype, relative to the business-as-usual (BAU) scenario.

1970s Vintage Buildings



1990s Vintage Buildings

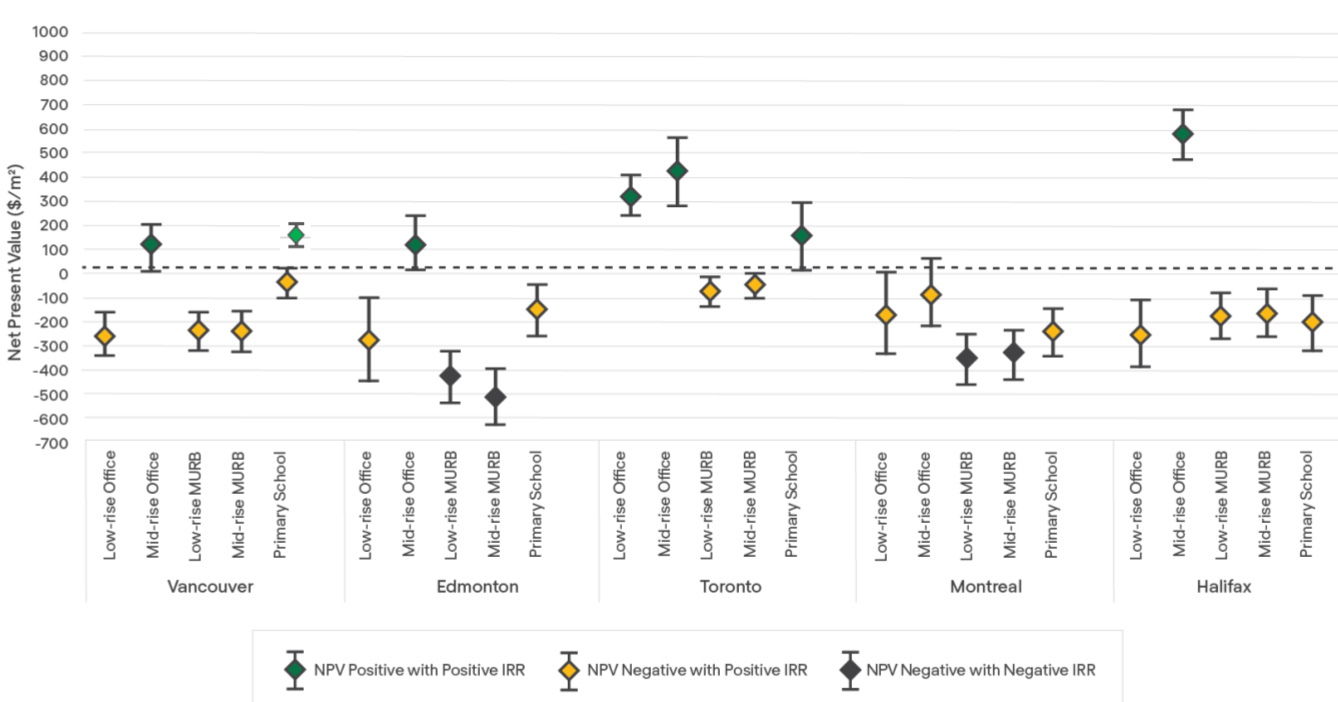


Figure 4. Net Present Value ($/m²) of the Deep Carbon Retrofit with PV Scenario by Archetype (relative to BAU Scenario)

Current technologies can achieve deep carbon reductions.

The carbon reduction measures for the deep retrofit pathways were all established based on what is currently feasible with available products and/or building practices. As technology performance improves over time, alternative systems are developed, and costs decrease, more ways for buildings to lower carbon emissions will become available.

As an example, the use of heat pumps is rapidly expanding. As this market evolves, system capacity, supply temperature and cold climate performance are expected to improve. For climates that experience temperatures below -15°C (all locations except Vancouver and Halifax), a peaking condensing gas boiler was used to meet the difference between -15°C and the temperature assumed for modelling purposes. In these instances, the gas boiler provides approximately 1 to 7 per cent of the total heating energy load. While this is an extremely small share, the gas boilers limit the number of heat pumps required, which helps control capital costs. As heat pump technology develops, these top-up boilers may be excluded in future equipment replacement cycles.

A zero carbon transition plan is essential.

Achieving deep carbon savings relies on having a zero carbon transition plan in place for the building that outlines a series of building improvements and the situations that may trigger them.

Retrofits should be aligned with key building system renewal cycles to reduce incremental capital costs and increase operational savings. These decisive moments must be clearly identified in the zero carbon transition plan to make sure that the building owner is ready when the time comes.

If feasible, any HVAC upgrades should be preceded by measures that can reduce energy loads, including improving building envelopes, lighting upgrades, and plug load reduction.

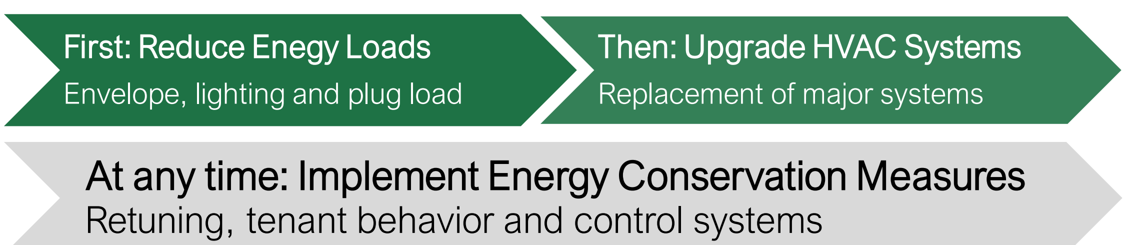


Figure 5. Load Reduction Should Preceded HVAC Upgrades

Since the size of a building's mechanical system is dependent on the building's heating and cooling needs, if loads are not first reduced, the building will need to install replacement systems that are larger and more expensive than ultimately required. Moreover, proper sequencing can allow elements of the existing HVAC system to be retained, reducing costs. Downsizing replacement HVAC equipment can also help mitigate the challenges of space constraints on existing roofs or at grade near the building, and potential structural constraints on rooftops. Importantly, it can reduce the likelihood of requiring costly electrical service upgrades.

Enclosure upgrades are a one-time opportunity that can't be missed.

Among energy-demand reduction activities, enclosure upgrades are the highest priority. Enclosure renewals occur very infrequently, typically every 20 to 100 years, depending on the assembly type and condition (most occur after about 40 years). As such, existing buildings are likely to only undergo a single enclosure upgrade between now and 2050. Each enclosure upgrade therefore represents a rare and critical opportunity to advance decarbonization. Upgrades also provide a range of additional benefits including:

Increased energy savings: The enclosure upgrades in the 1970s buildings achieved a reduction of approximately 20 to 50% in energy use, resulting in lower operating costs and less exposure to future utility cost escalation.

Resilience to climate change by supporting passive survivability and lessening dependence on grid energy to maintain livable space conditions.

Building durability, which can reduce maintenance and repair costs as well as increase building longevity.

Lower peak demand, which can enable replacement equipment to be downsized and reduce overall operational costs, especially for building types and locations with high utility demand charges.

Peak electricity demand must be addressed.

Except for offices, the electrification of space heating and service hot water systems increases annual peak electricity demand. The increases are greater for 1990s archetypes, highlighting the importance of demand reduction strategies, such as enclosure upgrades, heat recovery, and optimized operations. Onsite renewable energy, thermal and battery storage, as well as demand response programs, may help harness energy when it is available and mitigate higher peak demands on the grid.

Failure to mitigate peak demand can result in significantly higher costs due to the need for electrical service upgrades and localized improvements to electrical grid distribution.

A range of barriers are slowing extensive deep carbon retrofits.

There are a wide range of barriers preventing the uptake of retrofits at the pace and depth required to help meet Canada's climate change mitigation targets. Some of these barriers are specific to deep carbon retrofits, while others are common to all construction-related activities. We summarize these known barriers below and explain them in greater detail later in this report.

Economic Barriers	Market Barriers	Financing Barriers
• Misalignment between carbon savings and energy savings • Long payback periods • Large incremental capital cost requirements	• Lack of energy or carbon awareness • Low return on investment and implementation hassle • Cost-saving split incentives • Lack of confidence in project performance and results • First-mover disadvantage, technological and logistical readiness	• Lack of access to attractive financing • Uncertainty with developing standard investment risk profiles • High loan transaction costs • Availability of secured, on-balance sheet debt

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 retrofit projects that achieve deep carbon reductions and a range of other social and environmental benefits, such as improved air quality and increased affordability. 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.

Owners should choose procurement paths carefully and tackle barriers early.

Owners can choose from various retrofit implementation pathways, each offering a different level of flexibility, capital requirement, risk, benefit, and duration. For deeper carbon retrofit activity and to avoid known barriers, owners must consider innovative approaches to develop and implement projects. Options on the table include zero up-front capital payments, off-balance sheet debt treatment, sharing project loan costs and benefits with tenants, and reducing building owner risk through performance guarantees.

To date, most retrofit procurement approaches assume financial savings from retrofits will more than pay for financing costs. Yet carbon reduction actions do not always maximize energy cost savings, and in many cases, conventional project development and financing approaches fall short. This is even the case for approaches that can promote more holistic outcomes, such as the turnkey delivery methods used by energy service companies (ESCOs).

Turnkey delivery methods take a deep carbon retrofit from start to finish, including managing the financial, technical, and operational complexity and risks. They can be well suited for whole-building deep retrofits. Public sector organizations have primarily used this method since the investment horizons for the buildings they manage are typically long-term, and they typically have a bigger stake in optimizing operations than their commercial sector peers.

Governments, lending institutions, and stakeholders must identify new turnkey retrofit providers and approaches to design, implement, and finance deep carbon retrofits to scale up effective whole-building commercial-sector retrofits. These could be Super ESCOs, Special Purpose Vehicles, or aggregated project financing programs such as the Canada Infrastructure Bank's $2 billion Building Retrofits Initiative.

The benefits of using innovative project development and implementation approaches can include no up-front payments, off-balance sheet treatment, passing costs to tenants, and reducing building owner risk through performance guarantees.

There is no "one size fits all" solution for implementing and procuring a deep carbon retrofit project for the building archetypes discussed in this report. But there is a common best-practices approach, illustrated below, that all building owners and operators should follow to help ensure success.

Figure 6. Steps for Achieving Deep Carbon Retrofits

The Canada Infrastructure Bank's Building Retrofits Initiative offers a new and innovative financing solution for building owners in Canada with the potential to significantly scale up deep carbon retrofits. Since the Initiative targets large-scale investments of $25 million or more, most building owners will likely participate in the initiative indirectly through retrofit project aggregators like ESCOs and Super ESCOs.

Along with the carrots, bring out the sticks.

With less than a decade remaining to cut carbon emissions by 40 to 45 per cent, we cannot afford to wait any longer for significant action. After decades of carrots, the time has come for governments to enact carbon performance requirements and codes for existing buildings.

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. Retrofit codes and performance requirements are under development in BC and Quebec, yet most of the deployed provincial policies are still primarily focused on energy efficiency measures rather than specifically targeting carbon emissions.

The federal government has committed to developing a model code for existing buildings by 2025, which will be crucial to help drive activity and improvements. However, progress to date has been slow, and implementation is not close on the horizon.[11]

It is imperative that key federal departments step up and move quickly to finalize the code and ensure that carbon performance requirements are a core focus. Provinces should move quickly to adopt the model code or pursue their own mandatory performance requirements.

The imperative of an all-hands-on-deck approach.

To scale up deep carbon retrofits, governments will need to effectively integrate and align policies and initiatives. Many of the policies described in this report are complementary. For example, building rating and disclosure policies can easily integrate performance requirements, and governments and utilities can roll together financing with incentives to offer building owners a seamless experience. With efforts underway at the local, regional, provincial, and federal levels, policy decision makers will need to coordinate and collaborate to avoid introducing a patchwork of policies across different jurisdictions.

Incentives are needed to close the gap and create a positive business case for low and mid-rise MURBs, which are typically 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.

British Columbia, Ontario, Quebec, and Nova Scotia are the regions with the highest readiness for financing carbon retrofits. Several financing tools are already available in these provinces, including Property Assessed Clean Energy (PACE) and On-Bill Financing (OBF). However, it should be noted, 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 (C-PACE).

At the federal level, the CIB's Building Retrofits Initiative has the potential to transform the retrofit market by providing large-scale financing for the archetypes in the report, encouraging new innovative business models, crowding in private capital, and helping to establish retrofits as a distinct asset class.

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[11] "We need a national retrofit code sooner, rather than later." Kevin Lockhart. Efficiency Canada. September 29, 2021. Retrieved from https://www.efficiencycanada.org/national-retrofit-code-sooner/.

Recommendations

This study demonstrates that all building archetypes can achieve deep carbon reductions and, in some cases, can achieve it cost-effectively today. However, few retrofits currently take place, and those that do typically pursue modest savings. With less than a decade left to cut emissions by 40-45 per cent, further action is needed to improve cost-effectiveness and accelerate the pace of deep carbon retrofits.

Broadly speaking, building owners and operators must:

1. Reduce/replace fossil fuel use for space heating, mainly through electrification,
2. Implement energy demand-reduction measures, with a focus on enclosure upgrades and,
3. Incorporate and/or install on-site renewable energy systems.

Beyond changes to physical building systems and efficiency improvements, industry must develop or strengthen best practices for carbon reduction management and governments must introduce innovative policy and program measures.

For their part, building owners and/or managers must:

1. Align low-carbon improvement activities with building-specific infrastructure and equipment maintenance renewal cycles, with special attention given to “once-in-a-building-lifetime” enclosure renewals.
2. Move away from improvement measures to single systems and embrace a more holistic and comprehensive approach to retrofit project planning.
3. Do it now. As we enter the critical decade of climate action, building owners and managers need to either develop transition plans to reduce carbon significantly or implement proven reduction measures now.
4. Expand the use of innovative approaches for project development, implementation, and procurement, such as no up-front capital payments, off-balance sheet debt treatment, owner-tenant shared project costs and benefits and reduced project risk through performance guarantees.

To do their part, policy-makers must:

1. Continue to align retrofit cost savings and deep carbon reductions through planned carbon pricing increases and/or other means.

2. Support and establish innovative retrofit loan programs, such as property-assessed clean energy (PACE) and on-bill financing (OBF)[12], and develop credit enhancements, such as loan-loss reserves, loan guarantees, and interest buy-downs.[13]

3. Expand incentives, rebates, and supportive programs for deep carbon retrofits.

4. Develop and enforce mandatory performance standards for existing buildings.

5. Develop and enact mandatory energy performance benchmarking and disclosure programs.

6. Ramp up education, low-carbon skills training, and industry capacity.

7. Accelerate the shift in focus of building performance policy from energy reductions to carbon reductions.[14]

For the building sector to maximize its contribution to Canada's climate goals, it needs to address existing buildings using a combination of strategies and supports. We summarized these key strategies and mechanisms below. Ideally, the real estate sector and governments would implement these mechanisms in a coordinated manner, but the urgency of climate action is now overwhelming. All these support mechanisms should be developed now and implemented simultaneously to support retrofit market transformation.

[12] PACE and OBF programs allow for the needed retrofit capital to be loaned to an owner and are typically tied to the building, with the required loan payments processed through a municipal property tax or utility bill system.
[13] Credit enhancements are ways in which retrofit financing costs can be reduced, allowing for marginally attractive investments to be better positioned.
[14] Certain policies and standards, such as British Columbia's BC Energy Step Code, focus solely on energy efficiency but are silent on fuel source and greenhouse gas emissions.

	Clear Technical Pathways	Informed Market	Workforce and Industry Capacity	Implementation Support	Accelerate the Pace
Objectives	Clear Technical Pathways	Informed Market	Workforce and Industry Capacity	Implementation Support	Accelerate the Pace
Actions	Leveraging infrastructure renewal events Strategic sequencing of upgrade measures On-site renewable energy Mitigate peak electricity demand	Mandatory rating and disclosure policies Standardization and reporting Demonstration projects	Education and training programs Collaborate with industry and manufacturers	Carbon pricing mechanisms Financial incentives targeting CRMs Financing mechanisms (C-PACE, credit enhancement) Procurement solutions	GHG operational performance requirements and building retrofit codes
Outcomes	Technical Solutions	Market Awareness and Confidence	Market Readiness	Attractiveness for Building Owner	Demand for Decarbonization Retrofits

Figure 7. Steps Towards Zero Carbon Buildings

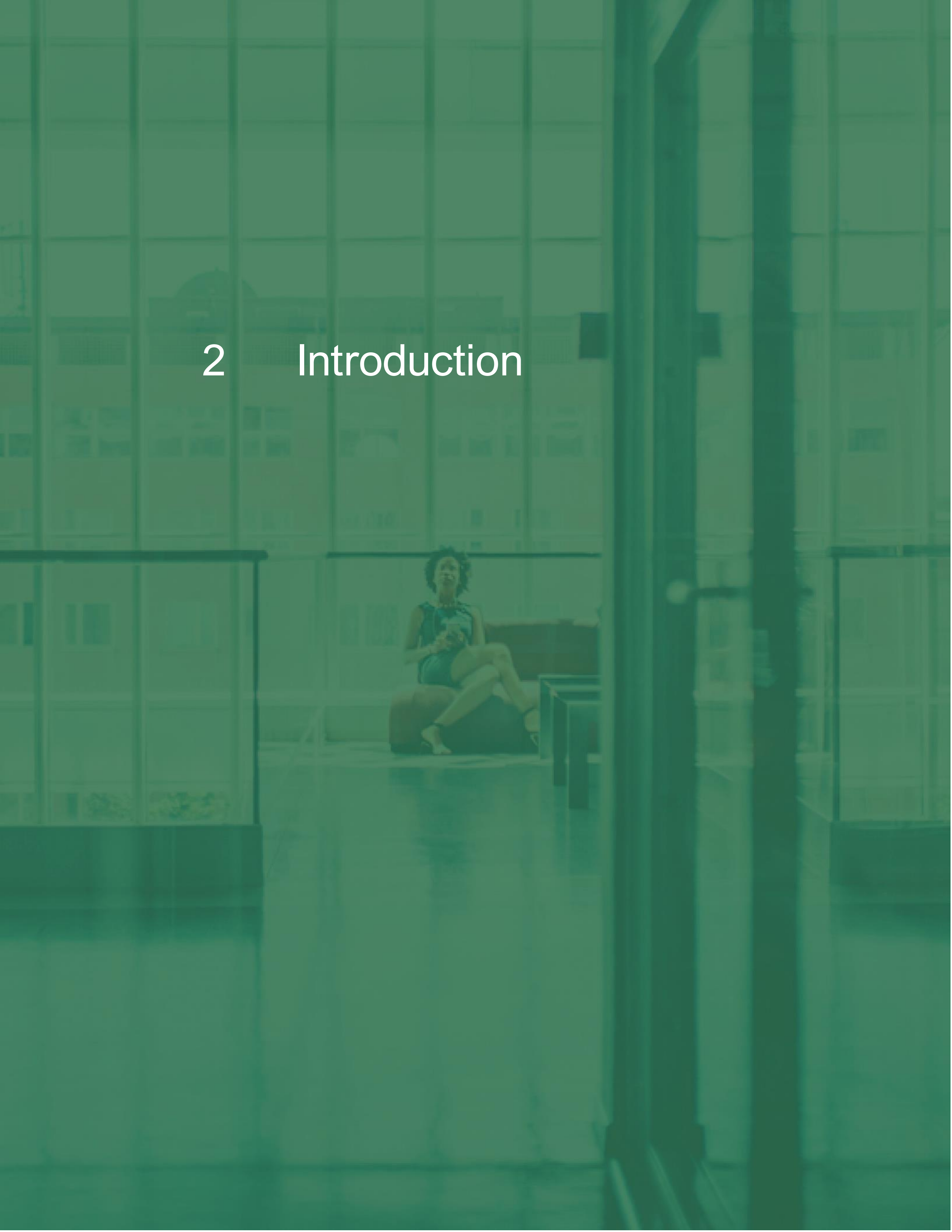
Table of Contents

Table of Contents

List of Figures

List of Tables

2 Introduction



Introduction

For Canada to achieve its 2030 and 2050 climate targets, building owners and operators will need to upgrade, retrofit, and ultimately decarbonize hundreds of millions of square metres of space.

While new buildings are increasing in efficiency, many of the apartment complexes, offices, and schools built in the 1970s and 1990s – when energy performance codes were less stringent or even non-existent – will still be in use through to 2050. By that time, all buildings will need to be upgraded and overhauled to achieve net-zero carbon performance.

The work to decarbonize Canada's built environment is daunting for the many decision-makers across the building sector, from policymakers, to utilities, to building owners and managers. But it must begin now. We can no longer ignore climate change and leave action to future leaders. Canada's building sector must recognize its contribution to the climate challenge and become a significant part of the solution.

To understand the challenge of scaling up retrofit action, support industry decision-making, and inspire leadership, CaGBC commissioned RDH Building Science Inc. (RDH) and Dunsky Energy + Climate Advisors (Dunsky) to carry out an ambitious assessment of the costs and approaches intertwined in the need for retrofits. This work was supported by the Government of Canada, the Real-Estate Foundation of BC, and the Province of Nova Scotia.

The research team used whole-building energy modelling to evaluate deep carbon retrofit opportunities across 50 different building archetypes. These archetypes reflect a range of building types (office, multi-unit residential, and primary school), sizes (low-rise and midrise), ages (1970s and 1990s) and regions (Halifax, Montreal, Toronto, Edmonton, and Vancouver).

For each building archetype, the researchers developed baselines and assessed business-as-usual upgrades—that is, those activities routinely undertaken as building systems reach their anticipated service life. The researchers then identified and assessed the performance outcomes resulting from deep carbon retrofits and conducted financial analyses of the retrofit measures for each archetype.

Finally, the researchers examined procurement approaches and recommended policy and support mechanisms needed to create actionable decarbonization pathways for building owners.

3 Methodology

This Section provides an overview of the building archetypes studied and explores the carbon reduction measures (CRMs) modelled. It also provides an overview and discussion of other methodology considerations.

Methodology

The technical pathways to retrofits vary significantly across different building types, vintages, and locations. To understand the potential energy and GHG savings, cost, and financial viability of retrofit projects, a range of building archetypes and carbon reduction measures (CRMs) were developed and modelled for this study. This Section provides an overview of the building archetypes studied and explores the CRMs modelled.

Key Information Summary

1. A total of fifty baseline archetypes were developed, comprising five building types, five locations, and two vintages (construction eras).
2. The building typologies (offices, MURBs and primary schools) were chosen because they constitute a large portion of Canada's existing building and associated emissions: in 2018, these typologies represented approximately 31 per cent of existing building floor space and approximately 30 per cent of its building-related emissions.
3. The following building types are addressed in this report:
   - Low-rise commercial office building (3,000 m^2)
   - Mid-rise commercial office building (21,000 m^2)
   - Low-rise multi-unit residential building (6,000 m^2)
   - Mid-rise multi-unit residential building (13,000 m^2)
   - Primary school (6,900 m^2)
4. To account for regional differences in climate, electricity grid carbon intensity, and fuel choice for heating, the archetypes have been modelled in Vancouver, Edmonton, Toronto, Halifax, and Montreal.
5. To capture the cost-effectiveness benefits of timing retrofits to coincide with natural renewal cycles, buildings of 1970s and 1990s vintages were studied. Buildings from the 1990s were assumed to require mechanical and electrical upgrades, while buildings from the 1970s were assumed to also require enclosure upgrades.
6. Retrofits are assumed to be completed in 2022, when the price of carbon will be $50/tonne. The price of carbon is assumed to rise to $170 by 2030 and to $300 by 2050.
7. It is assumed that the electrical, enclosure, and mechanical upgrades are undertaken concurrently for time- and cost-efficiency. However, the types of upgrades were modelled separately to assess potential phased delivery and to better understand the impact of the electrical and enclosure measures prior to implementing the mechanical upgrade measures.

3.1 – Deep Carbon Retrofit Pathways

To assess the technical pathways for deep carbon retrofits under different scenarios, a total of fifty building archetypes were developed including five building types, five locations, and two vintages (construction eras).

For each archetype, a baseline was developed representing the buildings as they exist today. Each baseline archetype had a unique set of enclosure and heating, ventilation, and air conditioning (HVAC) system characteristics. The baseline archetypes were developed by RDH staff familiar with the construction, enclosure assemblies and HVAC systems of each building type. This knowledge was further augmented by local subject matter experts in each location, and the baseline archetypes were then reviewed by the Canada Green Building Council Energy and Engineering Technical Advisory Group. More details on the baseline condition of the building archetypes are provided in Section 2.2.

A business-as-usual (BAU) scenario was also developed for each archetype. The BAU scenarios represent the future retrofit measures that most building owner/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. The BAU measures are used as a reference point for assessing the incremental costs and carbon reductions associated with deep carbon retrofits.

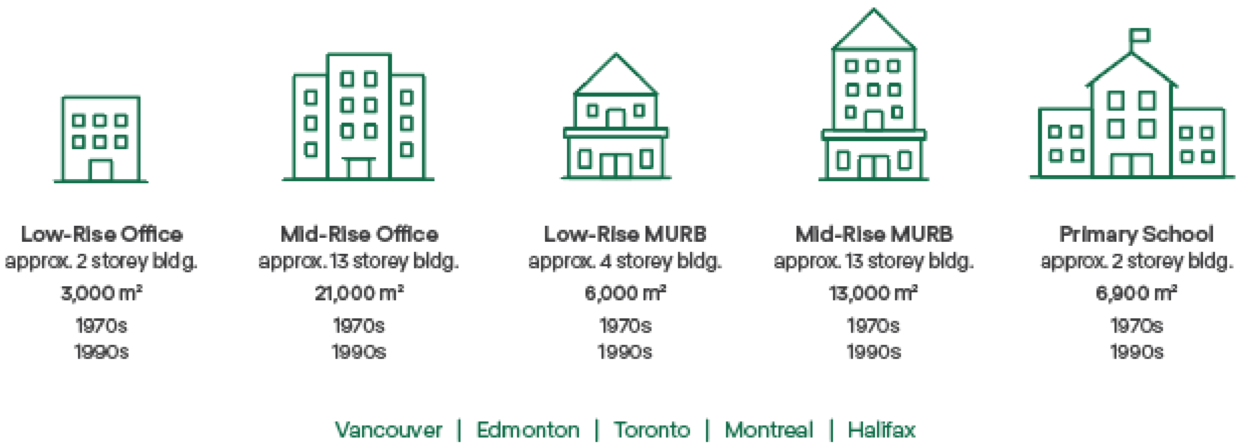
Finally, carbon reduction measures (CRMs) were chosen for the deep carbon retrofit scenario. The CRMs were specific to each building archetype, varying as a function of building type, location, and vintage. The measures were determined through industry consultation and experience.

A deep carbon retrofit broadly consists of carbon reduction measures applied to the following systems:

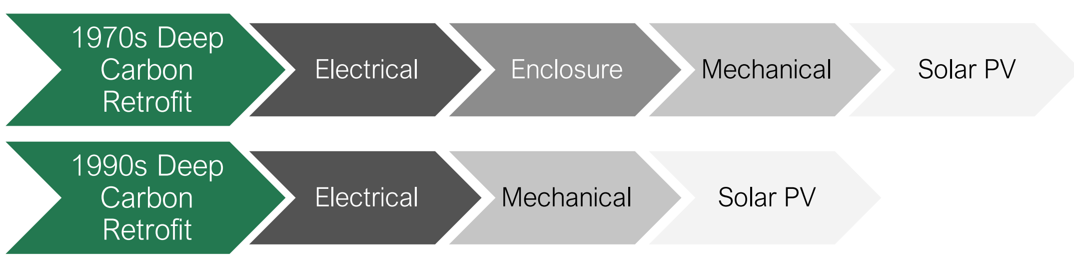
Electrical	Mechanical	Enclosure
• Lighting (including assumption for daylighting and occupancy controls), appliances, plug loads	• Heating, ventilation and air conditioning	• Roofs, walls, windows

The archetypes are illustrated below. Building types were selected to be reflective of a large portion of Canada's existing building space and associated emissions: in 2018, offices, MURBs, and primary schools represented approximately 31 per cent of Canada's existing building floor space and approximately 30 per cent of building-related emissions.[15] Vintages were chosen to be reflective of building ages at which major investments in mechanical systems and enclosures are likely. Locations were chosen to represent different climatic regions, utility costs and electrical grids.

[15] Canada's Comprehensive Energy Use Database (CEUD) available at https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm



Deep carbon retrofits require the replacement of major building systems and/or structural components, which can lead to high upfront costs that are not always cost-effective over the life of the new equipment and systems. As described below, it is most cost-effective to **implement high performance building upgrades at the time of regularly scheduled building system renewals, following a logical sequencing process**. These renewals correspond to the periodic replacement of parts of the building or building systems that have reached the end of their useful life (e.g., replacement of a boiler system or replacement of a roof membrane). Therefore, for each building vintage, the following package of carbon reduction measures (CRMs) was selected to achieve deep carbon reductions while maximising cost-effectiveness.



The study assumes that deep carbon retrofits for the 1970's building archetypes include electrical, enclosure and mechanical upgrades to maximize emissions reductions and support cost-effectiveness. For the 1990's archetypes, the deep carbon retrofit pathways includes electrical and mechanical upgrades, with the assumption that enclosure upgrades will occur in the future, in line with regular building renewal cycles.

The study assumes that electrical, enclosure, and mechanical upgrades are undertaken concurrently for time and cost-efficiency purposes. However, the measures were modelled separately to reflect potential project phasing and to better understand the impact of the electrical and enclosure upgrade measures prior to adding the mechanical scope of work.

The CRMs for the deep retrofit pathways were all established based on what is currently feasible with available products and/or building practices. Space heating is the largest energy end use for all archetypes in all locations. Therefore, the CRMs chosen focused on space heating demand reduction as well as improving system efficiency to reduce energy consumption. However, a deep carbon retrofit is an opportunity to review building operations holistically and improve the occupant's experience, including their health and wellness. Perhaps most importantly, a deep carbon retrofit should evaluate the need and opportunity to enhance the provision of fresh, clean air.

The table below provides an overview of the baseline building characteristics, BAU measures, and deep carbon retrofit measures.

Table 2: Overview of Baseline Building Assumptions and Retrofit Measures

		Electrical and Enclosure	Mechanical
Baseline Building Condition	1970s	Lighting has been upgraded to electronic ballast fluorescent. Original enclosure is in need of renewal.	Mechanical systems have been replaced, circa 1990-2000, and are in need of renewal again.
	1990s	Lighting has been upgraded to electronic ballast fluorescent. Original enclosure is not yet up for renewal.	Mechanical systems (boilers) have not been replaced and are in need of renewal.
BAU Retrofit	1970s	LED lamp replacement: windows are replaced with code-minimum performance products; enclosure renewal occurs without energy improvements.	Mechanical systems are replaced with code-minimum efficiency equipment.
	1990s	LED lamp replacement: in general, no enclosure renewal occurs.	Mechanical systems are replaced with code-minimum efficiency equipment.
Deep Carbon Retrofit	1970s	Lighting re-design with LED lamps and fixtures; windows are upgraded to high performance products (triple glazed); exterior insulation is added during enclosure renewal.	Mechanical systems are fuel-switched, and ventilation systems may be upgraded, as applicable. On-site solar PV is installed.
	1990s	Lighting re-design with integrated LED lamps fixtures; in general, no enclosure renewal occurs.	Mechanical systems are fuel-switched, and ventilation systems may be upgraded, as applicable. On-site solar PV is installed.

Aligning CRMs with regular building renewal schedule

The largest, most expensive building systems (HVAC equipment and building envelopes) are not typically replaced until end of service life. Carbon reduction measures are most cost effective when they are implemented at these critical milestones.

Enclosure renewals (windows, roof, envelope) occur very infrequently, typically every 20 to 100 years depending on the assembly type and condition (most occur after about 40 years). As such, existing buildings are likely to only undergo one enclosure upgrade between now and 2050. **It is critical that the rare opportunity that each enclosure renewals represents is leveraged to support full decarbonization.**

Table 3 summarizes the typical replacement/renewal cycle for mechanical and enclosure systems.

Table 3: Typical Renewal Cycle for Mechanical and Enclosure Systems

Building System	Building Sub System	Replacement / Renewal
Electrical	Lamps	10 to 15 years, driven by improved lamps
	Fixtures	15 to 20 years, driven by redesigning lighting system to best take advantage of improved lamps
Mechanical	Minor HVAC Equipment *e.g., fans and pumps*	10 to 15 years
	Primary HVAC Equipment *e.g., boilers, chiller, and rooftop units*	15 to 25 years
	HVAC Distribution *e.g., hydronic piping, ductwork and terminal heating/cooling, control valves and dampers*	40 to 60 years
Enclosure	Windows	20 to 50 years
	Opaque Enclosure – Roofs	20 to 30 years
	Opaque Enclosure – Vertical	50 to 100 years
Structure		100+ years

Logical Sequencing of Retrofit Measures

To mitigate costs and positively impact retrofit payback, strategic sequencing of CRMs is critical. As highlighted in NRCan's *Major Energy Retrofit Guidelines*[16], a staged approach leverages energy interactions in a building to maximize effectiveness.

Figure 8 shows that some low or no-cost measures such as tenant awareness programs or scheduling adjustments can be implemented at any time as they do not substantially impact major system design. However, load reduction measures should ideally precede replacement of HVAC systems in order to take full advantage of the savings from down-sizing HVAC equipment.

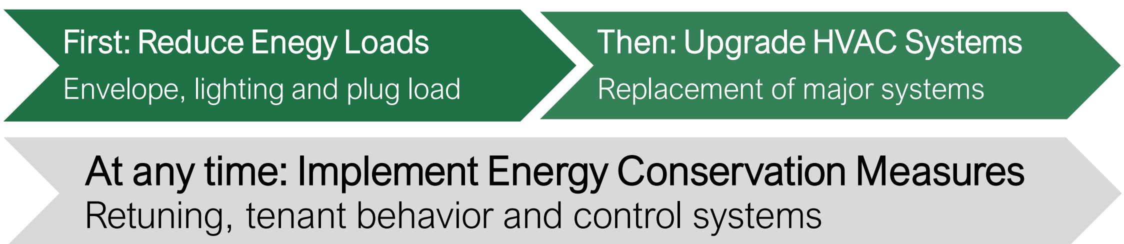


Figure 8. Load Reduction Should Precede HVAC Upgrades

Since the size of a building's mechanical system is dependent on the building's heating and cooling needs, if loads are not first reduced, the building will need to install replacement systems that are larger and more expensive than ultimately required. For example, an enclosure upgrade will decrease the space conditioning loads, potentially enabling downsizing of mechanical equipment, including chillers, fan coils and ductwork sizes. For this reason, enclosure upgrades should be considered in the first phase of work, if possible, followed by HVAC upgrades.

Moreover, proper sequencing can allow elements of the existing HVAC system to be retained, reducing costs. For example, upgrading to an electric, low-temperature space heating system will reduce the heating capacity of many terminal heating systems, and without significant enclosure upgrades to reduce heating demand, a building's heating and cooling system could require costly changes to its thermal distribution systems.

Downsizing replacement HVAC equipment can also help mitigate the challenges of space constraints on existing roofs or at grade near the building, and potential structural constraints on rooftops. Importantly, it can reduce the likelihood of requiring costly electrical service upgrades.

[16] Natural Resources Canada. Retrofitting - Major Energy Retrofit Guidelines. Accessed at https://www.nrcan.gc.ca/energy-efficiency/buildings/existing-buildings/retrofitting/20707

Although enclosure renewals are often done when the enclosure has degraded substantially and requires repairs, enclosure renewals may be done earlier in the building's lifecycle for a variety of reasons, including:

Providing energy savings. This study found that the enclosure upgrades in the 1970s buildings enable a reduction of approximately 20 to 50% in energy use, resulting in lower operating costs and less exposure to future utility cost escalation.

Resilience to climate change by supporting passive survivability and lessening dependence on grid energy to maintain livable space conditions.

Building durability improvements, which can reduce maintenance and repair costs as well as increase building longevity. It can also improve building appearance.

Lower peak electricity demand, which can enable replacement equipment to be downsized and reduce overall operational costs, especially for building types and locations with high utility demand charges.

Although it is possible to complete targeted repairs, from a cost efficiency perspective it makes most sense to do bigger projects rather than a series of smaller ones spread out over time. Sometimes the proposed sequencing is not feasible, such as an unpredicted breakdown of major equipment. If load reductions measures cannot happen first, mechanical replacements can be designed with future reduced loads in mind.

3.1.1 – Electrical Upgrades

The electrical CRMs focus on lighting upgrades and include lighting re-design with integrated LED luminaires. LEDs that can be used to re-lamp fixtures are currently very common in the industry, so this is a low barrier upgrade that can be easily implemented for all building types in all locations. The lighting re-design with integrated LED luminaires, rather than solely re-lamping existing fixtures, is a higher capital expenditure, but can yield between 50 and 100 per cent more savings than re-lamping alone.

3.1.2 – Enclosure Upgrades

Adding continuous exterior insulation and upgrading windows are effective ways to decrease heating energy demand, thus enclosure renewals are critical to achieving deep carbon savings.

The enclosure CRMs include upgrading the thermal performance of the windows, roofs, and walls, as well as reducing infiltration by upgrading enclosure components and re-detailing air barriers. Enclosure upgrades are implemented for buildings constructed in the 1970s but are omitted for buildings constructed in the 1990s as replacement timelines and renewal schedules would not normally trigger a re-investment at this time (enclosures are typically not replaced until after 50 years at the earliest for walls and 20-30 years for roofs, and more often longer than that).

Modelled CRMs include:

- **Windows** are assumed to be upgraded to triple glazed windows with thermally broken frames. Triple-glazed windows, although less common than double-glazed, are currently available in the Canadian market and are gaining popularity due to their improved thermal performance.
- **Walls** are assumed to be upgraded by adding exterior insulation, specifically 4” of rigid insulation attached with long screws or low-conductivity clips. Airtightness improvements are assumed to occur by adding an improved air barrier system during the wall upgrade.
- **Roofs** are assumed to be upgraded by adding exterior insulation to meet code minimum prescriptive requirements (~Reff-20 to Reff-40 depending on location).

The enclosure upgrade measures have proven to be effective at reducing heating energy consumption and corresponding carbon emissions in the Canadian context. A higher R-value may be feasible for the walls and roofs; however, depreciating returns and cost-effectiveness of ultra high-performance components were accounted for when establishing the upgrade scenarios. Higher R-values also result in greater embodied carbon impacts.

3.1.3 – Mechanical Upgrades

Mechanical CRMs include switching space and water heating systems to run on electricity, as well as ventilation system upgrades. Based on discussions with project partners, the mechanical CRMs were developed with the following general objectives in mind:

- **Electrify all space heating and service hot water systems.** This reflects the critical importance of reducing carbon emissions from natural gas and oil combustion.
- **Limit the HVAC upgrades as much as possible to the plant** (e.g., boiler) **and air handlers**; leverage the existing heat distribution systems to reduce capital costs. There are occasional exceptions to this approach due to the baseline HVAC system and the priority of electrification.
- **Spaces that were not actively cooled are to remain uncooled** even if the HVAC retrofit system has cooling ability. Additional considerations for resilience to mitigate overheating are discussed in Section 2.3.7.

Where gas fired make-up air and dedicated outdoor air systems (DOAS) were present in the existing design, a low ambient direct expansion (DX) heat pump make-up handler (or DOAS) was assumed to be the replacement. These units can typically supply heat near their rated capacity down to -25°C ambient temperature. In some cases where a hydronic heating system was already in the building, the CRM make-up air handler utilized a hydronic heating coil, supplied with heat from the new electrified hydronic heating system.

In all cases, exhaust air heat recovery was included as a CRM using the underlying assumption that exhaust air would be readily co-located with the existing outdoor air intake for the building. It was recognized that in practice this will not always be the case.

The baseline multi-unit residential buildings (MURBs) archetypes were all assumed to have make-up air provided at 47 L/s (100 CFM) per dwelling unit through corridor pressurization. The air is then assumed to be exhausted through dwelling unit exhausts and exfiltration from the building.

The ventilation CRM included installing energy recovery ventilators (ERVs) in the dwelling units with direct outdoor air and exhaust. This measure provides substantial heating energy savings while also significantly improving air quality in the building. Dwelling unit ventilation rates match ASHRAE 62.1-2016 (e.g., 30 to 40 L/s). Corridor air pressurization was reduced to 14 L/s (30 CFM) per dwelling unit, which is common practice for MURBs with in-suite ventilation through ERVs. The reduced corridor pressurization, when combined with weather stripping three sides of the suite doors, controls odour migration to the corridors and provides make-up air for the dwelling unit exhaust devices.

MURBs with existing electric resistance space heating in the dwelling units retained their electric resistance systems. MURBs using fan coils for dwelling unit heating/cooling retained the fan coils, and as the fan coils in these scenarios are sized for cooling, the reduced temperature of the water supplied by the retrofitted air to water heat pumps does not necessitate replacing all the fan coils. MURBs using water loop heat pumps for dwelling unit heating/cooling also retained the water loop heat pumps. For buildings that did not provide cooling, and where it was assumed that occupants installed their own cooling systems (through-wall sleeves or through-window installations), it was assumed that these remained.

The most challenging existing HVAC systems to propose low-carbon retrofit solutions for were those that used gas-fired Variable Volume and Temperature, as well as those using Single Zone Constant Volume air handlers (found in school archetypes). At present, retrofit options for these systems are limited, with no suitable cold-climate air source heat pump replacements available and inherent challenges to retrofitting exhaust air heat recovery on these air handler types. Thus, cold climate DOAS make-up air units were used as the chosen CRM option. As the existing air handlers provide ventilation and space heating and cooling, while the DOAS only provides ventilation, space heating and cooling systems were required. Air cooled VRF was selected, requiring the installation of local VRF heating/cooling fan coils and the refrigerant piping between the heat pump condensers (on the roof) and the VRF fan coils. This exception applied to some low-rise office and school archetypes, depending on location.

For the 1990s era buildings, which were not subject to an enclosure upgrade, the need to electrify space heating required that the terminal heating systems be upgraded with larger convectors to make them compatible with the lower (50°C) hot water temperatures delivered by the heat pump systems. This was not the case for buildings that used local fan coils for both heating and cooling. For these buildings, coils were typically sized larger for the needed building cooling capacity, making them oversized for the required building heating capacity, thus enabling them to function without alterations at lower hot water temperatures.

For the 1970s buildings, it was assumed that the enclosure upgrades would reduce heat loss through the enclosure by at least 50 per cent, thereby allowing the existing terminal units to meet interior set points even at the lower distribution temperatures.

Service water heating (e.g., domestic hot water) is more challenging to electrify. To control bacterial growth, such as legionella, hot water should be heated to 60°C for at least half an hour (distribution temperatures are typically 50 to 55°C to prevent scalding). This is on the edge of the capabilities of most air to water heat pumps on the market in the capacities required for the building archetypes in this study.

Service hot water retrofit measures associated with specific building archetypes were chosen as a function of annual service hot water demand, as outlined below:

1. **Low Demand** (offices): Local electric resistance domestic hot water (DHW) tanks.
2. **Low-Medium Demand** (primary schools): A dedicated air to water heat pump, like the space heating heat pump systems, supported by an electric resistance boiler for temperature top-up and to meet demand when the heat pump capacity is reduced by low ambient temperatures.
3. **Medium Demand** (low-rise residential): A dedicated air to water heat pump, like the space heating heat pump systems, supported by a condensing gas boiler for temperature top-up and to meet demand when the heat pump capacity is reduced by low ambient temperatures. An electric resistance boiler is not considered feasible in this scenario, as this could result in requiring an electrical transformer replacement to meet peak summer electrical loads.
4. **High Demand** (mid-rise residential): A wastewater heat recovery heat pump. This option assumes the high demand justifies the cost of installing a wastewater tank in the building basement, and possibly rerouting the waste and sanitary drains to a suitable location as well as installing a heat pump. A small natural gas back-up is used for the approximately 20 per cent of the hot water load that is not available from the building wastewater heat recovery system.

3.1.4 – On-site Solar PV

On-site solar PV is applied in all the deep carbon retrofit scenarios. The solar PV capacity is estimated for each archetype based on three parameters:

- available roof area,
- utility net metering limits as defined in each location, and
- annual electricity consumption (not to be exceeded).

The solar PV system size for one archetype may vary between locations since the annual electricity consumption and utility net metering differ. Regional solar irradiation data along with standard assumptions on typical system installation were used to estimate annual electricity generation.

3.1.5 – Menu of Carbon Reduction Measures

The table below provides a summary of key carbon reduction measures that can be employed to help establish viable carbon emission reduction pathways, regardless of a building's age or location. It is important to note that while the deep carbon retrofit pathways outlined in this study provide important information to guide building owners and policy makers, they do not replace the case-by-case analysis that needs to occur for each building before undergoing a deep carbon retrofit.

Table 4: Deep Carbon Retrofit Pathway Summary

Building System		Carbon Reduction Measures
Electrical - Lighting		LED retrofit, including full lighting system redesign.
Enclosure	Windows/Doors	Upgrade to triple glazed windows.
	Walls	Upgrade performance with exterior insulation and improved air barrier system.
	Roofs	Upgrade performance with installation of exterior insulation to meet Reff-20 to Reff-40 performance.
Mechanical	Space heating/cooling	Replace existing system with low ambient air to air or air to water heat pump system.
	Air distribution systems in offices	For archetypes with constant air volume multi-zone systems, convert to multi-zone variable air volume systems.
	Ventilation	Install energy recovery ventilators.
	Hot water heating	Replace gas systems with a dedicated air to water heat pump, supported by an electric resistance or condensing gas boiler for temperature top-up, or a wastewater heat recovery heat pump and storage tank.
Renewable Energy System		Maximize on-site renewable energy generation through solar PV system installation, as determined by available roof area, utility regulations, and annual electrical load (not to be exceeded).

3.2 – Baseline Building Assumptions

The baseline building archetypes represent the building conditions prior to any retrofits. This section summarizes the key characteristics of the different types of baseline buildings studied, including their total energy use intensity (TEUI) and greenhouse gas intensity (GHGI) profiles. Baseline assumptions vary by vintage and location, and are detailed in Appendix A.

Key Metrics

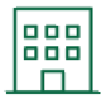
- Total energy use intensity (TEUI):
  The TEUI provides a measure of a building's total energy use, per meter of building floor area per year.
- Greenhouse gas intensity (GHGI):
  GHGI is determined by the total amount of energy supplied to the building by type (electricity, natural gas, hot water, steam, etc.) multiplied by the energy's carbon intensity (a measure of the greenhouse gas emissions associated with its use), per meter of building floor area per year.

The baseline building archetypes were designed to reflect typical building characteristics and HVAC systems for each location and building type. There are many variations in building characteristics that will impact the potential carbon reductions from implementing a deep retrofit project. For example, a building with electric heating systems in a location with a low carbon intensity electrical grid would likely not see as high a net carbon reduction, whereas a gas heated building with deferred maintenance that intends to only do the bare minimum as their business-as-usual scenario may achieve greater than expected net carbon reduction from implementing a deep retrofit.

Other unique aspects of individual buildings may impact the ability of the project to implement the designs selected for deep retrofit in this study. For example, projects may have limited space or structural limitations for the new mechanical equipment. Lot line or limiting distance requirements for fire safety may impede a building's ability to install exterior insulation as this may encroach on adjacent buildings or egress routes.

Designers should consider the information in this report in conjunction with the specifics of their project and the advice of subject matter experts to arrive at a design that best addresses the objectives of each building owner and the needs of each specific project.

3.2.1 – Low-rise Office



Low-Rise Office

The low-rise office archetype is a 2-storey steel-frame building, approximately 3,000 m² (32,000 ft²) in size, without a parkade.

Table 5: Main Building Characteristics – Low-Rise Office

		Enclosure	Space heating	Hot Water
1970s Vintage	Vancouver	• Steel stud walls w/batt insulation • Single glazed, non-thermally broken aluminum frames • Window-to-Wall Ratio: 40%	Gas-fired (80% efficient), constant volume make-up air units ducting ventilation to distributed units. Distributed water-to-air heat pumps for zone heating (COP-3.3) and cooling (COP-2.7).	Central gas-fired boiler (80% efficient).
	Edmonton		Constant volume rooftop units with hydronic heating coil for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient), and air-cooled chiller (COP-2.5).	
	Toronto			
	Montreal			
	Halifax		Dual duct variable air volume (VAV) rooftop units with hydronic heating and cooling coil. Gas-fired boiler (80% efficient) and water-cooled chiller (COP-5.2).	
1990s Vintage	Vancouver	• Steel stud walls w/batt insulation • Double glazed, non-thermally broken aluminum frames • Window-to-Wall Ratio: 65%	Gas-fired (80% efficient) constant volume make-up air units ducting ventilation to distributed units. Four-pipe fan coil units connected to gas-fired boiler (80% efficient) and air-cooled chiller (COP-2.5)	Central gas-fired boiler (80% efficient).
	Edmonton		Variable air volume rooftop units with hydronic heating coil for pre-heat and cooling coil. Hydronic baseboards and reheat coils. Gas-fired boiler (80% efficient), and air-cooled chiller (COP-2.5).	
	Toronto		Variable air volume and temperature (VVT) rooftop units with gas-fired heating coil (80% efficient) and DX cooling coil (COP-2.5).	
	Montreal		Constant volume rooftop units with gas-fired heating coils (80% efficient) for pre-heat and DX cooling coil (EER-8.5). Hydronic baseboard convectors connected to gas-fired boiler (80% efficient) and reheat coils at zone level. Gas-fired boiler (80% efficient)	
	Halifax		Variable air volume (VAV) rooftop units with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Oil-fired boiler (80% efficient) and air-cooled chiller (COP-2.5).	Central oil-fired boiler (80% efficient).

Energy and GHG Profile

The baseline TEUI ranges from 213 to 925 kWh/m²/yr for the 1970s archetype, and from 222 to 830 kWh/m²/yr for the 1990s archetype as illustrated in Figure 9. The highest total energy use intensity is seen in the 1970s Halifax baseline building archetype, followed by the 1970s Edmonton baseline building archetype. The low-rise office archetypes have a wide variety of HVAC systems, which contributes to the wide range in baseline energy performance.

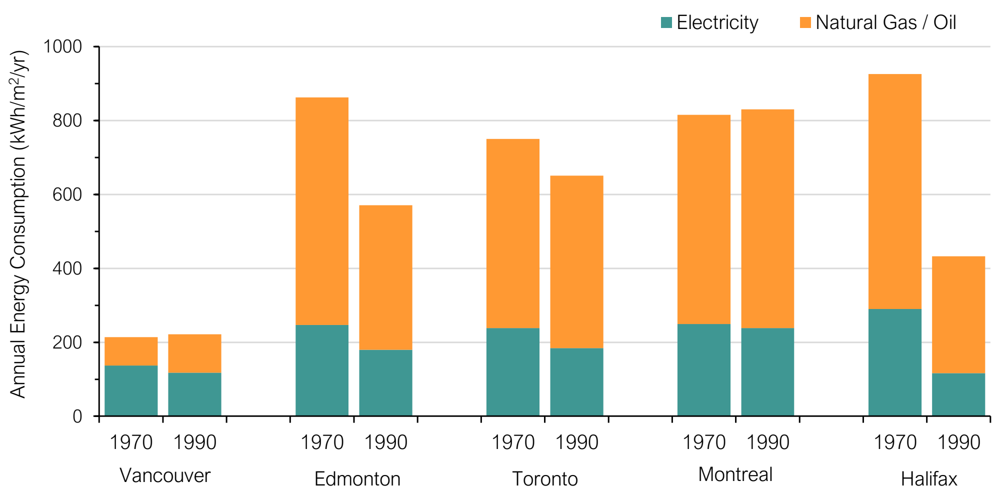


Figure 9. Total energy use intensity (TEUI) for the 1970s and 1990s low-rise office baseline building archetypes

Figure 10 shows the baseline annual greenhouse gas intensity (GHGI) for the 1970s and 1990s low-rise office building archetypes, with the GHGI ranging from 15 to 312 kgCO_2eq/m²/yr for the 1970s vintage buildings, and from 20 to 205 kgCO_2eq/m²/yr for the 1990s vintage buildings. The 1970s low-rise office baseline building archetypes had relatively similar total energy consumption in all locations, with the exception of Vancouver (as illustrated in Figure 9). Conversely, there is significant variation in greenhouse gas intensities from location to location.

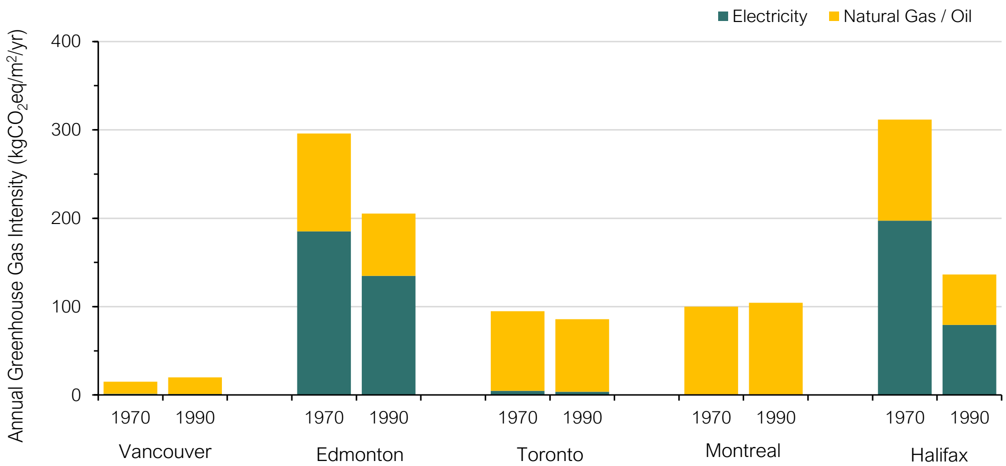


Figure 10. Greenhouse gas intensity (GHGI) for the 1970s and 1990s low-rise office baseline building archetypes

3.2.2 – Mid-rise office

Mid-Rise Office

The mid-rise office archetype is a 13-storey non-combustible building with a 1-level underground parkade, approximately 21,000 m² (224,000 ft²) in size.

Table 6: Main Building Characteristics – Mid-Rise Office

		Enclosure	Space heating	Hot Water
1970sVintage	Vancouver	• Steel stud walls w/batt insulation • Single glazed • Window-to-Wall Ratio: 40%	Constant volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80%) and water-cooled chiller (COP 5.5)	Central gas-fired boiler (80%)
	Edmonton	• Precast concrete walls, steel stud w/batt insulation • Double glazed • Window-to-Wall Ratio: 40%	***Core:*** Constant volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Reheat coils at zone level. ***Perimeter:*** Dedicated outdoor air system (constant volume) with hydronic heating and cooling coil. Four-pipe induction coils. Hydronic heating coils connected to gas-fired boiler (80%) and cooling coils to water-cooled chiller (COP-5.5)	
	Toronto	• Steel stud walls w/batt insulation • Double glazed • Window-to-Wall Ratio: 40%	Constant volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80%) and water-cooled chiller (COP 5.2)	

	Montreal		Variable air volume air handling units (AHUs) with hydronic heating coil for pre-heat and cooling coil. Steam radiators at zone level. Gas-fired steam boiler (80%) and water-cooled chiller (COP-5.2).	
	Halifax		Dual duct variable air volume with hydronic heating and cooling coils. Gas- fired boiler (80%) and water-cooled chiller (COP-5.2).	
1990s Vintage	Vancouver	• Steel stud walls w/batt insulation • Double glazed • Window-to-Wall Ratio: 60%	Variable air volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80%) and water-cooled chiller (COP-5.2).	Central gas-fired boiler (80%)
	Edmonton	• Steel stud walls w/batt insulation • Double glazed • Window-to-Wall Ratio: 40%	Variable air volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80%) and water-cooled chiller (COP-5.2).	
	Toronto	• Reinforced concrete frame • Double glazed • Window-to-Wall Ratio: 40%	Variable air volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80%) and water-cooled chiller (COP-5.2).	
	Montreal			
	Halifax	• Steel stud walls w/batt insulation • Double glazed • Window-to-Wall Ratio: 40%		

Energy and GHG Profile

The baseline TEUI ranges from 388 to 750 kWh/m²/yr for the 1970s archetype, and from 439 to 667 kWh/m²/yr for the 1990s archetype as illustrated in Figure 11 The mid-rise office archetypes have a wide variety of HVAC systems, which contributes to the wide range in energy performance values.

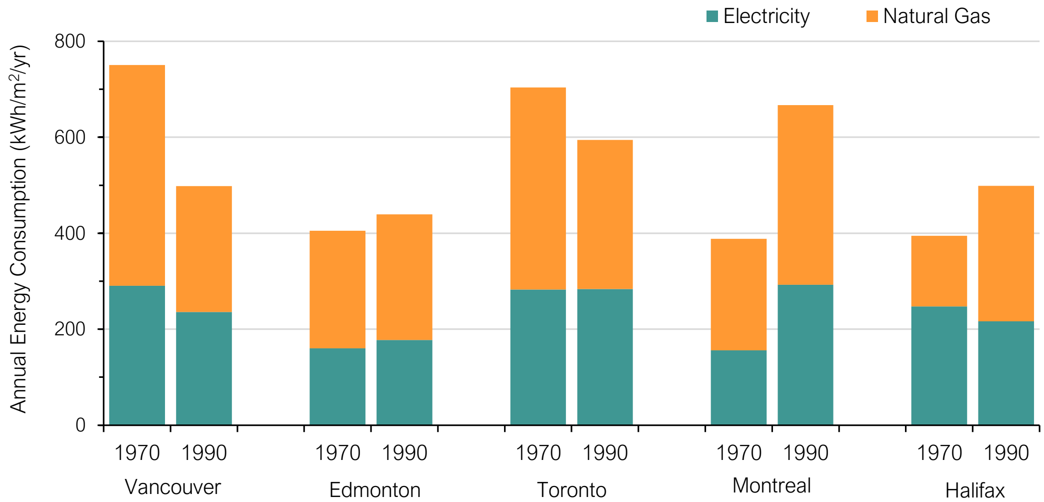


Figure 11. Total energy use intensity (TEUI) for the 1970s and 1990s mid-rise office baseline building archetypes

Figure 12 shows the annual baseline GHGI for the 1970s and 1990s mid-rise office baseline building archetypes, with the GHGI ranging from 41 to 195 $kgCO_2eq/m^2/yr$ for the 1970s archetype, and from 49 to 198 $kgCO_2eq/m^2/yr$ for the 1990s archetype.

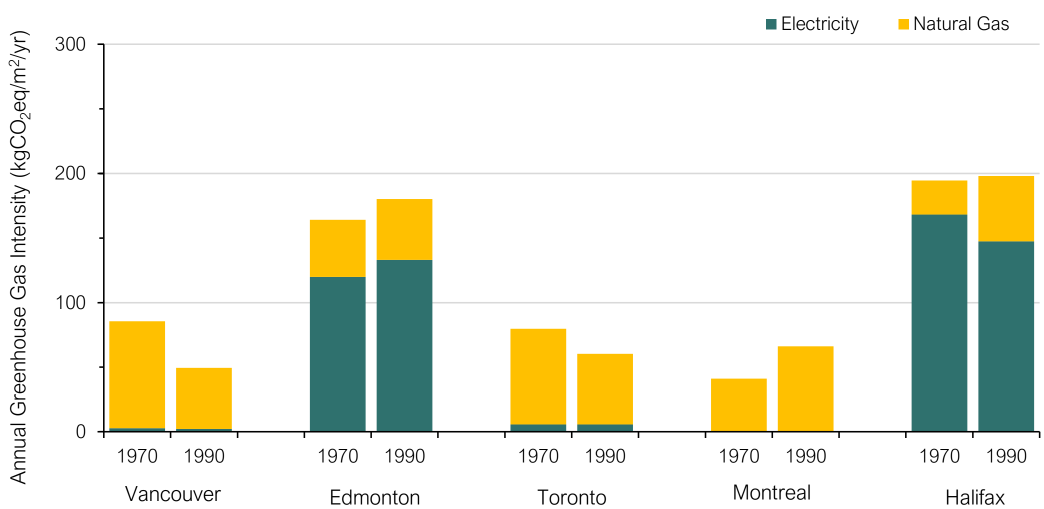
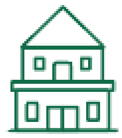


Figure 12. Total greenhouse gas intensity (GHGI) for the 1970s and 1990s mid-rise office archetypes

3.2.3 – Low-rise MURB



Low-Rise MURB

The low-rise multi-unit residential building (MURB) archetype is a 4-storey wood-frame building without a parkade, approximately 6,000 m² (65,000 ft²) in size.

Table 7: Main Building Characteristics

<table>
<tr><th></th><th></th><th>Enclosure</th><th>Space heating</th><th>Hot Water</th></tr>
<tr><td rowspan="5">1970sVintage</td><td>Vancouver</td><td rowspan="2">• Wood frame w/batt insulation, no balconies
• Single glazed
• Window-to-Wall Ratio: 20%</td><td>Constant volume unheated make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80%)</td><td rowspan="3">Central gas-fired water heater (80%)</td></tr>
<tr><td>Edmonton</td><td>Constant volume gas-fired (80%) make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80%)</td></tr>
<tr><td>Toronto</td><td rowspan="3">• Wood frame w/batt insulation
• Double glazed with single glazed sliders
• Window-to-Wall Ratio: 20%</td><td>Constant volume gas-fired (80% efficient, upgraded) make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient). 75 per cent of suites use window installed A/C units.</td></tr>
<tr><td>Montreal</td><td>Bathroom exhaust (no make-up air). Hydronic baseboard convectors connected to oil-fired boiler (80% efficient), 50 per cent of suites use window installed A/C units.</td><td>Central oil-fired water heater (80%)</td></tr>
<tr><td>Halifax</td><td>Gas-fired (80% efficient, upgraded) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient), 40 per cent of suites use window installed A/C units.</td><td>Central gas-fired water heater (80%)</td></tr>
<tr><td rowspan="4">1990s Vintage</td><td>Vancouver</td><td rowspan="2">• Wood frame w/batt insulation, balconies
• Double glazed
• Window-to-Wall Ratio: 30%</td><td rowspan="2">Constant volume gas-fired (80% efficient) make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80%)</td><td rowspan="4">Central gas-fired water heater (80%)</td></tr>
<tr><td>Edmonton</td></tr>
<tr><td>Toronto</td><td rowspan="2">• Wood frame w/batt insulation
• Double glazed
• Window-to-Wall Ratio: 30%</td><td>Constant volume gas-fired (80% efficient) make-up air units. Two-pipe fan coil units connected to gas-fired boiler (80% efficient).</td></tr>
<tr><td>Montreal</td><td>Gas-fired (80% efficient) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient), 50 per cent of suites use window installed A/C units. Gas-fired boiler (80% efficient).</td></tr>
</table>

		Enclosure	Space heating	Hot Water
	Halifax		Oil-fired (80% efficient) constant volume make-up air units. Hydronic baseboard convectors connected to oil-fired boiler (80% efficient), 40 per cent of suites use window installed A/C units.	Central oil-fired boiler (80% efficient).

Energy and GHG Profile

The baseline TEUI ranges from 185 to 343 kWh/m²/yr for the 1970s archetype, and from 213 to 333 kWh/m²/yr for the 1990s archetype as illustrated in Figure 13. The 1970s and 1990s baseline building archetypes have relatively similar TEUIs, except in Montreal, where the TEUI rose significantly. This suggests that the energy efficiency of typical low-rise MURBs did not improve between the 1970s and 1990s. This is consistent with previous energy use studies such as the *Energy Consumption in Low-Rise Multi-Family Residential Buildings in British Columbia* report.[17]

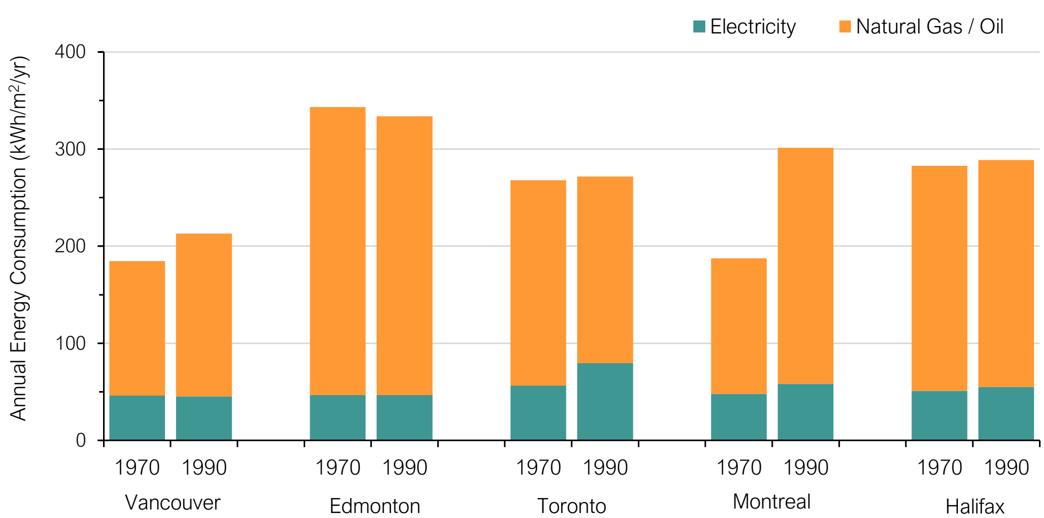


Figure 13. Total energy use intensity (TEUI) for the 1970s and 1990s low-rise MURB baseline building archetypes

[17] BC Housing (May 2017), Energy Consumption in Low-Rise Multi-Family Residential Buildings in British Columbia, authored by RDH https://www.bchousing.org/research-centre/library/building-science-reports/low-rise-energy-study

Figure 14 shows the annual GHGI for the 1970s and 1990s low-rise MURB baseline building archetypes, which ranges from 25 to 88 $kgCO_2eq/m^2/yr$ for the 1970s archetype, and from 31 to 87 $kgCO_2eq/m^2/yr$ for the 1990s archetype.

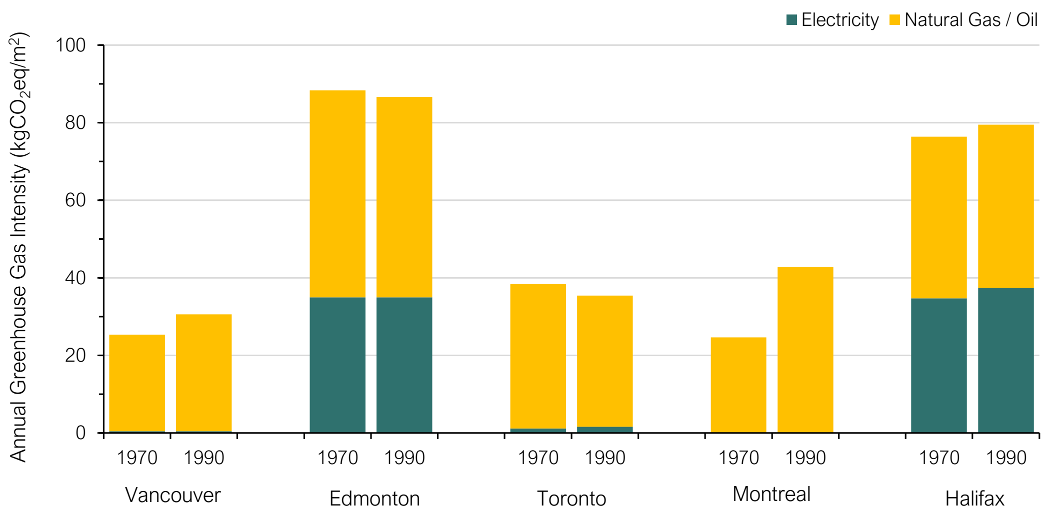


Figure 14. Total greenhouse gas intensity (GHGI) for the 1970s and 1990s low-rise MURB baseline archetypes

3.2.4 – Mid-rise MURB

Mid-Rise MURB

The mid-rise multi-unit residential building (MURB) archetype is a 13-storey non-combustible building, approximately 13,000 m² (140,000 ft²) in size with a 1-level underground parkade.

Table 8: Main Building Characteristics

		Enclosure	Space heating	Hot Water
1970sVintage	Vancouver	• Exposed concrete walls w/interior insulation, non-thermally broken balconies • Single glazed • Window-to-Wall Ratio: 40%	Gas-fired (80%) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80%)	Central gas-fired water heater (80%)
	Edmonton	• Exposed concrete walls w/interior insulation, non-thermally broken balconies • Double glazed • Window-to-Wall Ratio: 30%		
	Toronto		Gas-fired (80%) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80%), 50 per cent of suites use window installed A/C units.	
	Montreal		Gas-fired (80%) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80%), 50 per cent of suites use window installed A/C units.	
	Halifax		Constant volume make-up air units with hydronic heating coil. Hydronic baseboard convectors. Gas-fired boiler (80%).	
1990s Vintage	Vancouver	• Exposed concrete walls w/interior insulation • Double glazed • Window-to-Wall Ratio: 60%	Gas-fired (80%) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80%).	Central gas-fired water heater (80%)
	Edmonton	• Exposed concrete walls w/interior insulation • Double glazed • Window-to-Wall Ratio: 50%		

	Toronto		Gas-fired (80%) constant volume make-up air units. Two-pipe fan coil units, heating coil connected to gas-fired boiler (80%) and cooling coil connected to water-cooled chiller (COP-4.2).	
	Montreal	• Exposed concrete walls w/interior insulation • Double glazed • Window-to-Wall Ratio: 40%	Gas-fired (80% efficient) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient), 50 per cent of suites use window installed A/C units. Gas-fired boiler (80%)	
	Halifax		Constant volume make-up air units with hydronic heating coil. Hydronic baseboard convectors. Oil-fired boiler (80%)	Central oil-fired water heater (80%).

Energy and GHG Profile

The baseline TEUI ranges from 261 to 376 kWh/m²/yr for the 1970s archetype, and from 284 to 386 kWh/m²/yr for the 1990s archetype. There is a slight increase in TEUI for the 1990s archetypes in all locations; this is because the 1990s archetypes have a higher window-to-wall ratio compared to the 1970s archetypes. It is assumed that there is no change in window and wall thermal performance for the 1990s archetype compared to the 1970s archetype, and therefore the higher window-to-wall ratio results in a higher overall U-value and ultimately higher heating demands. The results suggest that the energy efficiency of typical mid-rise MURBs slightly worsened between the 1970s and 1990s, which is consistent with previous studies such as the *Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia* report.[18]

[18] BC Housing (2012), Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia, authored by RDH Building Science. https://www.bchousing.org/research-centre/library/building-science-reports/energy-efficency-MURBs

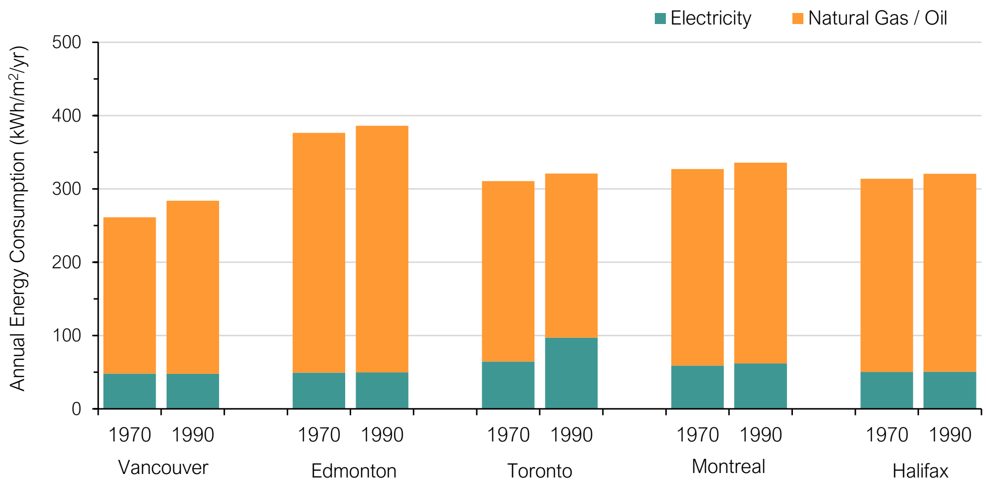


Figure 15. Total energy consumption (TEDI) for the 1970s and 1990s mid-rise MURB baseline building archetypes

Figure 16 shows the annual GHGI for the mid-rise MURB baseline building archetypes, with the GHGI ranging from 39 and 96 $kgCO_2eq/m^2/yr$ for the 1970s mid-rise MURB, and from 41 to 98 $kgCO_2eq/m^2/yr$ for the 1990s mid-rise MURB.

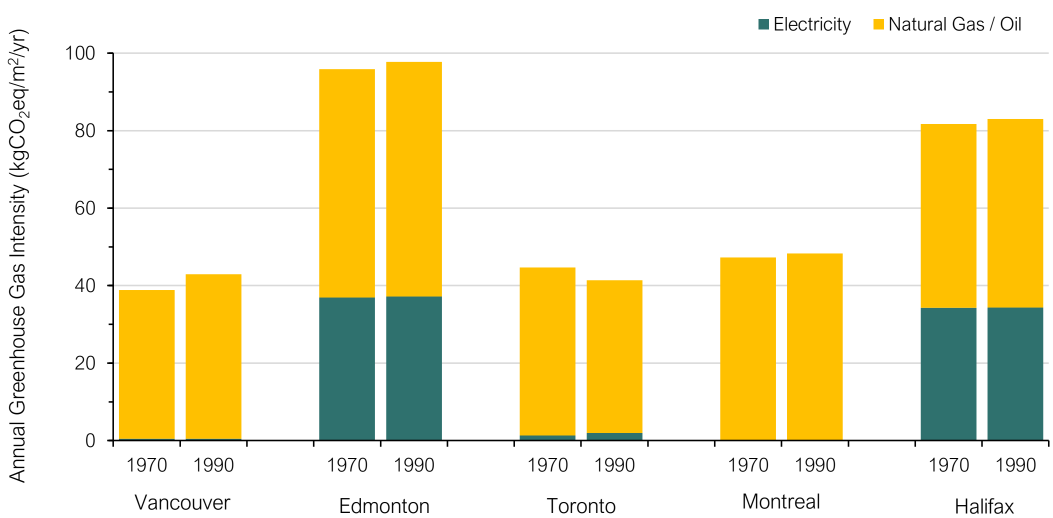


Figure 16. Total greenhouse gas intensity (GHGI) for the 1970s and 1990s mid-rise MURB baseline building archetypes

3.2.5 – Primary School

Primary School

The primary school archetype is a 1-storey building approximately 6,900 m² (74,000 ft²) in size. The enclosure and HVAC assumptions are unique to the location and age category.

Table 9: Main Building Characteristics

		Enclosure	Space heating	Hot Water
1970sVintage	Vancouver	• Wood-frame w/batt insulation • Single glazed • Window-to-Wall 35%	Constant volume rooftop units with hydronic heating coil for pre-heat. Single zone constant volume rooftop unit with gas-fired heating coil (80% efficient*) serving the gym. Hydronic baseboards and reheat coils connected to gas-fired boiler (80% efficient*). DX split system cooling (COP-2.5) supplying admin and computer classroom only	Supplied from building boiler (80%)
	Edmonton	• Concrete structure (uninsulated) • Double glazed • Window-to-Wall 25%	Gas-fired (80%) constant volume make-up air units. Hydronic baseboards connected to gas-fired boiler (80%).	
	Toronto	• Concrete structure (uninsulated) • Double glazed with single glazed sliders • Window-to-Wall Ratio: 35%	Gas-fired (80% efficient*) constant volume make-up air units. Gas-fired (80% efficient*) constant volume rooftop units with DX cooling (EER-8.5) serving admin area. Hydronic baseboards connected to gas-fired boiler (80%).	
	Montreal		Constant volume make-up air unit with hydronic heating coil supplying gym only. Local exhaust balanced with infiltration for remainder of building ventilation. Hydronic baseboards connected to gas-fired boiler (80%).	
	Halifax		Gas-fired (80%) constant volume make-up air units. Hydronic baseboards connected to gas-fired boiler (80%).	
1990s Vintage	Vancouver	• Steel-frame w/batt insulation • Single glazed • Window-to-Wall 35%	Variable air volume rooftop units with hydronic heating coil for pre-heat, rooftop unit serving admin and computer classroom contains DX cooling coil (EER-8.5). Single zone constant volume rooftop unit with gas-fired heating coil (80%) serving the gym. Hydronic baseboards and reheat coils. Gas-fired boiler (80%).	Supplied from building boiler (80%)
	Edmonton	• Concrete structure w/ exterior insulation, • Double glazed • Window-to-Wall 30%	Gas-fired (80% efficient) constant volume make-up air units. Gas-fired (80% efficient) constant volume rooftop unit with DX cooling (EER-8.5) supplying admin area. Hydronic baseboards connected to gas-fired boiler (80%).	
	Toronto	• Concrete structure w/ exterior insulation,	Gas-fired (80% efficient) constant volume make-up air unit ducting ventilation to distributed units. Distributed water-to-air heat pumps,	

		Enclosure	Space heating	Hot Water
		• Double glazed • Window-to-Wall Ratio: 35%	heating coil (COP-3.3) and cooling coil connected to fluid cooler (COP-2.7).	
	Montreal		Constant volume rooftop units with hydronic heating coil and hydronic baseboards connected to gas-fired boiler (80%).	
	Halifax		Oil-fired constant volume make-up air units. Hydronic baseboards connected to oil-fired boiler (80%).	

Energy and GHG Profile

The baseline TEUI ranges from 388 to 623 kWh/m²/yr for the 1970s primary school archetype, and from 388 to 571 kWh/m²/yr for the 1970s primary school archetype. Like the MURB archetypes, there is a relatively minor difference in TEUI between the age categories. However, the 1990s Edmonton, Montreal and Halifax archetypes show a slightly lower TEUI than the 1970s archetypes; this is because of a better overall enclosure thermal performance.

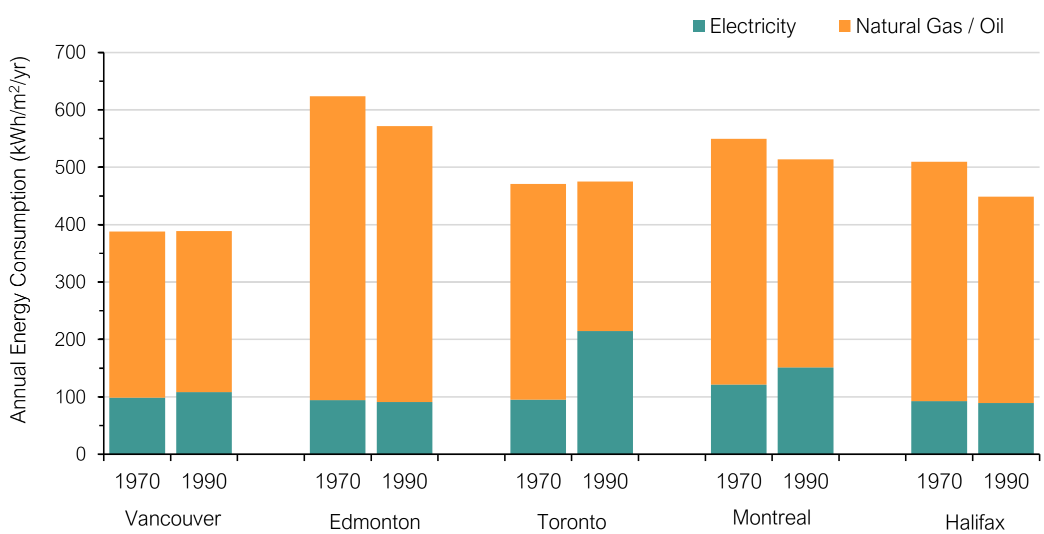


Figure 17. Total energy consumption (TEUI) for the 1970s and 1990s primary school baseline building archetypes

Figure 18 shows the annual baseline GHGI for the 1970s and 1990s primary school baseline building archetypes, with the GHGI ranges from 53 and 166 kgCO_2eq/m²/yr for the 1970s archetype, and from 50 to 155 kgCO_2eq/m²/yr for the 1990s archetype.

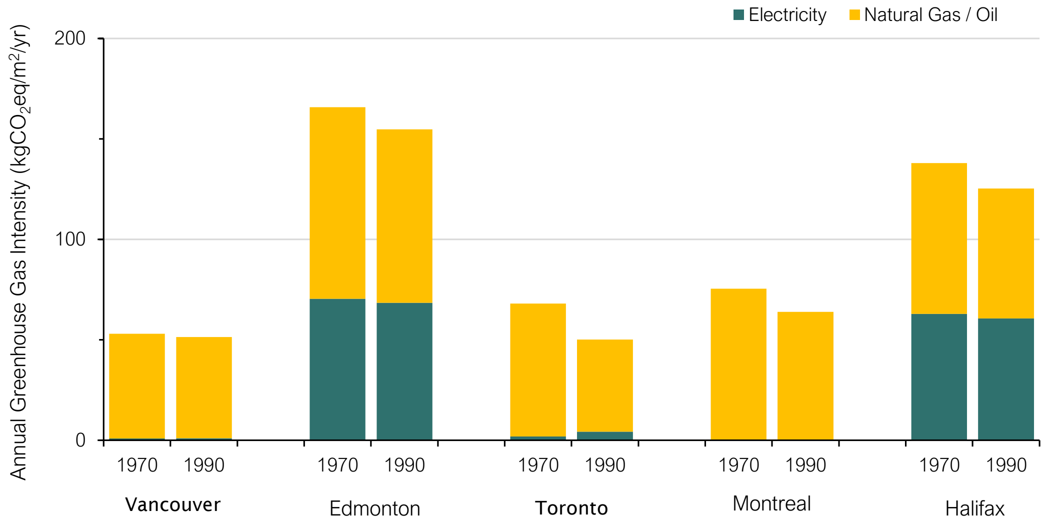


Figure 18. Total greenhouse gas intensity (GHGI) for the 1970s and 1990s primary school baseline archetypes

3.3 – Other Methodology Considerations

3.3.1 – Key Financial Analysis Variables

Assumptions about discount rate, timeframe for analysis, and utility cost escalation are summarized in Table 10.

Table 10: Key Financial Analysis Variables

Variable	Value	Justification
Timeframe for analysis	40 years	Measures in this study include both mechanical and enclosure upgrades. These have significantly different life-cycles. Forty years was used as an average. For simplicity and ease of comparison, the same value was also used for 1990s retrofits, which did not include enclosure upgrades.
Discount rate	5% / year	This rate represents a blend of lower discount rates expected by government and institutional owners on one hand, and higher rates expected by commercial owners on the other.
Utility escalation rate	2% / year	This rate reflects the consumer price index (CPI) escalation rate over the last 20 years. Over shorter timeframes, utility price escalation rates can be higher or lower than those of the CPI, however, over longer terms, such as the 40-year timeframe used in this study, escalation rates for CPI and utilities are similar.

3.3.2 – Energy Supply Mix and Carbon Intensity

Building locations were selected to account for variations in the energy supply mix in different provinces. Figure 19 shows the breakdown of energy sources in buildings across Canada. Retrofit measures will have different carbon reduction potentials depending on the building's location and energy supply mix.

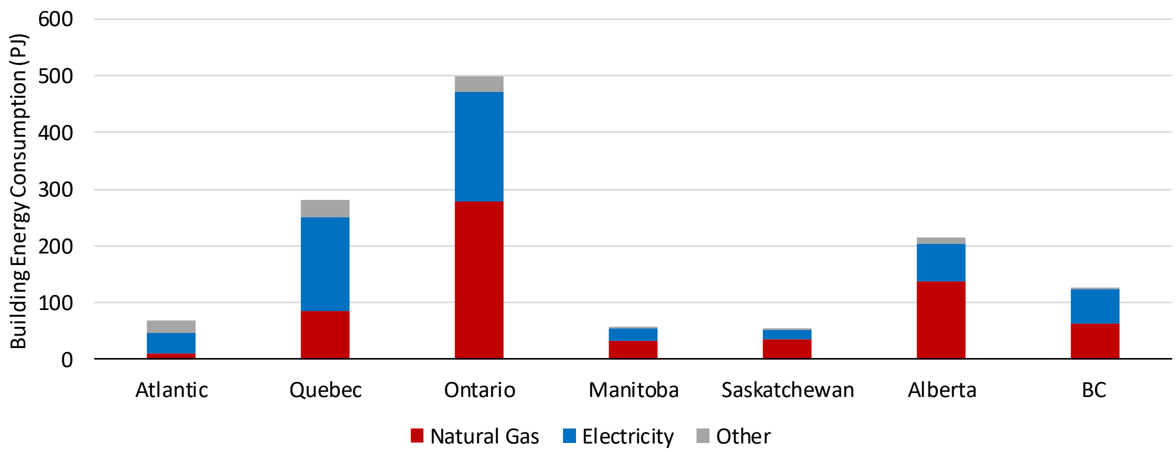


Figure 19. Energy consumption of commercial, institutional and apartment buildings, 2017[19]

The carbon intensity of the electrical grids is a major factor contributing to total carbon emissions. In provinces with low carbon intensity grids (Quebec, Ontario, Manitoba, and BC), natural gas use in buildings is the key driver of emissions. In provinces with more carbon intensive grids (Alberta, Saskatchewan, and the Atlantic provinces), electricity generation is responsible for most of the building sector's emissions.

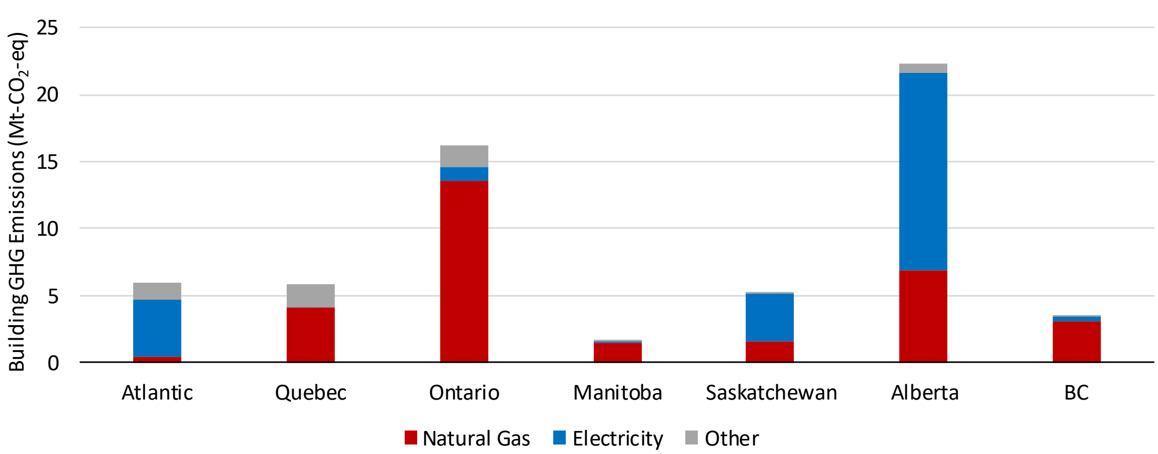


Figure 20. GHG emissions by fuel type for commercial, institutional and apartment buildings, 2017[20]

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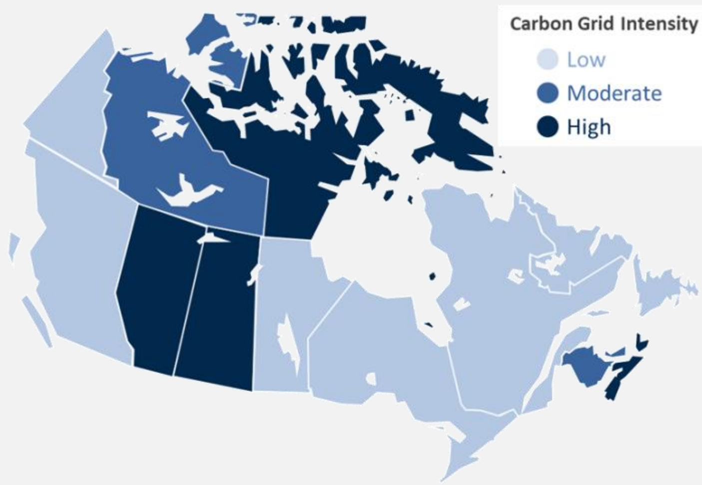
[19] Natural Resources Canada, *Comprehensive Energy Use Database* (2017). Data for small residential (single-family homes, townhouses, and mobile homes) was excluded. Electricity and natural gas represent 93% of energy consumption for large buildings. The other 7% includes a variety of fuels such as wood, or fuel oil.
[20] Natural Resources Canada, *Comprehensive Energy Use Database (2017)*. Does not include small residential (single-family homes, townhouses, and mobile homes.

The GHG impact of reducing electricity use in regions with carbon intensive grids will be greater than in other regions. However, as this study demonstrates, this does not change the strategies for reaching zero carbon, including fuel switching to electricity for space heating and service hot water. Nor does it delay the implementation of these strategies, as they lead to deep carbon reductions today and it is critical that owners immediately begin to take advantage of one-time building envelope renewal opportunities.

How carbon intensive is Canada's grid?

The average electrical grid carbon intensity of the provinces and territories can be split into three categories:

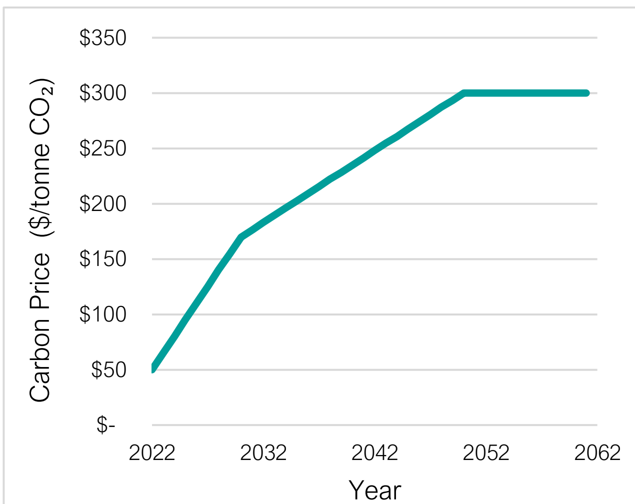
- **Low carbon grid**: 0-80 gCO_2/kWh (BC, MB, ON, QC, NL, YT)
- **Moderate carbon grid**: 80-420 gCO_2/kWh (NB, PE, NT)
- **High carbon grid**: >420 gCO_2/kWh (AB, SK, NS, NU)



Implementing the retrofit measures in regions with carbon intensive electrical grids not only provides immediate carbon reductions, it also positions buildings for the clean electricity grids of the future. Provincial and national plans are in place to ensure regions that rely on coal, natural gas and/or oil-fired power generation reduce their reliance on these carbon intensive energy sources. While the timelines vary, the carbon intensive electrical grids of Alberta, Saskatchewan, and Nova Scotia are targeting significant reductions in carbon emission rates by 2030.

3.3.3 – Carbon Pricing

The impact of the price on carbon pollution is reflected in the energy cost assumptions modelled in this study. Carbon pollution costs for both electricity and natural gas are based on their current carbon intensity.



Retrofits are assumed to be completed in 2022, when the price of carbon is projected to be $50/tonne.

Between 2022 and 2030, the price of carbon is assumed to rise $15/tonne/year until it reaches $170, as announced by the Government of

Canada in 2020.[21] After 2030, the cost of carbon was assumed to rise $6.50/tonne/year and reach $300/tonne/year in 2050 – aligned with industry values for typical internalized carbon abatement costs.

3.3.4 – Energy Costs

Energy costs vary across Canada and have a significant impact on the cost-effectiveness of retrofit measures. The annual energy costs in year one are estimated using the utility cost rates summarized in Table 11. Due to the large number of building types and locations in this study, the analysis was simplified by creating a single, averaged annual utility cost in jurisdictions where electricity costs have time-of-day charges or charges based on tiers of use. The table also clearly differentiates energy charges, which are calculated based on the amount of energy (kWh) consumed, and demand charges, which depend on the maximum amount of power (kW) drawn for a given time interval (typically 15 minutes) during the billing period. It is critical to assess these two metrics separately as they will both affect the building owners' utility bill.

Table 11: Utility Cost Rates

		Electricity		Natural Gas	
		Energy Charge ($/kWh)	Demand Charge ($/kW or kVA)	Energy Charge ($/GJ)	($/kWheq)[22]
Vancouver	Offices and School[23]	$0.096/kWh	$5.370/kW (Bi-monthly)	$6.50/GJ	$0.023 kWheq
	MURBs[24]	$0.12/kWh	n/a	$7.12/GJ	$0.026 kWheq
Edmonton	Offices and School[25]	$0.093/kWh	$0.408/kW/day, (~$7.50/kW/month)	$5.72/GJ	$0.021 kWheq

[21] Government of Canada (2020) A Healthy Economy and A Healthy Environment. https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf
[22] GJ converted to kWh equivalent using a conversion metric of 277.8kWhe/GJ.
[23] Electricity rates are based on BC Hydro Medium General Service rates for business customers with an annual peak demand between 35kW and 150 kW and that use less than 550,000 kWh of electricity per year. Electricity price is an average of Step 1 and Step 2 rates. Natural gas rates are based on Fortis Rate 3 rates for customers that use more than 2,000 GJ annually.
[24] Electricity rates are based on BC Hydro Residential rates. Natural gas rates are based on Fortis Rate 2 rates for customers that use less than 2,000 GJ annually.
[25] Electricity rates are based on EPCOR Regulated Commercial rates for commercial buildings, a power factor of one has been assumed. Natural gas rates are based on Alberta Cooperative Energy estimated rates for commercial buildings.

	MURBs[26]	$0.127/kWh	n/a	$5.73/GJ	$0.021 kWheq
Toronto	Offices and School[27]	$0.186/kWh	$12.13/kW/month	$5.69/GJ	$0.020 kWheq
	MURBs[28]			$5.87/GJ	$0.021 kWheq
Montreal	Offices and School[29]	$0.044/kWh	$14.58/kW/month	$6.25/GJ	$0.022 kWheq
	MURBs[30]	$0.077/kWh	>50 kW or >4kW/unit, $6.21/kW/month		
Halifax	Offices and School[31]	$0.123/kWh	$10.50/kW/month	$12.10/GJ	$0.044 kWheq
	MURBs[32]	$0.158/kWh	n/a	$16.14/GJ	$0.058 kWheq

3.3.5 – Business-as-Usual Costs

The timing and scope vary greatly among "typical" building renewals. Usually, building systems and equipment are replaced according to their individual timelines. This means a "renewal" may happen over several years or decades, rather than all at once. In some cases, a building is demolished before windows or cladding are replaced. For buildings that do renew the cladding, failing cladding may be replaced in small sections as required. Alternatively, the building owner may choose a total cladding renewal to avoid frequent, repetitive, construction activities. Renewing the cladding all at once also allows the owner to change the enclosure design in order to improve the appearance, comfort, and performance of the

[26] Electricity rates are based on EPCOR Regulated Commercial rates for residential buildings. Natural gas rates are based on ATCO Residential North Delivery Service rates.

[27] Electricity rates are based on the average rate for customers with monthly peak demand between 50 kW and 999 kW. Energy costs are based on a multi-year average of HOEP prices. Natural gas rates are based on Enbridge Gas rates for businesses and residential buildings.

[28] Ibid.

[29] Electricity rates are based on Hydro Quebec Rate M for customers with an annual peak demand greater than 50 kW, using an average of low and high consumption brackets. Natural gas rates are based on Énergir's natural gas supply rates.

[30] Electricity rates are based on Hydro Quebec Rate DM for multiunit residential buildings, using an average of low and high consumption brackets. Natural gas rates are based on Énergir's natural gas supply rates.

[31] Electricity rates are based on Nova Scotia Power Commercial rates for customers with an annual peak demand less than 1,800 kW and that use 32,000 kWh of electricity or more per year. Buildings are assumed to use less than 200 kWh/kw peak in a typical month. Natural gas rates are based on Heritage Gas Rate Class 1a for customers that use between 500 GJ and 4,999 GJ per year.

[32] Electricity rates are based on Nova Scotia Power Residential rates. Natural gas rates are based on Heritage Gas Residential rates.

building. Since this study assumes that the 1970s baseline archetypes require a total cladding renewal, a total cladding renewal was also assumed for the business-as-usual (BAU) renewal costs.

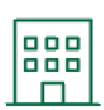
BAU costs are based on the electrical, enclosure and mechanical retrofits of the Vancouver 1970s archetypes. Vancouver was used because the lead author of this study has a well-developed library of costs from many completed and on-going renewal project in that market. These BAU scenarios assume heating distribution and electrical systems are not replaced, and that heating, cooling and ventilation equipment is simply replaced with new, more efficient units. Enclosure assemblies are assumed to be replaced with new units with code-minimum performance. It is assumed that no new systems are added to the buildings – such as cooling equipment or direct ventilation - that did not exist before.

Enclosure renewal costs are based on project experience with building renewals in Vancouver, and mechanical upgrade costs are based on project experience and industry costing resources such as supplier quotes and RSMeans. The total costs for typical renewals and for the deep retrofits include construction costs, a 10% contingency, and a landscaping allowance. Engineering and permitting fees are not included but might add in the range of 5%-15% to project costs, depending on the scope of design services and local permitting costs.

Examples of Business-as-Usual Costs

In contrast to new construction project budgeting and costing, the total project cost of renewals and retrofits varies widely depending on the scope of the base work being done. In this section, incremental costs for the deep retrofit of the Vancouver 1970s archetypes are compared to the estimated total cost of the corresponding BAU retrofit. The 1970s archetype retrofits all include enclosure upgrades, which are much costlier than mechanical equipment; thus, renewals that are mechanical-only would have much lower costs for the BAU scenario.

Construction costs vary by region throughout Canada, and renewal costs can be extrapolated to other locations using resources such as the Altus guide. However, location is less influential on overall project costs than other variables, such as the presence of hazardous materials, the condition of plumbing and electrical systems, and deterioration due to water ingress. The specific characteristics of individual buildings have a large impact on the overall project costs, overshadowing regional construction cost variations in the five major cities in this study, which are typically within a ±25% cost range.



Low-Rise Office

The example building is a 2-storey office building resembling the 1970s Vancouver low-rise office archetype in the study.

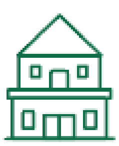
- **Building Characteristics:** 2-storey, steel stud walls, constructed c. 1970s, 40% window-to-wall ratio, ventilated by 100% outdoor air gas-fired MAU. Heated and cooled with distributed water-to-air heat pumps, a gas-fired boiler, and a fluid-cooler. GFA: 3,000 m².
- **Base Renewal Project Description:** Roof membrane renewal with no additional insulation, cladding replacement with no additional insulation and minor improvements to

airtightness, and window replacement with double-glazed thermally-broken aluminum-frame windows (code minimum).
  - Space heating and DHW boilers replaced with condensing units. MAU replaced in kind.
  - Lighting upgrade to LED bulbs.
- **Estimated Total Cost for BAU Renewals:** $900-1400/m², corresponding to $3,500,000 average total project cost for the example building.
- **Estimated Incremental Cost for Deep Retrofit:** $260-380/m² (27% increase).

Mid-Rise Office

The example building is a 13-storey office building resembling the 1970s Vancouver Mid-rise office archetype in the study.

- **Building Characteristics:** 13-storeys, steel stud walls, constructed c. 1970s, punched-windows, 40% window-to-wall ratio, constant volume AHUs with hydronic heating and cooling, heated with hydronic reheat coils and hydronic baseboards. Hot and cold water supplied with gas-fired boiler and water-cooled chiller. GFA: 20,800 m².
- **Base Renewal Project Description:** Roof membrane renewal with 2-inch rigid insulation, cladding replacement with no additional insulation and minor improvements to airtightness, and window replacement with double-glazed thermally-broken aluminum-frame windows (code minimum).
  - Space heating boiler replaced with near-condensing unit, DHW boiler replaced with condensing unit. Constant volume AHUs replaced in kind.
  - Lighting upgrade to LED bulbs.
- **Estimated Total Cost for BAU Renewals:** $700-1000/m², corresponding to $17,300,000 average total project cost for the example building.
- **Estimated Incremental Cost for Deep Retrofit:** $250-410/m² (40% increase).



Low-Rise MURB

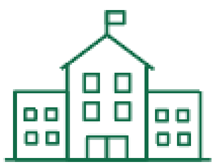
The example building is a 4-storey wood frame multifamily building resembling the 1970s Vancouver Low-Rise MURB archetype in the study.

- **Building Characteristics:** 4-storey, wood frame, constructed c. 1970s, 20% window-to-wall ratio, ventilated with unheated MAU, heated with hydronic baseboards and gas-fired boiler. GFA: 6000 m².
- **Base Renewal Project Description:** Roof membrane renewal with no additional insulation, cladding replacement with no additional insulation and minor improvements to airtightness, and window replacement with double-glazed vinyl windows.
  - Space heating boiler replaced with near-condensing unit, DHW replaced with condensing boiler Unheated MAU replaced in kind.
  - Lighting upgrade to LED bulbs in common areas.
- **Estimated Total Cost for BAU Renewals:** $600-900/m², corresponding to $4,300,000 average total project cost for the example building.
- **Estimated Incremental Cost for Deep Retrofit:** $220-340/m² (39% increase).

Mid-Rise MURB

The example building is a 13-storey multifamily building resembling the 1970s Vancouver Mid-Rise MURB archetype in the study.

- **Building Characteristics:** 13-storey, exposed concrete walls, constructed c. 1970s, 40% window-to-wall ratio, ventilation supplied with gas-fired MAU, heated with hydronic baseboards and gas-fired boiler. GFA: 13,000 m².
- **Base Renewal Project Description:** Roof membrane renewal with no additional insulation, re-cladding with no additional insulation and minor improvements to airtightness, and window replacement with double-glazed thermally-broken aluminum-frame windows (code minimum).
    - Space heating boiler replaced with near-condensing unit, DHW replaced with condensing boiler. Gas-fired MAU replaced in kind.
    - Lighting upgrade to LED bulbs in common areas.
- **Estimated Total Cost for BAU Renewals:** \$600-900/m², corresponding to \$10,200,000 average total project cost for the example building.
- **Estimated Incremental Cost for Deep Retrofit:** \$230-350/m² (37% increase).



Primary School

The example building is a 1-storey school building resembling the 1970s Vancouver Primary School archetype in the study.

- **Building Characteristics:** 1 storey wood-frame, constructed c. 1970s, 35% window-to-wall ratio, ventilation supplied with 100% outdoor air hydronic RTUs. Additional heating provided with hydronic baseboards and a gas-fired boiler. DX cooling for admin and computer rooms only. GFA: 6,900 m².
- **Base Renewal Project Description:** Roof membrane renewal with no additional insulation, re-cladding with no additional insulation and minor improvements to airtightness, and window replacement with double-glazed thermally-broken aluminum-frame windows (code minimum).
    - Space heating and DHW boilers replaced with near-condensing unit. Hydronic RTU replaced in kind.
    - Lighting upgrade to LED bulbs.
- **Estimated Total Cost for BAU Renewals:** \$1000-1500/m², corresponding to \$8,300,000 average total project cost for the example building.
- **Estimated Incremental Cost for Deep Retrofit:** \$290-430/m² (30% increase).

3.3.6 – Heat Pump Considerations

Central air-to-water heat pumps were generally chosen to replace oil/natural gas boilers and electrify space heating and service hot water. In a few cases, air cooled variable refrigerant flow (VRF) heat pumps were used, complete with refrigerant distribution and local refrigerant to air heating/cooling fan coils.

All the CRMs for the deep retrofit pathway were established based on what is currently feasible with available products and/or building practices. At least two current suppliers of air-to-water heat pumps can provide with capacities of up to 90 tons that are able to deliver water temperatures of 50°C, down to systems ambient temperatures of -15°C at 70 to 80 per cent of their rated heat capacity. Serval other manufacturers are developing similar products. These systems were applied in the deep retrofit scenarios studied.

For climates that experience temperatures below -15°C (all locations except Vancouver and Halifax), a “peaking” condensing gas boiler was used to meet the difference between -15°C and the temperature assumed for modelling purposes. **In these instances, the gas boiler provides approximately 1 to 7 per cent of the total heating energy load.** While this is an extremely small share, the gas boilers limit the number and size of heat pumps required, which helps control capital costs.

Packaged roof top DOAS that were gas fired, with or without DX cooling, were replaced with low ambient DX heat pumps, which are currently capable of -25°C ambient temperatures with most of their design capacity output.

Heat pumps are a rapidly expanding market and as this market evolves, system capacity, supply temperatures and cold climate performance are expected to improve. Though a few years away from commercialization, larger capacity R-744 (CO_2) air to water heat pumps are being developed for the Canadian market. Not only does the CO_2 refrigerant have a much lower global warming potential than other refrigerants, these systems are also capable of supplying 90°C hot water in cold ambient conditions. However, these systems were not considered in this study.

Finally, ground source heat pumps were not evaluated as a CRM because space constraints limit the ability to physically accommodate a geo-exchange field on many existing building sites, and the cost and complexity of placing the field under existing buildings are prohibitive.

3.3.7 – Climate Adaptation and Resilience

The focus of this study is on carbon reduction retrofits, however the measures studied also provide some climate resilience benefits. The enclosure upgrades included for the 1970s archetypes contribute to passive survivability by helping to maintain interior comfort during power outages, which is especially important for residential buildings. The addition of solar PV, when coupled with battery systems and control systems, can also provide some measure of relief during power outages.

To improve a building’s resiliency to extreme heat events, other passive resilience measures could include fixed overhangs/fins, operable shading devices, or greenery. Refuge areas can be established, with space conditioning that can be operated on back-up power. Rainwater and flood management should also be considered, as well as resistance to increased wind and snow loads.

With cooling loads in Canada anticipated to increase as the climate changes, retrofits should include considerations for adapting to the need for additional cooling. For example, when new HVAC systems are installed, designers may wish to design the sizing of ductwork and distribution systems to ensure there will be adequate capacity to deliver future cooling loads. In building types that did not already have cooling, the deep retrofit designs in this study generally did not add full mechanical cooling as this would add to the energy consumption and carbon emissions. Retrofit project design teams should assess the risk of overheating on a case-by-case basis, using future climate information, to confirm that occupant comfort will be maintained even during extreme heat events.

How buildings are used should also be considered as part of the resiliency risk assessment. For example, primary schools are largely unoccupied during summer months, when overheating is most likely to occur.

3.3.8 – Peak Electrical Demand

As Canada's economy transitions to zero carbon, many sectors will be seeking to use electricity to provide energy where fossil fuels might have previously been used. This is expected to drive an increase in demand for electricity. At the same time, the electrical grids are having to become more complex, adapting to intermittent power generation from solar and wind, as well as distributed power sources including buildings that may have solar PV, battery storage, or fleets of electric vehicles. The smart grid of the future must be able to manage all these changes, and more (e.g., resilience to more extreme weather).

Buildings have a responsibility to be good grid citizens, minimizing any negative impacts that result from their current or, in the context of deep carbon retrofits, their future operations. This can help control capital infrastructure needs and operating costs for electrical utilities, helping to manage increases to customer billing rates.

In order to be good grid citizens, the most important metric to manage is peak electrical demand, which is the maximum amount of power (kW) drawn for a given time interval (typically 15 minutes). It is typically assessed over a year, a season (e.g., summer and winter peak demand), a month, or a billing period.

The peak demand of a building is important because it represents the maximum amount of power the electrical grid needs to be designed to supply. This has implications at the building level, and if peak demand from many customers coincides, it can have implications at the local, regional, provincial, and national levels. Simply put, any increase in the peak demand of buildings resulting from the electrification of space heating and service hot water represents a new burden on the electrical grid. This burden will increase the investments in grid infrastructure that are needed and may result in additional marginal ("peak") power generation from fossil fuels.

While conventionally assessed annually, peak demand is increasingly being evaluated seasonally. This better reflects the seasonal impacts of changes that may be made to buildings, such as installing solar PV (which provides more power, over more of the day, in the summer), maximizing solar gain from windows (which will decrease winter peak demand but may increase summer peak demand), and increasing insulation (which will decrease winter peak demand but may increase summer peak demand if there are high internal heat gains).

Assessing peak demand seasonally informs how the electrical grid must be managed. For example, while hydro power generation dams may currently seek to store capacity over the winter and spring in order to meet summer peak demand, operations may change if electric space heating requires more power over the winter and, as a result of the efficiency of heat pump technology, less power over the summer.

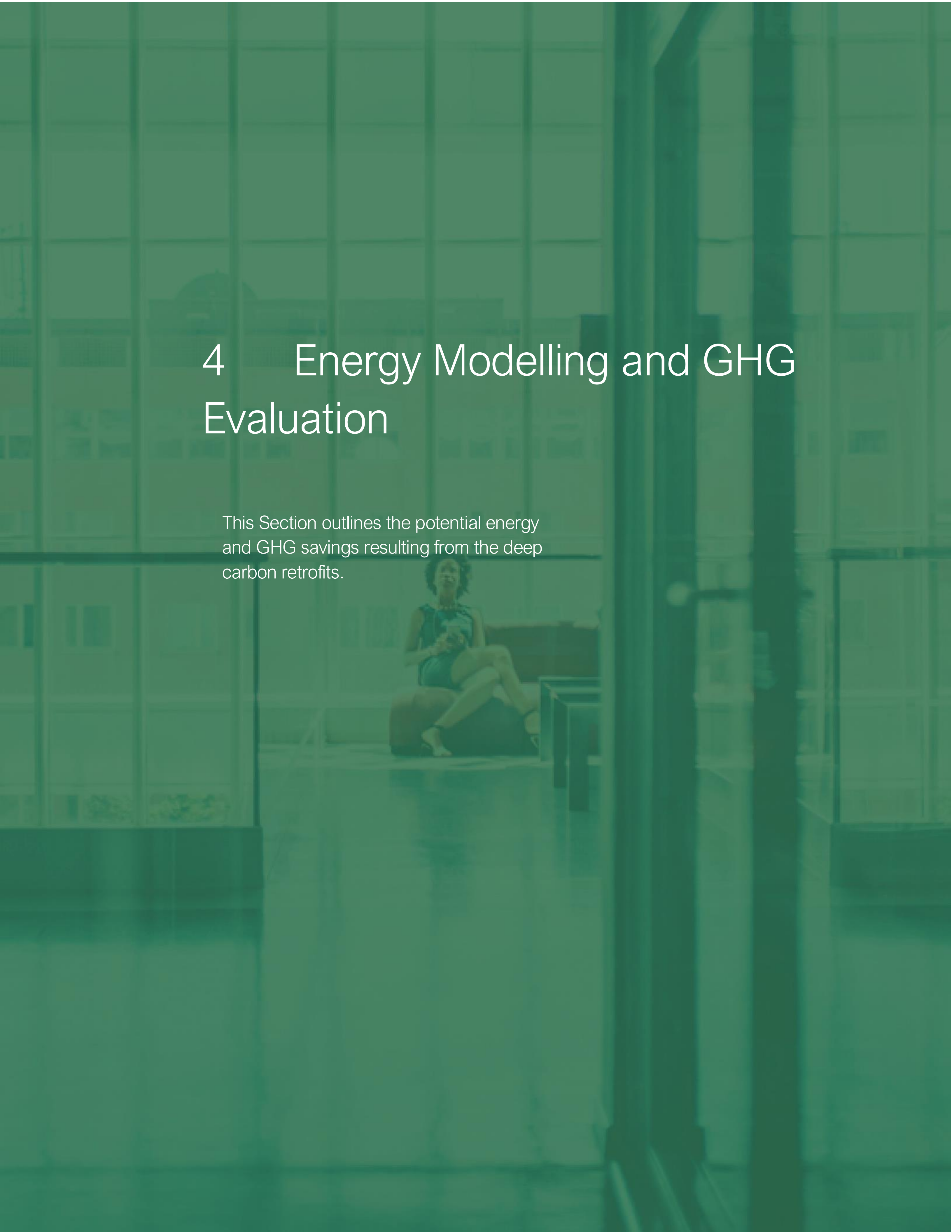
Fuel switching to electric space heating and service hot water is critical to achieving zero carbon buildings. For building owners considering such a switch, peak demand is important because it can affect utility rates and even drive the need to upgrade a building's electrical service, which can be costly.

This study includes an evaluation of annual and seasonal peak demand for each of the archetypes, and speaks to some of the measures that can be used to manage increases in peak demand.

3.3.9 – Embodied Carbon

This study demonstrates that decarbonization can be achieved through retrofitting existing buildings, yielding dramatic embodied carbon reductions relative to demolition and reconstruction.

The study does not include an assessment of the embodied carbon impacts of the deep carbon retrofit measures evaluated. Embodied carbon was minimized by timing deep retrofits to the natural end-of-life of major building systems, moderating the additional insulation in the enclosure upgrades, and minimizing the replacement of mechanical system components (in particular, maintaining distribution systems where possible). Additional project-specific opportunities to minimize embodied carbon should be considered as part of any deep carbon retrofit plan.



4 Energy Modelling and GHG Evaluation

This Section outlines the potential energy and GHG savings resulting from the deep carbon retrofits.

Energy Modelling and GHG Evaluation

By implementing packages of carbon reduction measures (CRMs) on existing buildings at the time of their regular infrastructure and equipment renewals, deep carbon emission reductions can be achieved – reaching nearly 100 per cent for some archetypes. As indicated by detailed modelling results of the archetypes studied, there are variations in the extent of achievable total energy use intensity (TEUI) and greenhouse gas intensity (GHGI) reductions, as well as differences in the impact on peak electrical demand, based on the building type, vintage, and location.

This Section provides a breakdown of each building archetype's potential energy and GHG savings from deep retrofits.

Key Information Summary

1- **The transition to zero carbon by 2050 can be completed for all building types if we get started today.** The retrofit measures achieved complete, or nearly complete, elimination of fossil fuel use for every building type. In Vancouver, Toronto, and Montreal - locations with low carbon intensity grids - all the building archetypes achieve nearly complete decarbonization today. Even in Halifax and Edmonton, locations where the carbon intensity of the electrical grids is currently higher, GHGIs were reduced on average 68% in the 1970s archetypes, and 53% in the 1990s archetypes. Furthermore, fossil fuel use was reduced at least 96% in each archetype, ensuring the retrofitted buildings are well positioned for the clean electrical grids of the future.

2- Generally, **the 1970s archetypes achieve a lower GHGI** compared to the 1990s archetypes due to the heating and cooling demand reduction from enclosure upgrades.

3- The TEUI results for the deep retrofit MURB archetypes are in line with the requirements for the upper steps/tiers of the BC Energy Step Code and Toronto Green Standard, which guide new construction. The indicates that **it is feasible to adopt performance-based metrics for existing buildings.**

4- Generally, the electrification of space heating and service hot water systems results in an increase in annual peak electricity demand. This highlights the **importance of efficiency and demand response programs to mitigate the creation of new peaks.**

5- PV is most suitable for buildings with large roof areas in locations with carbon intensive electricity grids and without utility net metering size limitations.

4.1 – Energy and GHG Analysis

This section summarizes the energy and greenhouse gas analysis results for the business-as-usual (BAU) and deep retrofit pathways for each building archetype in the five locations. Note that the scale used in the figures is held consistent for ease of comparison.

4.1.1 – Low-rise Office

This section summarizes the energy and greenhouse gas results for the low-rise office. The low-rise office archetype is a 2-storey steel-frame building, approximately 3,000 m² (32,000 ft²) in size, without a parkade.

4.1.1.1 – Energy

Figure 21 and Figure 22 below show the modelled TEUI results for the business-as-usual (BAU) and deep retrofit (DR) scenarios for the 1970s and 1990s low-rise office archetypes, respectively.

Summary of Results

Building Vintage	Energy Reduction	TEUI (kWh/m^2/yr)
1970s	68 – 94%	45 - 70
1990s	62 – 85%	73 - 117

Figure 21 shows that as a result of enclosure upgrades in the deep retrofit scenario, reducing the impacts of heating demand variations in the different locations and climates, the final TEUIs of the retrofitted 1970s archetypes are very similar. In addition, Figure 21 also illustrates that the BAU window upgrades that might be anticipated in the 1970s low-rise offices can provide a noticeable reduction in TEUI (especially for the Edmonton, Montreal, and Toronto locations). However, far greater reductions are possible with deep enclosure upgrades, which include superior windows and the addition of insulation.

1970s

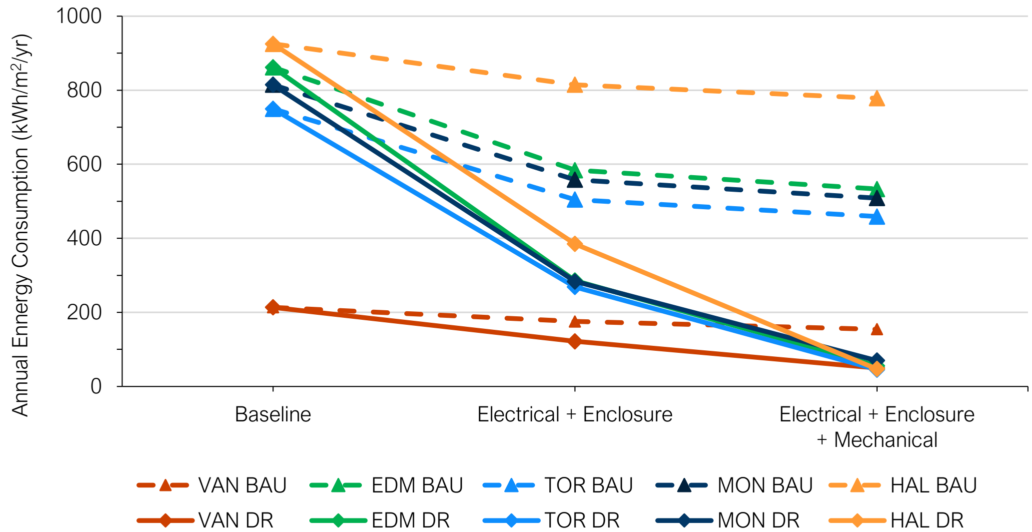


Figure 21. Total energy use intensity (TEUI) for the 1970s low-rise office archetype.

1990s

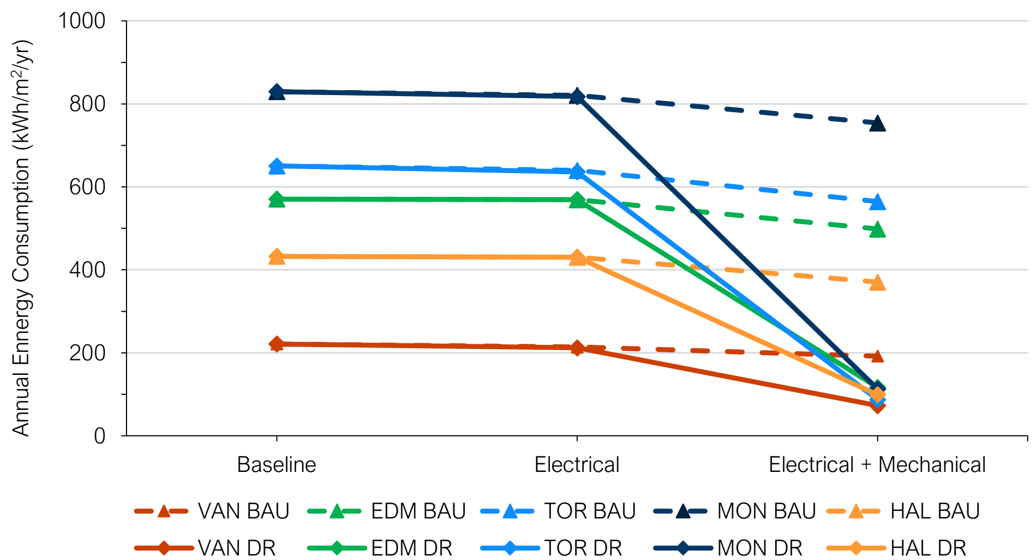


Figure 22. Total energy use intensity (TEUI) for the 1990s low-rise office archetype.

Figure 23 to Figure 27 below show the modelled TEUI results by fuel type for each location and the energy savings (per cent) compared to the BAU scenario.

Generally, the deep retrofits for the 1970s archetype show higher energy savings as compared to the 1990s archetype because they include enclosure upgrades. The 1970s and 1990s Vancouver low-rise office archetypes result in lower relative energy savings compared to the other locations; this is because the baseline TEUI is significantly lower and thus the CRMs have a lower reduction potential.

Figure 23 to Figure 27 also show the modelled electricity use intensity results for the addition of mechanical upgrades with and without on-site solar PV. The annual power generation from solar PV varies across the locations due to differences in regional solar irradiation and system size, which was limited to available roof area. The solar PV system size is further restricted in Vancouver, Montreal, and Halifax by the utility net metering size limitations; therefore, these locations result in the lowest annual solar PV electricity generation. For archetypes without capacity limiting regulations, up to 50% of the energy consumption could be displaced by PV, while only 10% to 30% could be displaced where there are capacity limiting regulations.

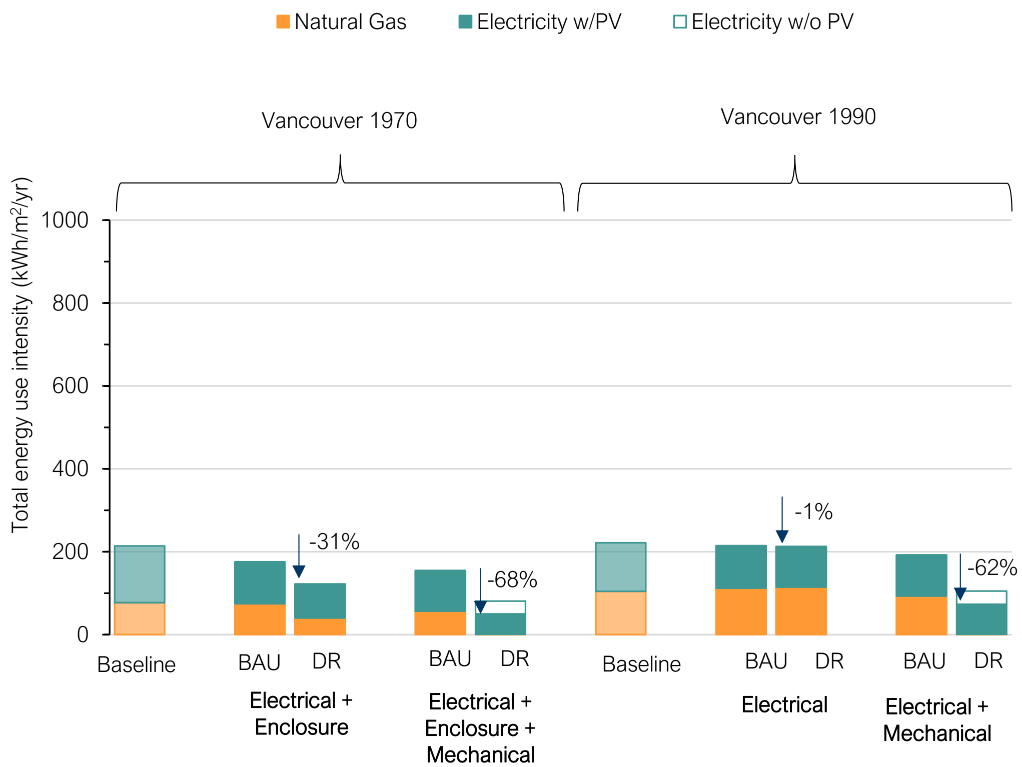


Figure 23. Total energy use intensity presented by fuel type for the 1970s and 1990s Vancouver low-rise office.

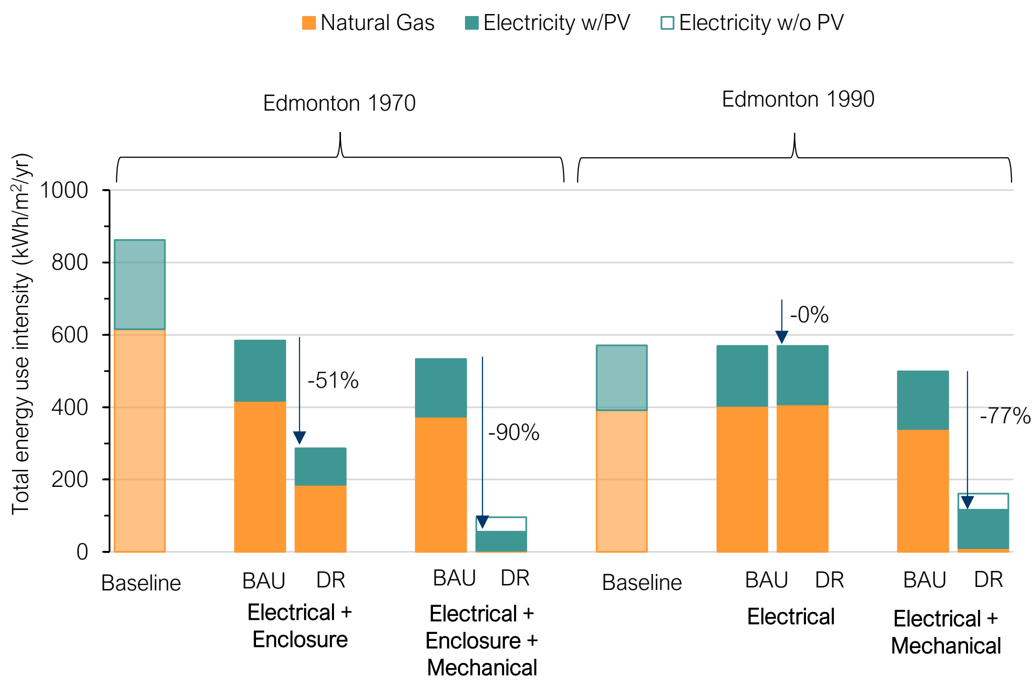


Figure 24. Total energy use intensity presented by fuel type for the 1970s and 1990s Edmonton low-rise office.

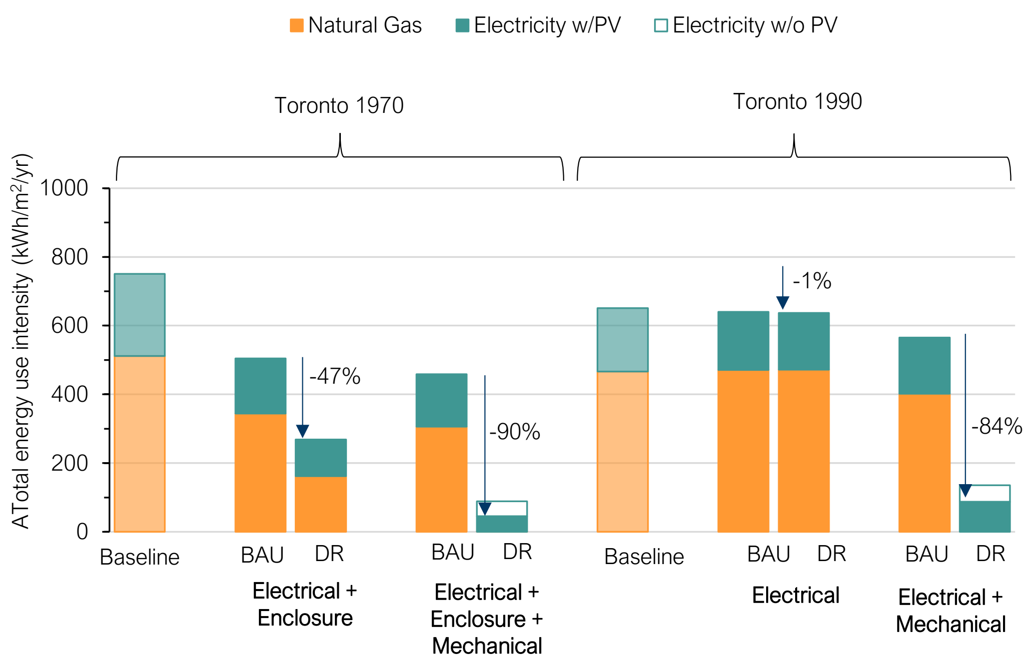


Figure 25. Total energy use intensity presented by fuel type for the 1970s and 1990s Toronto low-rise office.

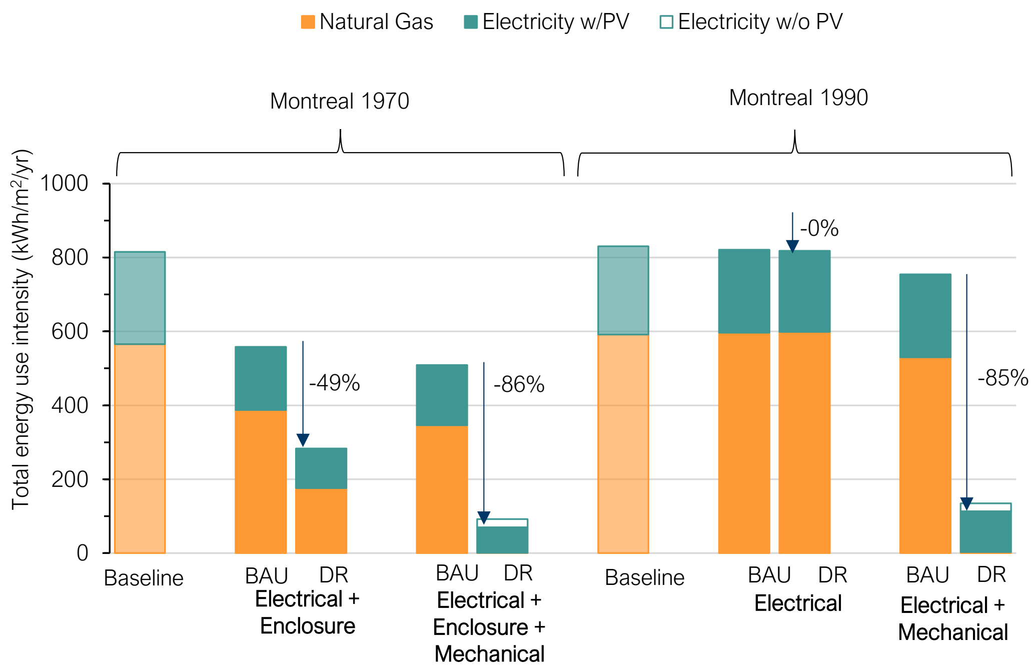


Figure 26. Total energy use intensity presented by fuel type for the 1970s and 1990s Montreal low-rise office.

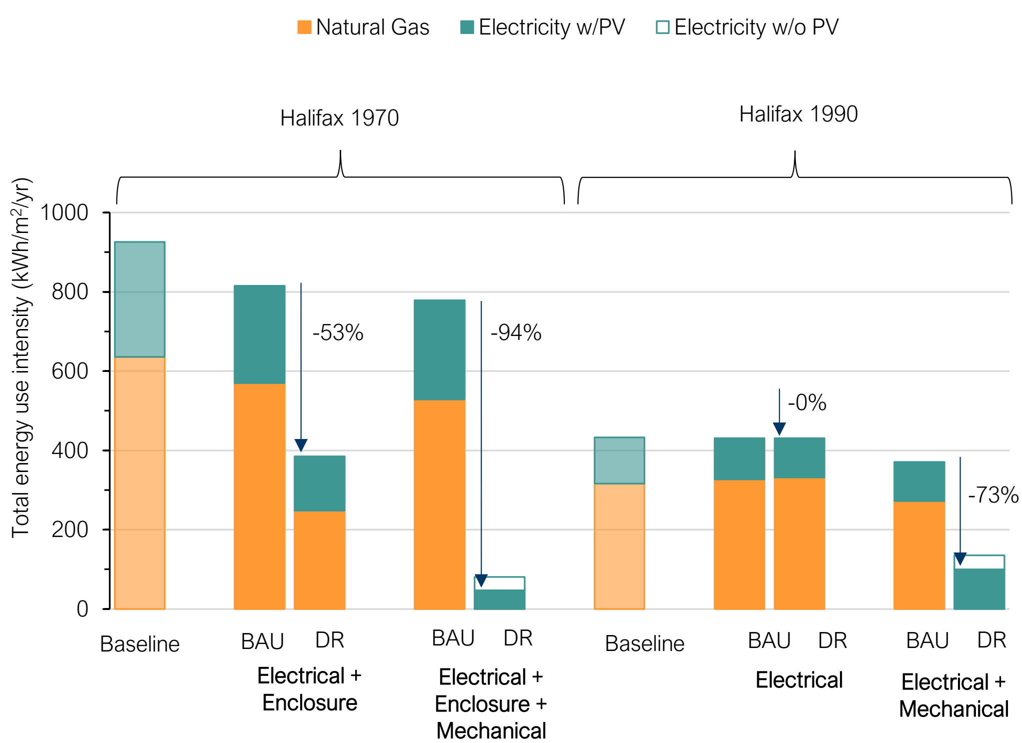


Figure 27. Total energy use intensity presented by fuel type for the 1970s and 1990s Halifax low-rise office.

4.1.1.2 – Carbon Emissions

Figure 28 and Figure 29 below show the modelled GHGI results for the 1970s and 1990s low-rise office archetype, respectively.

Summary of Results

Building Vintage	GHG Reduction	GHGI
1970s	84 – 100%	0 - 29 $kgCO_2eq/m^2/yr$
1990s	43 - 100%	0 - 74 $kgCO_2eq/m^2/yr$

Although the deep retrofit package achieves similar TEUIs across the different locations, the GHGIs vary significantly due to difference in the carbon intensity of the regional electricity grids. The low-rise offices located in Montreal, Toronto, and Vancouver achieve a significantly lower GHGI than those in Edmonton and Halifax. Important to note, however, is the fact that the GHGIs in the Edmonton and Halifax deep retrofit scenarios are still lower than their BAU scenarios and will drop over time as the electrical grids in those regions are further decarbonized.

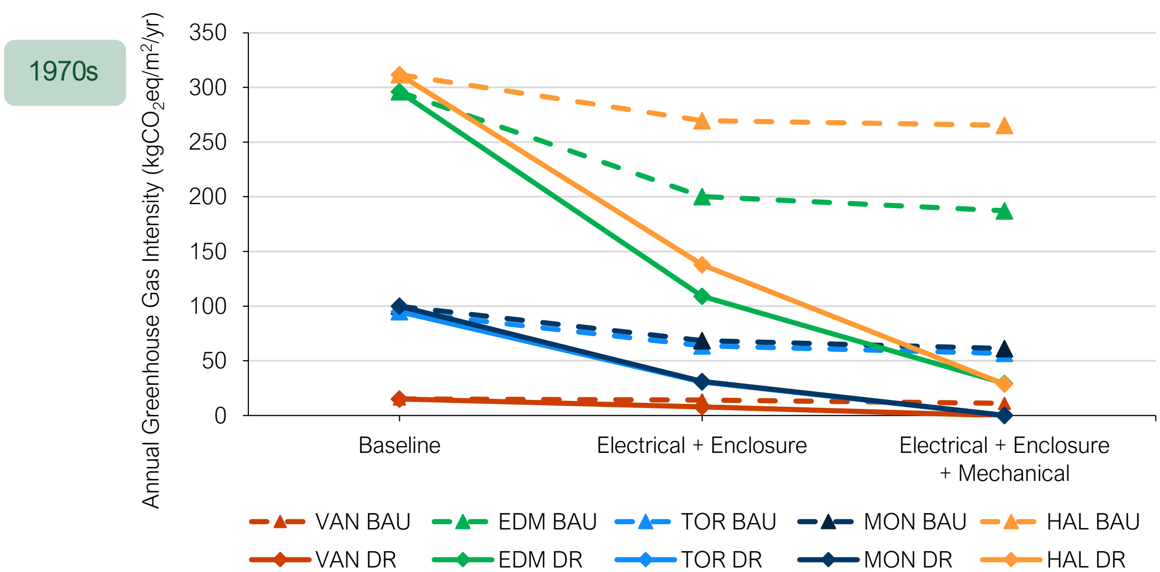


Figure 28. Greenhouse gas intensity (GHGI) for the 1970s low-rise office.

1990s

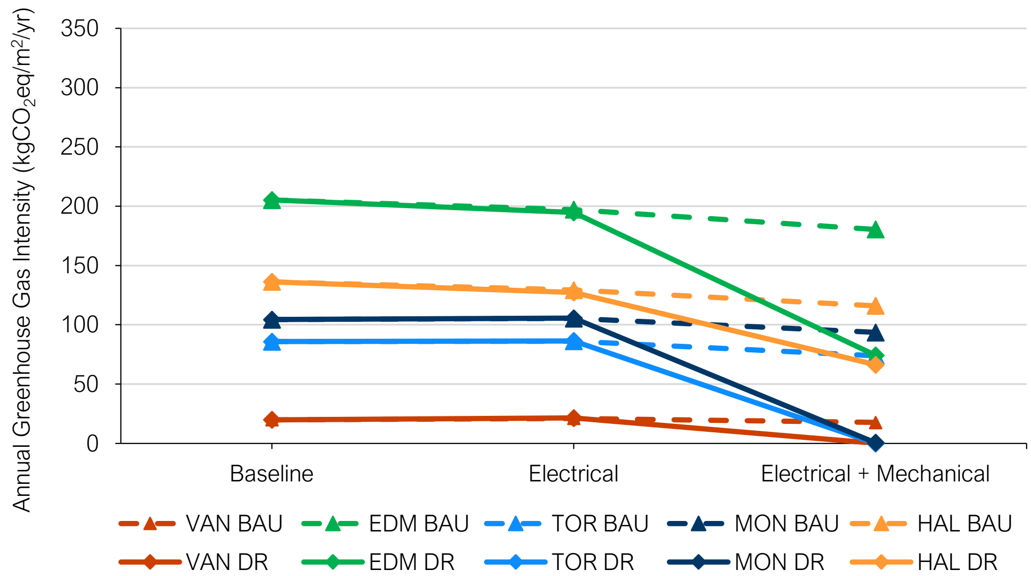


Figure 29. Greenhouse gas intensity (GHGI) for the 1990s low-rise office.

Figure 30 to Figure 34 below show the modelled GHGI results by fuel type for each location. The figures also show the greenhouse gas emissions reduction (per cent) compared to the BAU scenario.

The lowest GHGI values and greatest greenhouse gas reductions (between 99 to 100 per cent) are achieved in Vancouver, Toronto, and Montreal. This is because the mechanical CRMs include fuel switching measures (transitioning from fossil fuel to electricity) for space heating and service hot water, and the carbon intensity of the electrical grid in these locations is low.

The deep carbon retrofit pathway for the low-rise office archetype in Edmonton results in the highest GHGI value and most modest greenhouse gas reductions, followed by Halifax. Even though the CRMs achieve between 73 to 94 per cent energy savings in Edmonton and Halifax, the GHGI reductions are in the 43 to 89 per cent range due to the higher carbon intensity of the electrical grid.

The electrical CRMs package for the 1990s archetype consists of lighting upgrades, which generally results in minor carbon emission reductions overall, however, for the Vancouver 1990s low-rise office archetype the results showed an increase in carbon emissions. This is because the LED lighting installed produces less heat, increasing space heating demand, which is met by natural gas boilers until such time as the mechanical upgrades are implemented and heat pumps are installed.

Figure 30 to Figure 34 also show the modelled GHGIs after mechanical upgrades, with and without solar PV implementation. As illustrated, the GHG emission reductions achieved from implementing solar PV in regions with higher carbon intensity electrical grids (Edmonton and Halifax) will be a crucial component to realizing low carbon targets in existing buildings.

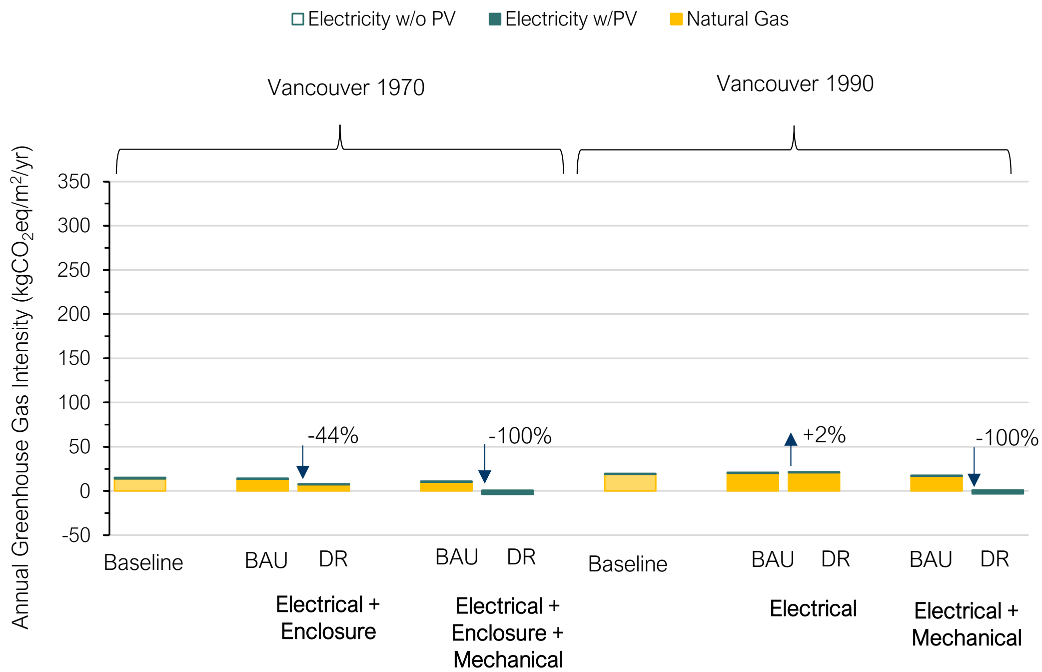


Figure 30. Greenhouse gas intensity by fuel type for the 1970s and 1990s Vancouver low-rise office.

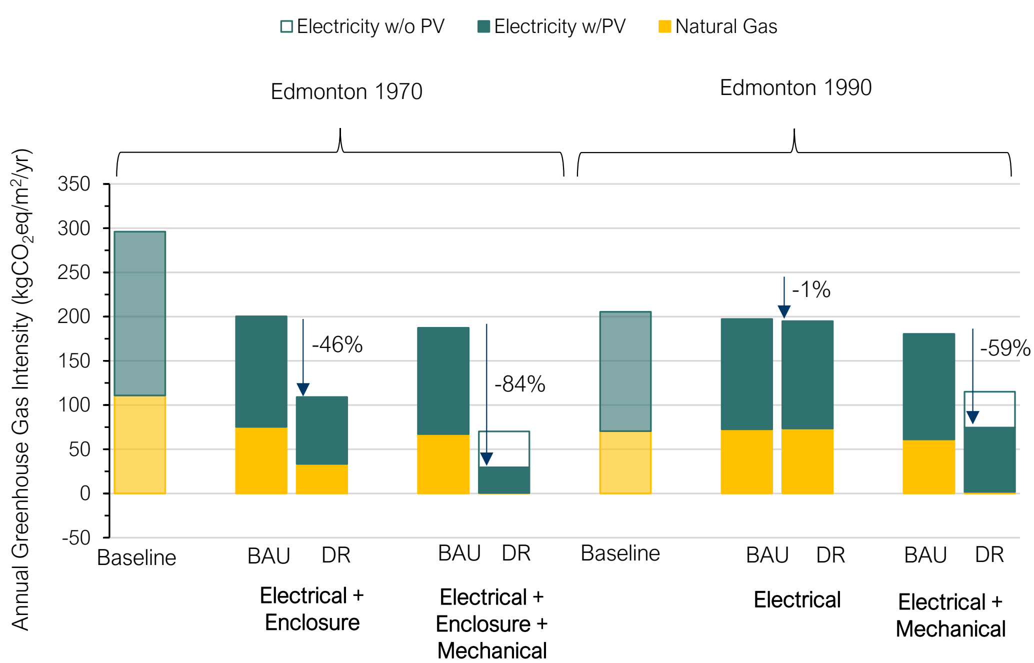


Figure 31. Greenhouse gas intensity by fuel type for the 1970s and 1990s Edmonton low-rise office.

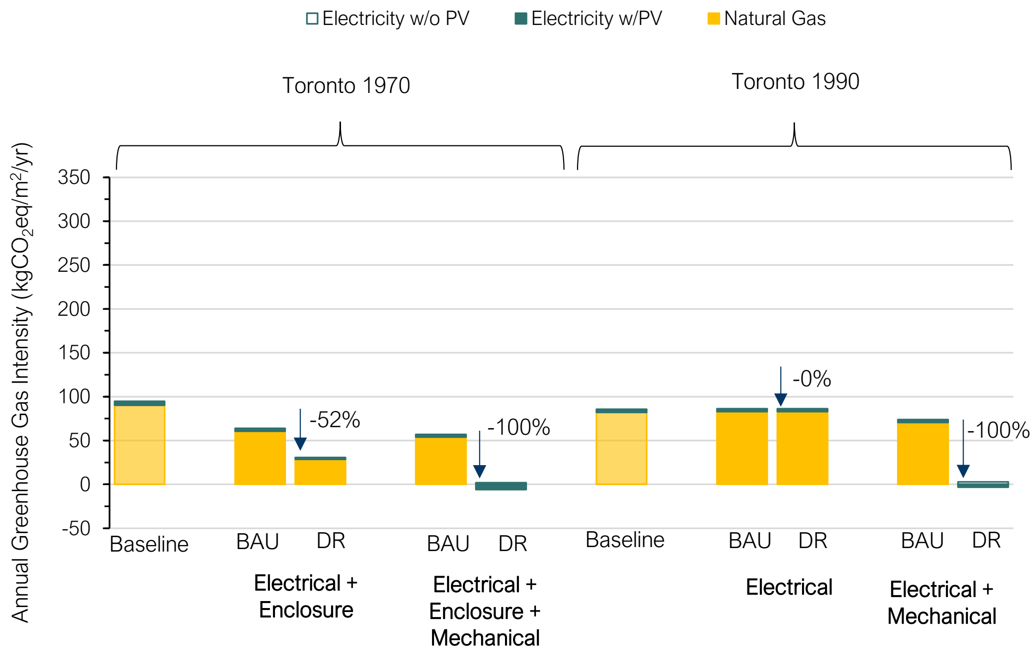


Figure 32. Greenhouse gas intensity by fuel type for the 1970s and 1990s Toronto low-rise office.

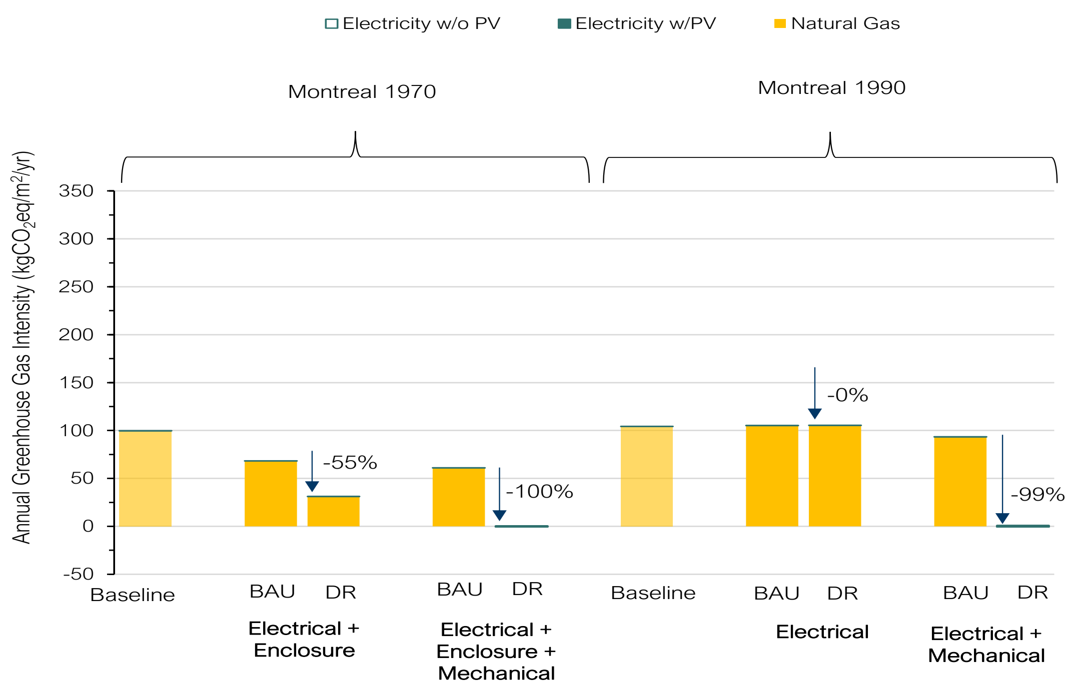


Figure 33. Greenhouse gas intensity by fuel type for the 1970s and 1990s Montreal low-rise office.

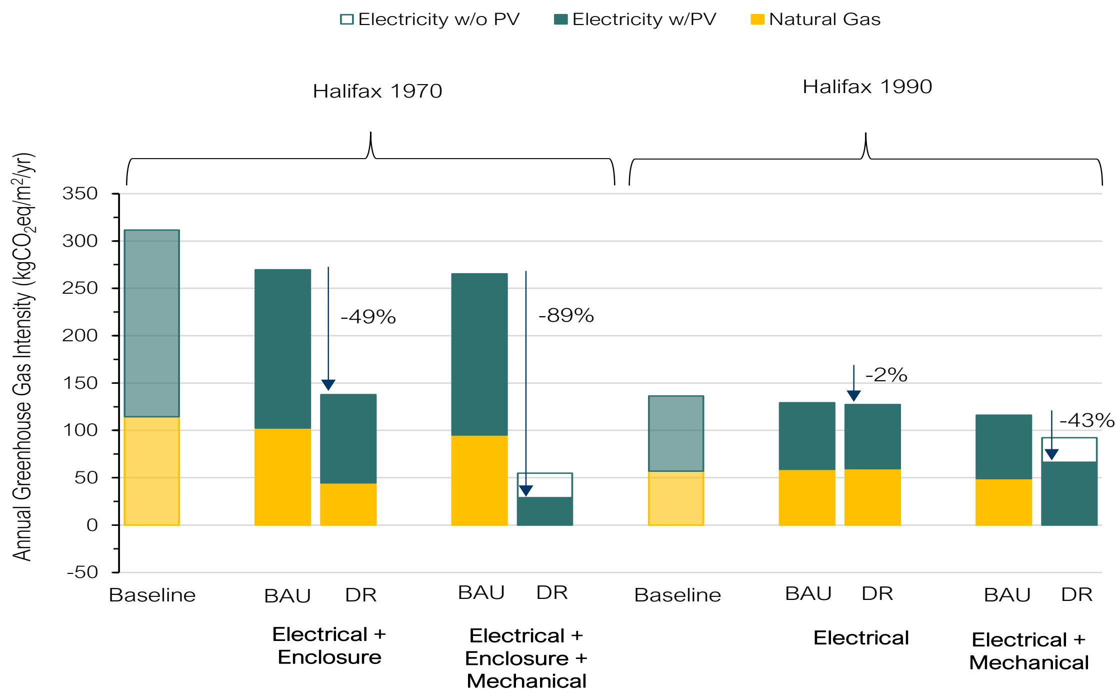


Figure 34. Greenhouse gas intensity by fuel type for the 1970s and 1990s Halifax low-rise office.

4.1.1.3 – Electricity Demand

Figure 35 and Figure 36 below show the modelled peak electricity demand results for the 1970s and 1990s low-rise office archetype, respectively.

In general, the lighting upgrades achieve decreases in peak electricity demand in both the BAU and deep retrofit scenarios, with further decreases achieved through enclosure upgrades in the 1970s archetype buildings.

Peak demand is reduced in the deep retrofit package for the 1970s Vancouver, Toronto, and Halifax archetypes due to space heating system efficiency upgrades. The Montreal and Edmonton 1970s archetypes realize an increase in peak demand of 16 and 59 per cent respectively, compared to BAU.

Summary of Results

Building Vintage	Peak demand impact
1970s	-30% to +59%
1990s	+3 to 207%

The deep retrofit packages increase the annual electricity demand for all 1990s low-rise office archetypes compared to BAU, as demand-reducing enclosure upgrades were not included as part of the studied package. Some typical time of year shifts in peak demand are discussed in Section 3.2.1.

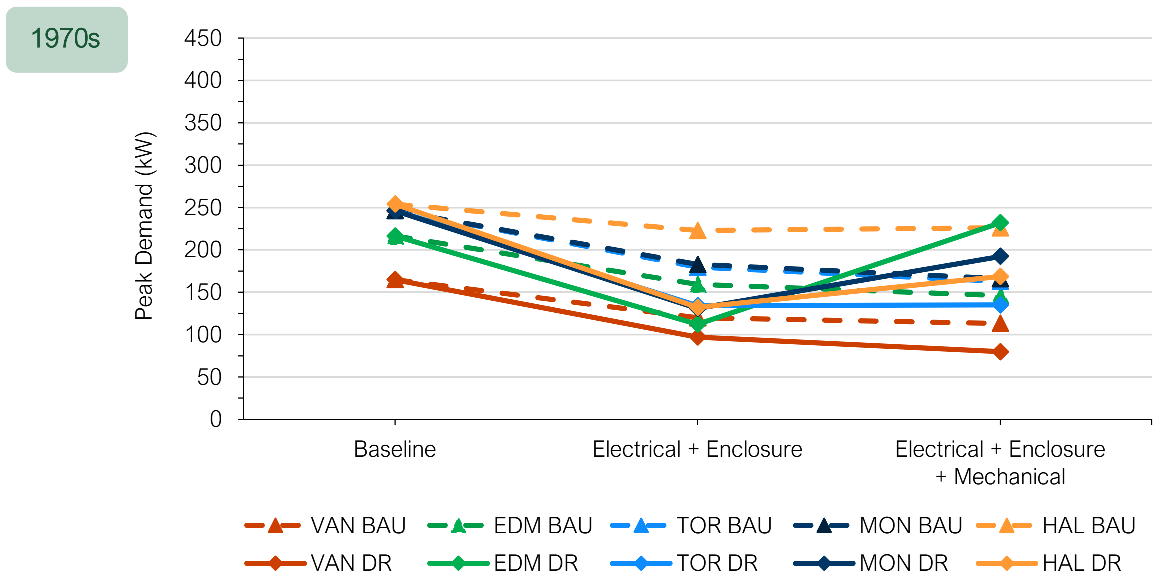


Figure 35. Peak electricity demand for the 1970s low-rise office.

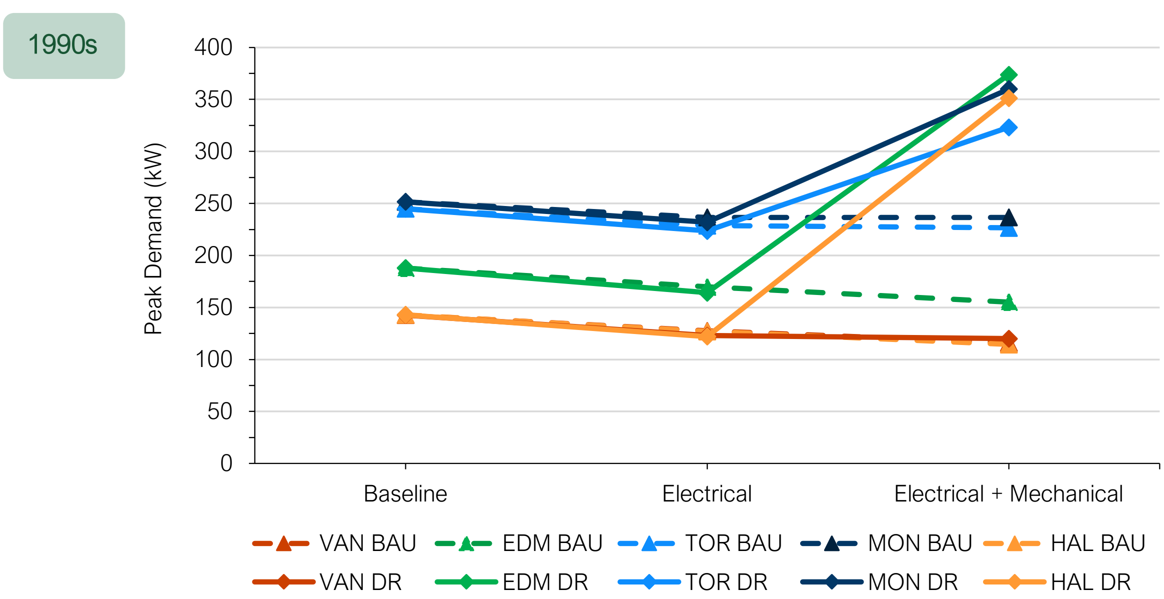


Figure 36. Peak electricity demand for the 1990s low-rise office.

4.1.2 – Mid-rise Office

This section summarizes the energy and greenhouse gas results for the mid-rise office. The mid-rise office archetype is a 13-storey non-combustible building with a 1-level underground parkade, approximately 21,000 m² (224,000 ft²) in size.

4.1.2.1 – Energy

Figure 37 and Figure 38 below show the modelled TEUI results for the BAU and deep retrofit scenarios for the 1970s and 1990s mid-rise office archetype, respectively.

Like the low-rise office archetypes, the deep retrofit package for the 1970s mid-rise office archetypes achieves lower TEUIs due to enclosure upgrades.

Summary of Results

Building Vintage	Energy Reduction	TEUI
1970s	70 - 85%	55 - 79 kWh/m²/yr
1990s	81 - 83%	71 - 94 kWh/m²/yr

1970s

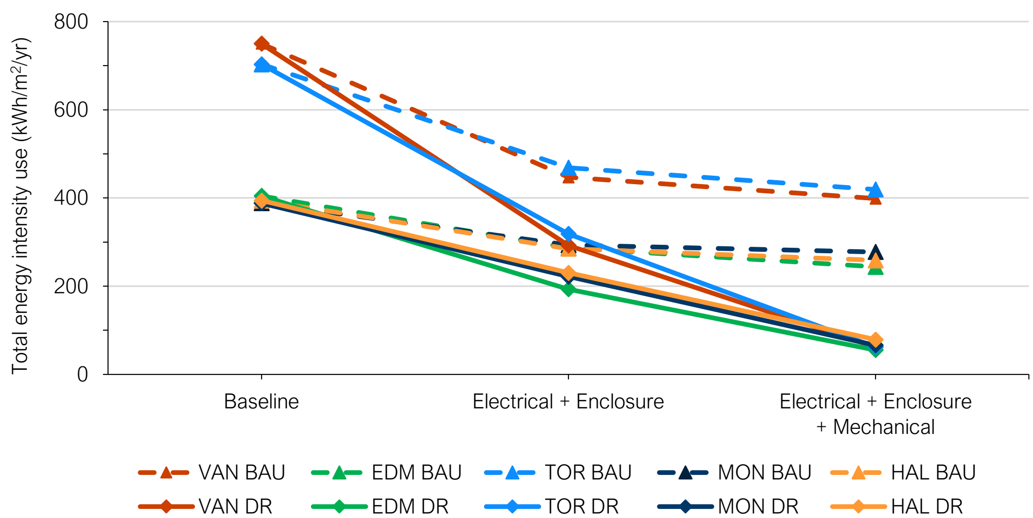


Figure 37. Total energy use intensity (TEUI) for the 1970s mid-rise office.

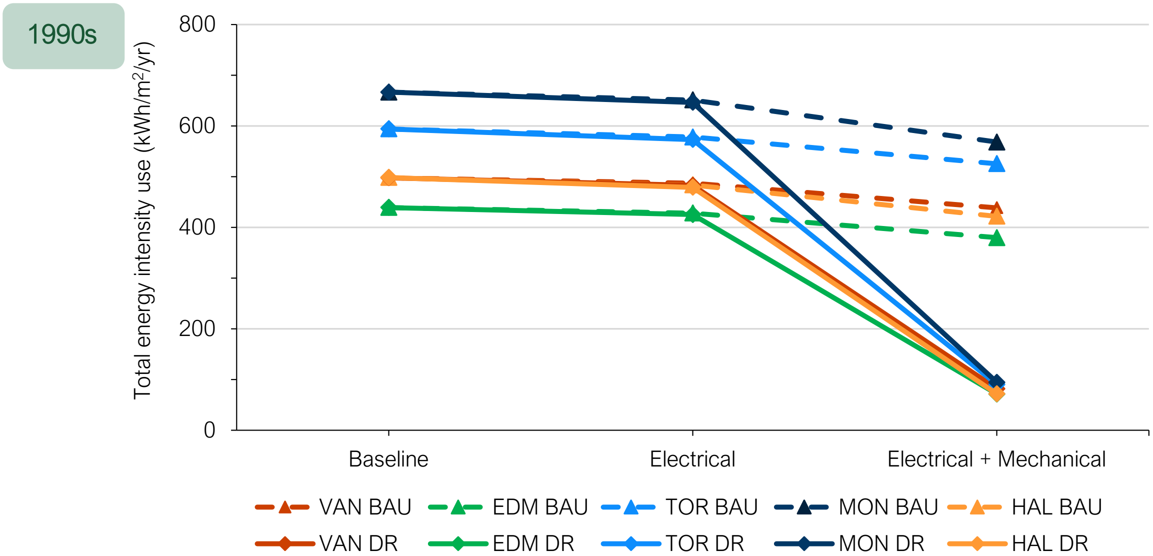


Figure 38. Total energy use intensity (TEUI) for the 1990s mid-rise office.

Figure 39 to Figure 43 below show the modelled TEUI results by fuel type for each location and the energy savings (per cent) compared to the BAU scenario.

The deep retrofit package achieves energy savings ranging from 70 to 85 per cent for the 1970s archetype, and from 81 to 83 per cent for the 1990s archetypes. Note that the range is narrower for the mid-rise office than for the low-rise office as the mid-rise office baseline building TEUIs are more similar across locations.

Figure 39 to Figure 43 also show the modelled electricity use intensity results for the mechanical upgrades with and without on-site solar PV. The annual solar PV power generation varies between locations due to differences in regional solar irradiation and system size, which is limited by roof-area and utility net metering size limitations. As illustrated, the implementation of solar PV only slightly reduces grid electricity consumption.

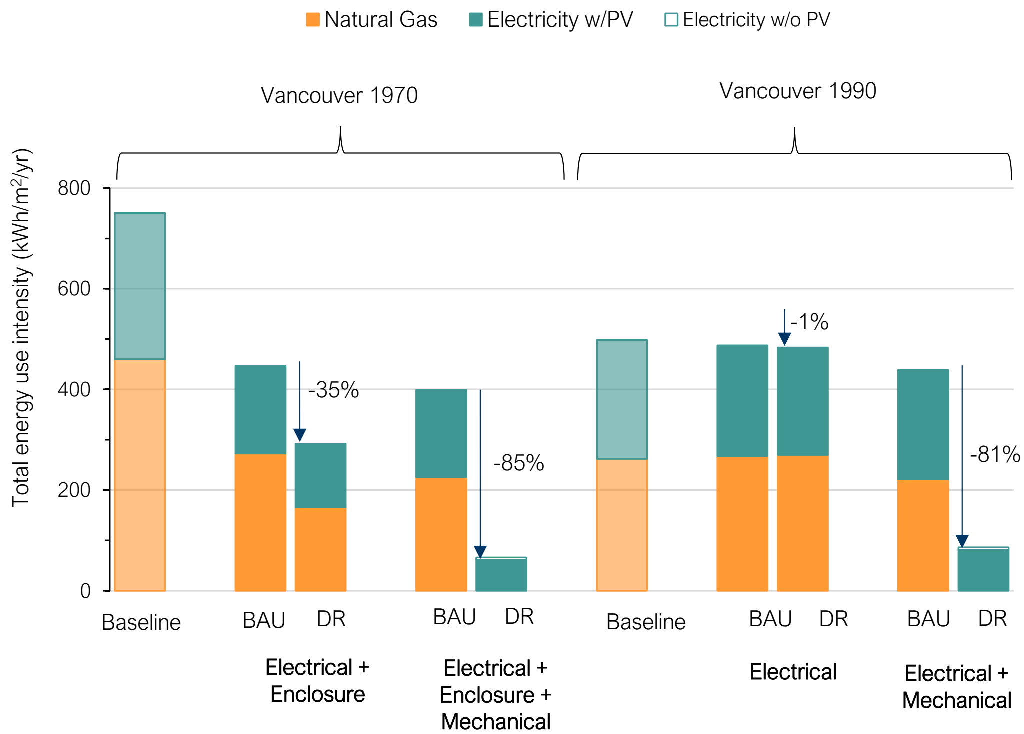


Figure 39. Total energy use intensity presented by fuel type for the 1970s and 1990s Vancouver mid-rise office.

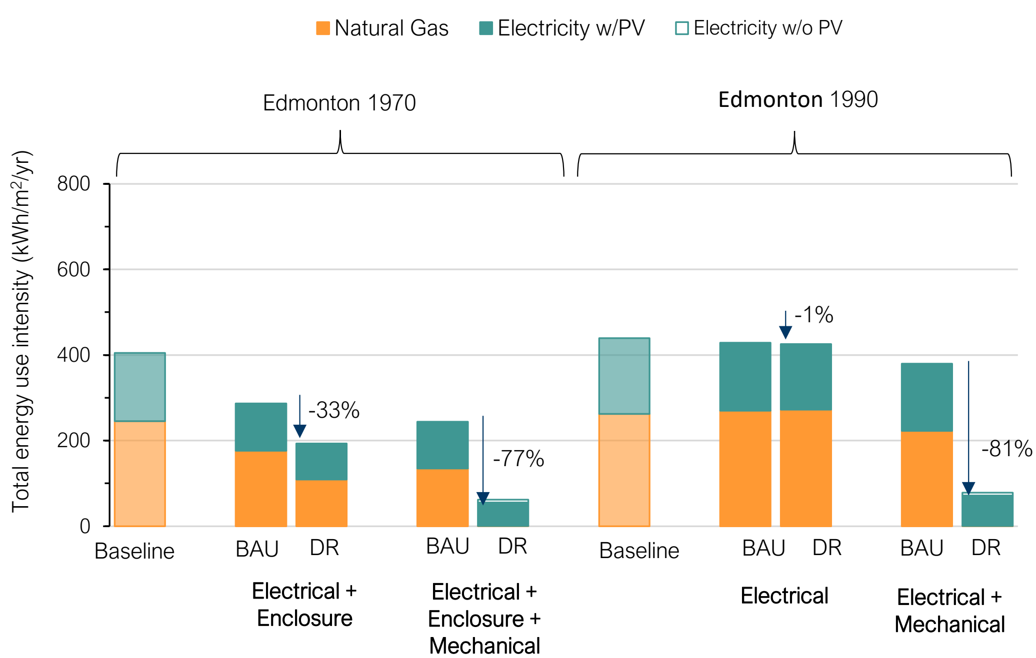


Figure 40. Total energy use intensity presented by fuel type for the 1970s and 1990s Edmonton mid-rise office.

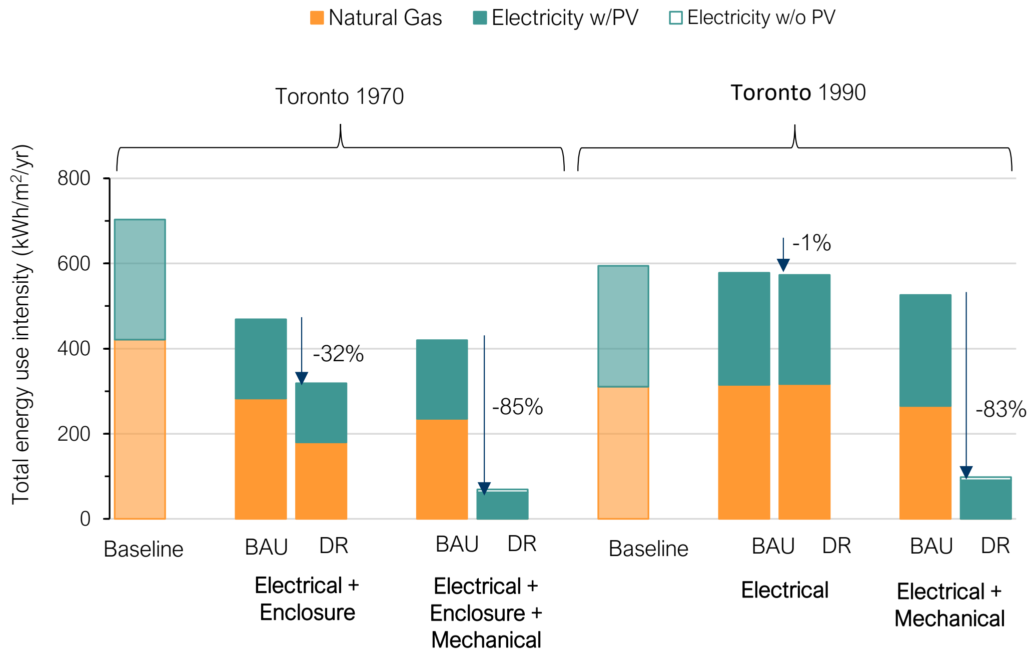


Figure 41. Total energy use intensity presented by fuel type for the 1970s and 1990s Toronto mid-rise office.

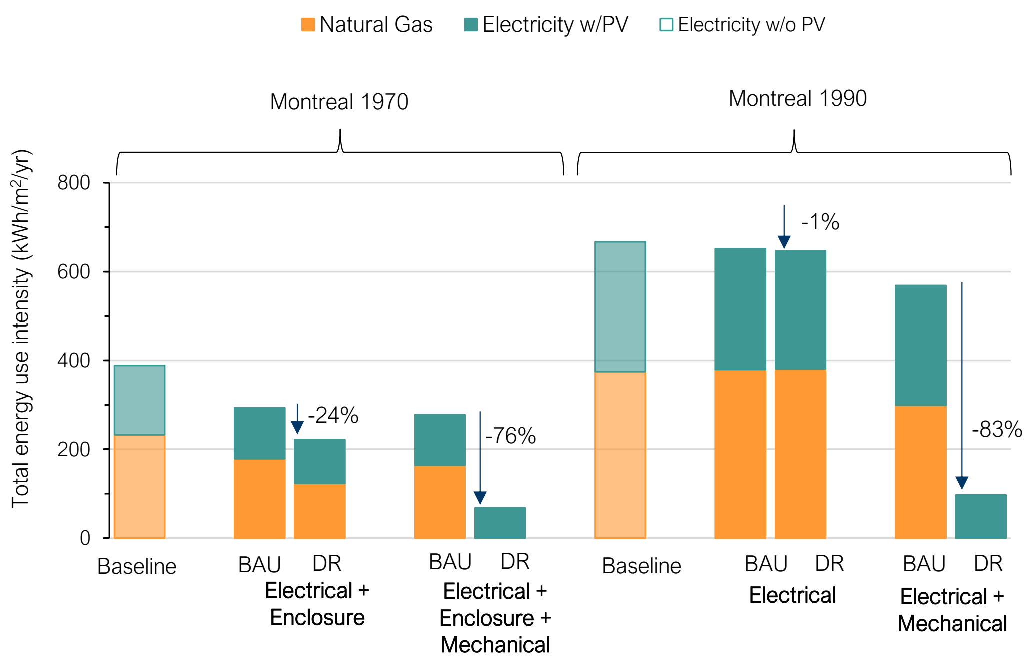


Figure 42. Total energy use intensity presented by fuel type for the 1970s and 1990s Montreal mid-rise office.

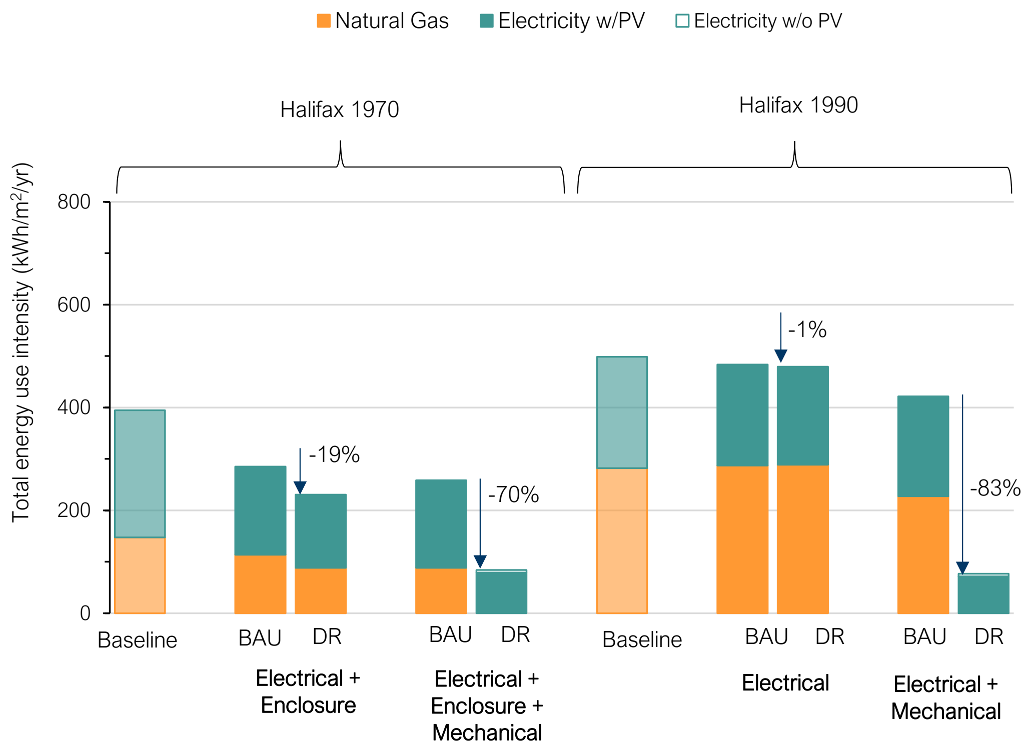


Figure 43. Total energy use intensity presented by fuel type for the 1970s and 1990s Halifax mid-rise office.

4.1.2.2 – Carbon Emissions

Figure 44 and Figure 45 below show the modelled GHGI results for the 1970s and 1990s mid-rise office archetypes, respectively.

Summary of Results

Building Vintage	GHG Reduction	GHGI
1970s	59 - 100%	0 - 54 $kgCO_2eq/m^2/yr$
1990s	67 - 100%	0 - 53 $kgCO_2eq/m^2/yr$

Like the low-rise office archetypes, the deep retrofit package for the 1970s and 1990s mid-rise office archetypes achieves varied GHGI results depending on location, with deep retrofits in Montreal, Toronto, and Vancouver resulting in significantly lower GHGIs than those in Edmonton and Halifax. It is important to note, however, that even Edmonton and Halifax see sizeable reductions in GHGI relative to BAU – 62% and 59% respectively for the 1970s archetypes, and 67% and 72% for the 1990s archetypes.

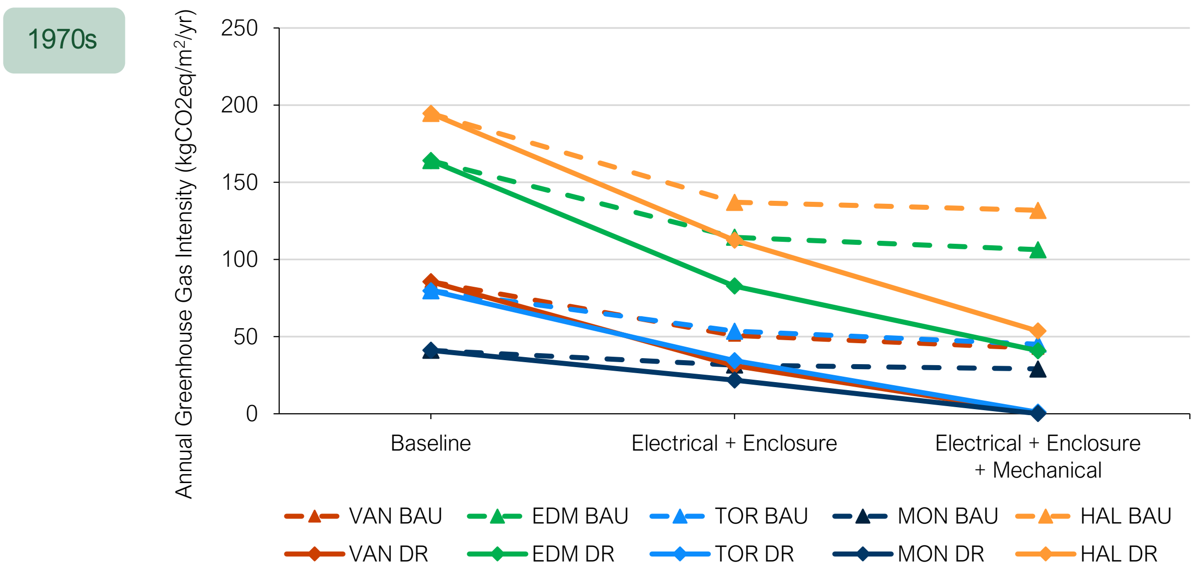


Figure 44. Greenhouse gas intensity (GHGI) for the 1970s mid-rise office archetype.

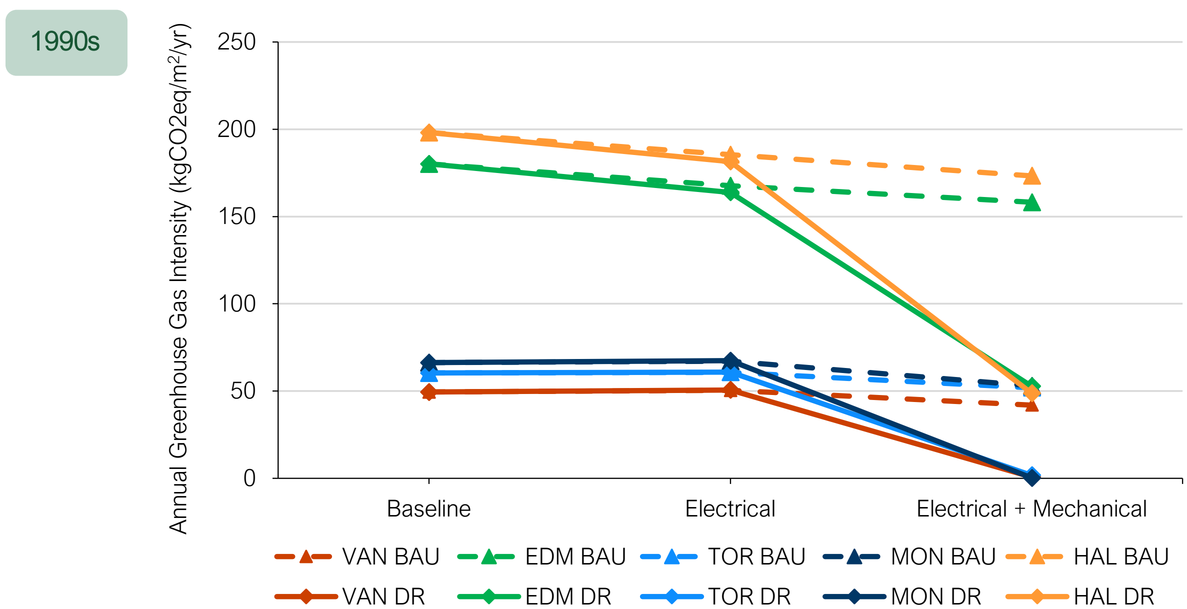


Figure 45. Greenhouse gas intensity (GHGI) for the 1990s mid-rise office archetype.

Figure 46 to Figure 50 below show the modelled GHGI results by fuel type for each location. The figures also show the greenhouse gas reduction (per cent) compared to the BAU scenario.

Figure 46 to Figure 50 also show the modelled GHGI results of mechanical upgrades, with and without solar PV implementation. In comparison to total electricity consumption, solar PV electricity generation potential is relatively minor, due to roof size and utility net metering size limitations. Therefore, the solar PV was shown to have a relatively small impact on TEUIs and GHGIs.

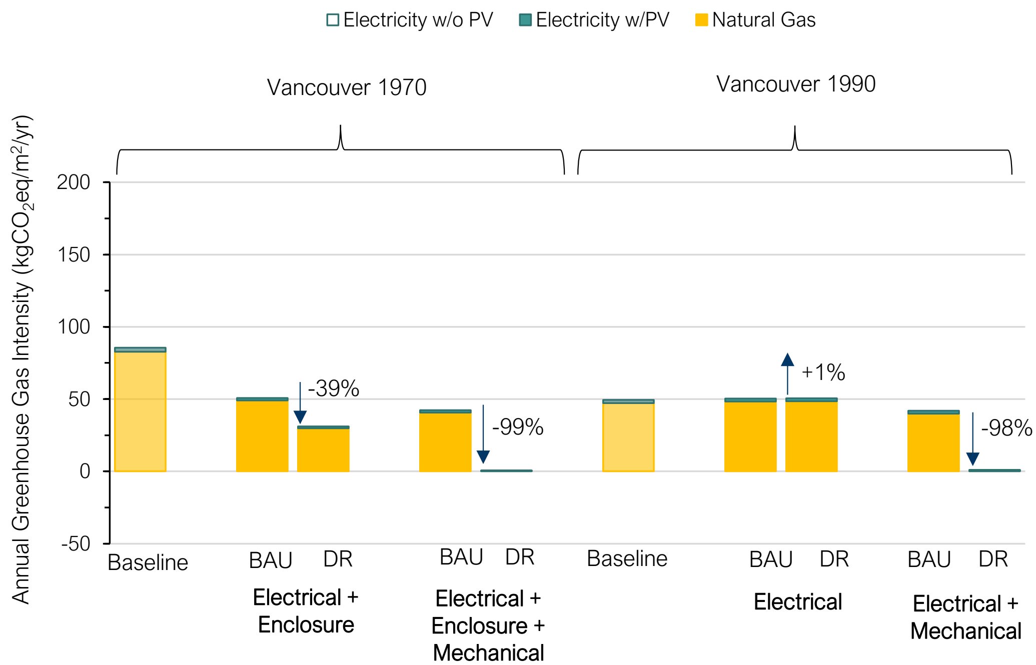


Figure 46. Greenhouse gas intensity by fuel type for the 1970s and 1990s Vancouver mid-rise office.

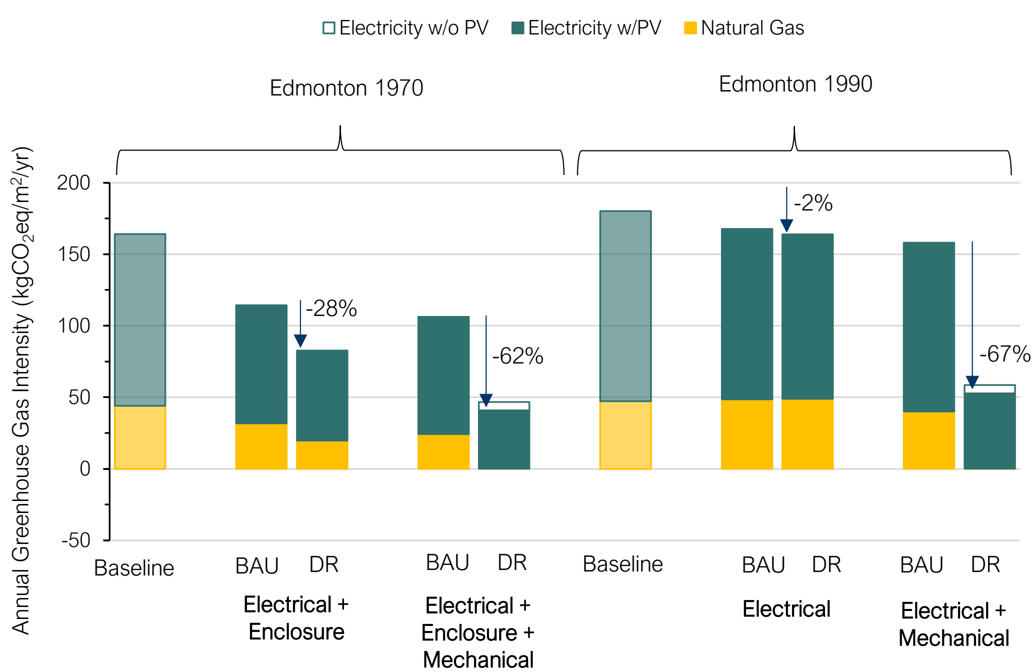


Figure 47. Greenhouse gas intensity by fuel type for the 1970s and 1990s Edmonton mid-rise office.

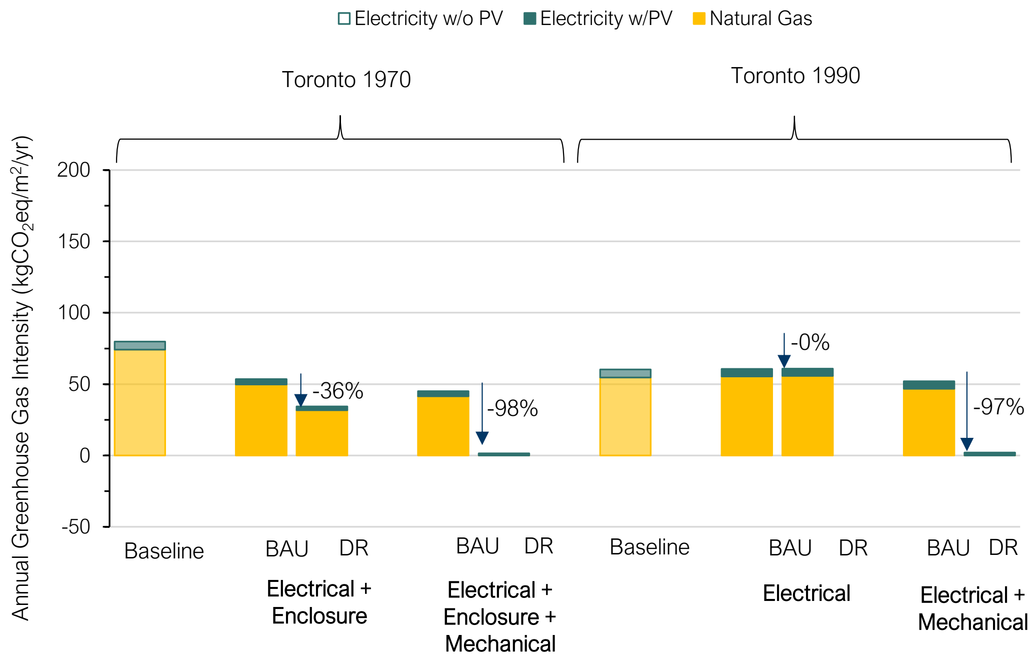


Figure 48. Greenhouse gas intensity by fuel type for the 1970s and 1990s Toronto mid-rise office.

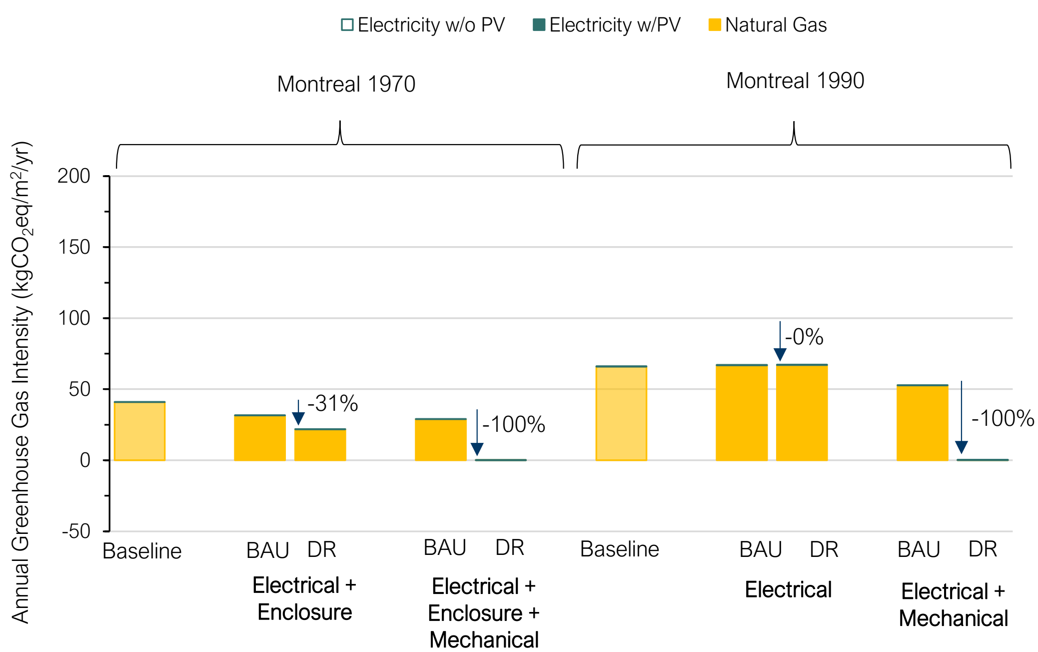


Figure 49. Greenhouse gas intensity by fuel type for the 1970s and 1990s Montreal mid-rise office.

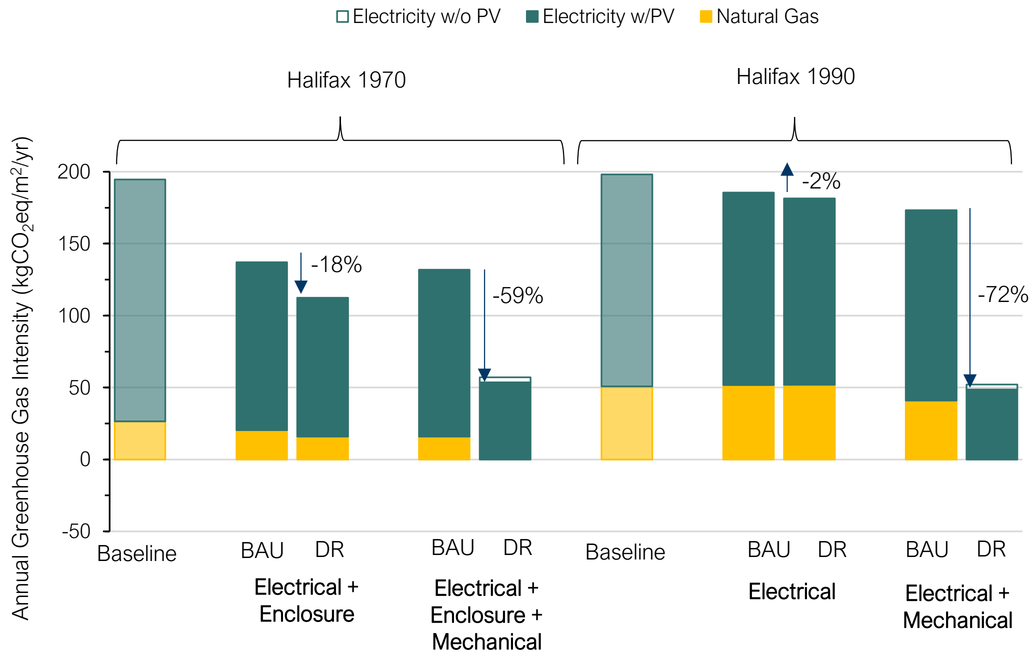


Figure 50. Greenhouse gas intensity by fuel type for the 1970s and 1990s Halifax mid-rise office.

4.1.2.3 – Electricity Demand

Figure 51 and Figure 52 below show the modelled peak electricity demand results for the 1970s and 1990s mid-rise office archetypes, respectively.

Summary of Results

Building Vintage	Peak demand impact
1970s	-15% to -38%
1990s	-11% to -25%

Unlike the low-rise office archetype, the mechanical upgrades achieve a decrease in peak demand for the mid-rise office archetypes, ranging from 11 to 38 per cent. This is because the mid-rise office has a higher cooling load. Further, the annual peak demand continues to occur during the summer after the electrification of heating and service hot water. Although overall the implementation of on-site solar PV does not achieve significant reductions in electricity consumption for mid-rise office archetypes, it does result in a reduced peak cooling demand (and annual peak demand) compared to the baseline, which is important to help mitigate the challenges of electrification across all buildings as well as other sectors of the economy.

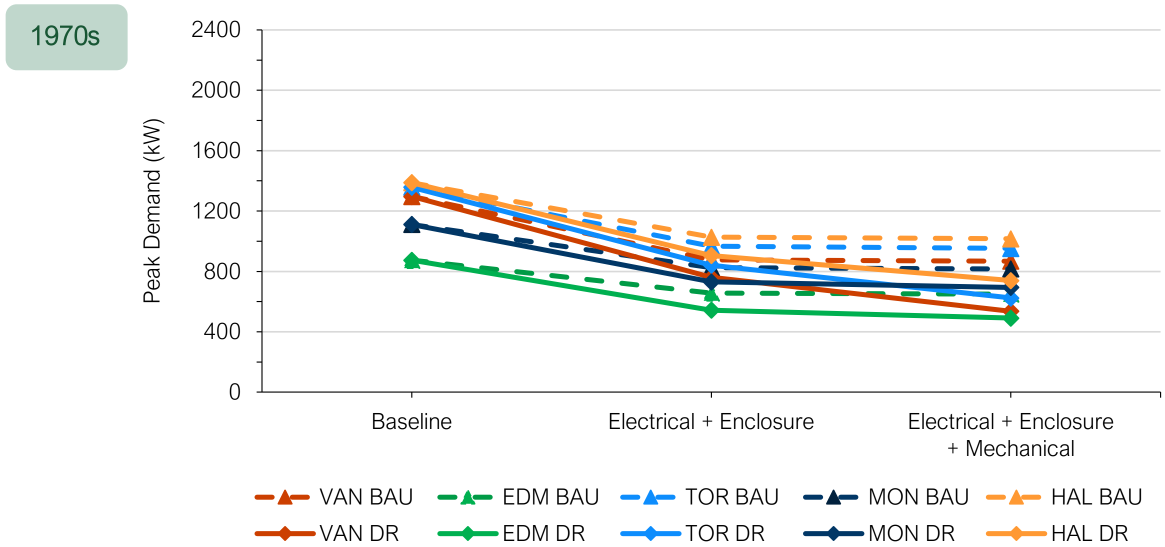


Figure 51. Peak electricity demand for the 1970s mid-rise office.

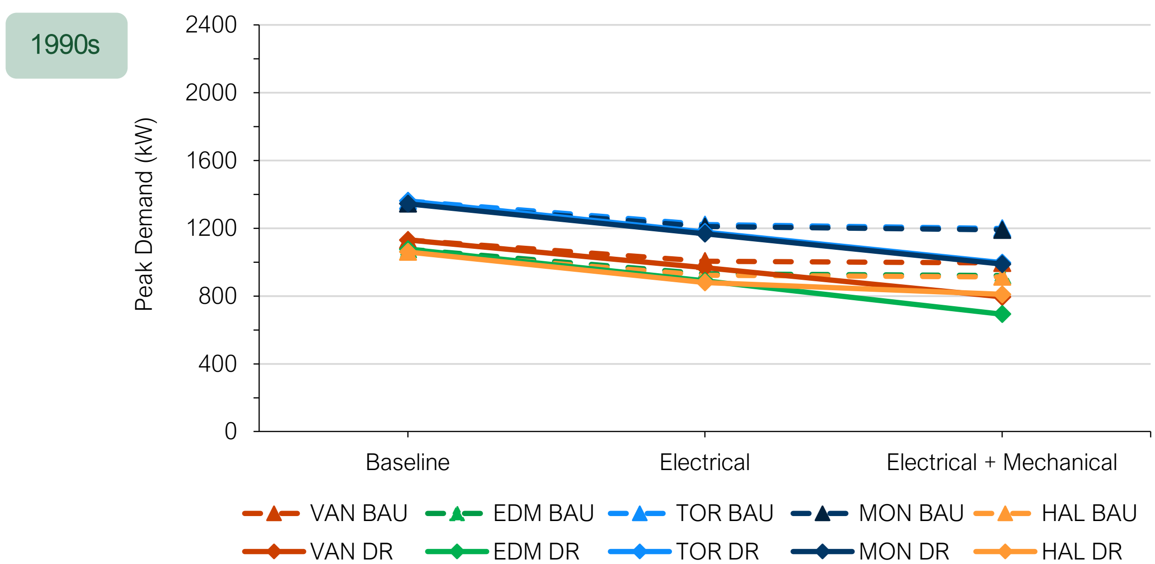


Figure 52. Peak electricity demand for the 1990s mid-rise office.

4.1.3 – Low-rise MURB

This section summarizes the energy and greenhouse gas results for the low-rise MURB baseline building archetypes. The low-rise MURB archetype is a 4-storey wood-frame building without a parkade, approximately 6,000 m² (65,000 ft²) in size.

4.1.3.1 – Energy

Figure 53 and Figure 54 below show the modelled TEUI results for the BAU and deep retrofit scenarios for the 1970s and 1990s low-rise MURB archetypes, respectively.

Summary of Results

Building Vintage	Energy Reduction	TEUI
1970s	64 - 81%	38 - 53 kWh/m²/yr
1990s	72 - 75%	50 - 79 kWh/m²/yr

Generally, TEUI in the 1970s and 1990s baseline building archetypes are similar, suggesting that the energy efficiency of typical 1990s low-rise MURBs has not improved significantly compared to 1970s.

The modelled TEUI results are in line with the requirements for the upper steps/tiers of the BC Energy Step Code (ESC) and Toronto Green Standard, which guide new construction. Deep retrofits at all low-rise MURB archetypes result in lower TEUI than required for the highest step (Step 4) of the BC ESC, which is 100 kWh/m²/yr.

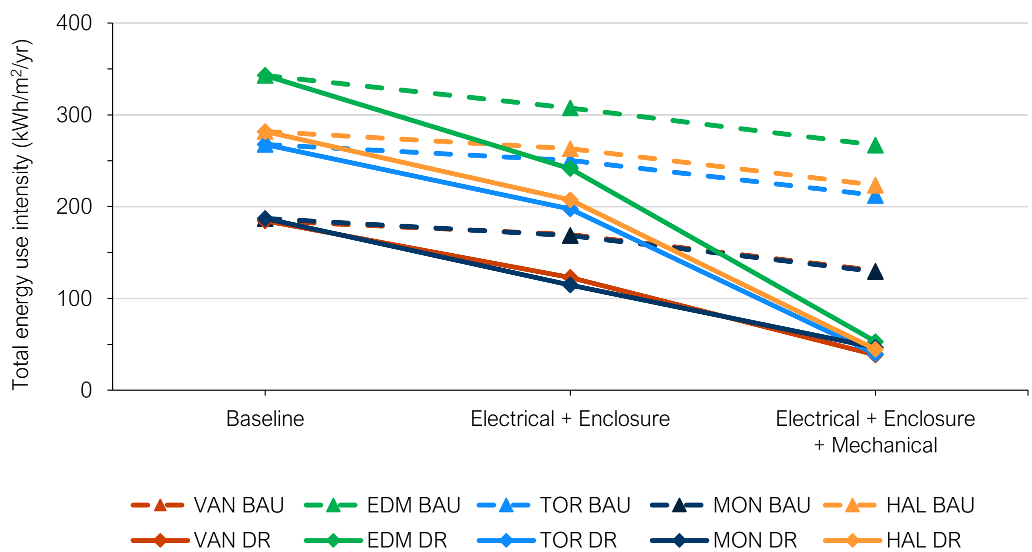


Figure 53. Total energy use intensity (TEUI) for the 1970s low-rise MURB archetype.

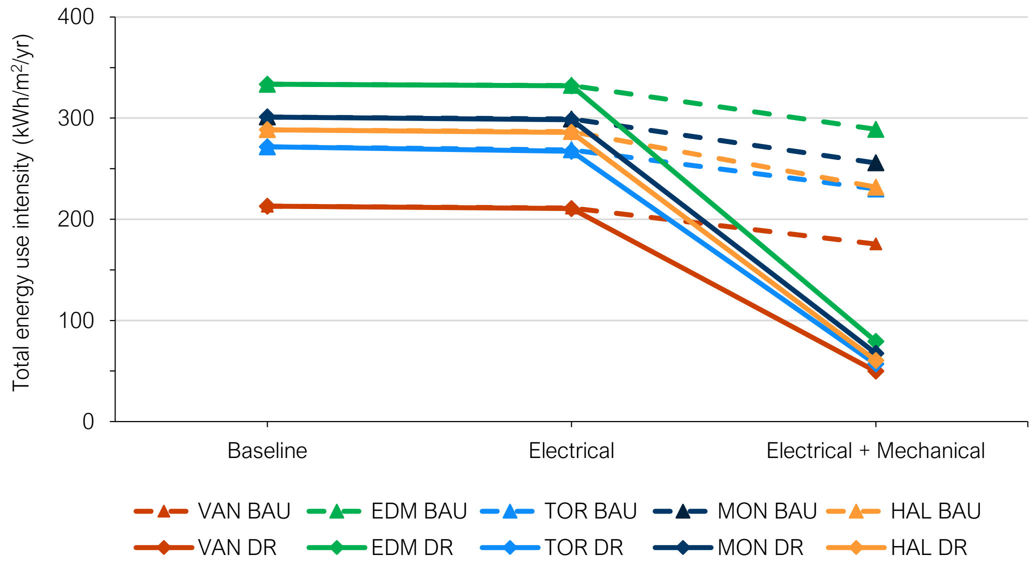


Figure 54. Total energy use intensity (TEUI) for the 1990s low-rise MURB archetype.

Figure 55 to Figure 59 below show the modelled TEUI results by fuel type for each location and the energy savings (per cent) compared to the BAU scenario. The low-rise MURB baseline buildings have lower TEUIs when compared to the office archetypes, and therefore the overall per cent energy savings are lower.

Figure 55 to Figure 59 also show the modelled electricity use intensity results for the addition of mechanical upgrades with and without on-site solar PV.

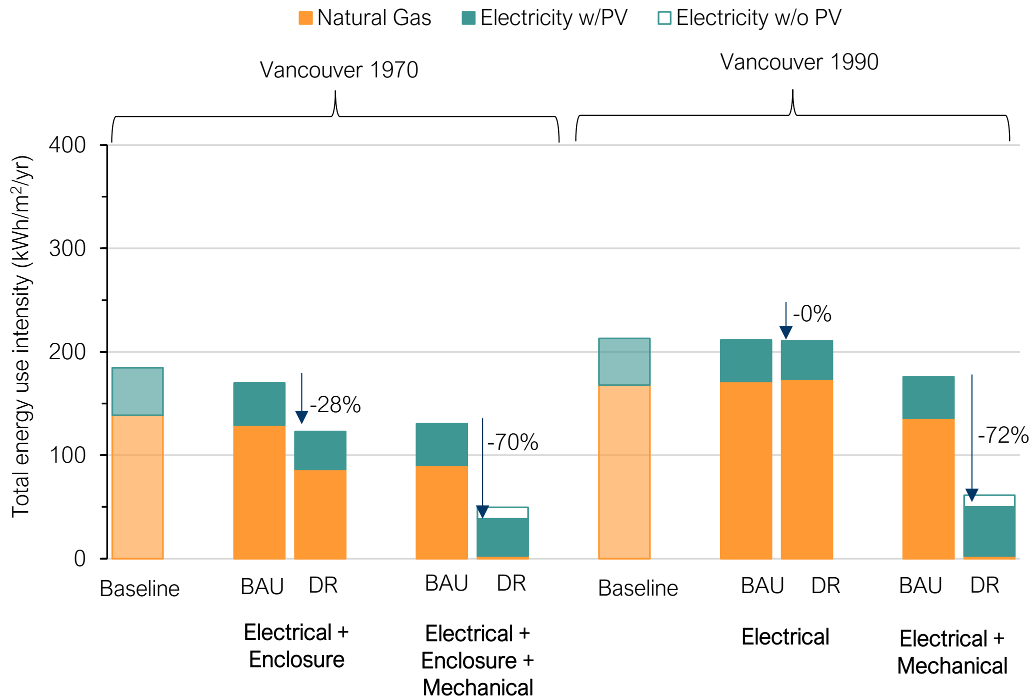


Figure 55. Total energy use intensity presented by fuel type for the 1970s and 1990s Vancouver low-rise MURB.

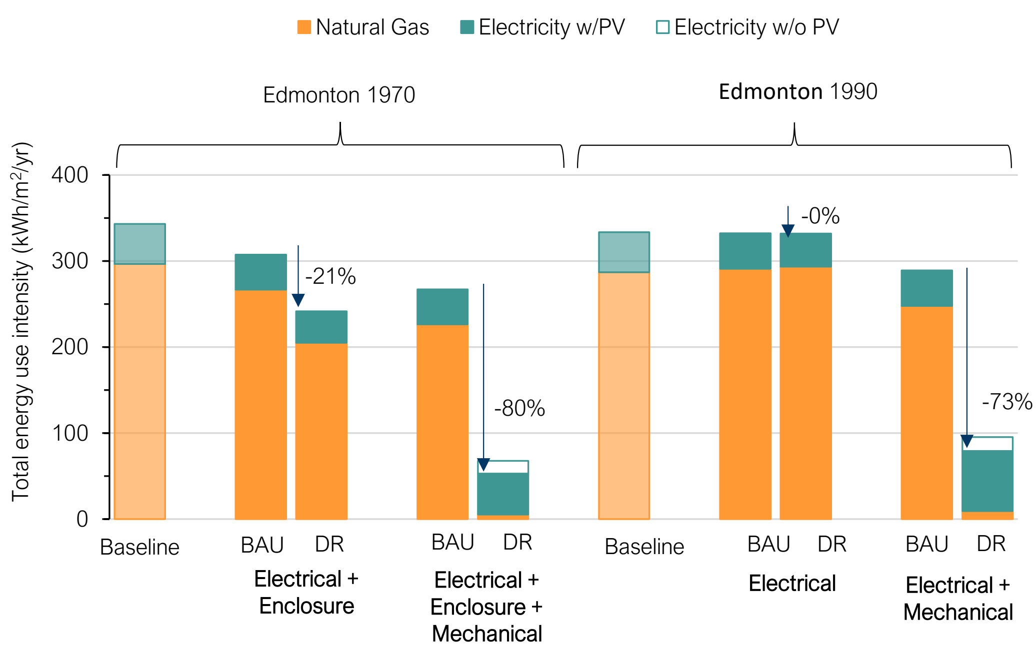


Figure 56. Total energy use intensity presented by fuel type for the 1970s and 1990s Edmonton low-rise MURB.

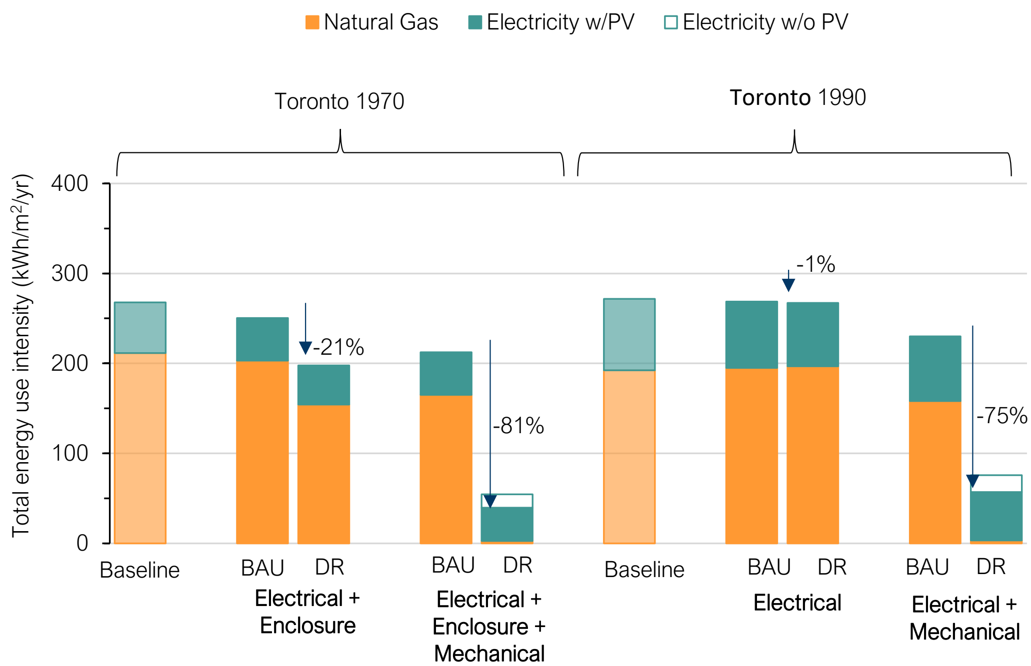


Figure 57. Total energy use intensity presented by fuel type for the 1970s and 1990s Toronto low-rise MURB.

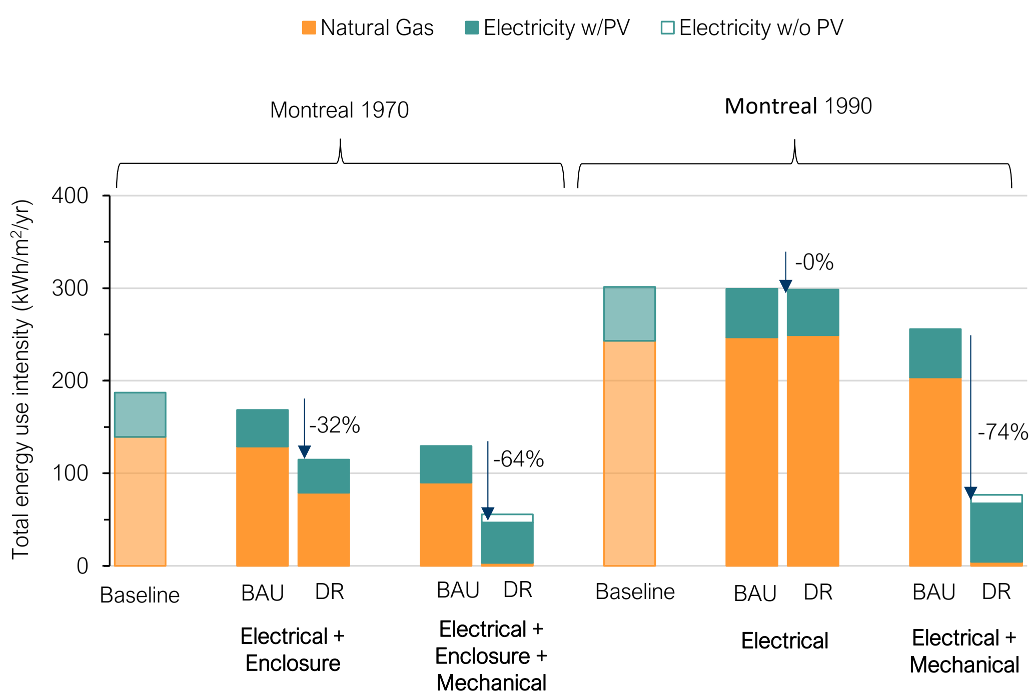


Figure 58. Total energy use intensity presented by fuel type for the 1970s and 1990s Montreal low-rise MURB.

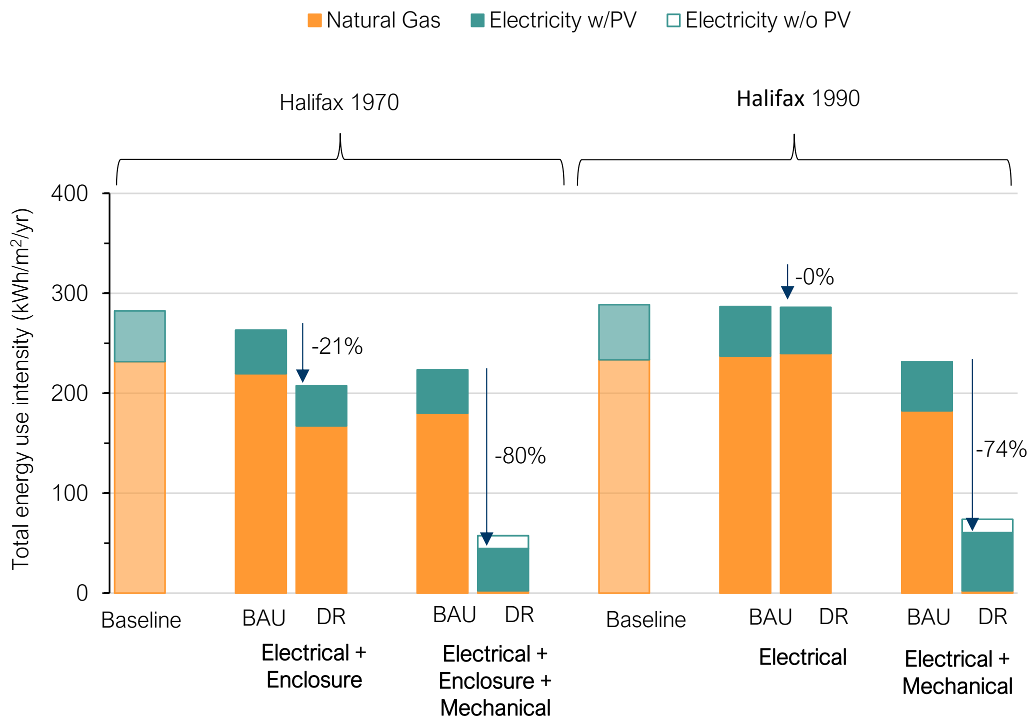


Figure 59. Total energy use intensity presented by fuel type for the 1970s and 1990s Halifax low-rise MURB.

4.1.3.2 – Carbon Emissions

Figure 60 and Figure 61 below show the modelled 1970s and 1990s low-rise MURB archetype, respectively.

Summary of Results

Building Vintage	GHG Reduction	GHGI
1970s	60 - 98%	0 - 28 $kgCO_2eq/m^2/yr$
1990s	39 - 98%	0 - 46 $kgCO_2eq/m^2/yr$

Like the studied office archetypes, the deep retrofit packages for the 1970s and 1990s low-rise MURB archetypes achieve varied GHGI results depending on location, with deep retrofits in Montreal, Toronto, and Vancouver resulting in near net zero operations. It is important to note that Edmonton and Halifax also see sizeable reductions in GHGI relative to BAU - 61% and 60% respectively for the 1970s archetypes, and 39% and 45% for the 1990s archetypes.

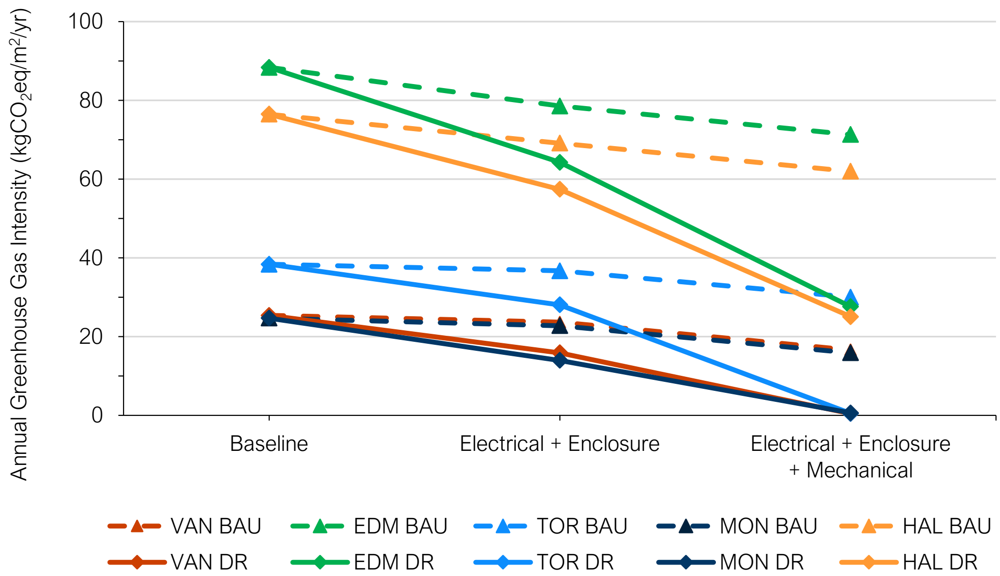


Figure 60. Greenhouse gas intensity (GHGI) for the 1970s low-rise MURB.

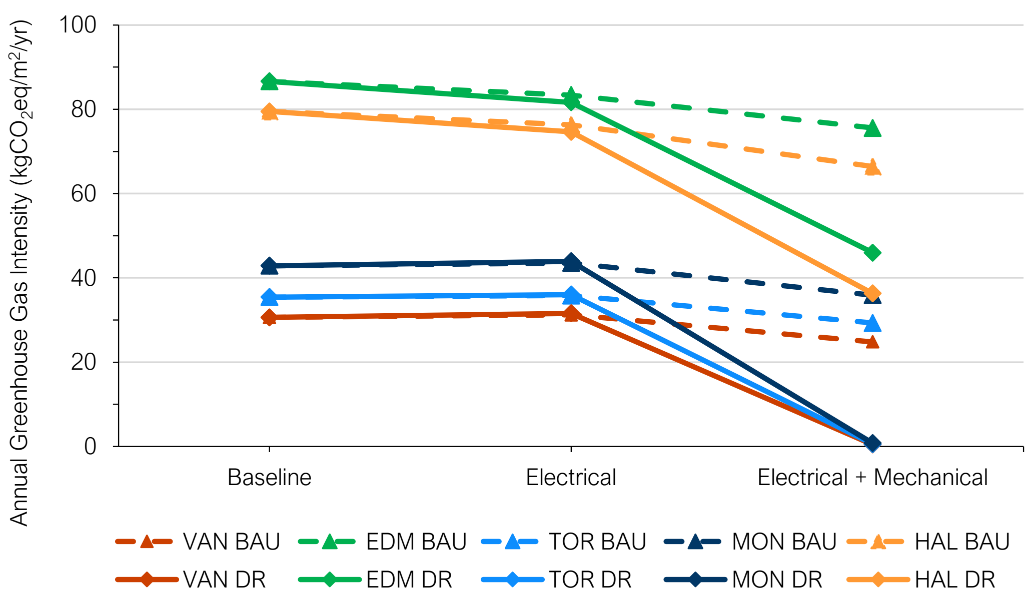


Figure 61. Greenhouse gas intensity (GHGI) for the 1990s low-rise MURB.

Figure 62 to Figure 66 below show the modelled greenhouse gas intensity results by fuel type for each location. The figures also show the greenhouse gas reduction (per cent) compared to the BAU scenario.

Figure 62 to Figure 66 also show the modelled greenhouse gas intensity results following mechanical upgrades, with and without solar PV implementation. It is noted that in higher carbon intensity regions (Edmonton and Halifax), solar PV systems provide substantial GHGI reductions. The GHGIs associated with electricity is negative for the deep retrofit archetypes in Vancouver and Toronto. This is because the avoided emissions due to the on-site solar PV electricity generation is greater than the GHGIs from grid electricity consumption.

The deep retrofit package achieves 73 and 74 per cent energy savings for the Edmonton and Halifax 1990s low-rise MURB archetypes, respectively, however, they result in relatively low greenhouse gas reductions (less than 50 per cent). As those regions transition to cleaner electrical grids, the electrification measures included in the deep retrofit package will achieve greater carbon reductions.

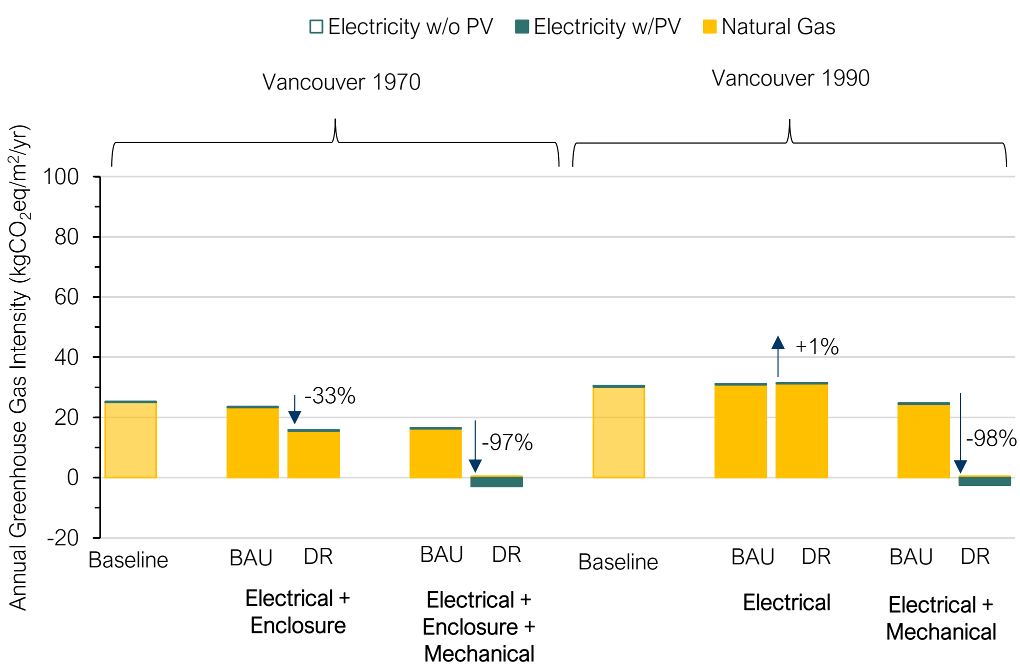


Figure 62. Greenhouse gas intensity by fuel type for the 1970s and 1990s Vancouver low-rise MURB.

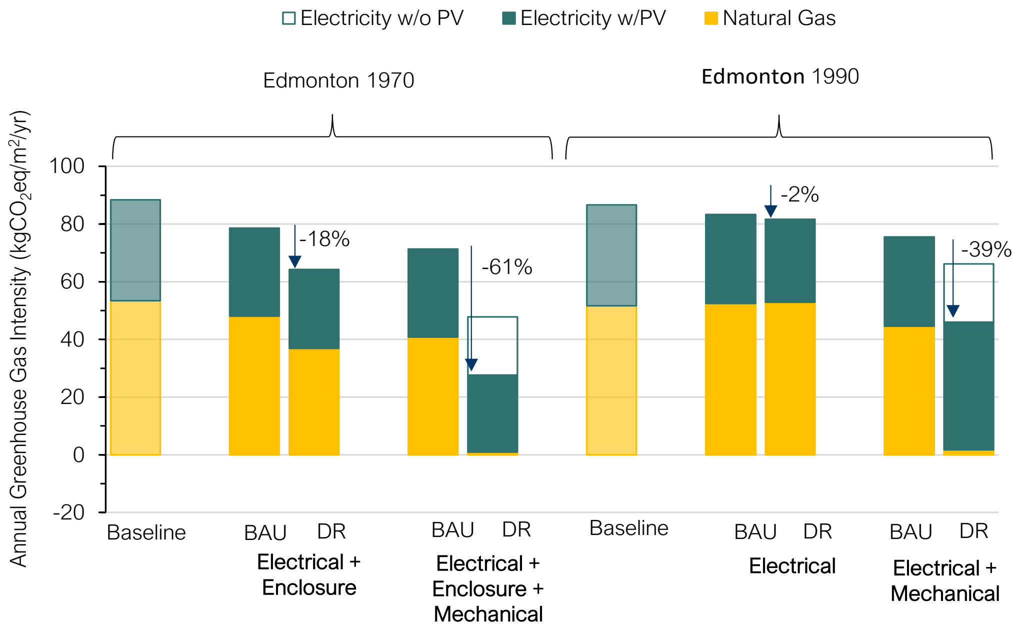


Figure 63. Greenhouse gas intensity by fuel type for the 1970s and 1990s Edmonton low-rise MURB.

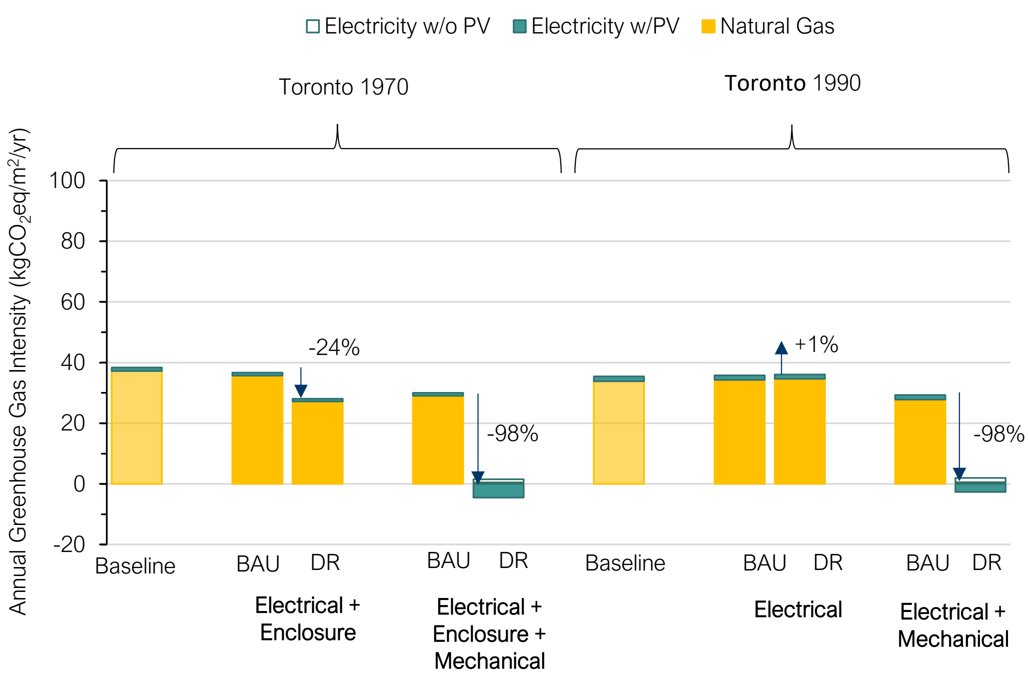


Figure 64. Greenhouse gas intensity by fuel type for the 1970s and 1990s Toronto low-rise MURB.

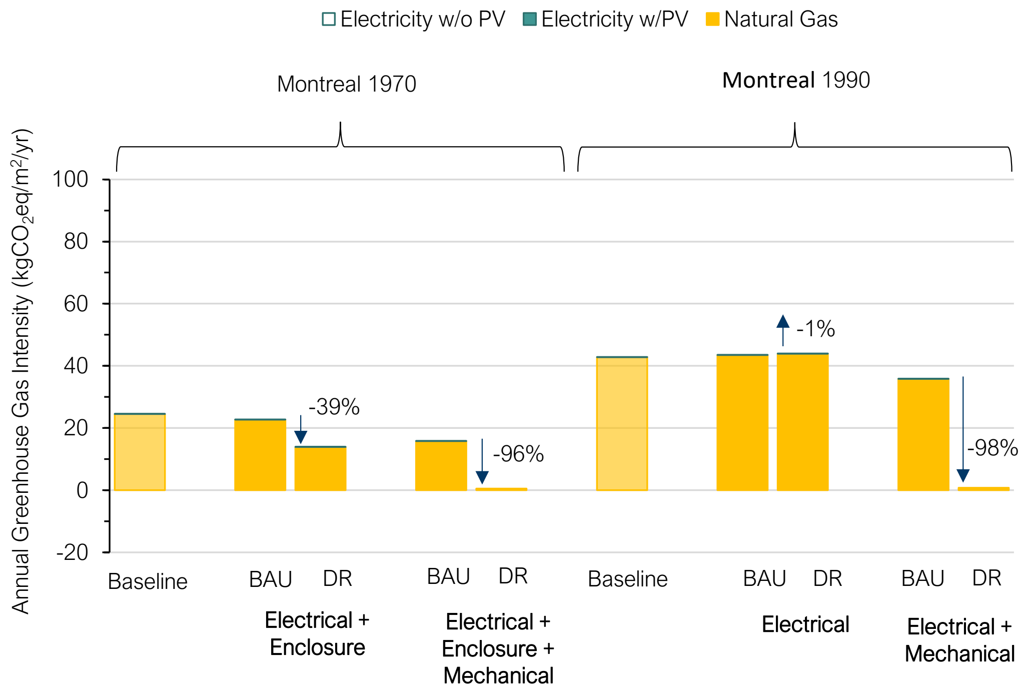


Figure 65. Greenhouse gas intensity by fuel type for the 1970s and 1990s Montreal low-rise MURB.

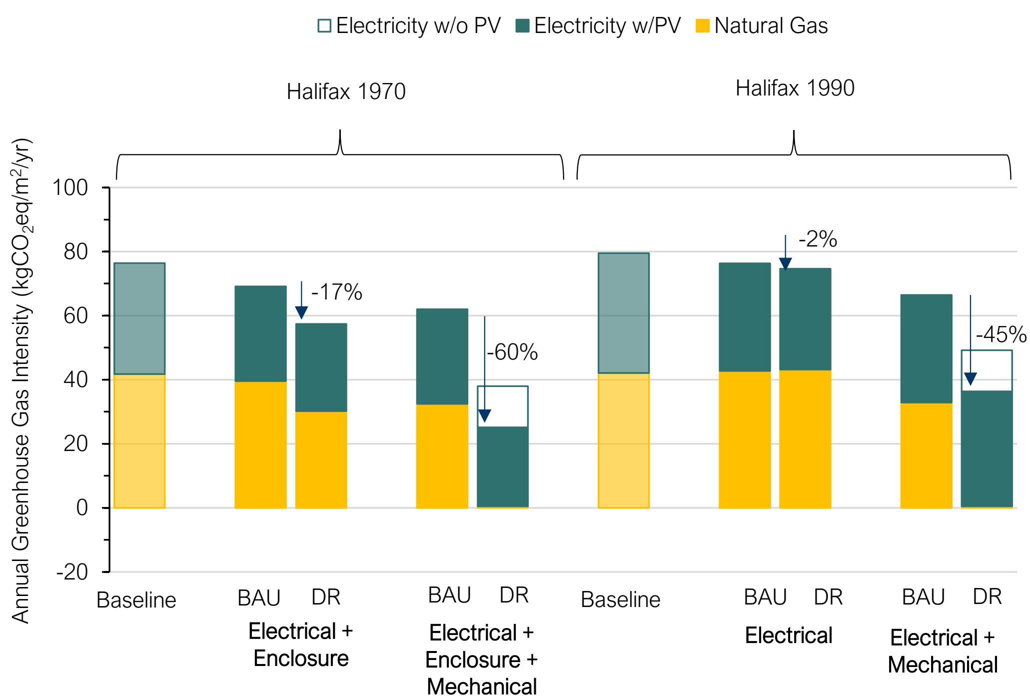


Figure 66. Greenhouse gas intensity by fuel type for the 1970s and 1990s Halifax low-rise MURB.

4.1.3.3 – Electricity Demand

Figure 67 and Figure 68 below show an overview of the modelled peak electricity demand results for the BAU and deep retrofit pathways for the 1970s and 1990s low-rise MURB archetypes, respectively.

Summary of Results

Building Vintage	Peak demand impact
1970s	+148 to 474%
1990s	+121 to 724%

The baseline annual peak demand for the low-rise MURB occurs during the summer months for the locations with cooling; for the remaining locations there is a slightly higher peak demand in the winter due to increased fan power (for space heating).

The electrification of space heating and service hot water resulted in an increase in the peak demand for all archetypes, with the annual peak demand occurring during the winter.

Compared to the office archetypes, the baseline annual electricity peak demand is lower for the MURBs (mainly due to lower cooling loads) and therefore the electrification of space heating has a larger impact overall on the peak demand.

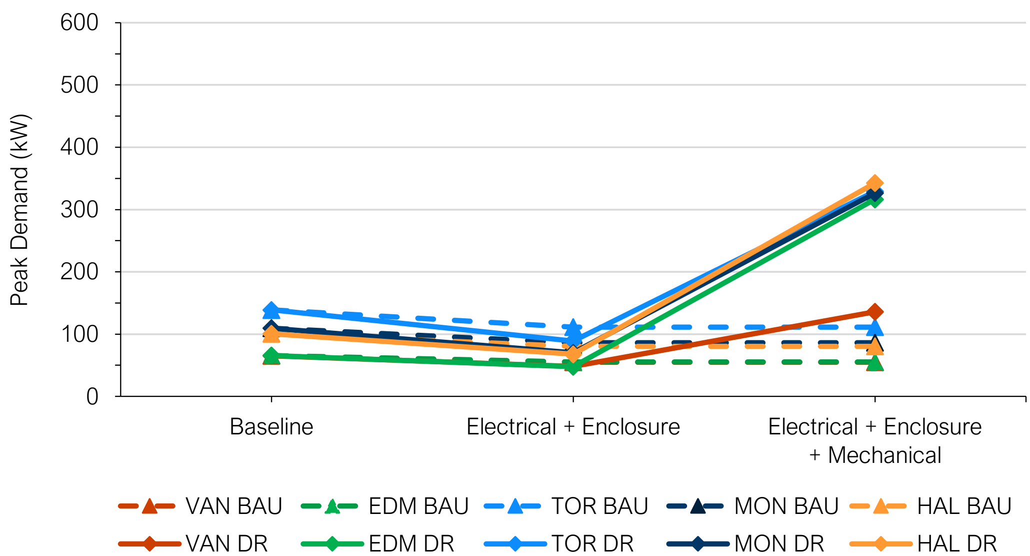


Figure 67. Peak electricity demand for the 1970s low-rise MURB.

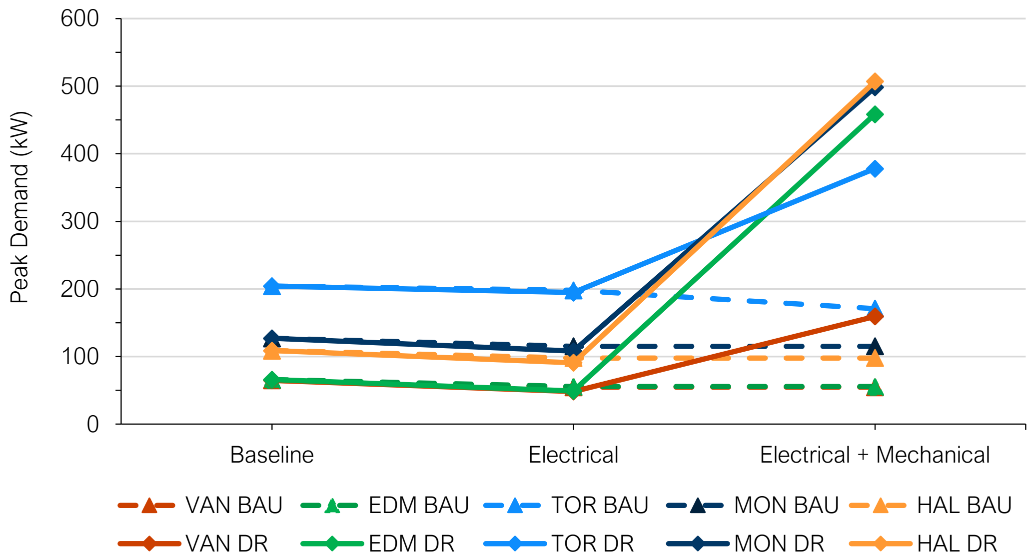


Figure 68. Peak electricity demand for the 1990s low-rise MURB.

4.1.4 – Mid-rise MURB

This section summarizes the energy and greenhouse gas results for the mid-rise MURB archetype. The mid-rise multifamily-residential archetype is a 13-storey non-combustible building, approximately 13,000 m² (140,000 ft²) in size with a 1-level underground parkade.

4.1.4.1 – Energy

Figure 69 and Figure 70 below show the modelled TEUI results for the BAU and deep retrofit scenarios for the 1970s and 1990s mid-rise MURB archetype, respectively.

Summary of Results

Building Vintage	Energy Reduction	TEUI
1970s	77 - 83%	40 - 63 kWh/m^2/yr
1990s	66 - 75%	63 - 93 kWh/m^2/yr

There is a slight decrease in TEUI for the 1990s archetype (for all locations), compared to the 1970s baseline building archetype. This is because the 1990s archetype have a higher window-to-wall ratio. The results suggest that the energy efficiency of typical mid-rise MURBs worsened between the two age categories. The highest energy reduction is seen for the 1970s and 1990s Halifax and Edmonton archetypes.

The TEUI results are in line with the requirements for the upper steps/tiers of the BC Energy Step Code (ESC) and Toronto Green Standard, which guide new construction. Deep retrofits at all mid-rise MURB archetypes result in lower TEUI than required for the highest step (Step 4) of the BC ESC, which is 100 kWh/m^2/yr.

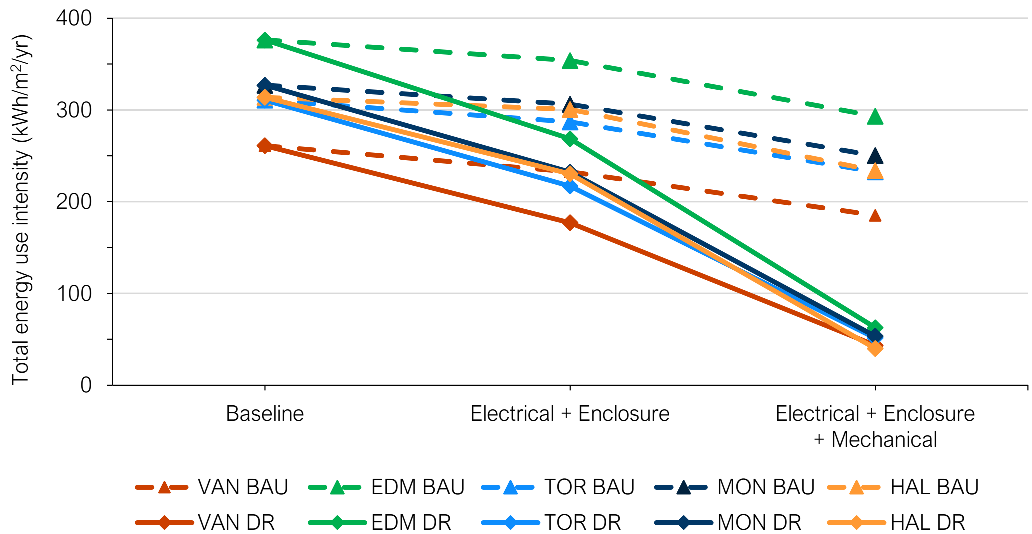


Figure 69. Total energy use intensity (TEUI) for the 1970s mid-rise MURB archetype.

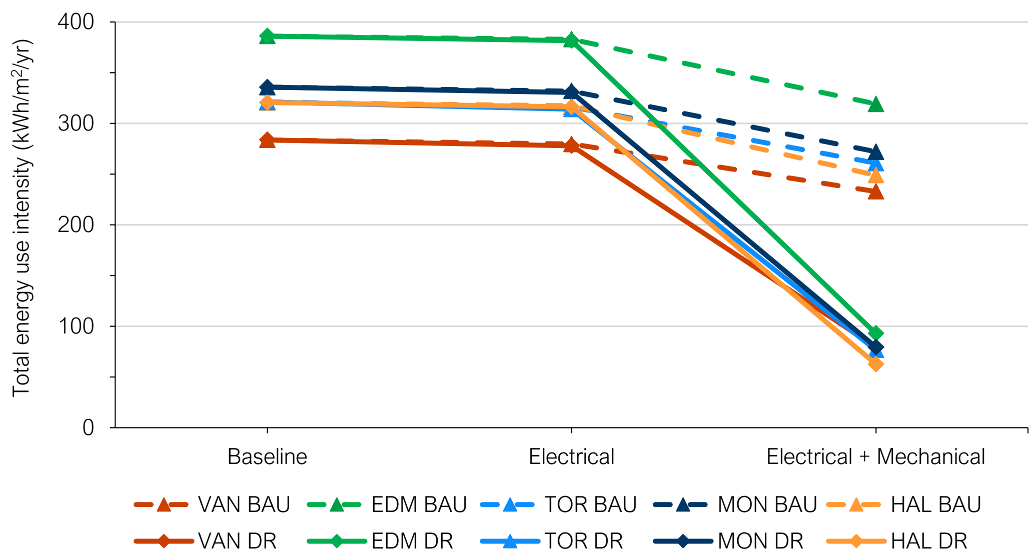


Figure 70. Total energy use intensity (TEUI) for the 1990s mid-rise MURB archetype.

Figure 71 to Figure 75 below show the modelled TEUI results by fuel type for each location and the energy savings (per cent) compared to the BAU scenario, as well as the modelled electricity use intensity results of the deep retrofit package with and without on-site solar PV. For both the 1970s and 1990s mid-rise MURB archetypes, the energy use reduction results from adding solar PV are relatively minor.

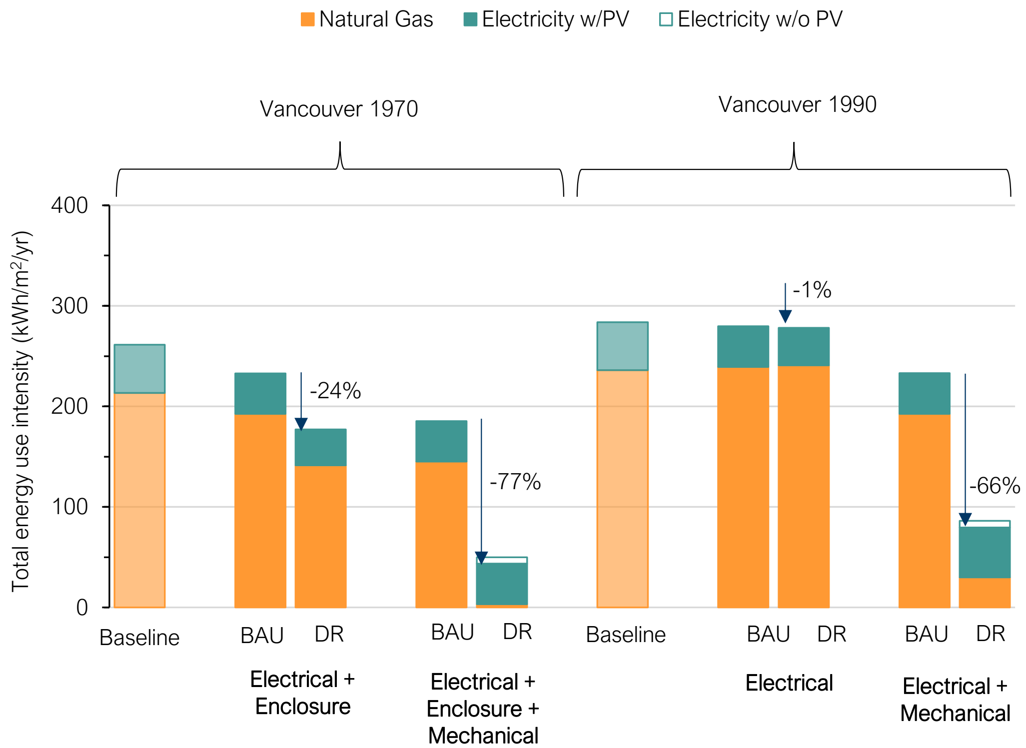


Figure 71. Total energy use intensity presented by fuel type for the 1970s and 1990s Vancouver mid-rise MURB.

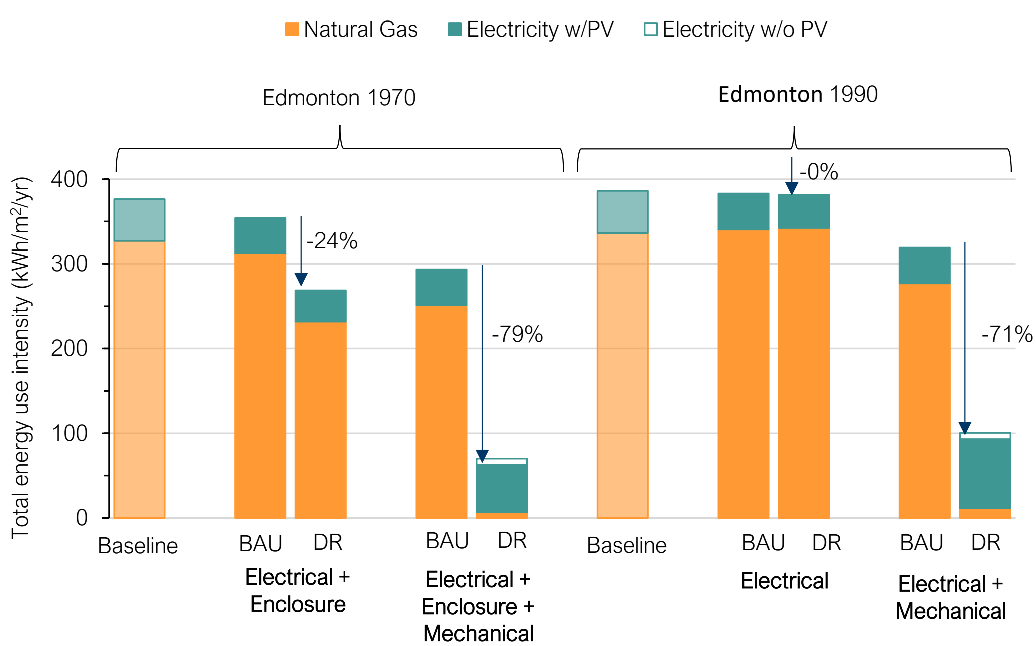


Figure 72. Total energy use intensity presented by fuel type for the 1970s and 1990s Edmonton mid-rise MURB.

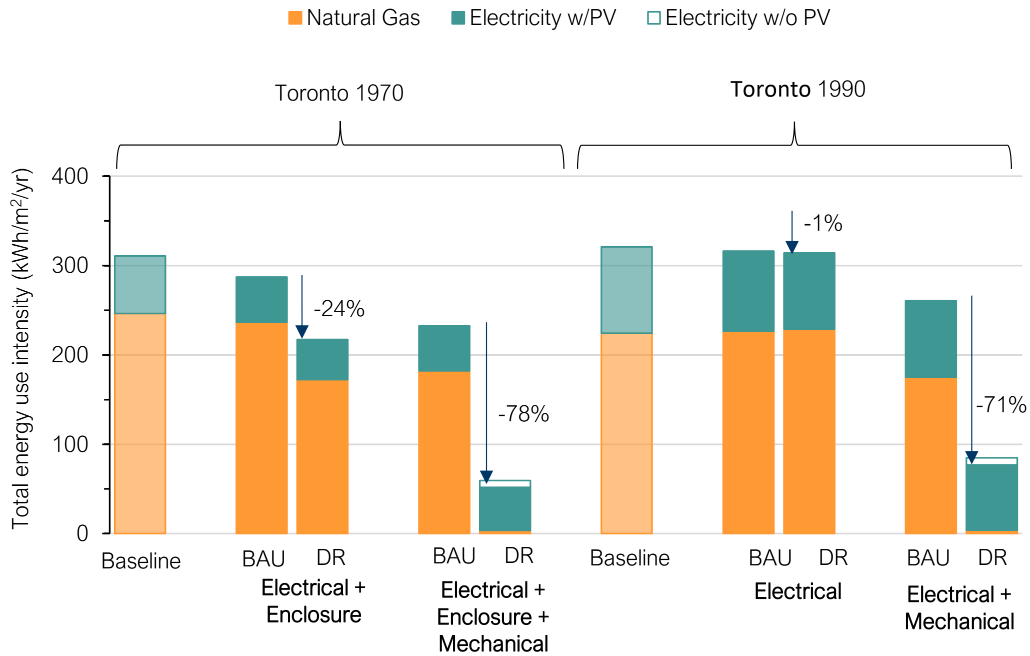


Figure 73. Total energy use intensity presented by fuel type for the 1970s and 1990s Toronto mid-rise MURB.

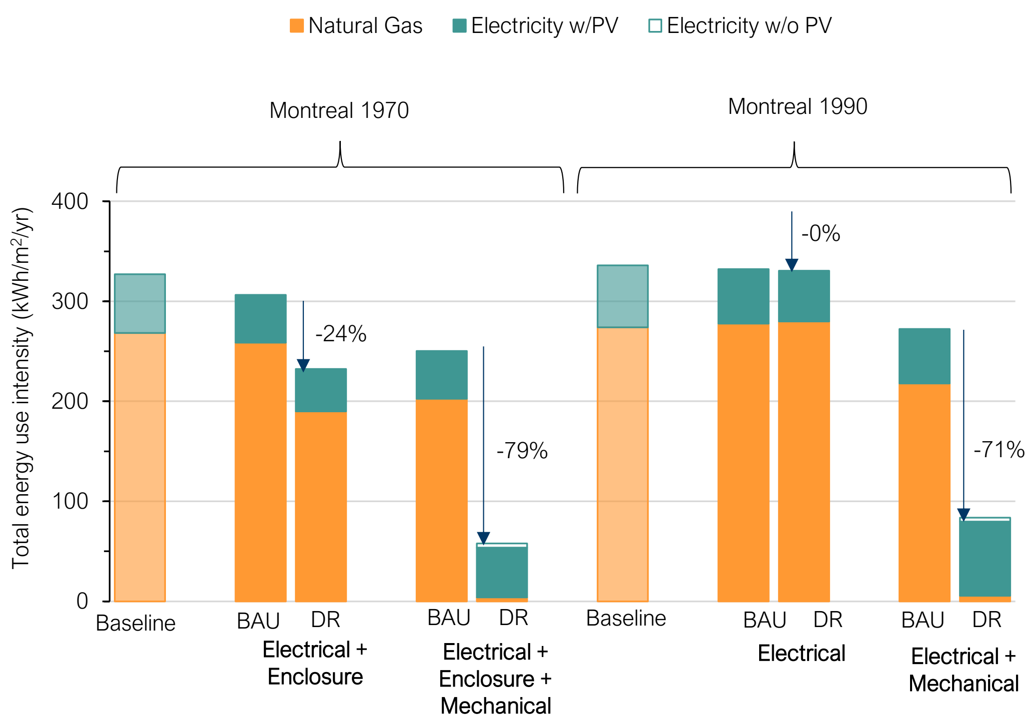


Figure 74. Total energy use intensity presented by fuel type for the 1970s and 1990s Montreal mid-rise MURB.

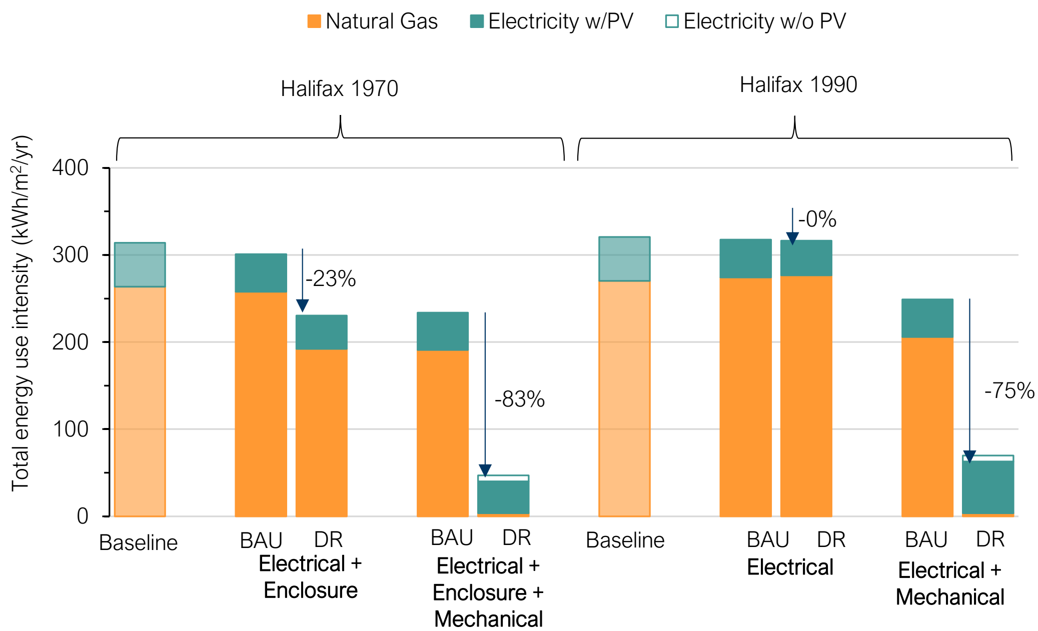


Figure 75. Total energy use intensity presented by fuel type for the 1970s and 1990s Halifax mid-rise MURB.

4.1.4.2 – Carbon Emissions

Figure 76 and Figure 77 below show an overview of GHGI for the 1970s and 1990s mid-rise MURB archetypes, respectively.

Summary of Results

Building Vintage	GHG Reduction	GHGI
1970s	44 - 98%	1 - 43 kgCO$_2$eq/m^2/yr
1990s	23 - 97%	1 - 63 kgCO$_2$eq/m^2/yr

The greatest GHGI reduction is seen for the 1970s and 1990s Montreal archetypes. The deep retrofit package almost completely eliminates natural gas use (except the gas needed for back-up boilers) for the Montreal archetypes. Due to the low carbon intensity of the electrical grid, greenhouse gas emissions are reduced 97-98 per cent.

Although the 1970s and 1990s Edmonton and Halifax archetypes achieve the highest energy use intensity reductions, they show the lowest GHGI reductions due to the higher electricity carbon intensities.

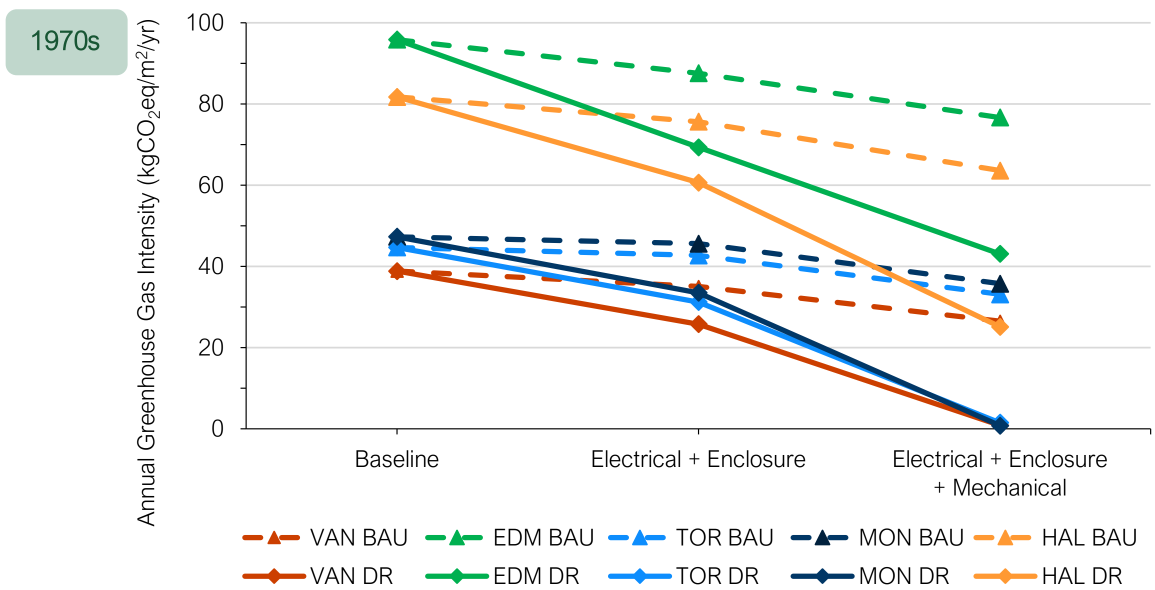


Figure 76. Greenhouse gas intensity (GHGI) for the 1970s mid-rise MURB.

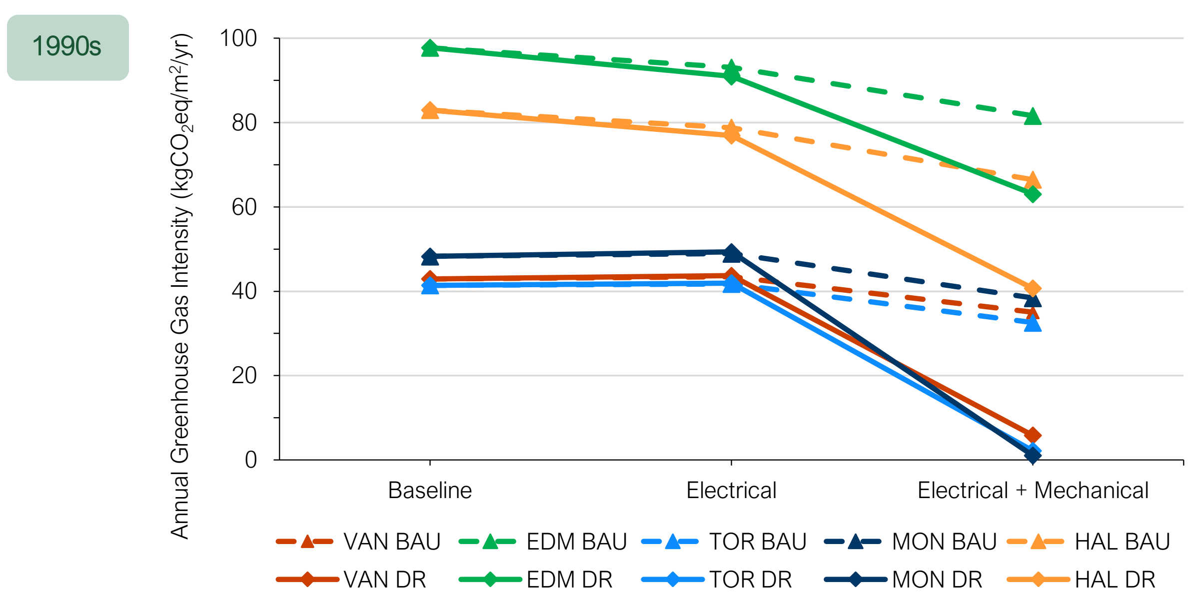


Figure 77. Greenhouse gas intensity (GHGI) for the 1990s mid-rise MURB.

Figure 78 to Figure 82 below show the modelled GHGI results by fuel type for each location. The figures also show the greenhouse gas reduction (per cent) compared to the BAU scenario.

Figure 78 to Figure 82 also show the modelled greenhouse gas intensity results associated with and without solar PV implementation in the second phase of the deep retrofit package. The benefit of implementing solar PV is greater in the locations with high carbon intensity electricity grids (Edmonton and Halifax), however the on-site solar PV electricity generation is relatively small compared to the total electricity consumption. Therefore, the implementation of solar PV has a relatively small impact on the GHGI results for all mid-rise MURB archetypes.

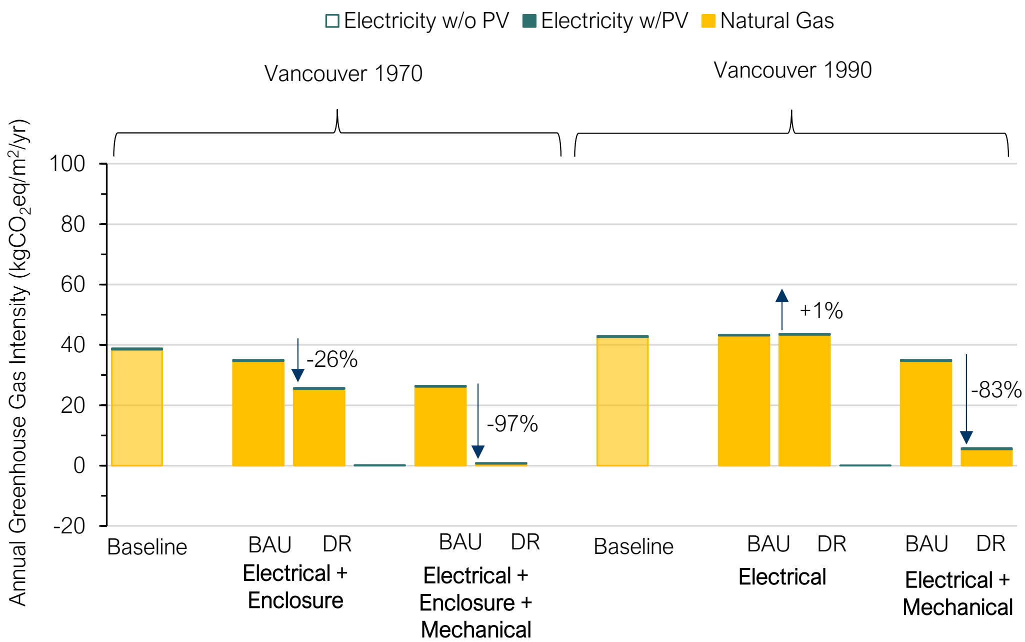


Figure 78. Greenhouse gas intensity by fuel type for the 1970s and 1990s Vancouver mid-rise MURB.

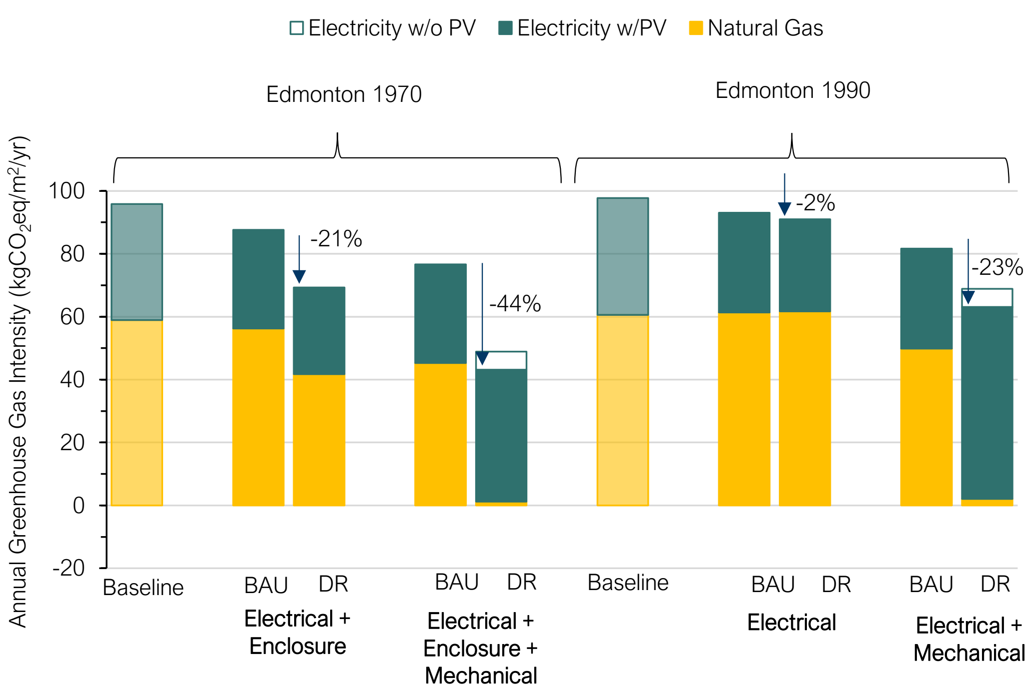


Figure 79. Greenhouse gas intensity by fuel type for the 1970s and 1990s Edmonton mid-rise MURB.

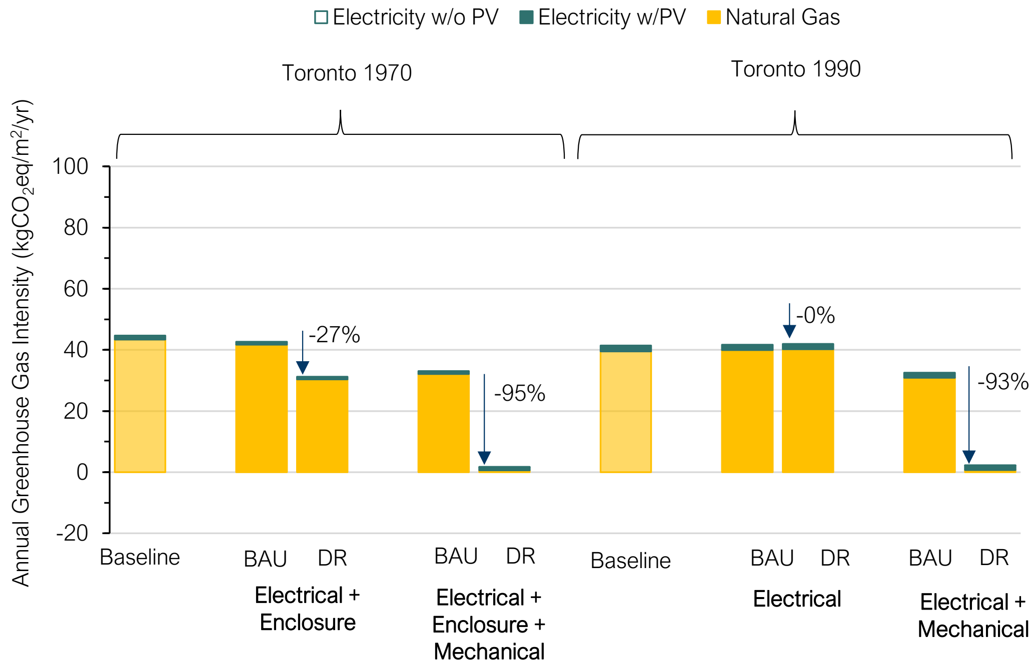


Figure 80. Greenhouse gas intensity by fuel type for the 1970s and 1990s Toronto mid-rise MURB.

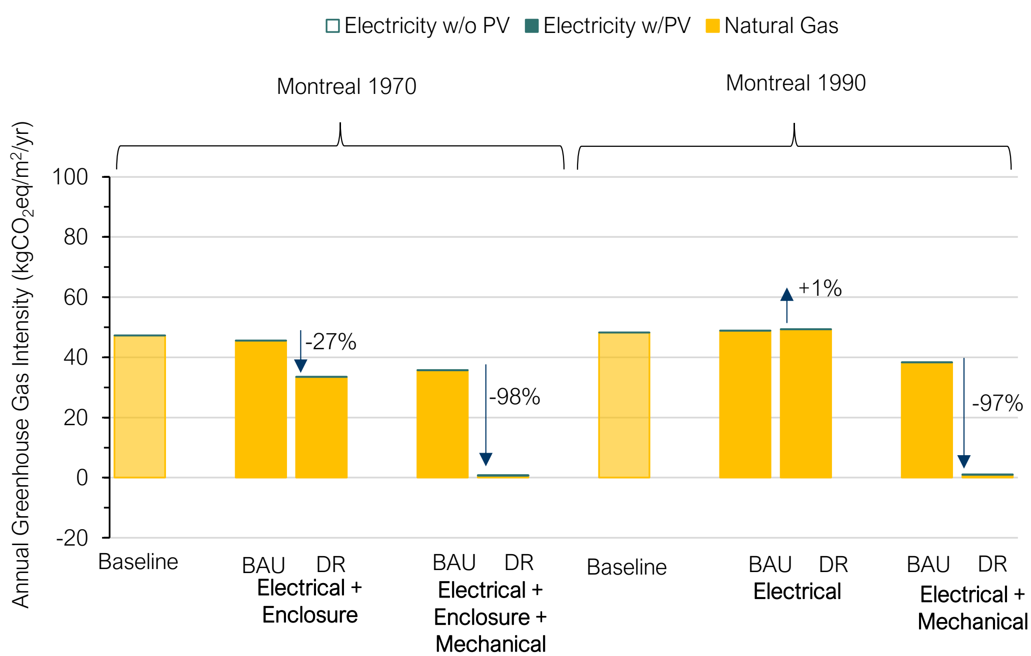


Figure 81. Greenhouse gas intensity by fuel type for the 1970s and 1990s Montreal mid-rise MURB.

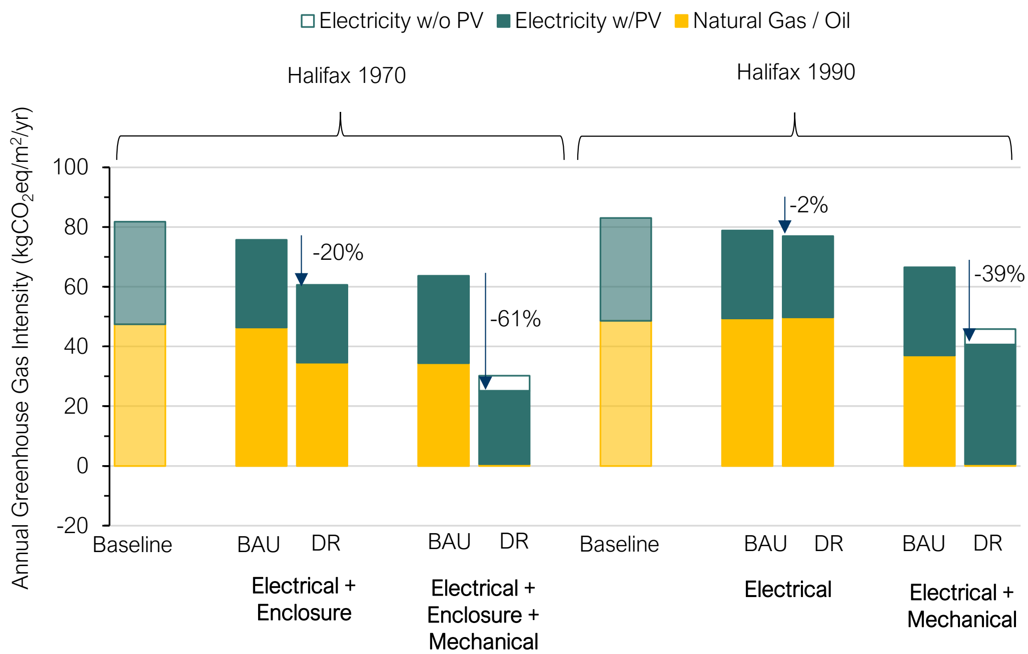


Figure 82. Greenhouse gas intensity by fuel type for the 1970s and 1990s Halifax mid-rise MURB.

4.1.4.3 – Electricity Demand

Figure 83 and Figure 84 below show the modelled peak electricity demand results for the 1970s and 1990s mid-rise MURB archetypes, respectively.

Like the low-rise MURB, the electrification of space heating and service hot water results in an increase in annual peak electricity demand for all archetypes, with the peak occurring during the winter.

Summary of Results

Building Vintage	Peak demand impact
1970s	+136 to 475%
1990s	+ 151 to 924%

1970s

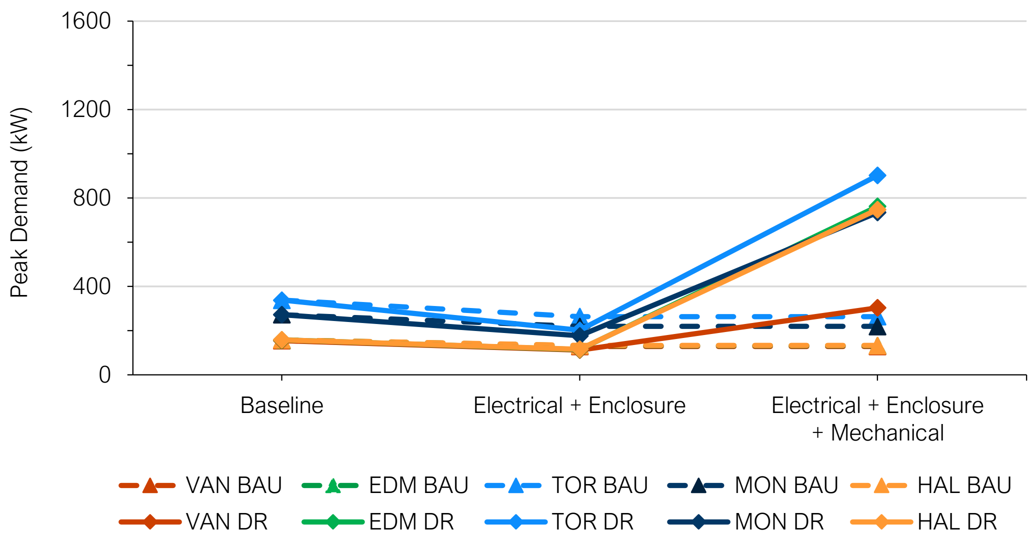


Figure 83. Peak electricity demand for the 1970s mid-rise MURB.

1990s

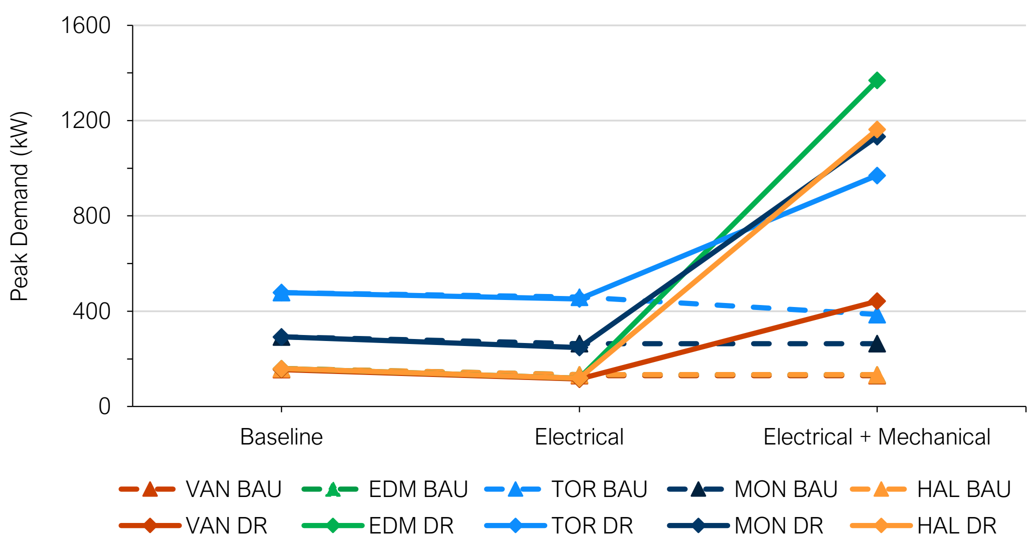


Figure 84. Peak electricity demand for the 1990s mid-rise MURB.

4.1.5 – Primary School

This section summarizes the energy and greenhouse gas results for the primary school baseline building archetype. The primary school archetype is a 1-storey building approximately 6,900 m² (74,000 ft²) in size.

4.1.5.1 – Energy

Figure 85 and Figure 86 below show the modelled TEUI results for the BAU and deep retrofit scenarios for the 1970s and 1990s primary school archetypes, respectively.

Similar reductions in TEUI were shown in all locations and vintages, with overall energy use reductions ranging from 64 to 91 percent.

Summary of Results

Building Vintage	Energy Reduction	TEUI
1970s	77 - 91%	38 - 91 kWh/m^2/yr
1990s	64 - 86%	60 - 156 kWh/m^2/yr

1970s

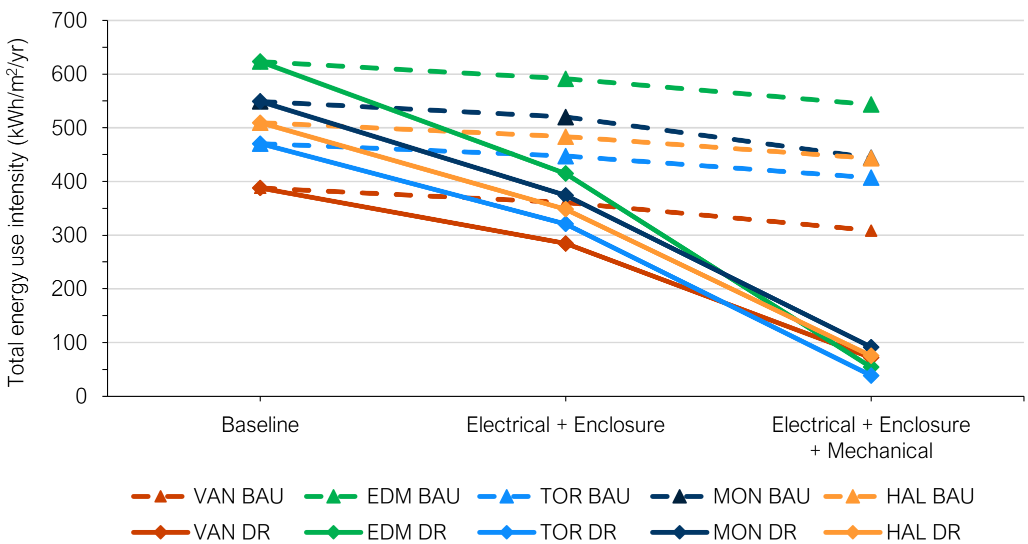


Figure 85. Total energy use intensity (TEUI) for the 1970s primary school archetype.

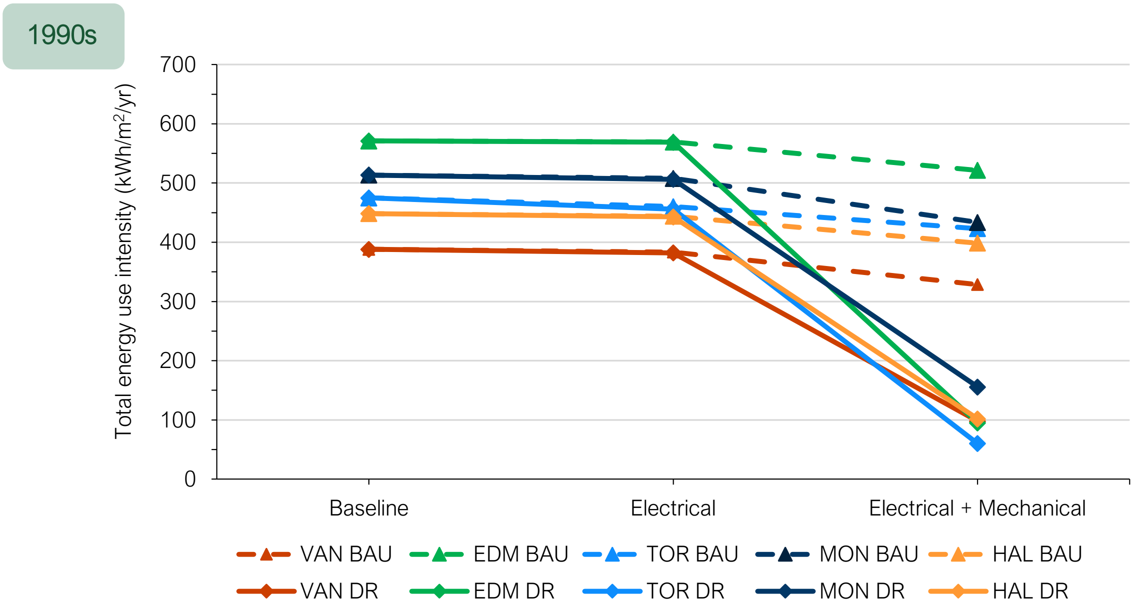


Figure 86. Total energy use intensity (TEUI) for the 1990s primary school archetype.

Figure 87 to Figure 91 below show the modelled TEUI results by fuel type, and the energy savings (per cent) compared to the BAU scenario.

Figure 87 to Figure 91 also show the modelled electricity use intensity results for the mechanical upgrades with and without on-site solar PV. The electricity generation from the solar PV is greatest for Edmonton and Toronto, offsetting 50% of their deep retrofit consumption. In all other locations, the system size is restricted by the utility net metering size limitations, and as a result energy use reductions from solar PV are minor.

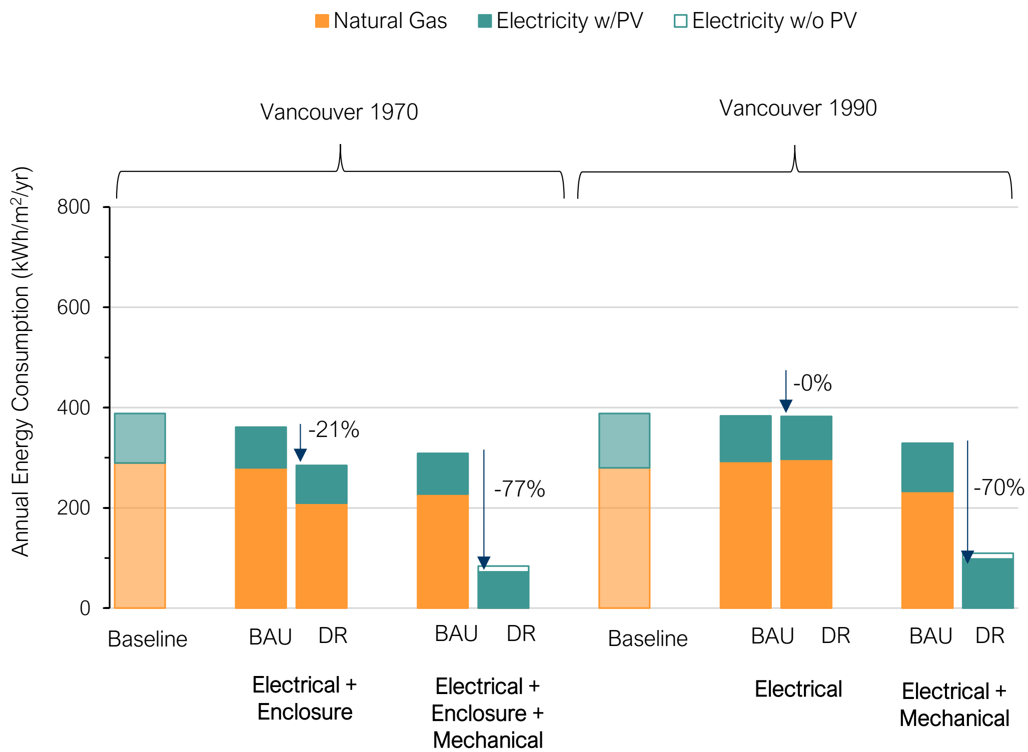


Figure 87. Total energy use intensity presented by fuel type for the 1970s and 1990s Vancouver primary school archetype.

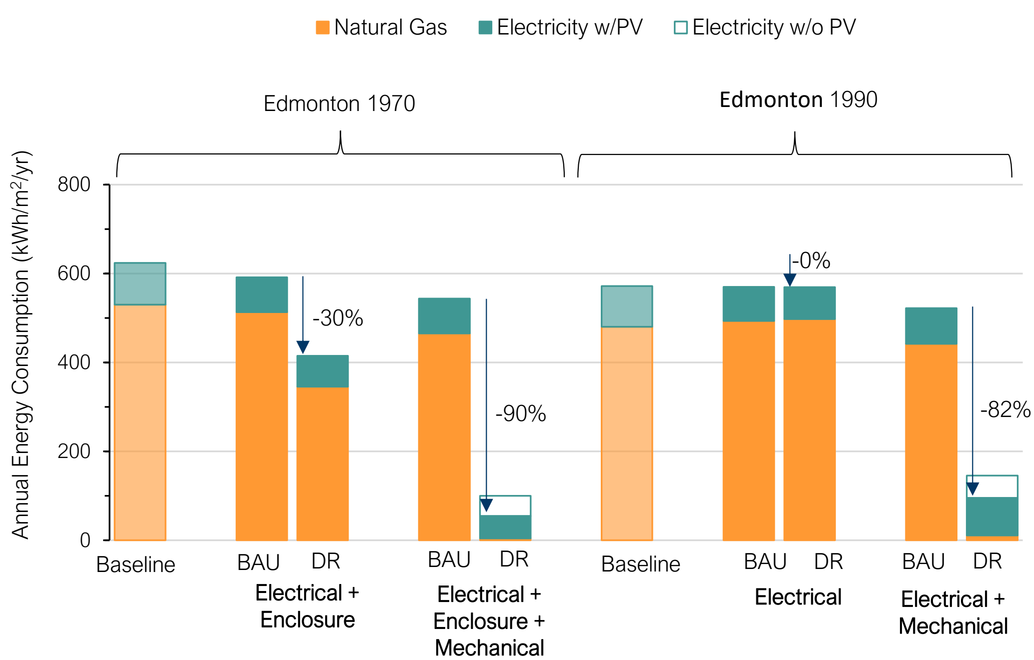


Figure 88. Total energy use intensity presented by fuel type for the 1970s and 1990s Edmonton primary school archetype.

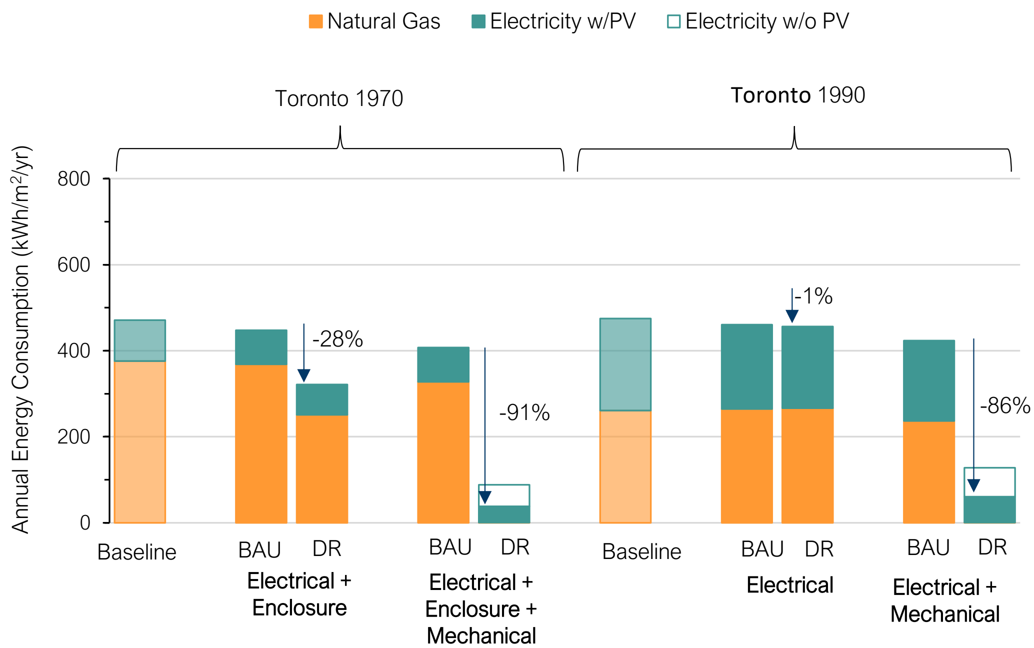


Figure 89. Total energy use intensity presented by fuel type for the 1970s and 1990s Toronto primary school archetype.

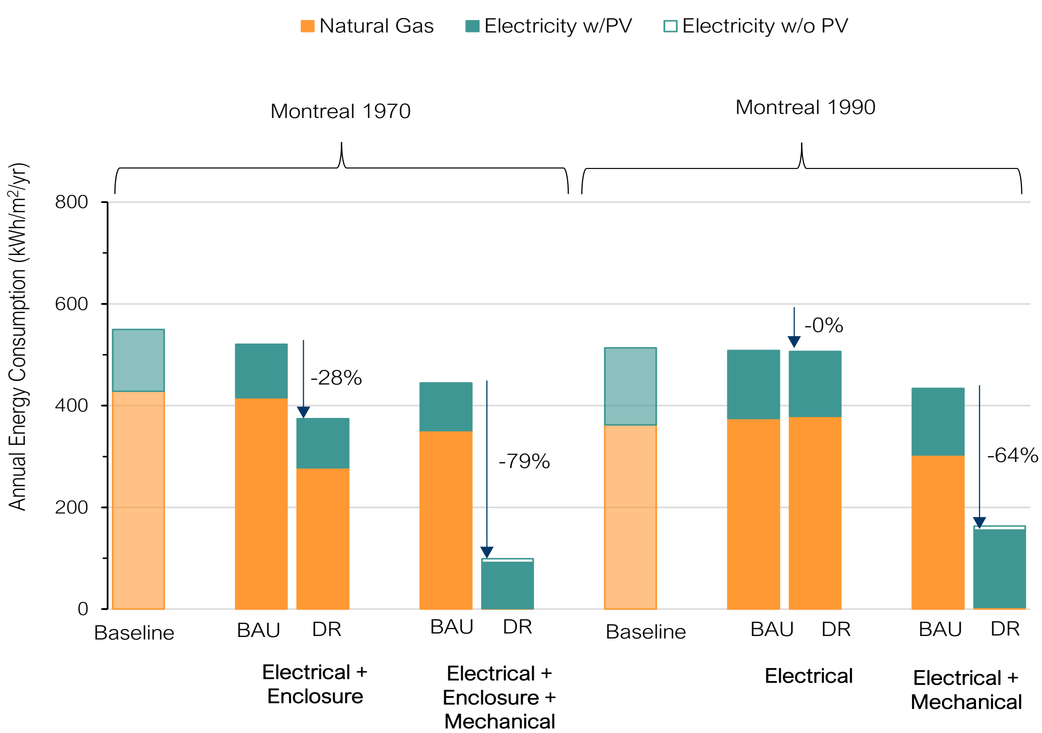


Figure 90. Total energy use intensity presented by fuel type for the 1970s and 1990s Montreal primary school archetype.

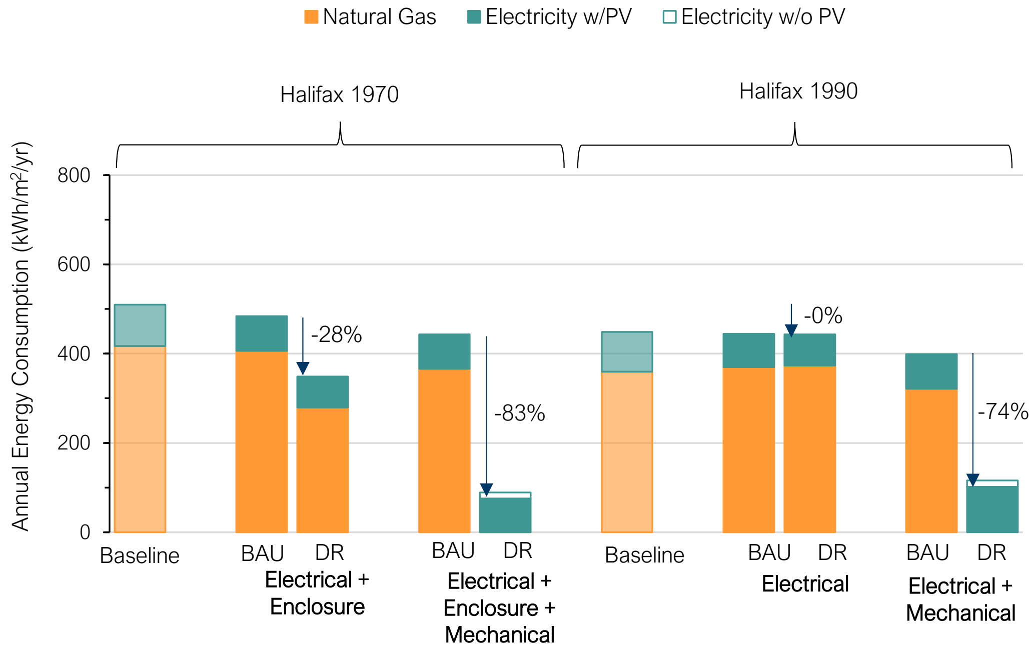


Figure 91. Total energy use intensity presented by fuel type for the 1970s and 1990s Halifax primary school archetype.

4.1.5.2 – Carbon Emissions

Figure 92 and Figure 93 below show the modelled GHGI results for the 1970s and 1990s primary school archetype, respectively.

Summary of Results

Building Vintage	GHG Reduction	GHGI
1970s	59 - 100%	0 - 49 $kgCO_2eq/m^2/yr$
1990s	39 - 100%	0 - 67 $kgCO_2eq/m^2/yr$

Figure 94 to Figure 98 below show the modelled GHGI results by fuel type. The figures also show the greenhouse gas reduction (per cent) compared to the BAU scenario. Finally, these figures also show the modelled GHGI results with and without solar PV .

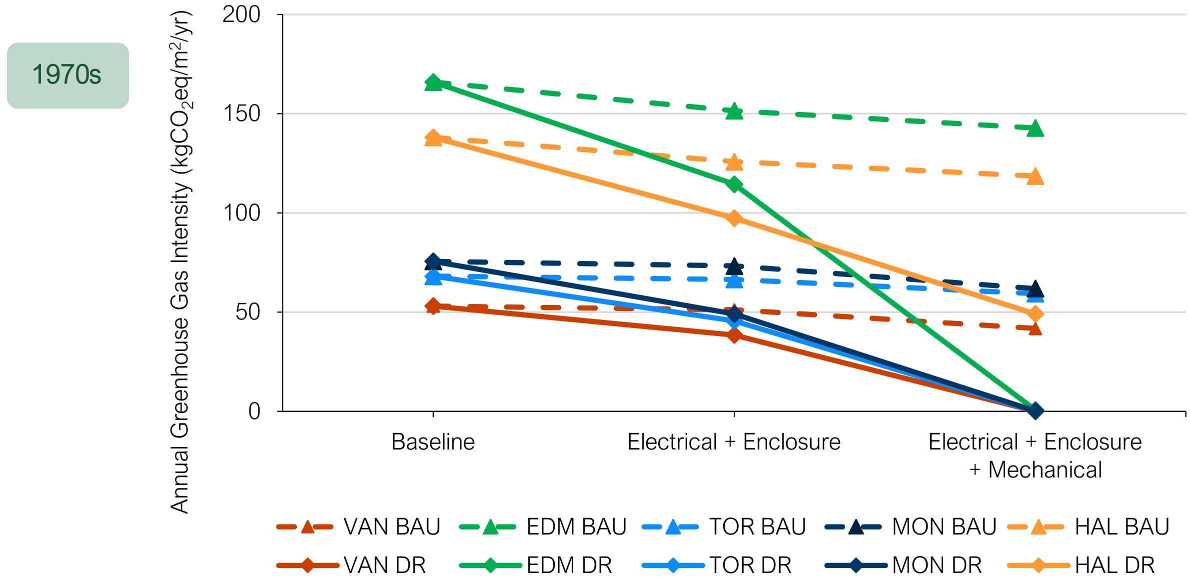


Figure 92. Greenhouse gas intensity (GHGI) for the 1970s primary school archetype.

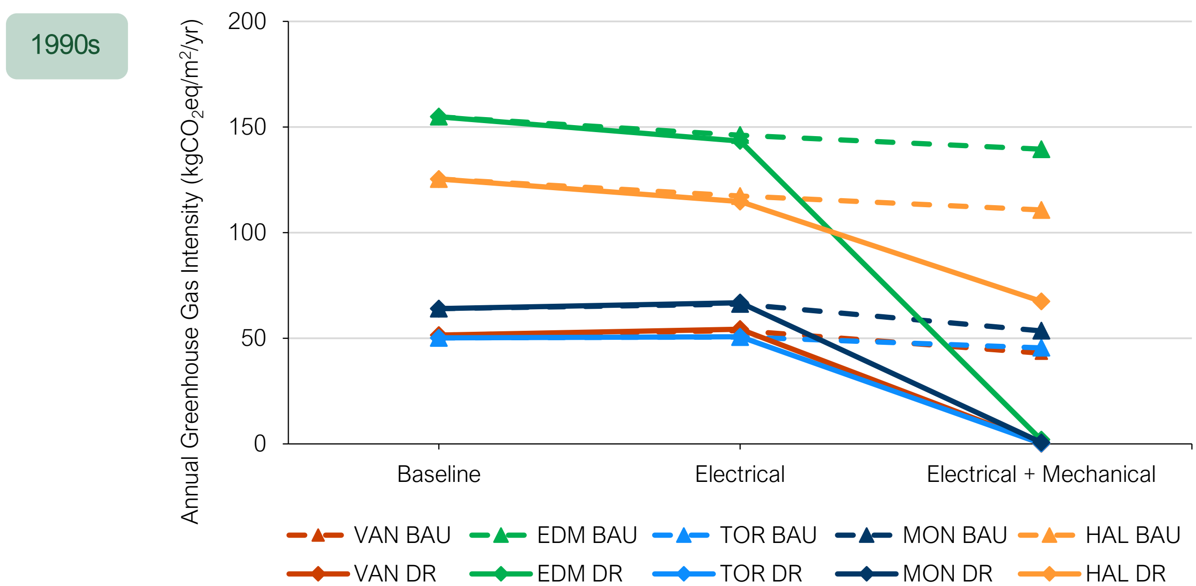


Figure 93. Greenhouse gas intensity (GHGI) for the 1990s primary school archetype.

Unlike the MURB or office archetypes in Edmonton, the deep retrofit package for the Edmonton primary school achieves similar GHGIs as the locations with less carbon intensive electricity grids. This is the result of the solar PV.

The primary school archetype is a 1-storey building that can hold a large capacity of solar PV panels relative to its total floor area. In addition, unlike Vancouver, Montreal or Halifax, local net metering rules do not limit the design capacity of on-site solar PV electricity generation, thus the Edmonton solar PV system is sized based on available roof area. The large solar PV system produces a large amount of electricity that can be exported off-site, and the avoided emissions from exporting this energy are higher than the emissions associated with grid electricity use. Toronto also has a negative GHGI because of exported electricity generated from solar PV.

The analysis of the primary school shows that solar PV is most effective at reducing GHGI for buildings with large roof areas in locations with carbon intensive electricity grids and without utility net metering size limitations for on-site solar PV.

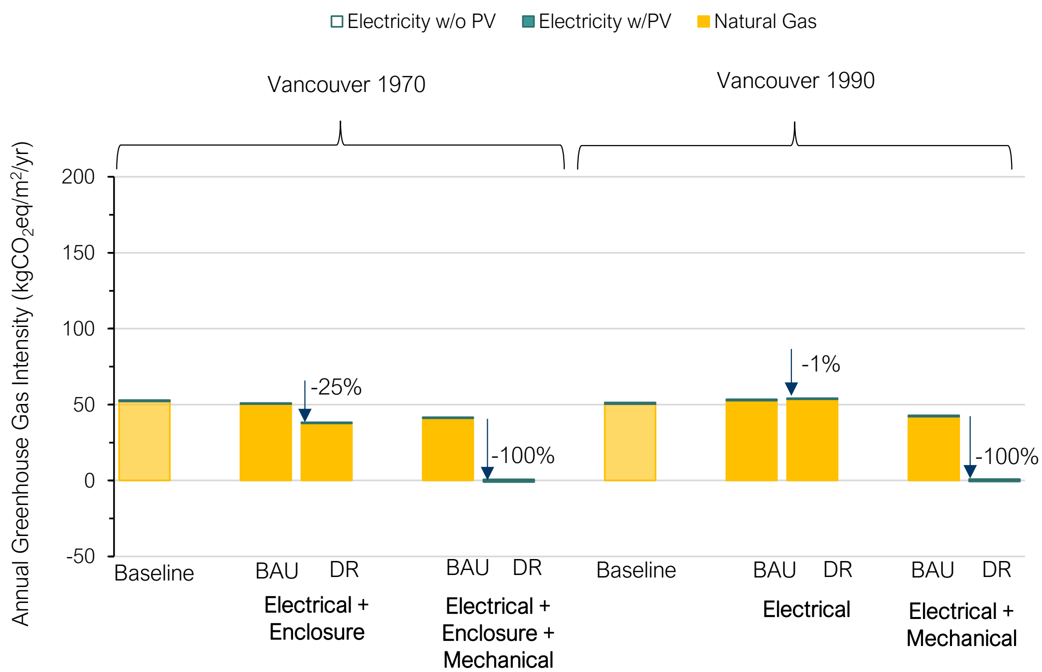


Figure 94. Greenhouse gas intensity by fuel type for the 1970s and 1990s Vancouver primary school archetype.

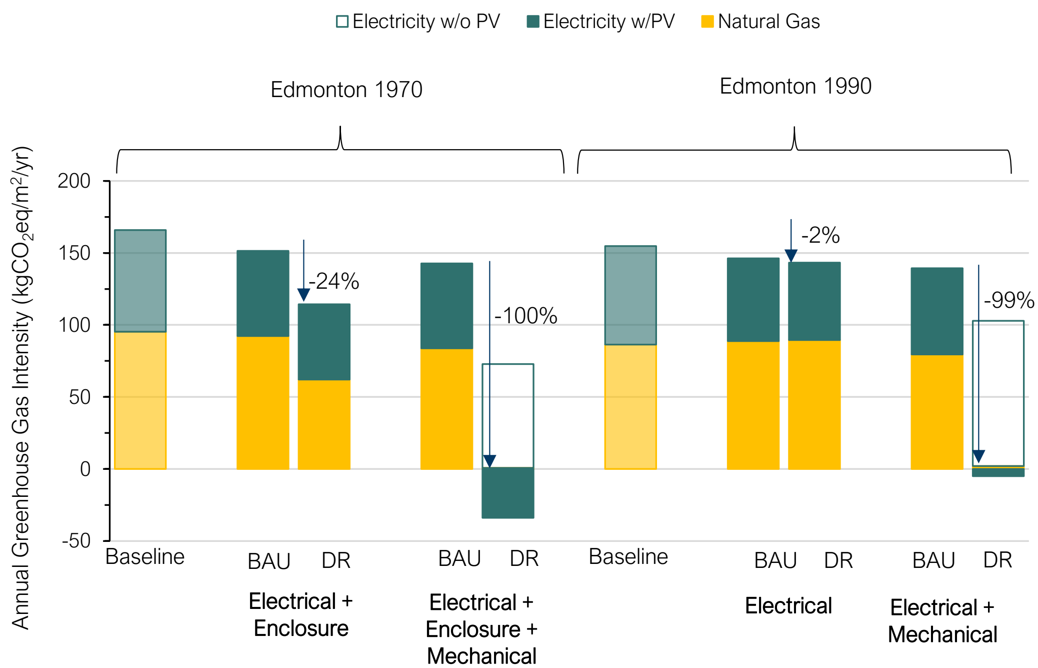


Figure 95. Greenhouse gas intensity by fuel type for the 1970s and 1990s Edmonton primary school archetype.

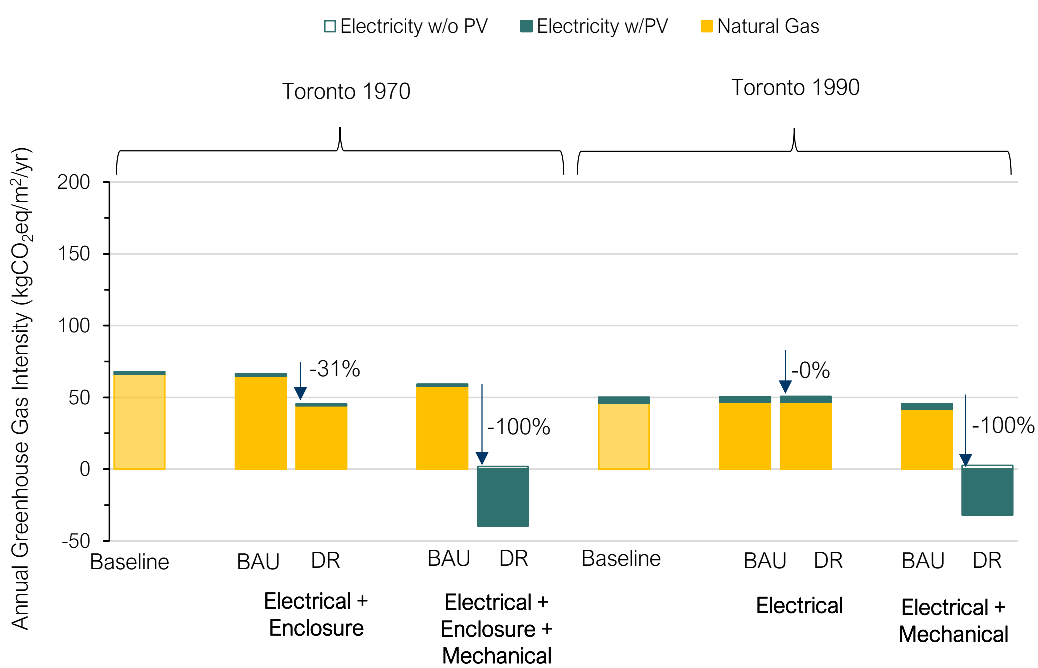


Figure 96. Greenhouse gas intensity by fuel type for the 1970s and 1990s Toronto primary school archetype.

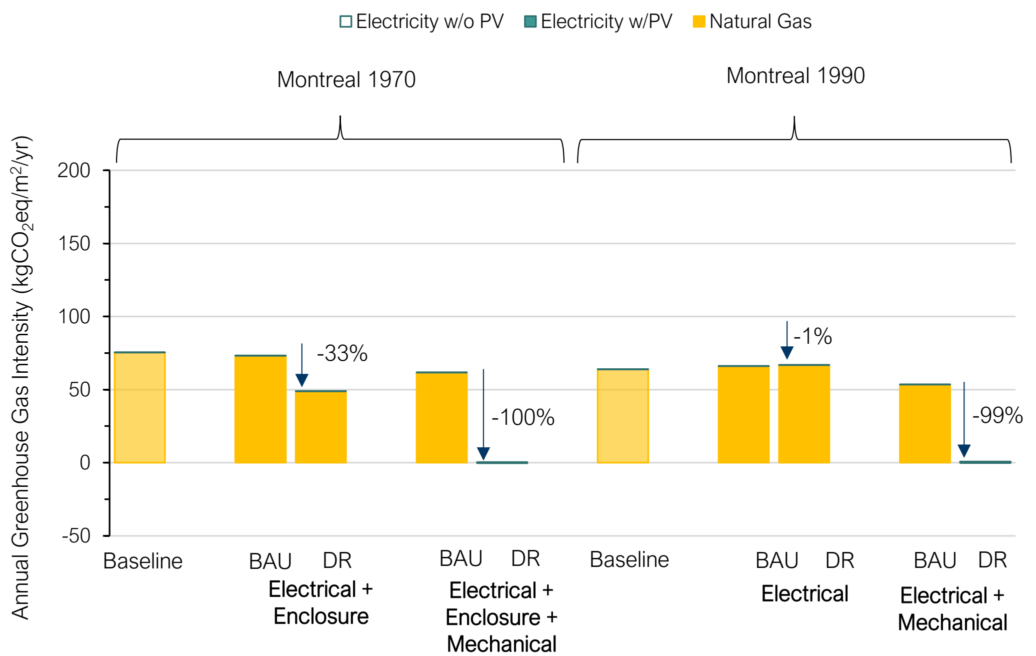


Figure 97. Greenhouse gas intensity by fuel type for the 1970s and 1990s Montreal primary school archetype.

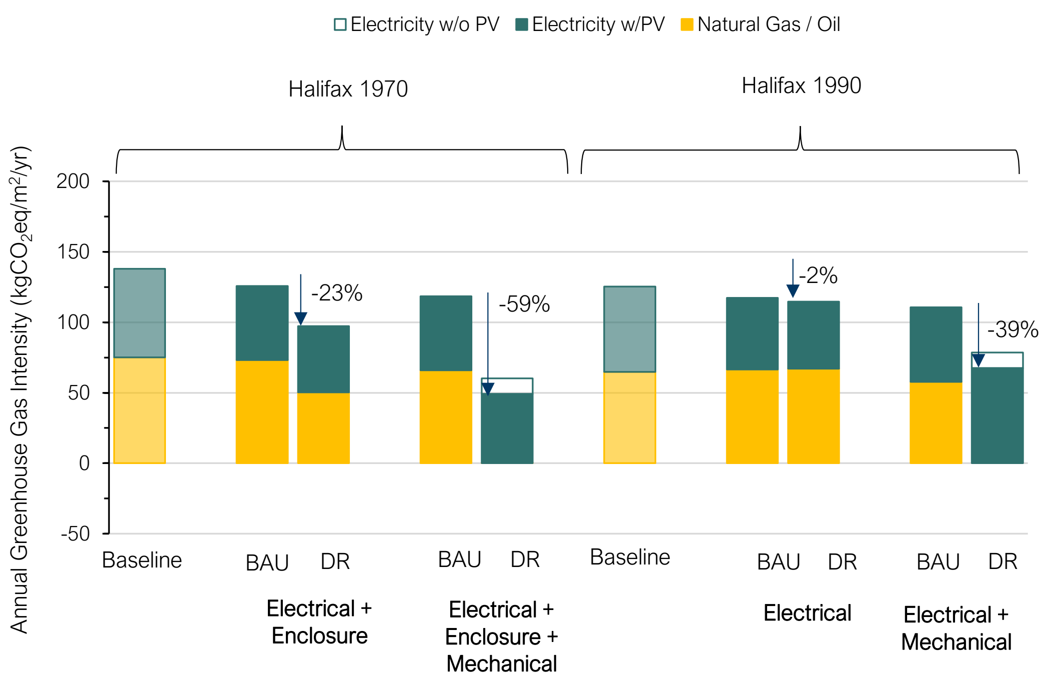


Figure 98. Greenhouse gas intensity by fuel type for the 1970s and 1990s Halifax primary school archetype.

4.1.5.3 – Electricity Demand

Figure 99 and Figure 100 show the modelled peak electricity demand results for the 1970s and 1990s primary school archetypes, respectively.

Summary of Results	
Building Vintage	Peak demand impact
1970s	+6% to 165%
1990s	-8% to +326%

The electrification of space results in a winter annual peak demand for all primary school deep retrofit archetypes except the 1990s Toronto archetype, which shows an 8 per cent reduction in annual peak demand. The 1990s Toronto baseline archetype is fully cooled, and the annual peak demand occurs during the summer. The improvement in cooling system efficiency and implementation of solar PV results in a decrease in peak demand.

1970s

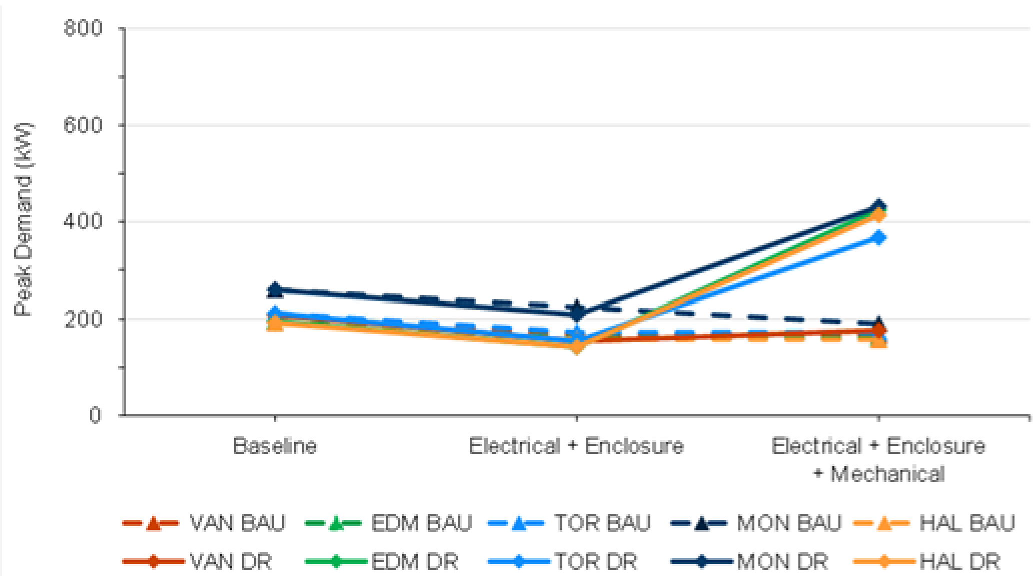


Figure 99. Peak electricity demand for the 1970s primary school building archetype.

1990s

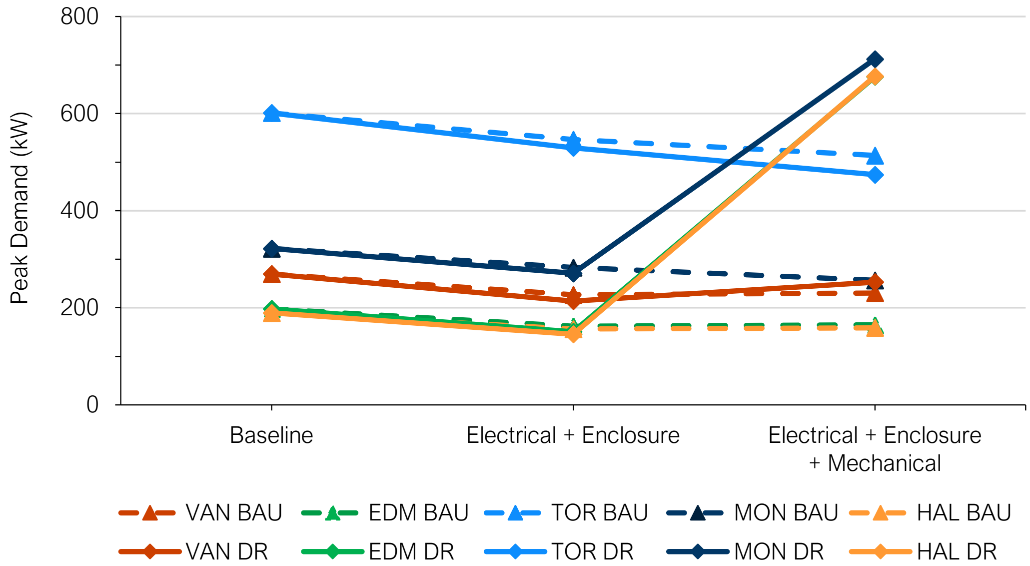


Figure 100. Peak electricity demand for the 1990s primary school building ***archetype.***

4.2 – Technical Considerations

4.2.1 – Peak Electricity and Service Upgrades

The evaluation of CRMs in Section 3.1 shows that the electrification of space heating and service hot water can increase peak electricity demand, as well as shift the annual peak demand from summer to winter. The highest increase in annual peak demand is shown for the archetypes without an existing cooling system and/or low cooling load. For the archetypes with cooling, the existing chiller is replaced with heat pump(s) that provide heating and cooling. Since these archetypes already have a higher summer peak demand (associated with the chiller), the implementation of heat pumps has a lower relative impact on the annual peak.

To illustrate these different scenarios, Figure 101 below shows the annual peak demand for the 1990s Halifax and Toronto primary school archetypes as well as the 1990s Vancouver mid-rise MURB. The 1990s Halifax primary school baseline does not have mechanical cooling, so the electrification of space heating results in a significant increase in peak demand and a shift in the annual peak demand from summer to winter. The 1990s Vancouver mid-rise MURB baseline is partially cooled, and the archetype has a low cooling load. Like the Halifax primary school, the implementation of heat pumps results in an increase in annual peak demand.

In comparison, the 1990s Toronto primary school baseline is fully cooled, and the baseline annual peak demand occurs during the summer. The second phase of the deep retrofit package includes replacing the existing cooling system with heat pumps for heating and cooling. The electrification of the heating system results in a switch from summer to winter peak. However, since the 1990 Toronto primary school already has a relatively high peak demand (associated with the cooling system), the electrification of the heating system has a lower relative impact. The improvement in cooling system efficiency, along with implementation of solar PV, also results in a decrease in summer peak demand compared to the baseline.

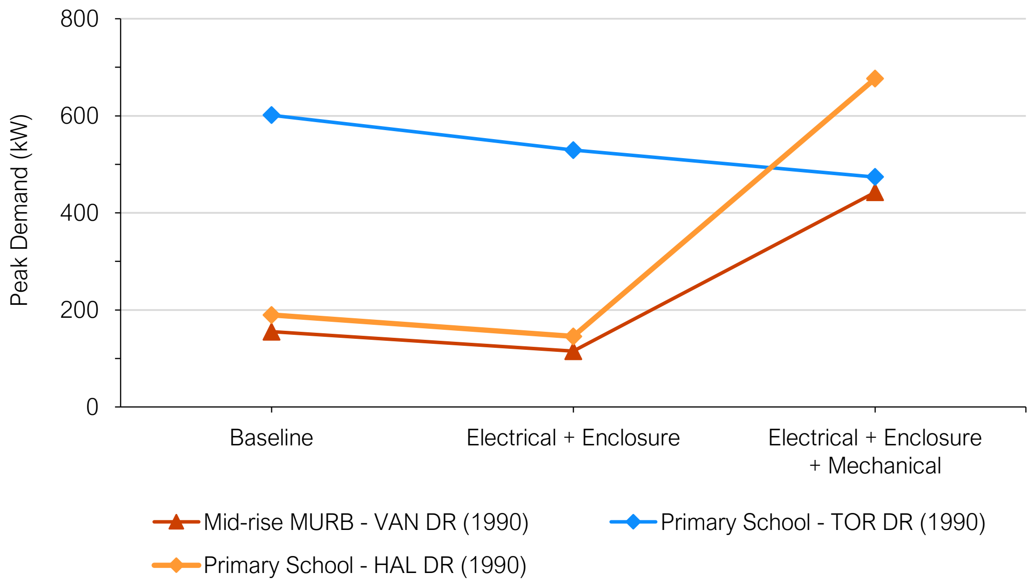


Figure 101. Annual peak electricity demand for the 1990s Toronto and Halifax primary school building archetype and 1990s Vancouver Mid-rise MURB.

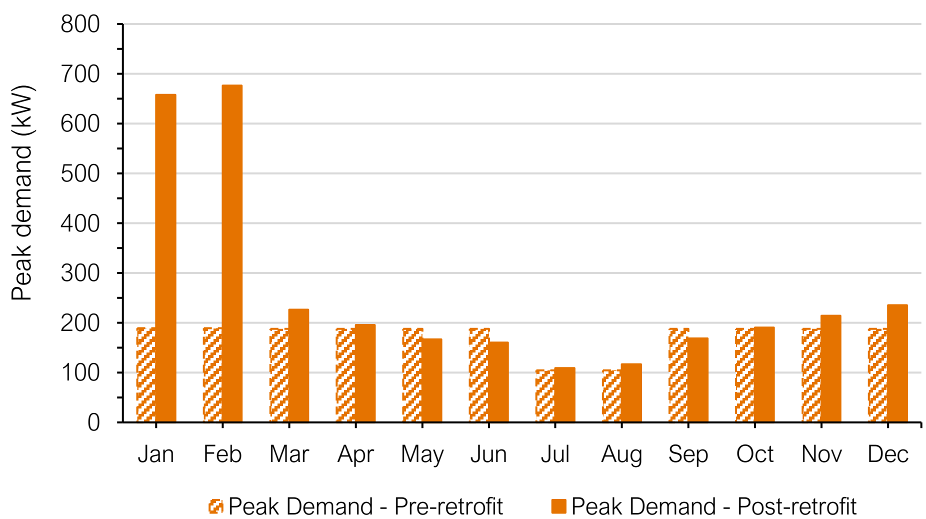


Figure 102. Monthly peak demand for the 1990 Halifax primary school building archetype.

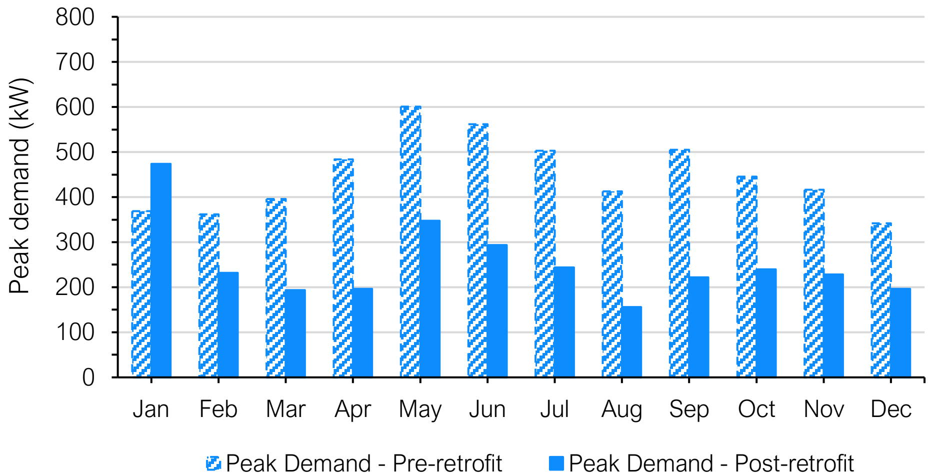


Figure 103. Monthly peak demand for the 1990 Toronto primary school building archetype.

In some cases, fuel switching measures may increase the electrical demand of a facility beyond its design capacity, requiring an electrical upgrade. The cost of these upgrades varies significantly from building to building, depending on the original electrical design and any changes to the building throughout its lifetime. It is common for the electrical service and building transformer to be over designed, especially for commercial buildings. It is also common for larger buildings to have surplus electrical capacity due to more generous original designs. In addition, most existing buildings that were constructed when high wattage lighting was more common have undergone lighting retrofits that have greatly reduced the electrical load. As a result of these factors, it is estimated that over 50 per cent of the archetype buildings would not require any electrical system upgrades when undergoing fuel switching/electrification retrofits.

Due to the large range in cost and the specificity to each project, electrical system capacity upgrades have not been included in the economic analysis of this study. However, there can sometimes be large electrical service upgrade costs required to support fuel switching measures, and this can make the economics of these retrofits very poor. Additional support mechanisms for projects that need electrical service upgrades would help to reduce this barrier. Utility providers and policy makers should continue to invest in building demand reduction initiatives and grid distribution improvements to help mitigate these known decarbonization cost barriers.

4.2.2 – The Greening of the Electrical Grids

As shown in the evaluation of CRMs in Section 3.1, the GHGIs of the archetypes following the deep retrofits vary widely from location to location due to differences in the carbon intensity of the electrical grids. Importantly, all the building types and vintages showed decreases in GHGI relative to the BAU scenarios, even in Edmonton and Halifax, which currently have electrical grids that are relatively carbon intensive (see Section 3.3.2 for details). Furthermore, the carbon intensity of these grids is falling as coal-fired power generation is phased out. Electrification of building systems will ensure that buildings benefit from this trend.

Figure 104 below shows the anticipated changes in the power generation sources within Alberta over the period between 2016 and 2030.[33] As can be seen, coal-fired power generation is expected to decline, although reliance on natural gas is expected to rise. The net effect is still a drop in the carbon intensity of electricity. In Nova Scotia, meanwhile, both coal and natural gas power generation are expected to decline.

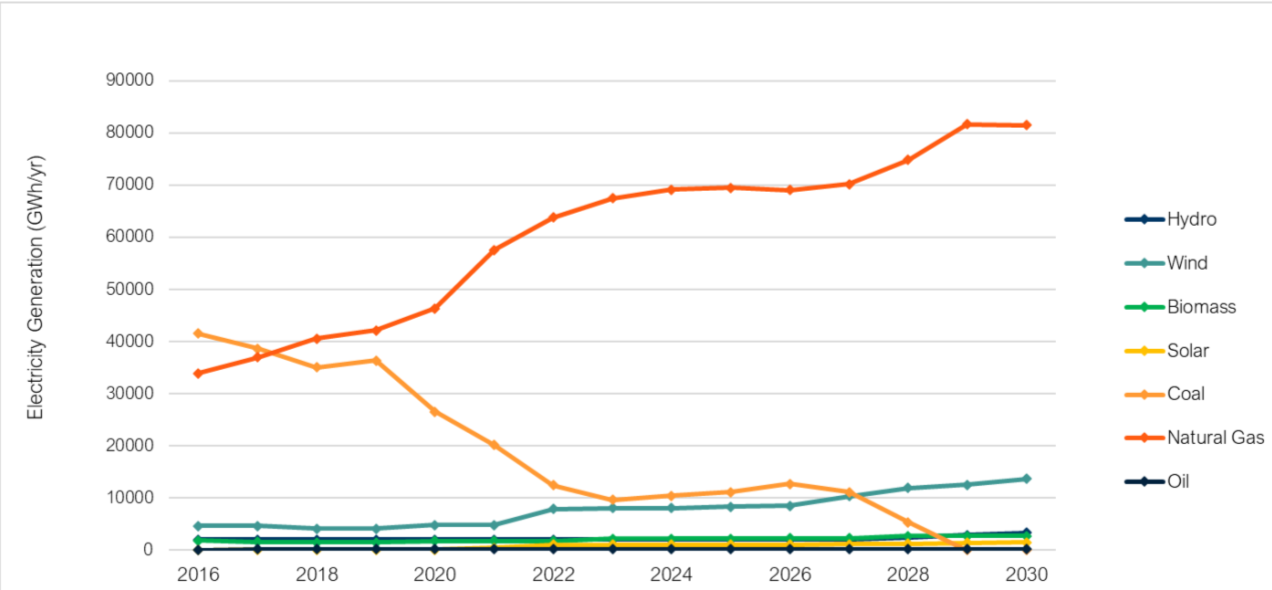


Figure 104. Anticipated power generation mix in Alberta.

4.2.3 – Assessing Emissions from Electricity

The carbon intensity of an electrical grid is represented by an emission factor, in units of gCO_2e/kWh. In the evaluation of CRMs in Section 3.1, “average” emission factors were used to calculate the GHGIs and potential carbon reduction results. Average emission factors represent the carbon intensity of all types of power generation within a province. These factors ignore hourly emissions variation in the types of power generation used and assume the grid will respond to demand reduction by reducing all types of generation equally.

An alternate analysis would be to assume that only the last power plant turned on during peak times of day will be impacted by decreasing demand. This, however, is also not completely accurate, as the last plant may be turned on in response to more localised demands on the grid or other factors. In the day-to-day management of the electrical grid, how the grid operator responds to demand reduction is dependant on the dispatchable power mix available (which is often determined by total grid demand), local demands on the grid infrastructure and nearby generation that can load balance better, and in unregulated markets the wholesale price being offered by generators, including cross border power purchases. All these factors

[33] Canada Energy Regulator. Canada's Energy Future Data Appendices.

can play into the emissions intensity of electricity grids, making it a challenge to estimate the expected reductions from various measures in different regions.

Nonetheless, as the electrification of space heating and service hot water systems may require additional grid power generation (especially if not coupled with demand reduction measures), some might argue that the marginal emissions factor is more appropriate than the average emissions factor. To investigate the impact of choosing to use the marginal emissions factor, an additional analysis was carried out for the 1970s Toronto low-rise office. This should be considered a worst-case, boundary condition as it unrealistically assumes that all the building's power (not only any incremental power) is provided by natural gas generation facilities, and that this is the case at all times of day.

For context, in Ontario, the marginal emission factor is 394 g CO_2e/kWh, which is about 20 times higher than the average emission factor (20 g CO_2e/kWh). This is because the marginal emission factor is determined based on the assumption that the power is generated by a natural gas plant, whereas the average factor includes all power generation facilitates including nuclear, hydro, natural gas, wind, and PV generation.

Figure 105 below shows the modelled GHGI results for the 1970s low-rise office in Toronto based on the average and marginal emission factors. As expected, the GHGIs are higher when the marginal emission factor is used. However, even in this worst-case assessment the GHGI of the retrofitted archetype (calculated using the marginal emission factor) is considerably lower than the GHGI of the BAU scenario (calculated using the average grid emissions factor). This illustrates that even if it is assumed that all the electricity requirements of the retrofitted building are met with additional natural gas power generation, deep retrofits still deliver carbon reductions.

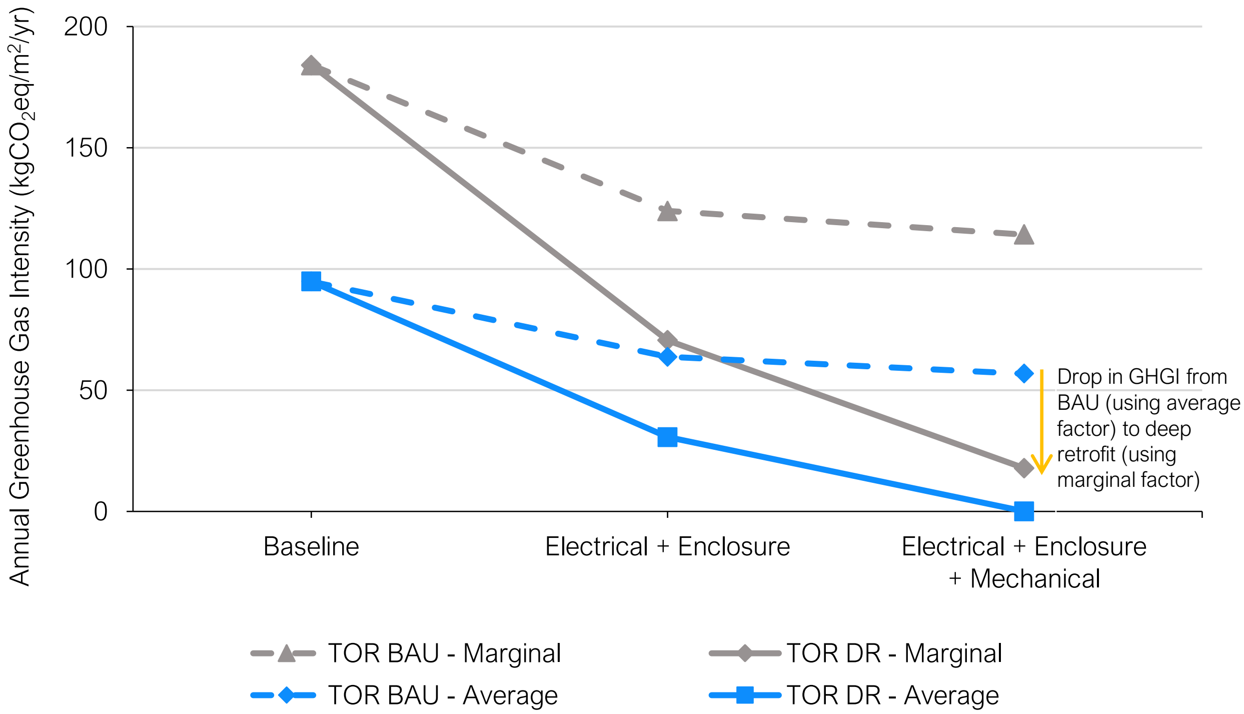


Figure 105. Annual greenhouse gas intensity for the 1970s Toronto low-rise office calculated based on the average emission factor and marginal emission factor.

4.3 – Summary of Key Findings

4.3.1 – Energy

- **Enclosure upgrades are critical to supporting decarbonization** – The enclosure upgrades in the 1970s buildings enable a reduction of approximately 20 to 50 per cent in energy use, reducing the capital cost of HVAC equipment, decreasing operating costs, and reducing exposure to future carbon pricing and utility cost escalation. Each building is likely to undergo only one enclosure upgrade between now and 2050, by which time buildings need to operate without carbon emissions. Therefore, it is critical to leverage the rare opportunity that each enclosure renewal represents in order to implement a comprehensive deep retrofit.

- **All building archetypes can achieve low TEUIs** – Generally, the deep retrofits (including electrical, enclosure and mechanical upgrades) for the 1970s archetypes achieve similar TEUIs, independent of location. This is partially because the enclosure upgrades reduce heating demand and therefore overall energy use is less impacted by climatic variations.

- **Energy savings are greatest for office buildings** - The deep retrofit package (including electrical, enclosure, and mechanical upgrades) for the office archetypes achieves a higher percentage energy savings than for the MURB archetypes and primary school. The baseline office archetypes have higher TEUIs and thus have more opportunities to reduce energy consumption.

- **Natural gas top-up boilers are currently still needed in some regions, but heat pump technologically is coming to replace them** – For climates that experience temperatures below -15°C (all locations except Vancouver and Halifax), a peaking condensing gas boiler was used for the heating loads incurred at temperature below -15°C. In the locations that use them, the gas boilers provide approximately 1 to 7 per cent of the total heating energy load. This limits the number of heat pumps required, which helps control capital costs. As heat pump technology develops, these top up boilers may be excluded in future equipment replacement cycles.

- **High-performance requirements for new construction can be achieved** – The TEUI results for the deep retrofit MURB archetypes are in line with the requirements for the upper steps/tiers of the BC Energy Step Code (ESC) and Toronto Green Standard, which guide new construction. All MURB archetypes result in lower TEUI than required for the highest step (Step 4) of the BC ESC, which is 100 $kWh/m^2/yr$. Similarly, all the office buildings achieve the upper step of the BC ESC, which is also 100$kWh/m^2/yr$. This indicates that adopting performance-based metrics is feasible for existing buildings, though additional support mechanisms, such as energy modelling guidelines, would need to be developed.

Figure 106 provides a summary of the impact of retrofits on energy consumption.

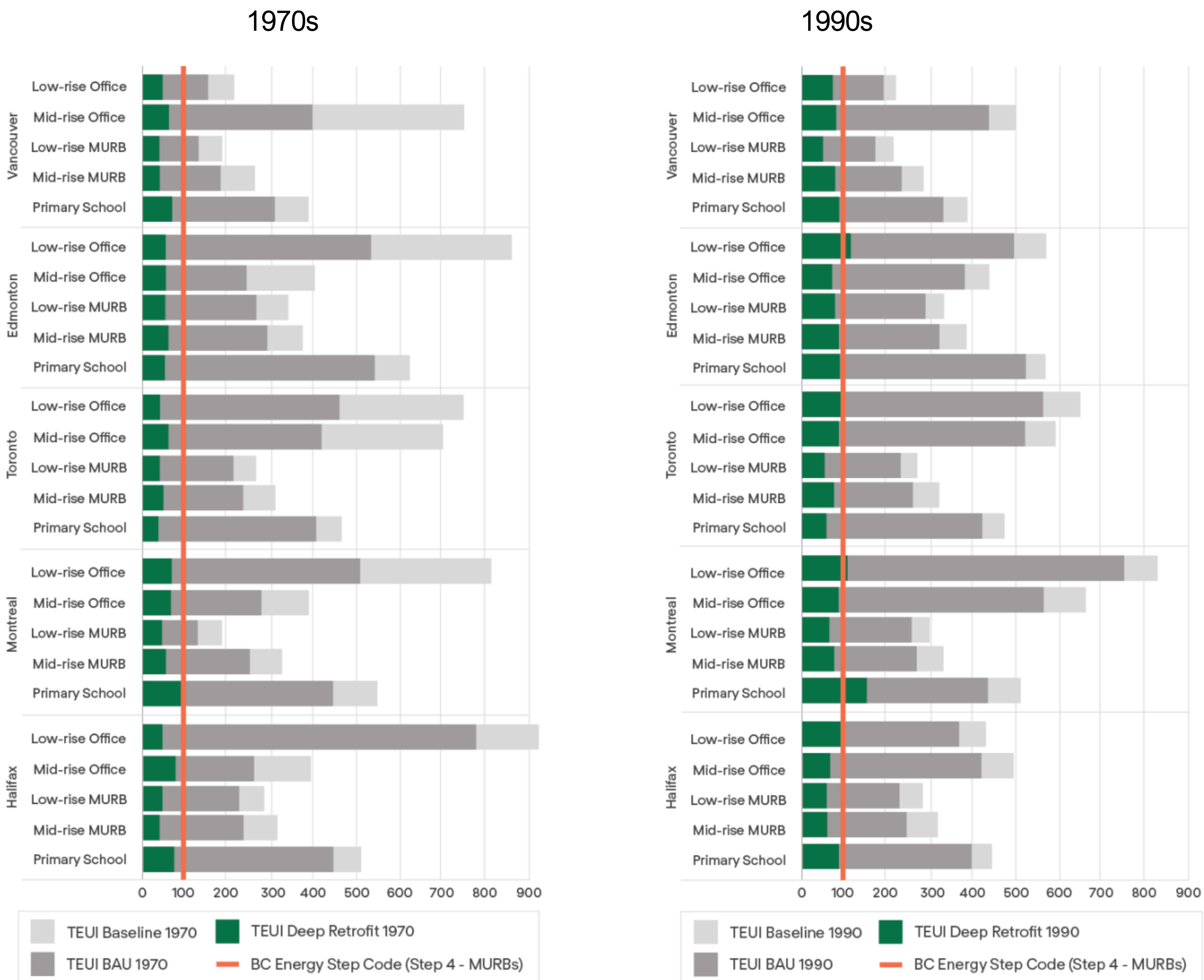


Figure 106: Total energy use intensity (TEUI) per archetype (kWh/m²/yr)

4.3.2 – Carbon Emissions

- **All the building types and vintages showed dramatic decreases in GHGI relative to the business-as-usual scenarios.** Although the deep retrofits result in similar endpoint TEUIs across the locations studied, the final GHGIs vary significantly due to differences in the carbon intensity of the electricity grids. In all cases, however, the decreases in GHGI are dramatic.
    - The archetypes located in Montreal, Toronto, and Vancouver all achieve GHGI reductions of at least 93 per cent, except for the mid-rise MURBs in Vancouver (83%). They obtain the lowest GHGIs and the most significant reductions because their electricity grids are relatively clean.

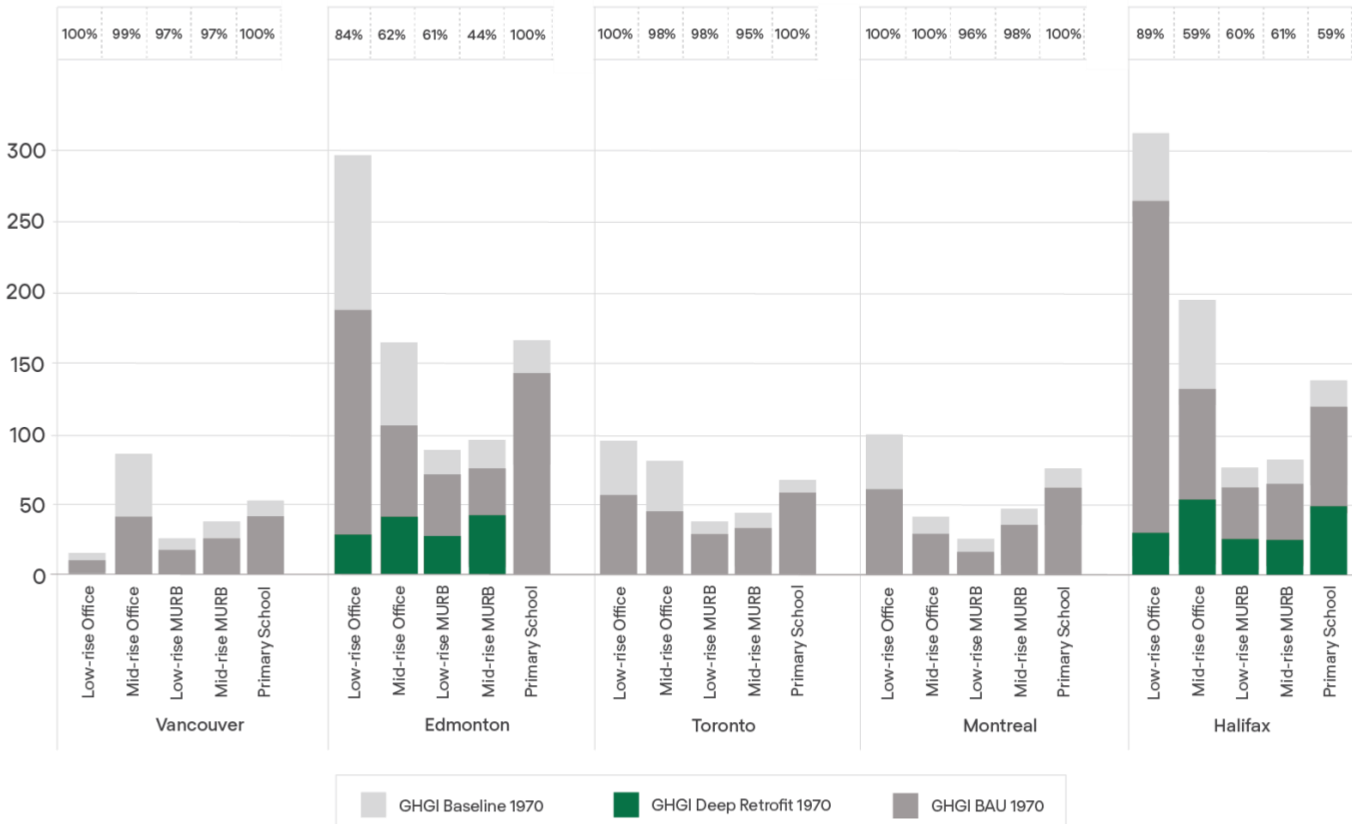
- In Edmonton and Halifax, GHGIs were reduced on average 68% in the 1970s archetypes, and 53% in the 1990s archetypes. Furthermore, fossil fuel use was reduced at least 96% in each archetype, ensuring the retrofitted buildings are well positioned for the clean electrical grids of the future. The carbon intensity of the grids in these regions is falling as coal-fired power generation is eliminated and renewable energy sources and natural gas play a larger role.[34] It should also be noted that even though the percentage of emission reductions were lower in Edmonton and Halifax, archetypes in these cities showed the largest absolute carbon reductions.

- **Demand reduction activities provide carbon emission reduction benefits.** Generally, the 1970s archetypes achieve a lower GHGI compared to the 1990s archetypes due to the heating and cooling demand reductions from enclosure upgrades. In absolute terms, demand reduction yields greater GHGI benefits in carbon intensive electrical grids.
- **On-site solar PV can play a key role in reducing emissions in certain locations.** Solar PV is most suitable for buildings with a large roof area, located in regions with carbon intensive electricity grids and no utility net metering size limitations. For example, the addition of solar PV on the large roof of the Edmonton primary school enabled that archetype to achieve emissions reductions of 99-100 per cent.
- **The market for heat pumps is rapidly expanding** and as this market evolves, system capacity, supply temperature and cold climate performance will improve.

[34] The latest electrical grid emission factors finalized in Canada's National Inventory Report, which are used in the Zero Carbon Building Standard and in this analysis, date from 2017; progress has been made on grid decarbonization since that time.

Figure 107 provides a summary of the impact of retrofits on GHG emissions.

1970s GHG Reduction (from BAU)



1990s GHG Reduction (from BAU)

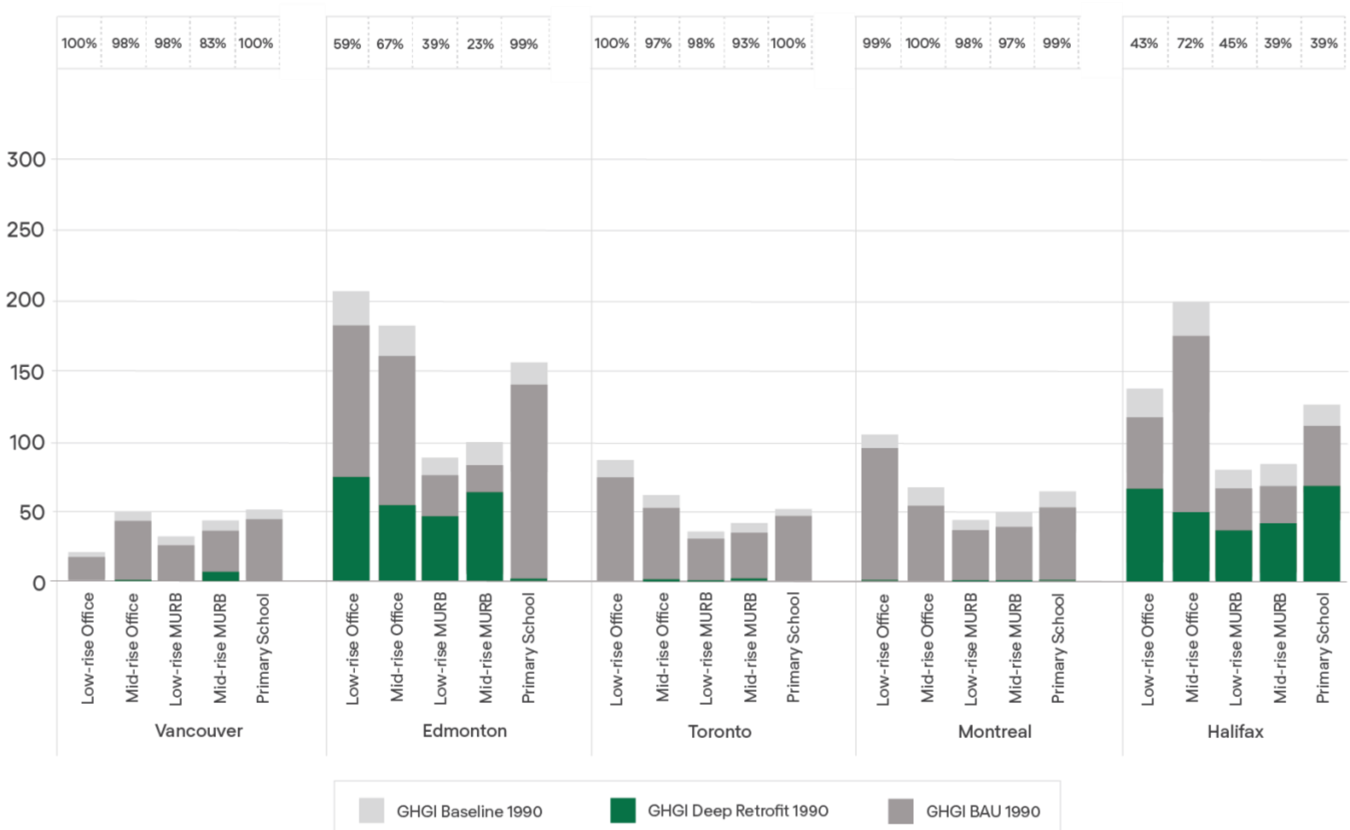


Figure 107. GHGI (kgCO$_2$eq /m^2/yr) for Baseline, BAU and Deep Carbon Retrofit with solar PV Scenario

4.3.3 – Electricity demand

- **Energy demand reduction is needed to offset electrification measures.** Except for, the electrification of space heating and service hot water systems increases in annual peak electricity demand. The increases are greater for 1990s archetypes, highlighting the importance of demand reduction activities, such as enclosure upgrades, heat recovery, and optimized operations. Onsite renewable energy, thermal and battery storage, as well as demand response programs, may help harness energy when it is available and mitigate higher peak demand on the grid.

- **Electrical service upgrades need to be avoided.** The highest increase in peak demand is shown for the archetypes with a low cooling load or without an existing cooling system, such as the low-rise MURB archetype. These archetypes may be at higher risk for requiring electrical service upgrades to sustain the additional electric heating and cooling equipment, which would make the deep retrofit business cases much worse.

- **In some cases, the season in which the annual peak occurs is shifted after the deep retrofit.** For example, the annual peak demand for the baseline low-rise MURB archetype occurs during the summer for the locations with cooling. The electrification of space heating and service hot water results in an increase in the peak demand, and a shift to winter annual peak. This is more pronounced in buildings with relatively low internal heat gains and summer cooling loads, such as residential buildings and schools.
- For the archetypes with full mechanical cooling, the existing chiller is replaced with heat pumps that provide heating and cooling. Since these baseline archetypes have a high summer peak demand (associated with the chiller), the implementation of heat pumps has a lower relative impact on the annual peak demand compared to archetypes without cooling. **In some cases, the annual peak demand remains in the summer after the electrification of space heating and the improvement of cooling system efficiency and implementation of solar PV reduce the annual peak demand below the baseline.**

5 Incremental Costing and Financial Analysis

This Section provides the results of the incremental costs and financial analysis. Drawing on the energy and GHG savings results in Section 3, as well as industry data on retrofit costs, the incremental costs of retrofit measures were compared to the business as usual approach and the financial viability of the deep carbon retrofit pathways were assessed.

Incremental Costing and Financial Analysis

The incremental cost and financial viability of retrofit measures varies substantially depending on the builidng type, vintage, location and carbon intensity of the energy supply. This section provides information on the modelled incremental capital costs (ICCs) of the deep retrofits, relative to a business-as-usual (BAU) scenario. It also summarizes the financial viability results including net present value (NPV), internal rate of return (IRR) and average cost of carbon abatement. Note that the scale used in the figures is held consistent for ease of comparison.

Key Findings

- **It pays to reduce carbon for many archetypes today** – Nearly all the archetypes (45 of 50) achieved a positive internal rate of return, and 17 achieved a positive net present value. The business case for deep retrofits is only going to get stronger as technology advances and the cost of carbon pollution rises.
- **Reducing heating demand improves cost-effectiveness -** Retrofits that start with heating demand reductions are found to generally result in lower ICCs and higher NPVs. However, building condition and renewal schedules may dictate what retrofit strategies are most feasible and cost-effective at a given point in time.
- **Office buildings are low-hanging fruit** – Office archetypes typically include cooling and have higher baseline electricity usage than other archetypes. Some offices also have less efficient systems, such as dual-duct or constant volume with reheat. The result is that offices retrofits can yield greater electricity savings and result in a higher NPV.
- **Higher utility rates improve the business case for deep retrofits -** Buildings in Halifax and Toronto may experience higher NPVs from deep retrofits due to above-average natural gas and above-average electricity prices, respectively.
- **Replacing natural gas boilers with air to water heat pumps (AWHPs) is a great fit for some archetypes** - When replacing boilers with AWHPs that deliver lower temperature water, upgrading the capacity of the hydronic terminal units can be one of the largest contributors to ICCs. However, 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), or if an enclosure deep retrofit is pursued, then costly upgrades of the terminal heating system may be avoided.

5.1 – Incremental Costing and Financial Analysis

This section summarizes the financial analysis results for the different building archetypes. For each archetype, incremental capital costs (ICCs), net present values (NPVs), internal rates of return (IRRs) and the average cost of carbon abatement (CCA) are presented.

NPV is calculated over a 40-year period and includes the cost of equipment replacements that would normally occur within that time.[35] The impact of an increasing price for carbon pollution is reflected in the energy cost assumptions modelled in this study, as discussed in Section 2.3.3. Regular maintenance activities, such as annual inspections and repairs, are not included in the analysis since in almost all cases these activities would be similar under both the deep carbon retrofit and BAU scenarios.

ICCs and NPVs are presented in dollars per square meter of floor area ($\$/m^2$). High and low values for ICC, IRR and NPV are presented, representing the uncertainty in estimated retrofit costs. Only one cost of carbon abatement is reported for each archetype, and it is based on the average of the high and low NPV.

Key Metrics

- **Discounted payback period:**
  Provides an indication of the profitability of a retrofit project. A discounted payback period gives the number of years it takes to break even from undertaking the initial expenditure, by discounting future cash flows and recognizing the time value of money.

- **Net present value (NPV):**
  The NPV of a retrofit project is determined by calculating today's value of forecasted revenue from energy cost savings. A negative NPV indicates that the internal rate of return is less than the discount rate applied (5% in this study).

  The cost-effectiveness of carbon abatement ($\$/tCO_2e$) is zero in cases where the deep retrofits have positive NPVs. Although a positive NPV indicates that there is a business case for the retrofits, there may still be capital cost barriers that will need to be addressed via policy mechanisms and support programs.

- **Internal rate of return (IRR):**
  The IRR is the annual rate of return that will be earned for implementing the retrofit. The IRR is the discount rate that makes the NPV equal to zero. The IRR is therefore expressed as a percentage, and it illustrates financial returns relative to the size of the investment.

  It should be noted that this study found that in most instances where a negative NPV was reported, the IRR was positive (i.e., between 0% and 5%). In other words, there was a positive financial return, but it was less than the expected cost of capital or borrowing rate.

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[35] Measures in this study include both mechanical and enclosure upgrades. While these measures have significantly different life-cycles in terms of replacement timelines, forty years was used as an average.

- **Incremental capital cost (ICC):**
  The incremental costing analysis consists of estimating the incremental capital cost (ICC) of each retrofit measure relative to upgrades that occur in the corresponding business-as-usual (BAU) scenario.

  ICCs are based on 2020 material and labour costing estimates for the carbon reduction measure (CRM) retrofit packages. These estimates are based on data from product suppliers, as well as industry reference databases such as RSMeans, and recent RDH and Dunsky project experience. While some costs are based on data from recent building renewal projects, in other instances costing data from new construction projects was used. In those cases, the cost estimates were increased by a factor of 1.5 to 2.5 to account for the additional cost and complexity typical of retrofit work. These additional costs include activities such as demolition, managing discovered building problems, and hazardous material remediation. The cost multiplier was decided on a system-by-system basis and was based on project experience. Construction costs known for one location are extrapolated to the other locations using industry standard cost factors from Altus Group reports.

- **Cost of carbon abatement (CCA):**
  The cost of carbon abatement ($/t$CO_2$e) is calculated by dividing the net present value (NPV) by the total GHG savings for a 40-year period (the timeframe used of the analysis). It represents the amount of funding that is required to off-set any the additional life-cycle costs of the carbon reduction measures.

  A negative net present value indicates a retrofit is not internally cost effective, based on the life-cycle costing assumptions, and will require additional external funding or support programs, such as government incentives, to be cost neutral.

  In scenarios with a positive NPV, the deep retrofit measures are internally cost effective (they generate positive cash flow via utility cost savings). As such, they are viewed as having no cost of carbon abatement, i.e., no additional funding would be required to achieve cost neutrality (NPV=0). For the purposes of this study the cost of carbon abatement in these scenarios is listed as 0 $/t$CO_2$e.

  Note that the CCA metric should not be confused with the levelized cost of carbon and should not be directly compared to the price of carbon pollution. Instead, assumptions about the future price of carbon pollution are included in the NPV calculation.

5.1.1 – Low-rise Office

Figure 108 and Figure 109 below show the calculated ICC results for the 1970s and 1990s low-rise office deep retrofits, respectively. The key cost drivers for the low-rise office deep retrofits are replacing the boilers with air-to-water heat pumps (AWHPs), and, for many of the 1990s low-rise office buildings, replacing the hydronic baseboards.

The 1970s Halifax low-rise office retrofit achieves the lowest ICC of any archetype considered in this study. This is due to the higher cost of the business-as-usual (BAU) scenario for this archetype, which includes the replacement of a large dual-duct air handler system. Replacing the dual-duct air handler is much more expensive than replacing a smaller air handler and boiler, which is typical of other locations. In the past, dual duct systems were common in some parts of Canada including Quebec and the Maritime provinces, but they are not as common today.

As a result of using variable refrigerant flow (VRF) to replace hydronic baseboards, the Toronto archetype has a lower ICC than the other 1990s low-rise office archetypes. VRF systems are typically more expensive to retrofit than AWHPs that maintain the existing distribution system and, where possible, hydronic baseboards. However, since the hydronic baseboards for AWHP systems are quite large and costly, for low-rise buildings with abundant ceiling space a VRF upgrade may be less expensive than replacing all hydronic baseboards, as is the case for the 1990s Toronto low-rise office.

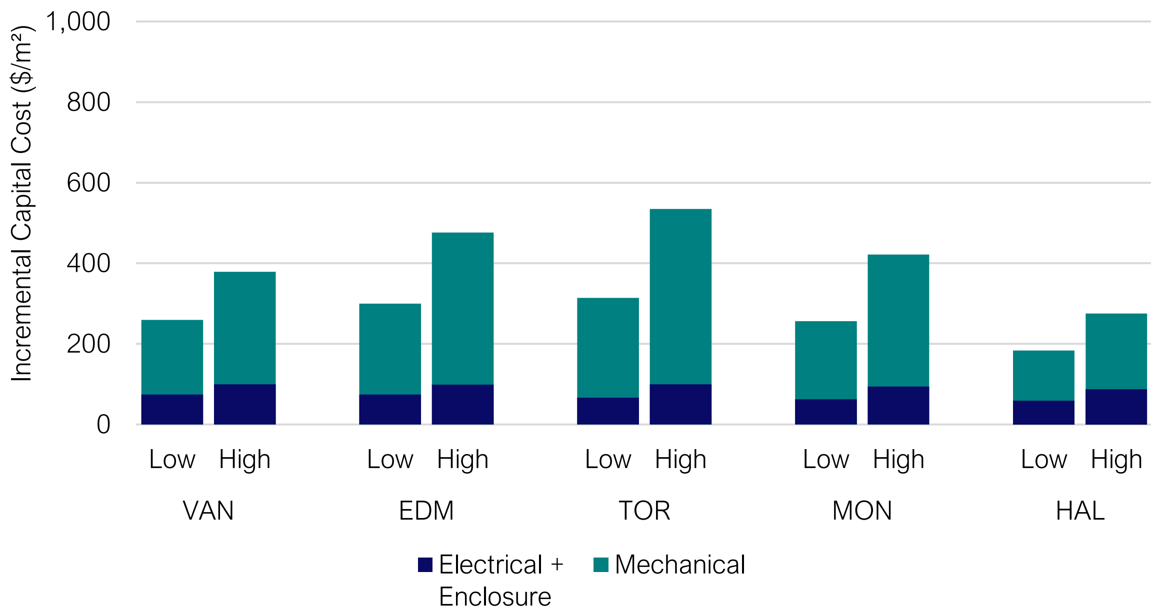


Figure 108. Incremental capital cost normalized per floor area for the1970s low-rise office deep carbon retrofits compared to the corresponding business-as-usual scenario.

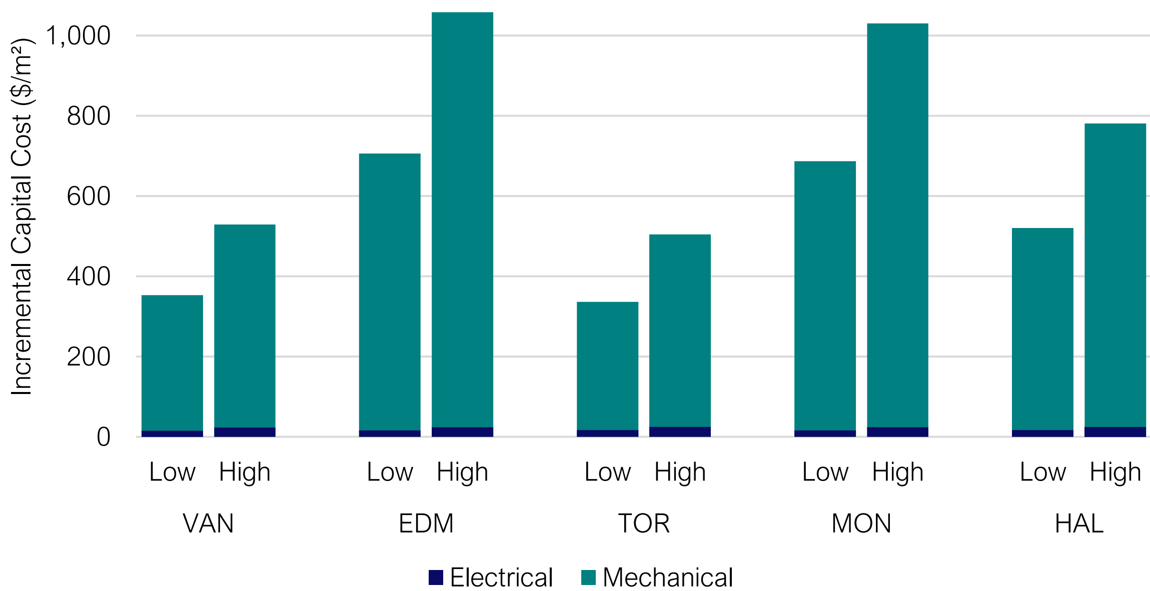


Figure 109. Incremental capital cost normalized per floor area for the 1990s low-rise office deep carbon retrofits compared to the corresponding business-as-usual scenario.

Figure 110 and Figure 111 below show the NPV and cost of carbon abatement results for the deep retrofit of the 1970s and 1990s low-rise office archetypes, respectively. The deep retrofit of the 1970s low-rise offices results in some of the highest NPVs of any archetype in this study. The NPVs for the 1970s low-rise offices are significantly higher than those of the 1990s low-rise offices because the ICCs for retrofitting the 1970s buildings are lower, and the baseline 1970s mechanical systems are less efficient than those in the 1990s archetypes.

The deep retrofit of the 1970s Halifax low-rise office yields the highest NPV of any of the scenarios studied, primarily because Halifax has the highest natural gas utility costs among the locations considered. This archetype also benefits from above-average reductions in natural gas use and below-average ICCs for the retrofit since the baseline archetype has a dual duct HVAC system. Dual duct systems provide heating and cooling simultaneously and supply a high volume of air. This results in high natural gas and electricity usage relative to other more efficient baseline HVAC systems, such as variable air volume (VAV) or dedicated outdoor air system (DOAS) with VRF heating and cooling.

The retrofits of the Vancouver low-rise offices have the lowest NPVs, due to the low energy use of the 1970s and 1990s baseline archetypes, and thus lower net savings from the deep retrofit. The low baseline energy use is due to the relatively efficient baseline mechanical systems including DOAS ventilation, distributed AWHPs for the 1970s archetype and fan coils for the 1990s archetype. As with the majority of cases where a negative NPV was found, the IRR is positive (1.4% for the 1970s building) but lower than the discount rate applied (5%). The Vancouver retrofits also result in the lowest carbon reductions among office retrofits, resulting in one of the highest costs of carbon abatement for any retrofit.

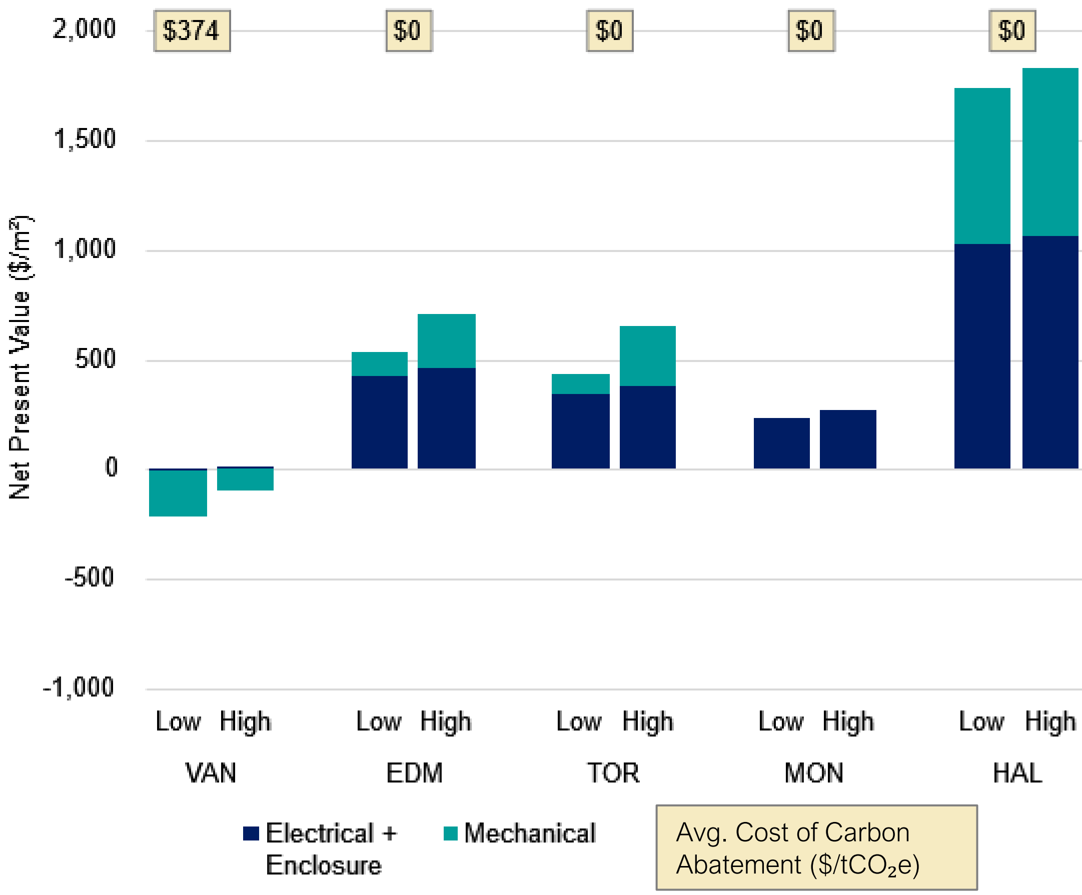


Figure 110. Net present value normalized per floor area for the 1970s low-rise office deep carbon retrofits compared to the corresponding business-as-usual scenario. NPV for Mechanical refers to the NPV of the full deep retrofit include electrical and enclosure upgrades. Cost of carbon abatement is for the deep retrofit including mechanical upgrades.

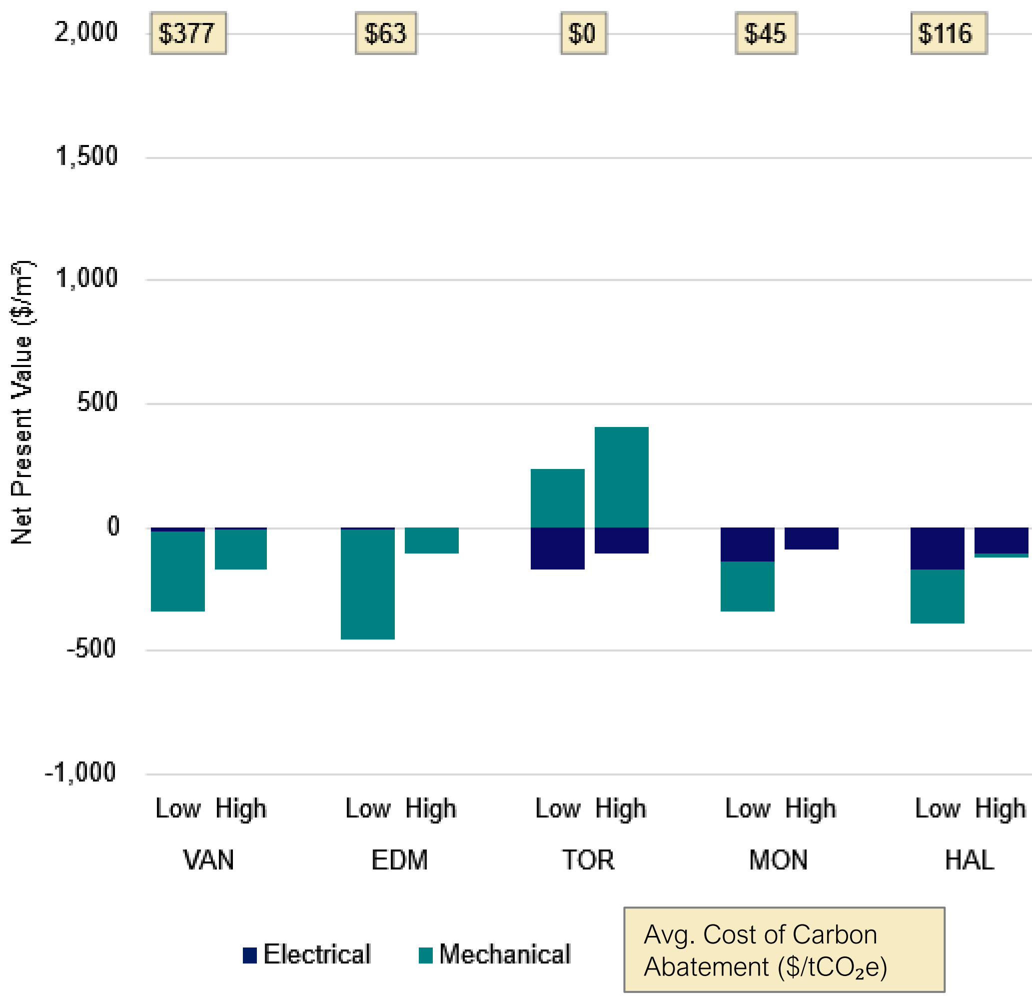


Figure 111. Net present value normalized per floor area for the 1990s low-rise office deep carbon retrofits compared to the corresponding business-as-usual scenario. NPV for Mechanical refers to the NPV of the full deep retrofit include electrical and enclosure upgrades. Cost of carbon abatement is for the deep retrofit including mechanical upgrades.

5.1.2 – Mid-rise Office

Figure 112 and Figure 113 below show the calculated ICC results for the 1970s and 1990s mid-rise office deep retrofit packages, respectively. The mid-rise office retrofits results are similar to the low-rise office retrofits in many respects: The deep retrofit of the 1970s archetypes generally result in lower ICCs than retrofitting the 1990s archetypes, and for both building types AWHP and hydronic baseboards are key cost drivers.

The mid-rise office ICCs have less variation compared to the corresponding low-rise office, due the reduced variety of existing building enclosure and ventilation systems assumed in each case.

The 1990s mid-rise office retrofits are more expensive than the 1970s mid-rise office retrofits, primarily due to the larger AWHP systems required, and because hydronic baseboards are replaced with larger capacity units.

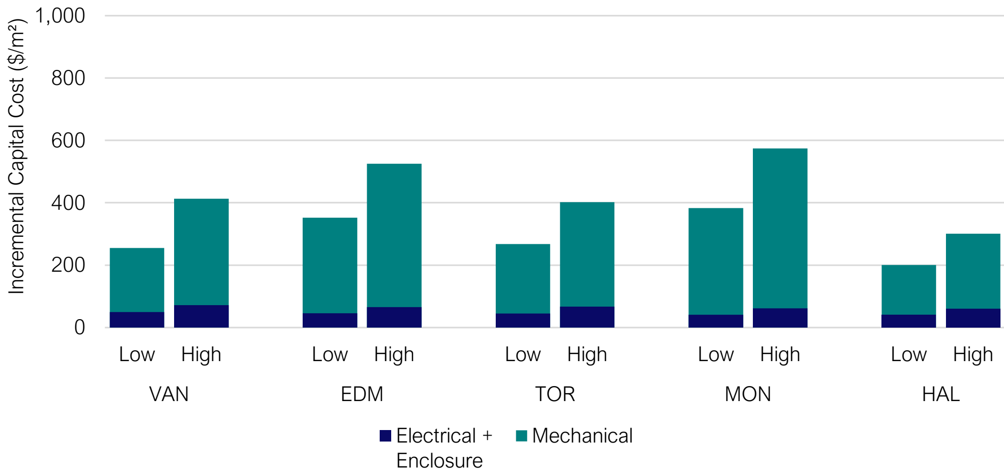


Figure 112. Incremental capital cost normalized per floor area for the 1970s mid-rise office deep carbon retrofits compared to the corresponding business-as-usual scenario.

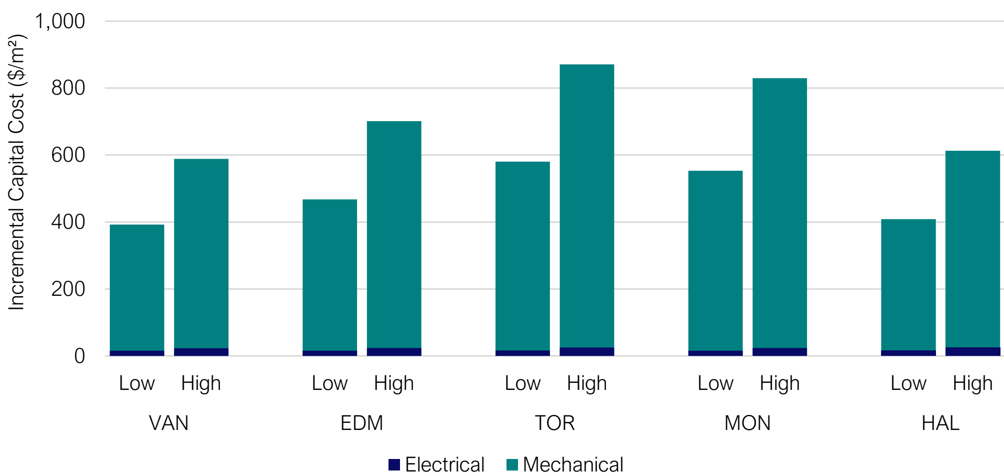
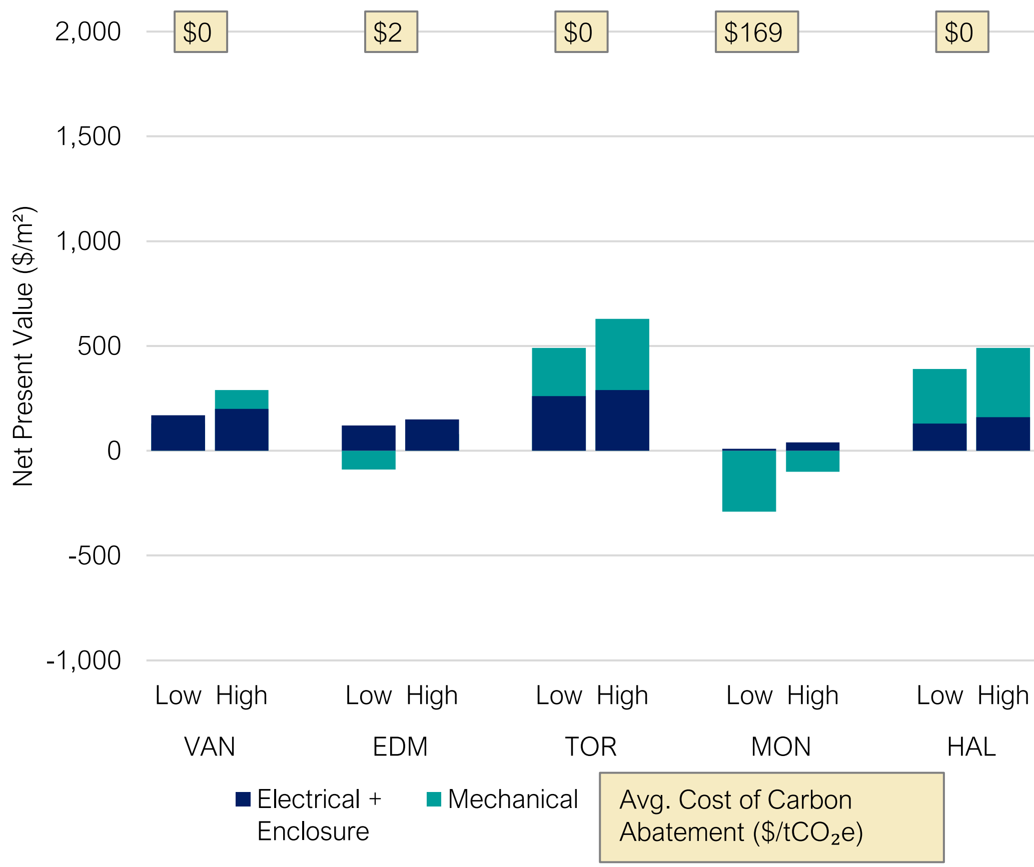


Figure 113. Incremental capital cost normalized per floor area for the 1990s mid-rise office deep carbon retrofits compared to the corresponding business-as-usual scenario.

Figure 114 and Figure 115 below show the calculated NPV and the cost of carbon abatement results for the deep retrofit of the 1970s and 1990s mid-rise office archetypes, respectively. Like the low-rise office archetypes, the mid-rise office retrofits result in positive NPVs in many cases. However, the NPVs are much more variable for mid-rise office archetypes due to a greater variety in baseline mechanical systems, resulting in a larger range of electricity savings. For the 1970s archetypes, Vancouver, Toronto, and Halifax have constant volume ventilation systems as a baseline, resulting in greater electricity use for cooling systems, pumps, and fans. Edmonton and Montreal use more efficient systems like DOAS and VAV, resulting in lower electricity savings and lower NPVs for the deep carbon retrofit.

The 1990s mid-rise office archetypes have fairly similar baseline HVAC systems, meaning any differences in financial analysis results are more due to difference in ICC and utility prices. Comparing the NPV of the 1990s Toronto and Montreal mid-rise office deep retrofits highlights the effects of varying electricity prices. While the retrofits have near-identical ICCs and result in similar electricity use savings, the average price of electricity in Toronto is roughly three times the price of electricity in Montreal. As a result, the 1990s mid-rise office archetype in Toronto has the highest NPV, while the archetype in Montreal has the lowest.

Because of NPVs were positive for most mid-rise office deep carbon retrofits, the associated cost of carbon abatement is zero for all locations with the exception of Montreal. The cost of carbon abatement for the 1970s Montreal mid-rise office archetype was estimated to be \$169/tCO_2e.



Net Present Value ($/m²)
2,000
1,500
1,000
500
0
-500
-1,000
$0
$2
$0
$169
$0
Low High
Low High
Low High
Low High
Low High
VAN
EDM
TOR
MON
HAL
Electrical + Enclosure
Mechanical
Avg. Cost of Carbon Abatement ($/tCO2e)

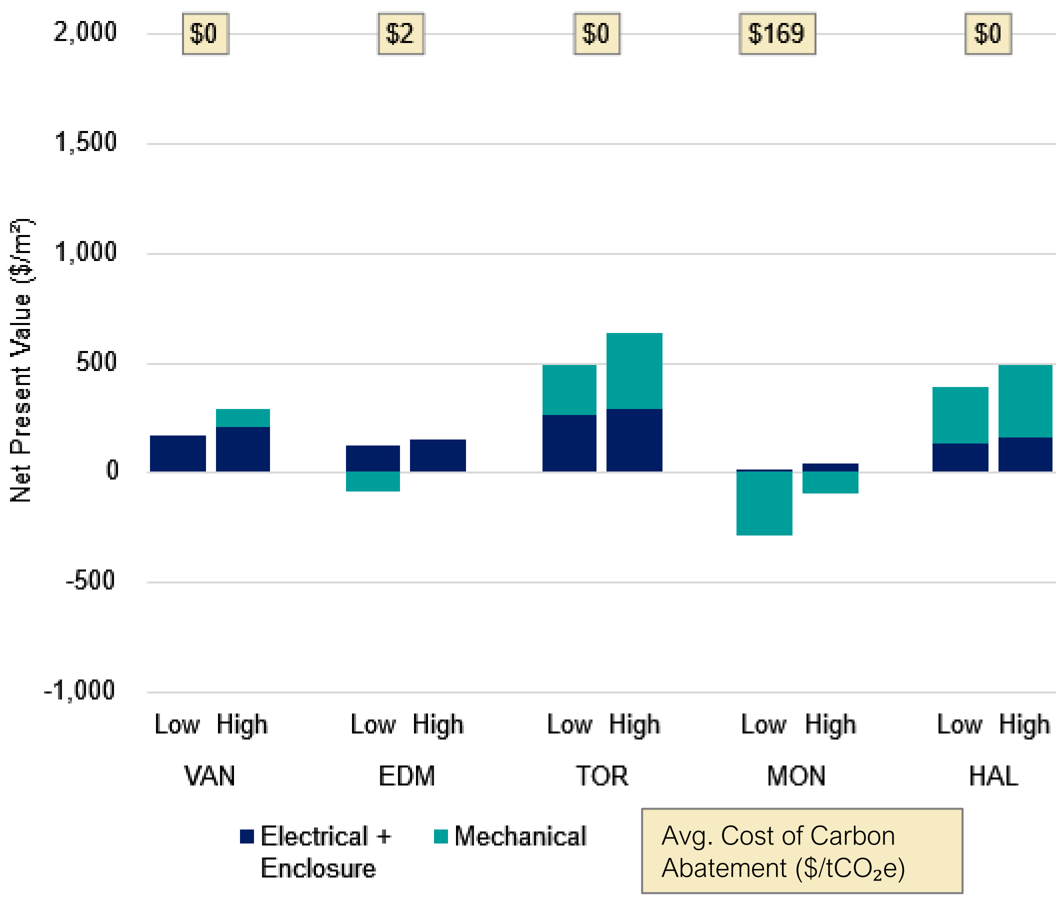


Figure 114. Net present value normalized per floor area for the 1970s mid-rise office deep carbon retrofits compared to the corresponding business-as-usual scenario. NPV for Mechanical refers to the NPV of the full deep retrofit include electrical and enclosure upgrades. Cost of carbon abatement is for the deep retrofit including mechanical upgrades.

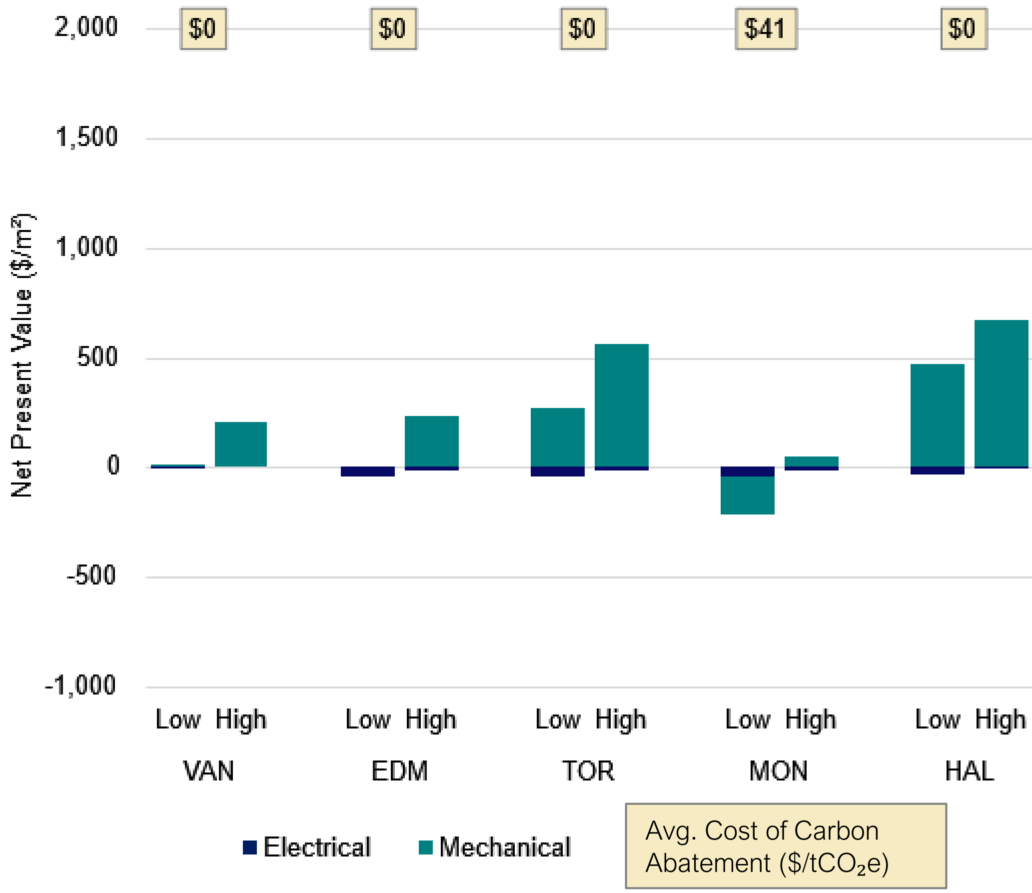


Figure 115. Net present value normalized per floor area for the 1990s mid-rise office deep carbon retrofits compared to the corresponding business-as-usual scenario. NPV for Mechanical refers to the NPV of the full deep retrofit include electrical and enclosure upgrades. Cost of carbon abatement is for the deep retrofit including mechanical upgrades.

5.1.3 – Low-rise MURB

Figure 116 and Figure 117 below show the calculated ICC results for the 1970s and 1990s low-rise MURB deep retrofit packages, respectively. Generally, the 1990s low-rise MURB retrofits will require hydronic baseboard replacement, which drives up the cost of the deep retrofit as compared to the 1970s scenarios. The exception to this is the Toronto low-rise MURB. Since Toronto has relatively hot and humid summers compared to the other locations, MURB buildings frequently have fan coils that are used for cooling as well as heating. The fan-coils are typically sized appropriately to be compatible with the retrofitted AWHP system. The cost savings from keeping the existing heating distribution system makes ICCs for Toronto archetype the lowest among 1990s low-rise MURBs.

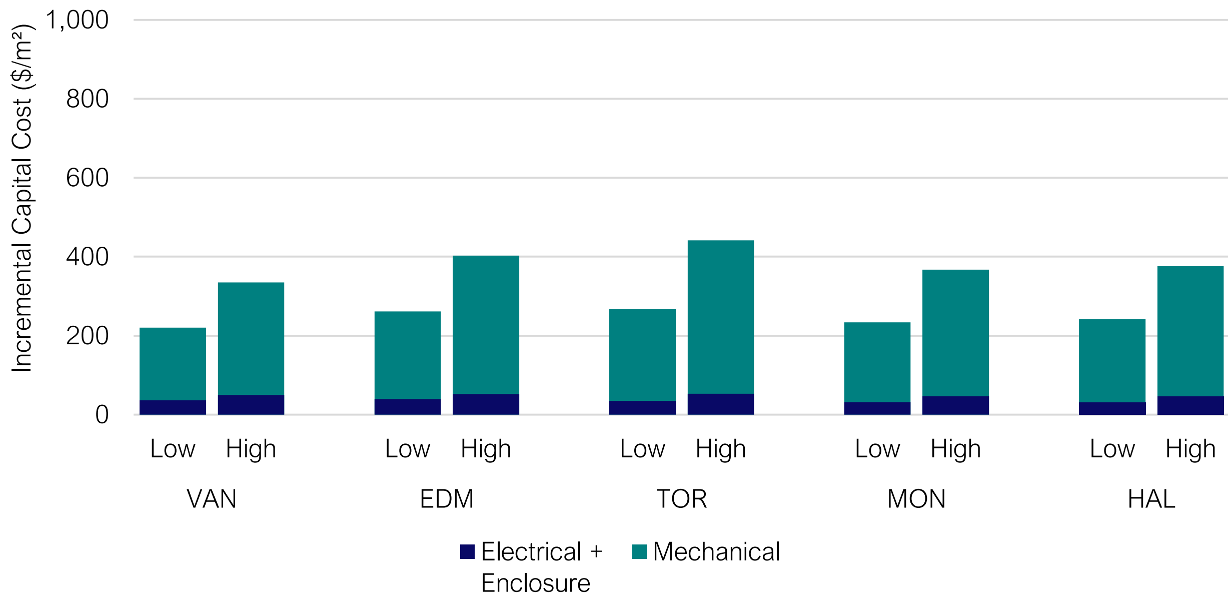


Figure 116. Incremental capital cost normalized per floor area for the 1970s low-rise MURB deep carbon retrofits compared to the corresponding business-as-usual scenario.

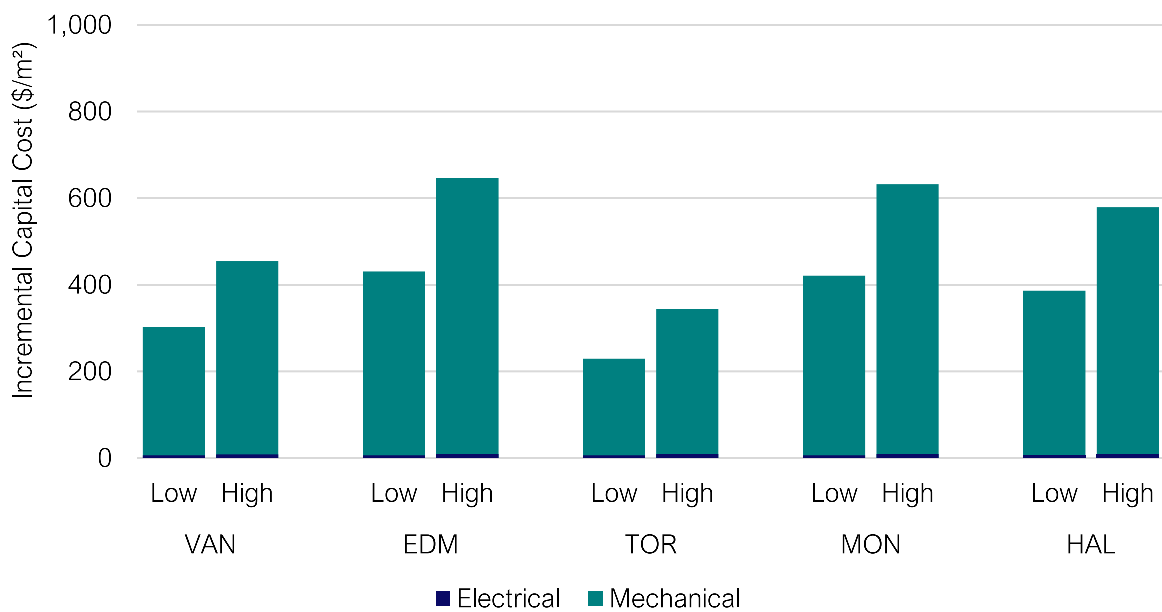


Figure 117. Incremental capital cost normalized per floor area for the 1990s low-rise MURB deep carbon retrofits compared to the corresponding business-as-usual scenario.

Figure 118 and Figure 119 below show the calculated NPVs and the cost of carbon abatement results for the deep retrofit of the 1970s and 1990s low-rise MURB archetypes, respectively. The low-rise MURB retrofits have consistently low NPV values, with all locations except the 1970s Halifax archetype retrofit having negative NPV values. Even then, the NPV for the 1970s Halifax low-rise MURB is low compared to a typical low-rise office retrofit. Despite having similar ICCs to the low-rise office, the low-rise MURB retrofit measures increase electricity use in six of ten scenarios, resulting in much lower energy cost savings overall.

The 1990s Edmonton low-rise MURB archetype has the lowest NPV, which is due to the high ICC of the retrofit package and an increase in electricity use relative to the BAU archetype.

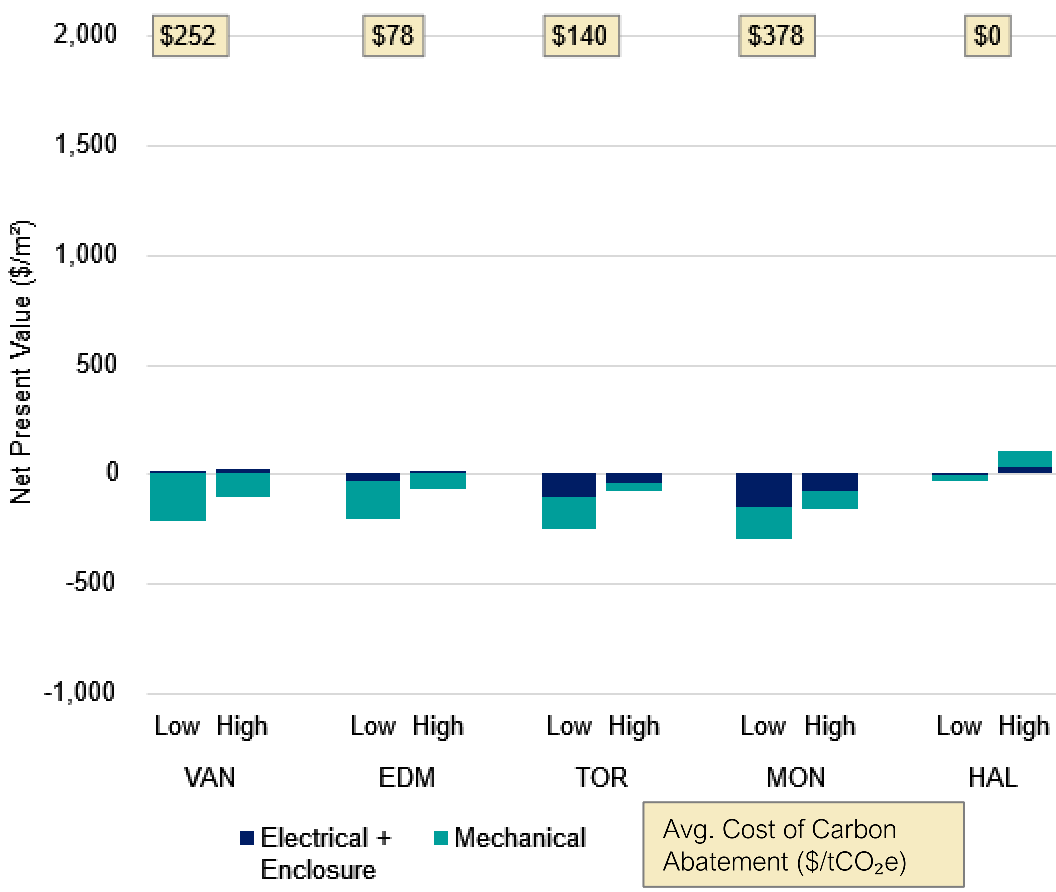


Figure 118. Net present value normalized per floor area for the 1970s low-rise MURB deep carbon retrofits compared to the corresponding business-as-usual scenario. NPV for Mechanical refers to the NPV of the full deep retrofit include electrical and enclosure upgrades. Cost of carbon abatement is for the deep retrofit including mechanical upgrades..

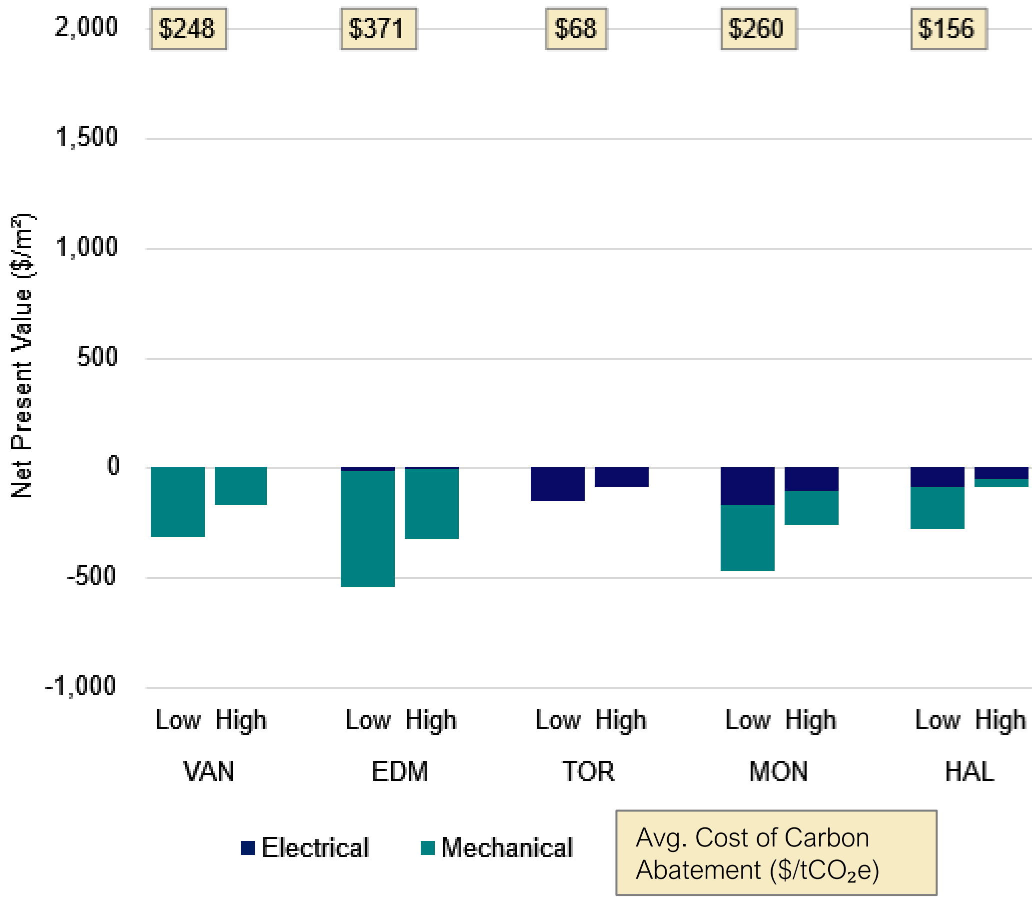


Figure 119. Net present value normalized per floor area for the 1990s low-rise MURB deep carbon retrofits compared to the corresponding business-as-usual scenario. NPV for Mechanical refers to the NPV of the full deep retrofit include electrical and enclosure upgrades. Cost of carbon abatement is for the deep retrofit including mechanical upgrades.

5.1.4 – Mid-rise MURB

Figure 120 and Figure 121 below show the calculated ICC results for the 1970s and 1990s mid-rise MURB deep retrofit packages, respectively. The mid-rise MURB deep retrofit ICCs are generally similar to those of the low-rise MURB archetypes, including slightly lower costs as compared to mid-rise and low-rise office retrofits overall.

Like the 1990s Toronto low-rise MURB, the 1990s Toronto mid-rise MURB retrofit was able to retain the existing fan-coils as part of an AWHP upgrade, resulting in the lowest ICCs among 1990s mid-rise MURB archetypes.

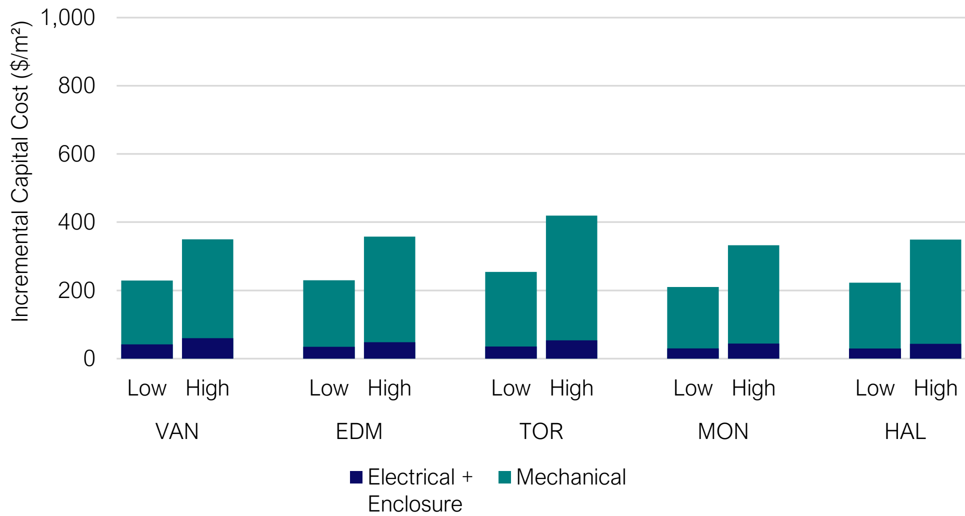


Figure 120. Incremental capital cost normalized per floor area for the 1970s mid-rise MURB deep carbon retrofits compared to the corresponding business-as-usual scenario.

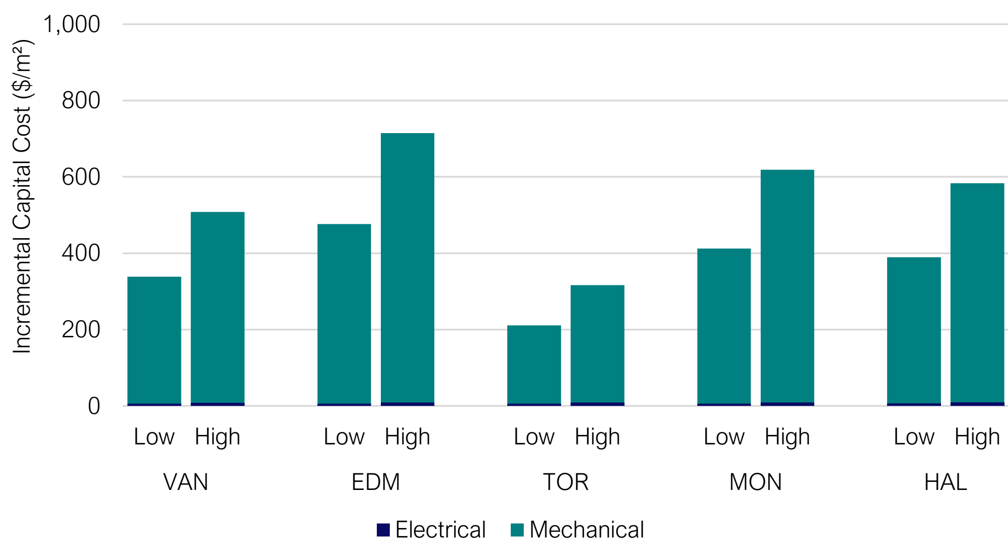


Figure 121. Incremental capital cost normalized per floor area for the 1990s mid-rise MURB deep carbon retrofits compared to the corresponding business-as-usual scenario.

Figure 122 and Figure 123 below show the calculated NPV and the cost of carbon abatement results for the deep retrofit of the 1970s and 1990s mid-rise MURB archetypes, respectively. Like the low-rise MURB retrofits, the mid-rise MURB retrofits result in relatively low NPVs. In contrast however, the NPV of 1970s mid-rise MURB retrofits are more favourable on average than those of the 1970s low-rise MURB retrofits, with positive NPVs for the 1970s Edmonton and Halifax archetypes. The 1990s mid-rise MURB retrofits result in negative NPVs for all locations. Like the 1990s low-rise MURB retrofits, 1990s mid-rise MURB retrofits that upgrade the mechanical systems result in either a minimal electricity use reduction or an increase in electricity use. This greatly diminishes achieved energy cost savings, and results in much lower NPVs than office archetypes, despite similar ICCs in many cases.

Although the deep retrofits for mid-rise MURBs involving space heating electrification often result in negative NPVs, the electrical and enclosure upgrades (without mechanical upgrades) for the 1970s archetypes all decrease electricity consumption, resulting in a positive NPV, with IRRs between 6.6% and 17.3% based on low ICC estimates.

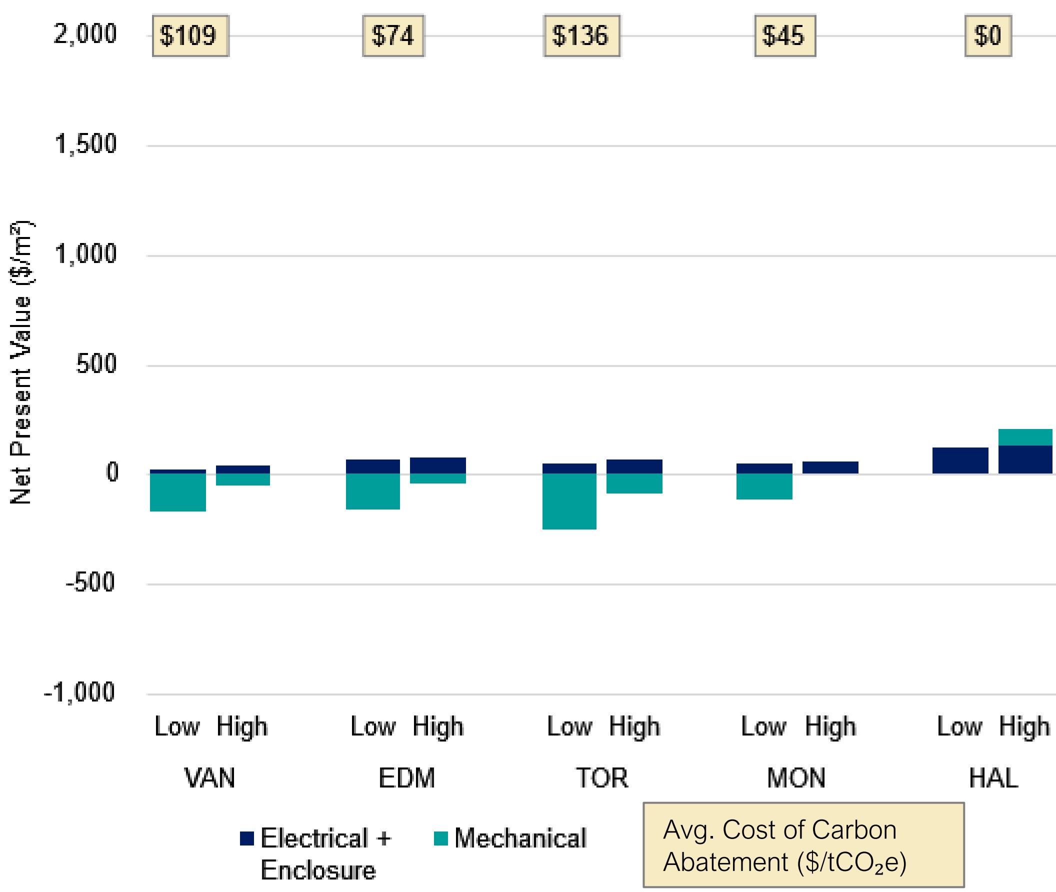


Figure 122. Net present value normalized per floor area for the 1970s mid-rise MURB deep carbon retrofits compared to the corresponding business-as-usual scenario. NPV for Mechanical refers to the NPV of the full deep retrofit include electrical and enclosure upgrades. Cost of carbon abatement is for the deep retrofit including mechanical upgrades.

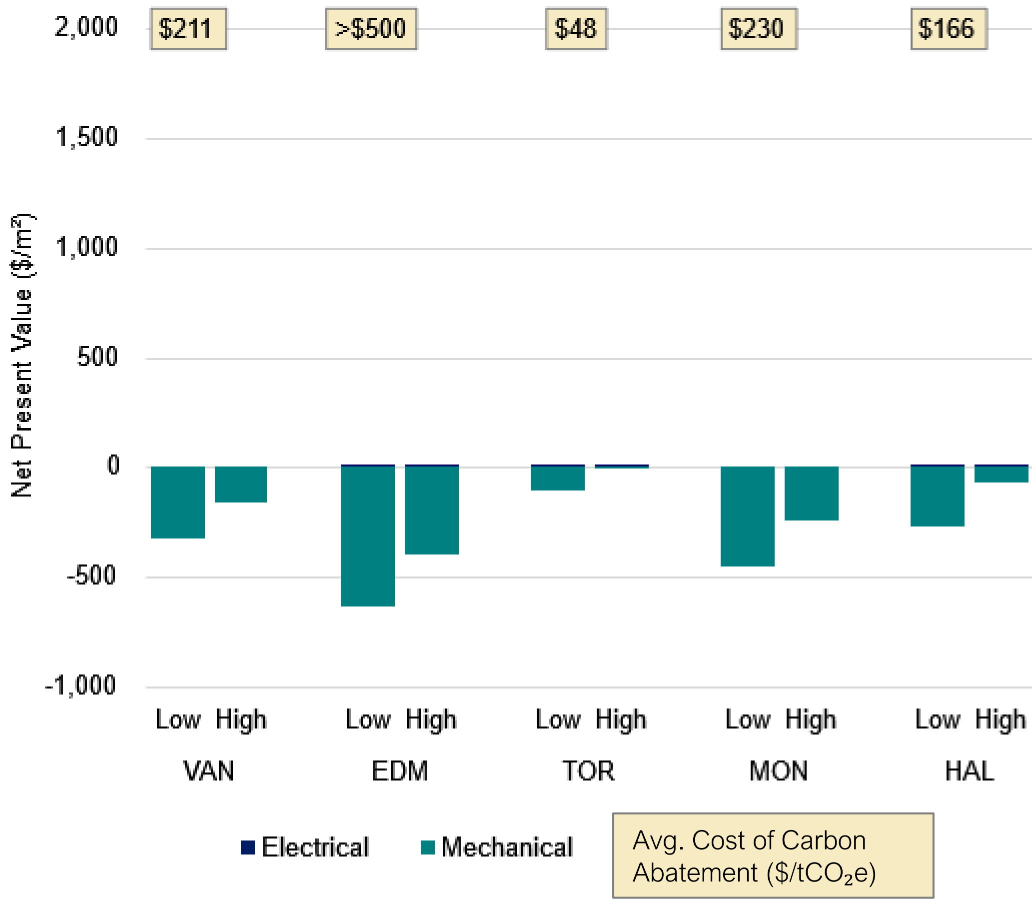


Figure 123. Net present value normalized per floor area for the 1990s mid-rise MURB deep carbon retrofits compared to the corresponding business-as-usual scenario. NPV for Mechanical refers to the NPV of the full deep retrofit include electrical and enclosure upgrades. Cost of carbon abatement is for the deep retrofit including mechanical upgrades.

5.1.5 – Primary School

Figure 124 and Figure 125 below show the calculated ICCs results for the 1970s and 1990s primary school deep retrofit packages, respectively. The ICC of the primary schools was least affected by vintage, because of different cost drivers. In addition to low-temperature baseboards and air-to-water heat pumps that similarly were key drivers for many of the other archetypes, heat pump rooftop air handling units (AHUs) and enclosure retrofits are just as important for the primary school. The AHUs are proportionally much larger than for the other building types due to large ventilation requirements, and enclosure retrofit costs are much greater due to the low, sprawling building form. As mentioned in previous sections, Edmonton and Toronto regional utility net metering allows large solar PV arrays to be installed when roof space is available. Although the large solar PV arrays in Toronto and Edmonton reduce operational energy costs, they increase ICCs by roughly $200/m^2 in those locations. The Toronto primary school archetype also has a large ventilation related cooling load, which further increases the size and cost of the replacement rooftop AHUs; although as part of this archetype retrofit, hydronic baseboards are replaced and a large solar PV array is installed, the rooftop AHUs replacement accounts for roughly two-thirds of ICCs.

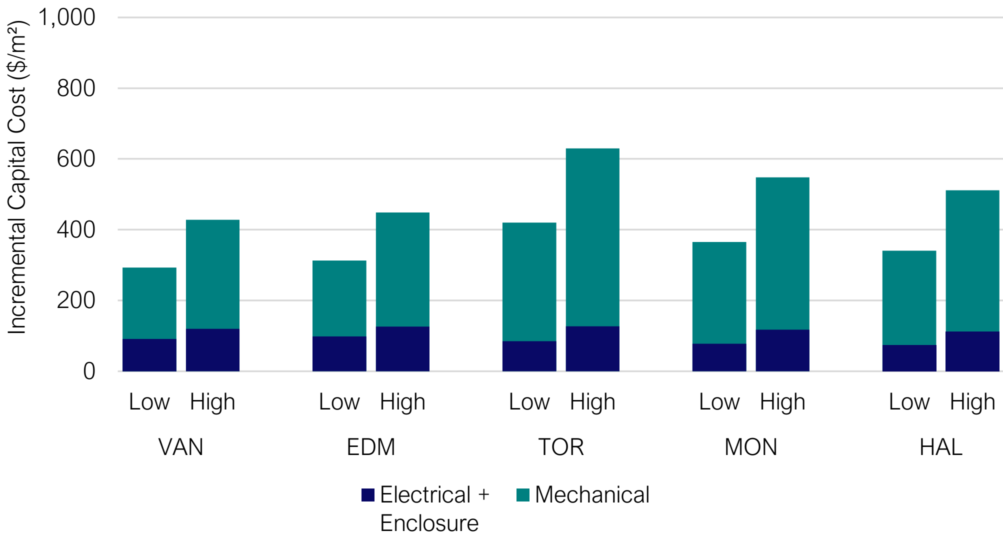


Figure 124. Incremental capital cost normalized per floor area for the 1970s primary school deep carbon retrofits compared to the corresponding business-as-usual scenario.

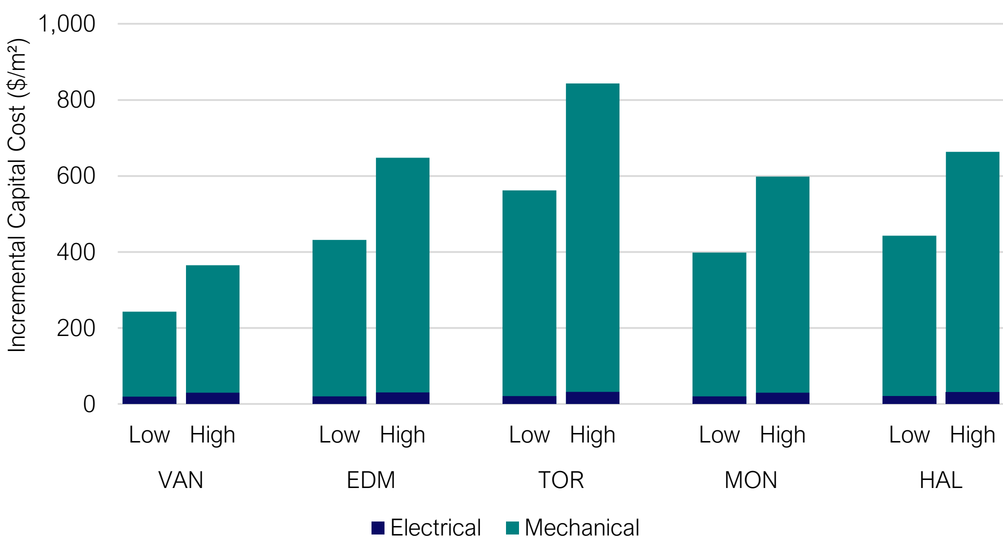


Figure 125. Incremental capital cost normalized per floor area for the 1990s primary school deep carbon retrofits compared to the corresponding business-as-usual scenario.

Figure 126 and Figure 127 below show the calculated NPV and the cost of carbon abatement results for the deep retrofit of the 1970s and 1990s primary school archetypes, respectively. The primary school retrofits result in a range of positive and negative NPVs depending on location and era of construction. The addition of PV impacts the associated ICCs and utility costs, depending on the size of the PV array allowed in specific locations and the base utility costs of the region. Including the installation of a solar PV array as part of the deep retrofit package has either a positive or negative impact on the NPV, depending on regional differences in utility prices and the amount of sunlight in a year. In locations with high electricity costs, such as Toronto, the inclusion of solar PV increases NPV values, while in locations with low electricity costs, such as Montreal, the inclusion of solar PV reduces the NPV values.

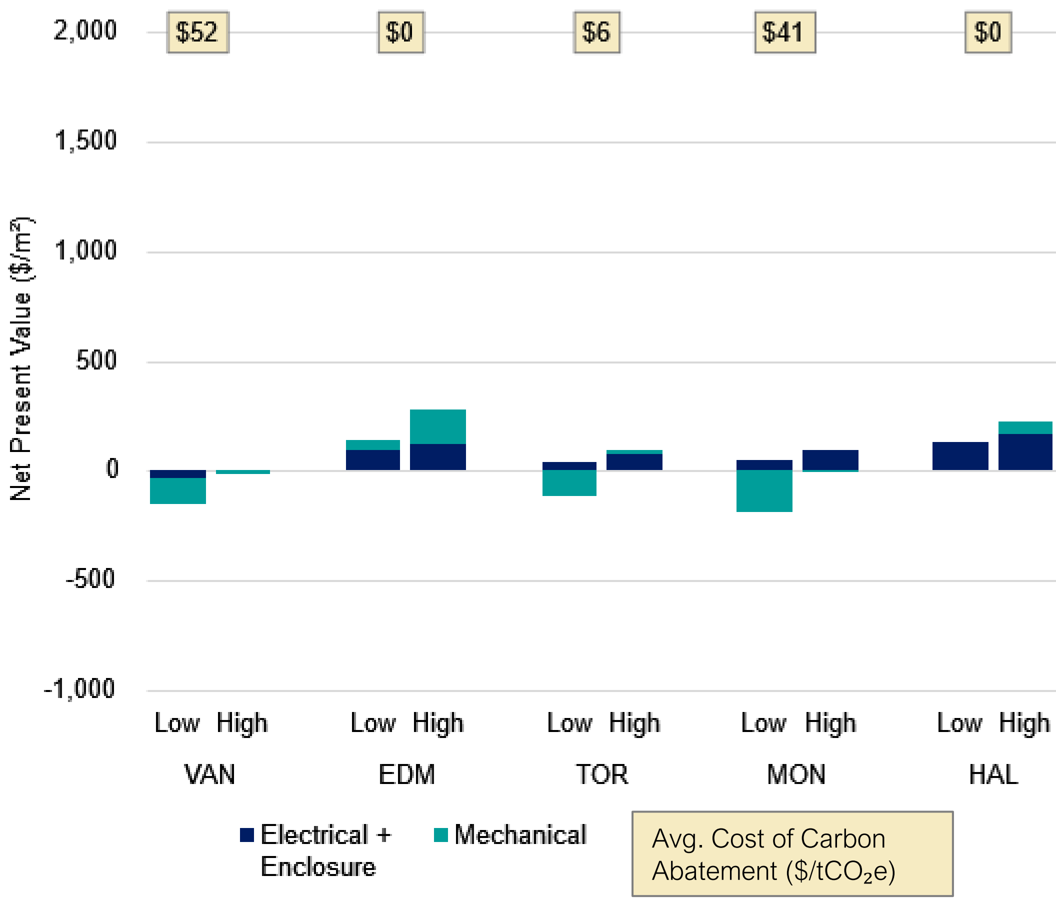


Figure 126. Net present value normalized per floor area for the 1970s primary school deep carbon retrofits compared to the corresponding business-as-usual scenario. NPV for Mechanical refers to the NPV of the full deep retrofit include electrical and enclosure upgrades. Cost of carbon abatement is for the deep retrofit including mechanical upgrades.

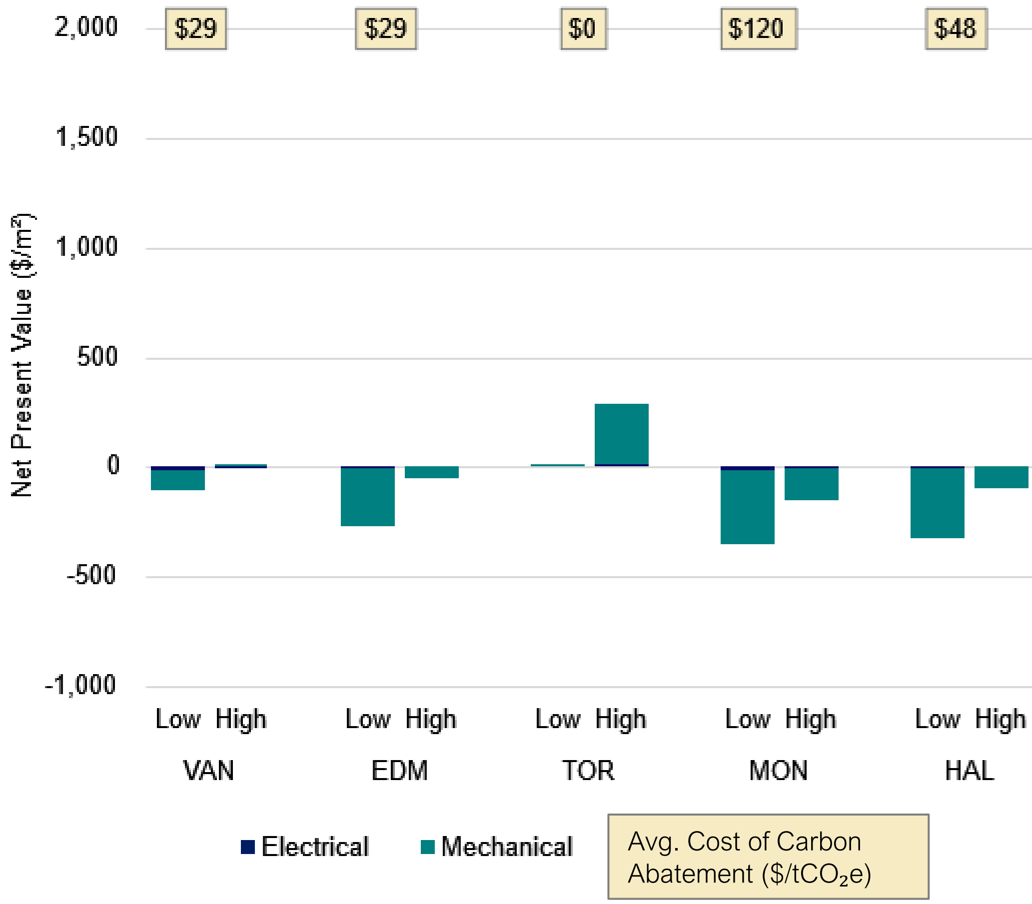


Figure 127. Net present value normalized per floor area for the 1990s primary school deep carbon retrofits compared to the corresponding business-as-usual scenario. NPV for Mechanical refers to the NPV of the full deep retrofit include electrical and enclosure upgrades. Cost of carbon abatement is for the deep retrofit including mechanical upgrades.

5.2 – Key Findings

- **It pays to reduce carbon for many archetypes today.** Nearly all the archetypes (45 of 50) achieved a positive internal rate of return, and 17 achieved a positive net present value. The business case for deep retrofits is only going to get stronger as technology advances and the cost of carbon pollution rises.

- **Reducing heating demand improves cost-effectiveness.** Retrofits that start with heating demand reductions are found to generally result in lower ICCs and higher NPVs. However, building condition and renewal schedules may dictate what retrofit strategies are most feasible and cost-effective at a given point in time.

- **Carbon abatement costs are in line with industry values for typical internalized carbon abatement costs.** A majority (32 of 50) of the archetypes had carbon abatement costs of less than $100/tonne, and only 5 archetypes had a carbon abatement cost of more than $300/tonne - a value sometimes suggested as the optimal threshold for driving decarbonization of the building sector across all market segments.

- **Office buildings are low hanging fruit.** Office archetypes typically include cooling and have higher baseline electricity usage than other archetypes. Some offices also have less efficient systems, such as dual-duct or constant volume with reheat. The result is that offices retrofits can yield greater electricity savings and result in a higher NPV.

- **Higher utility rates improve the business case for deep carbon retrofits.** Buildings in Halifax and Toronto may experience higher NPVs from deep retrofits due to above-average natural gas and above-average electricity prices, respectively.

- **Replacing natural gas boilers with air to water heat pumps (AWHPs) is a great fit for some archetypes.** When replacing boilers with AWHPs that deliver lower temperature water, upgrading the capacity of the hydronic terminal units can be one of the largest contributors to ICCs. However, 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), or if an enclosure deep retrofit is pursued, then costly upgrades of the terminal heating system may be avoided.

- **Financially, implementing deep decarbonisation retrofits will be the most challenging for MURB archetypes.** Deep carbon retrofits for almost all MURBs and primary school archetypes yielded negative NPVs, while office archetypes returned mostly positive NPVs. This is partially because retrofits of MURBs and schools do not reduce electricity use to the same degree as office building retrofits. That said, the incremental capital costs for MURBs and primary schools were similar or lower than those of other archetypes, especially in 1990s archetypes. Multi-family housing and primary schools are critical social infrastructure; as such, governments will need to develop specific policies and make strategic investments that support their upgrades and decarbonization.

- **The most critical building system upgrades are also the costliest.** Mechanical system upgrades, which provide electrification of heating and service hot water, are the most critical element of a deep carbon retrofit. However, these upgrades represent the costliest line item for most archetypes. New HVAC equipment typically represents more than 75 per cent of the total incremental capital costs needed for 1970s archetypes and more than 90 per cent for 1990s archetypes. This suggests that governments and owners will need to invest strategically in building mechanical system retrofits and space heating electrification, and optimize the sequencing of demand reduction activities (such as enclosure upgrades) to maximize cost effectiveness. It is worth noting that costly upgrades to terminal heating systems and distribution systems can sometimes be avoided, such as if fan-coils are already sized for cooling, or if an enclosure deep retrofit is pursued.

- Although deep enclosure retrofits can be costly, **the incremental costs are greatly reduced if the upgrades are implemented when renewal was already required** (as assumed in this analysis).

- **In many cases the ICC of a deep retrofit that includes enclosure upgrades is actually lower than the ICC without enclosure upgrades.** Enclosure upgrades minimize the size and cost of the air-to-water heat pumps (AWHPs). They also reduce the need to replace hydronic baseboards with larger capacity units to ensure proper operation with the lower temperature water provided by AWHPs (relative to boilers). Increased comfort, resilience and other benefits also flow from the enclosure upgrades.

- **Generally, the low-rise MURB retrofits have a lower ICC than office retrofits** because low-rise MURBs have a lower window to wall ratio and better insulated envelopes, which decreases the size of the ASHPs required.

- **Strategic investments will be needed to achieve low-carbon operations in primary schools.** Cost drivers for the primary school archetypes were different than those for other archetypes. On a per unit floor area basis, the ICCs for the primary school enclosure retrofits are higher due to a higher ratio of enclosure area to floor area. Rooftop air handling units (AHUs) are proportionally much larger than for the other building types. The proposed photovoltaic (PV) arrays were also a larger-than-usual cost driver for the primary schools located in regions where the full potential of the roof area could be used (utilities impose limits on the amount of solar PV that can be installed in some regions).

- **The deep retrofit of the 1970s low-rise offices results in some of the highest NPVs of any archetype** because of high energy savings and lower ICCs compared to other archetypes.

- The ability of solar PV to contribute positively to NPV is highly dependent on electricity prices and solar PV system size.

- **The business case for retrofits improves every year** due to the continuously rising cost of carbon: A project completed later than 2022 (the year of completion assumed for this study) will have a better NPV than reported in this study.

The following figures summarise the modelled results for the building archetypes in this study. Section 5.1.1 includes additional analysis of the results.

1970s Vintage Buildings

	Low-Rise Office 3,000 m²		Mid-Rise Office 21,000 m²		Low-Rise MURB 6,000 m²		Mid-Rise MURB 13,000 m²		Primary School 6,900 m²	
Vancouver	100%	$320	99%	$330	97%	$280	97%	$290	100%	$360
	-$160	1.4%	$210	8.4%	-$160	0.5%	-$110	2.4%	-$90	3.4%
Edmonton	84%	$390	62%	$440	61%	$330	44%	$295	100%	$380
	$620	12.2%	-$10	4.9%	-$140	2.2%	-$100	2.8%	$210	7.8%
Toronto	100%	$420	98%	$335	98%	$355	95%	$335	100%	$525
	$540	11.4%	$560	13.2%	-$170	1.7%	-$170	1.3%	-$10	4.8%
Montreal	100%	$340	100%	$475	96%	$300	98%	$270	100%	$460
	$180	7.8%	-$200	2.2%	-$230	-1.8%	-$60	3.5%	-$100	3.6%
Halifax	89%	$230	59%	$250	60%	$310	61%	$285	59%	$425
	$1,790	31.8%	$440	13.1%	$40	5.7%	$140	7.7%	$140	6.8%

GHGI Reduction	ICC ($/m²)
NPV ($/m²)	IRR%

Figure 128. GHGI reduction, incremental capital cost, net present value, and internal rate of return of the deep carbon retrofits in the 1970s vintage building archetypes.

1990s Vintage Buildings

City	Low-Rise Office 3,000 m²		Mid-Rise Office 21,000 m²		Low-Rise MURB 6,000 m²		Mid-Rise MURB 13,000 m²		Primary School 6,900 m²	
Vancouver	100%	$440	98%	$490	98%	$375	83%	$425	100%	$300
	-$260	0.6%	$110	6.3%	-$240	0.0%	-$250	0.6%	-$50	4.0%
Edmonton	59%	$885	67%	$585	39%	$540	23%	$595	99%	$540
	-$280	2.9%	$110	6.1%	-$440	-2.6%	-$520	-3.8%	-$160	3.1%
Toronto	100%	$420	97%	$725	98%	$285	93%	$265	100%	$700
	$310	8.9%	$420	8.2%	-$80	3.2%	-$60	3.6%	$150	6.3%
Montreal	99%	$860	100%	$690	98%	$525	97%	$515	99%	$500
	-$170	3.8%	-$90	4.2%	-$370	-0.7%	-$340	-0.3%	-$250	1.3%
Halifax	43%	$650	72%	$510	45%	$485	39%	$485	39%	$550
	-$260	2.3%	$570	10.5%	-$190	2.3%	-$170	2.6%	-$210	2.3%

GHGI Reduction	ICC ($/m²)
NPV ($/m²)	IRR%

Figure 129. GHGI reduction, incremental capital cost, net present value, and internal rate of return of the deep carbon retrofits in the 1990s vintage building archetypes.

6 Implementation Approaches and Policy Solutions

Leveraging the modelling results for the 50 building archetypes, this section presents implementation approaches and policy solutions for overcoming barriers to achieving deep carbon retrofits.

Implementation Approaches and Policy Solutions

Understanding the potential energy and GHG savings as well as the incremental cost and financial analysis of deep carbon retrofit projects across different building archetypes in different locations provides the foundation for policy makers and building owners to advance deep carbon retrofits. However, the current retrofit market will have to ramp up significantly in order to help reach climate targets. This will require novel implementation and policy solutions to address significant market barriers and increase retrofit activity.

Key Findings

- **Retrofits are a tough sell for many building owners – even for cost effective projects –** due to a range of economic, market and financial barriers.
- **Choose your procurement pathway wisely.** Retrofits can be implemented through various implementation pathways, which can have a profound impact on the retrofit project business case, with each providing a different level of flexibility, capital requirement, risk, benefit, and contract duration.
- **Key known barriers to retrofit implementation will be crucial to address early on.** To support deeper retrofit activity in existing buildings, some of the benefits to owners need to include no up-front payments, off-balance sheet treatment, passing costs to tenants, and guaranteed performance. The various alternatives to traditional owner-financed, design-bid-build procurement approaches reflect decades of effort to deliver and finance retrofits in a way that is most attractive to owners.
- **Traditional procurement approaches are not well suited for deep carbon retrofits.** Most retrofit procurement approaches are predicated on the assumption that retrofit savings will generate financial savings that will more than pay for the cost of financing. Therefore, the applicability of these approaches to achieving deep carbon retrofits will depend substantially on how well carbon savings align with financial savings and on external funding support availability.
- **Policy tools are needed** to overcome economic, market and financing barriers. There are many policy tools to help overcome these barriers, including regulatory, financing, and other strategies such as education and capacity building.
- Although several policy and financing tools have slowly started to emerge across Canada, there are significant gaps and most initiatives to date have **focussed on energy savings rather than GHGs.**
- **Instituting mandatory performance targets for existing buildings will be critical** for driving demand for and implementation of retrofits to help meet climate targets.

6.1 – Barriers to Deep Carbon Retrofits

There are a wide range of barriers preventing the uptake of retrofits at the pace and depth required to help meet Canada's climate change mitigation targets. Even for cost-effective projects, these barriers can be perceived as insurmountable. 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 retrofit projects that achieve deep carbon emissions reductions and a range of other social and environmental benefits, such as improved air quality and increased affordability. 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.

Summarized below are some of the most well-known economic, market, and financial barriers to implementing deep carbon retrofit projects.

Economic Barriers	Market Barriers	Financing Barriers
• Misalignment between carbon savings and energy savings • Long payback periods • Large incremental capital cost requirements	• Lack of energy or carbon awareness • Low return on investment and implementation hassle • Cost-saving split incentives • Lack of confidence in project performance and results • First-mover disadvantage, technological and logistical readiness	• Lack of access to attractive financing • Uncertainty with developing standard investment risk profiles • High loan transaction costs • Availability of secured, on-balance sheet debt

Some barriers are particular to deep carbon reduction retrofits, and some are common across many types of construction activity. To successfully move the building industry towards zero carbon operations, it is crucial to review and to clearly understand the most important barriers that are specifically problematic for deep carbon retrofits.

6.1.1 – Economic Barriers

First and foremost, the biggest barrier to deep carbon retrofits is financial viability for building owners.

While many energy saving measures generate a positive return on investment, deep carbon retrofits typically have a more challenging business case. Carbon savings do not always translate to cost savings. This alignment or misalignment is highly dependent on the cost and carbon intensity of the various energy sources and on the carbon pricing structure, which varies substantially across provinces as discussed in the previous sections. For instance, a building will reduce its carbon emissions by changing from burning natural gas for heating to using electric heat pumps. However, in some areas, it could be more expensive currently to operate that building with heat pumps due to the higher cost of electricity relative to natural gas, unless the replacement is paired with demand reduction energy efficiency measures.

As described in Section 4, **results from the financial analysis reveal that deep carbon retrofits can achieve a positive business case for several building types by bundling relevant measures together with key building renewal cycles.**

The financial viability of a deep carbon retrofit project depends on several overall factors that are detailed further below.

Misalignment Between Carbon Savings and Energy Savings

Energy cost savings do not always align with carbon savings. As a result, the cost-effectiveness of deep carbon retrofits varies.

To determine the cost-effectiveness of deep carbon retrofits for the chosen archetypes, the study analyzed the NPV by calculating today's value of forecasted revenue from energy savings.[36] A negative NPV indicates that the internal rate of return is less than the discount rate applied (5%). Figure 130 summarizes the findings and highlights the challenges that can be encountered by some archetypes.

Deep carbon retrofits are viable right now for many low- and mid-rise office archetypes, as well as a few MURBs and primary school archetypes (17 of the 50 archetypes). This highlights how "quick wins" could kickstart the decarbonization retrofit market.

In most cases where the models returned a negative NPV, the IRR was positive (i.e., between 0% and 5%). In other words, owners would see a positive financial return, but less than the estimated cost of capital or borrowing rate. Positive internal rates of return were achieved for 45 archetypes.

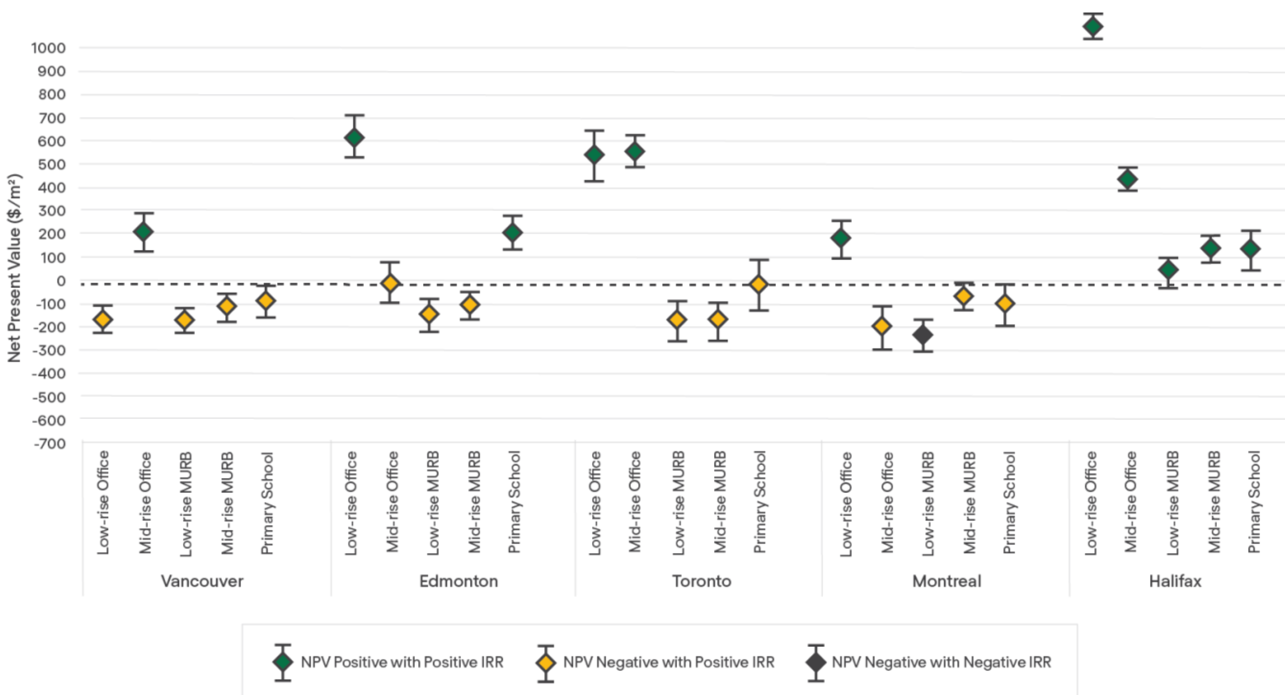
The financial analysis shows that deep carbon retrofits can be achieved cost-effectively by targeting key timing (equipment renewals) and sequencing opportunities (load reduction measures first) for some building archetypes. More specifically:

- **Low-rise and mid-rise offices built in 1970s can achieve attractive levels of cost-effectiveness** that are high enough to show great alignment between carbon savings and energy cost savings.
- **Substantial and strategic investments will be required** to improve the cost-effectiveness and viability of deep carbon retrofit projects in most multi-unit residential building (MURB) and primary school archetypes given the current divergence of carbon and cost savings for those archetypes.
- **The business case for retrofits will improve every year** due to the planned continuous rising cost of carbon pollution. A project completed later than 2022 will have a better NPV than reported in this

[36] Timeframe of 40 years with a discount rate of 5%.

study, which will lower the impact of this market barrier but will delay the realization of emissions reductions.

1970s Vintage Buildings



1990s Vintage Buildings

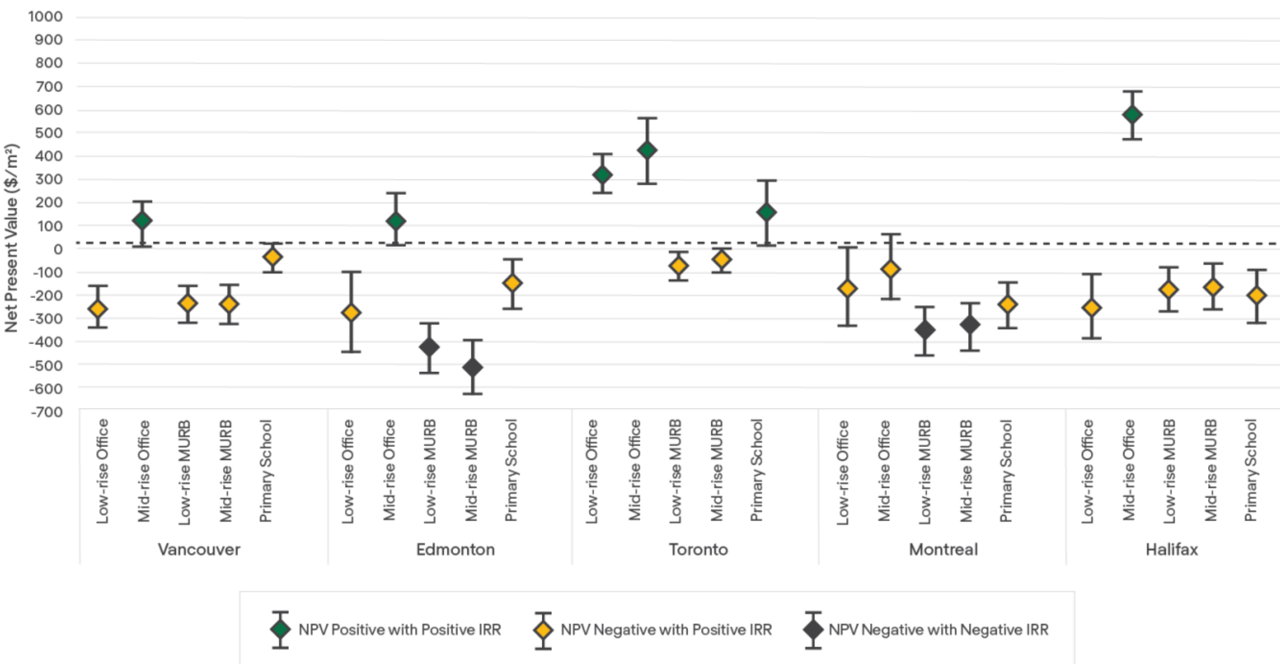


Figure 130. Net Present Value ($/m²) of the Deep Carbon Retrofit with Solar PV Scenario by Archetype (relative to BAU Scenario)

In evaluating deep carbon retrofits, it is important to remember that the goal is to reduce carbon emissions. Another key metric for evaluating projects is therefore the cost of carbon abatement (CCA). It represents the amount of funding that is required to off-set any the additional life-cycle costs of the carbon reduction measures.

The capital needed to address the investment gap is generally aligned with industry values for typical internalized carbon abatement costs. A majority (32 of 50) of the archetypes had carbon abatement costs of less than $100/tonne, and only five archetypes had a carbon abatement cost of more than $300/tonne.

	Low-rise Office	Mid-rise Office	Low-rise MURB	Mid-rise MURB	Primary School
1970					
Vancouver	$374	$0	$252	$109	$52
Edmonton	$0	$2	$78	$74	$0
Toronto	$0	$0	$140	$136	$6
Montreal	$0	$169	$378	$45	$41
Halifax	$0	$0	$0	$0	$0
1990					
Vancouver	$377	$0	$248	$211	$29
Edmonton	$63	$0	$371	>$500	$29
Toronto	$0	$0	$68	$48	$0
Montreal	$45	$41	$260	$230	$120
Halifax	$116	$0	$156	$166	$48

Table 12: Cost of Carbon Abatement per Archetype ($/t$CO_2$e)

Long Payback Periods

Forty-five of the 50 studied building archetypes reveal discounted payback periods greater than 15 years. Only low-rise offices in Halifax offer a payback period of fewer than five years (as shown in the table below). The unconventionally long payback period highlights the need for new and innovative approaches to assess carbon reduction investments and evaluate the financial viability of deep carbon retrofit projects. It also underscores the need for owners to schedule their deep carbon retrofit projects in conjunction with regular upgrades to minimize costs and to search out sources of more patient capital. Remember, the average building will be around for a century.

Table 12: Discounted Payback Period

	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

Large Incremental Capital Costs

Building owners must manage and secure the needed incremental costs as compared to BAU to undertake deep carbon retrofits. Based on the financial analysis, incremental costs for completing the deep retrofits varies between $210/m² and $1,060/m² (as shown below), which can be a barrier for some building owners, even in situations where there is a good return on investment.

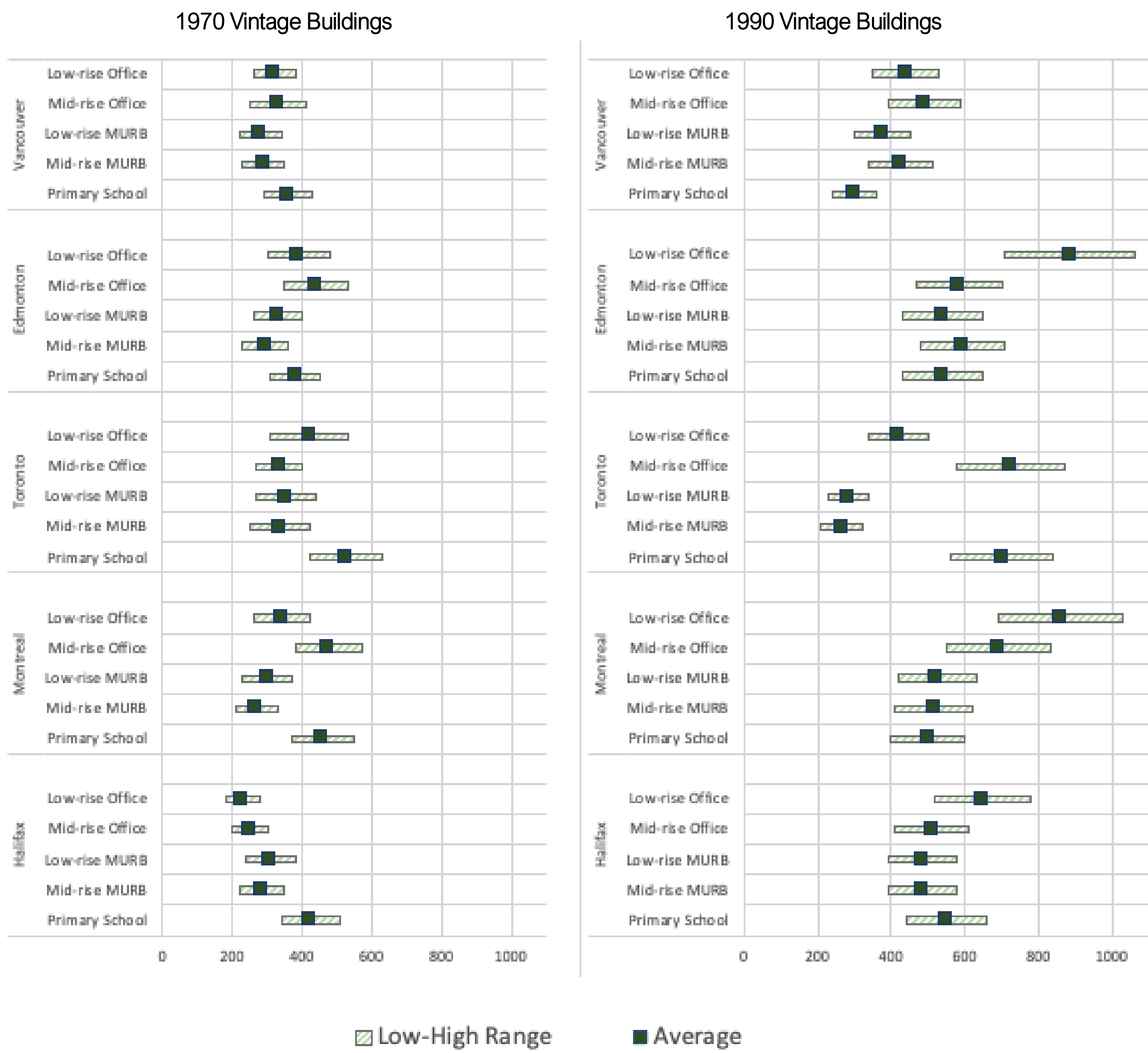


Figure 131. Incremental Capital Cost ($/m²)

6.1.2 – Market Barriers

In addition to economic barriers, there are significant market barriers preventing the widespread adoption of deep carbon retrofits. Even with an attractive business case, these additional barriers can be strong enough to prevent a building owner from moving forward.

Lack of Energy or Carbon Awareness

Across all building archetypes studied, managing energy and carbon emissions is not typically part of the core business of building owners. The cost of energy is not a large operational expense in comparison to others so even a major decrease in energy usage is unlikely to have a significant impact on operating costs. Many architects, engineers, contractors, and building operators understand standard energy saving measures to employ, but very few are experts on the benefits associated with deep energy retrofits partly due to the current lack of significant market demand.

Carbon emissions considerations are facing similar hurdles especially for measures less aligned with financial savings. Energy may be a small item on balance sheets, but at least it is present. In contrast there are currently no expense lines and payables for building carbon emissions, apart from direct carbon taxes in some jurisdictions. Some of the largest owners show increased attention to carbon emissions due to investor and Class A tenant priorities, but the typical owners and building professionals are not focused on building carbon emissions.

Energy Star Portfolio Manager

You can't manage what you can't measure. ENERGY STAR Portfolio Manager provides a platform for tracking energy efficiency in buildings. Input information includes building size, space usage, number of computers (for office buildings) and data on energy usage (updated by the owner or utility). Owners can use Portfolio Manager to track annual performance, set carbon and energy targets, and assess usage relative to the owner's portfolio or a national sample of similar buildings, using the 1-100 ENERGY STAR score rating or EUI median values.

Low Return on Investment and Implementation Hassle

The financial return on CRM investments – in absolute dollars and return on investment (ROI) – relative to the effort do not always compare well to other building improvement investment opportunities. A retrofit may have a positive ROI, but with a relatively small operating expense the absolute savings may not be substantial. Other investments, such as building tenant improvements, may offer a much more attractive return in comparison. Also, the retrofit complexity and hassle will heavily weigh in the owner decision to go forward or not. More broadly, deep retrofits mean construction activity. Most owners/managers will avoid the mess and trouble of construction if they can avoid it, whether for themselves or for their tenants.

This is particularly relevant for MURBs (especially low-rise), primary schools and the 1990s office buildings, which have low or negative returns on investment. However, by focusing on implementing upgrades when renewals are already required (as assumed in this analysis), the hassle barrier can be greatly reduced. Moreover, incremental costs can also be lowered for some archetypes thanks to the enclosure upgrade being implemented before HVAC upgrades.

Cost-saving Split Incentives

In some cases, the benefits of energy bill savings may not accrue to the party who paid for the retrofit improvements, such as when a landlord upgrades a suite-metered rental apartment. This barrier to deep carbon retrofits can take on various forms within each market segment:

For office and MURB archetypes the split occurs between the landlord and tenant. If the tenant is responsible for paying some or all of the utilities, the landlord bears none (or just a portion) of the energy operating costs and therefore has limited incentive to invest and reduce. If the landlord pays the utility bills and has an incentive to lower those costs, the tenant has no direct incentive to modify their behaviour, thus cutting into the potential energy savings. Under standard “triple-net” commercial leases, owners may actually make *less* money if they work to reduce energy costs for their tenants. Under these leases, owner management fees are a percentage of the building operating costs – the lower those costs, the lower the management payment.

For the primary school archetype, implementation of major energy retrofits often requires cooperation from multiple departments/divisions within a public organization. Different departments may have different priorities and incentives, which may conflict (e.g., minimize capital expenditures and improve energy efficiency). Utility cost savings may not flow to the division that occupies or operates the building(s), limiting the incentive to support a retrofit.

Lack of Confidence in Project Performance and Results

Across all building archetypes, building operators often lack awareness of the potential energy cost savings from energy efficiency investments. Although some CRMs identified in the analysis have proven their ability to reduce energy consumption and GHG emissions, these measures might still face general skepticism or reluctance from building owners and building professionals not accustomed with them.

Furthermore, the non-energy benefits (health and comfort, employee productivity, impact on building value, etc.) are difficult to monetize, and as a result are often overlooked or undervalued across all market segments. Often, building operators perceive retrofit savings as overrated and higher risk. And traditionally, building improvements are financed by building owners, leaving them exposed to performance risk.

Owners also do not typically share performance data on their projects, contributing to lack of industry confidence in retrofit opportunities. Given that the increased focus on carbon emissions is relatively recent, emissions performance data from retrofits is even more rare. Greater emphasis on standardization of data and reporting could play an important role in reducing this barrier.

First-Mover Disadvantage, Technological and Logistical Readiness

Even if owners have confidence that deep energy and carbon retrofits deliver on projected savings, undertaking a deep retrofit may involve using unfamiliar methods or technologies on their buildings. The construction techniques, materials, and equipment used in deep energy retrofits can be different from conventional projects, leaving owners and other market actors uncertain about the impact on longevity, maintenance, and building performance. Building owners and managers typically prefer technologies and approaches that they have used or seen before.

Moreover, while our modelling only considered available technologies, a significant market transition towards decarbonization could potentially create product availability challenges if the manufacturing industry is not well-prepared.

6.1.3 – Financing Barriers

Barriers to retrofit financing are faced by owners and lenders. Lenders can be wary of offering financing for energy efficiency, and owners can be reluctant to seek this financing even when it exists. Meanwhile, there is a limited track record of financing carbon retrofits.

Lack of Access to Attractive Financing

While access to inexpensive capital is not a challenge for many building owners, especially for Class A buildings, financing options are not well suited to deep carbon retrofits, which can involve novel new approaches and long payback periods. Loans outside of a mortgage have higher comparable rates and may not be permitted under the terms of the primary mortgage. Innovative financing like commercial property-assessed clean energy (C-PACE) and on-bill financing (OBF) are not yet available in most cities and provinces. There are few examples of pay for performance energy service agreements (ESAs) and managed energy service agreements (MESAs) in Canada. Before the Canada Infrastructure Bank program launched in 2021, there was no retrofit financing specifically targeted for carbon retrofits.

Furthermore, private sector lenders may be reluctant to develop new financing offers for deep carbon retrofits if there is not enough demand.

Uncertainty with Developing Standard Investment Risk Profile

For retrofits to become an investible asset class, there needs to be a known risk profile. However, it is challenging for lenders and owners to assign a risk profile to carbon retrofits given the limited amount of data available on carbon reduction specific retrofit project costs and savings, as well as varying levels of carbon emissions liability used. The information that is available is difficult to utilize because the retrofit industry does not generally follow standardized data collection and tracking methodologies.

Investor Confidence Project (ICP)

ICP is a series of protocols that help to standardize calculations and planning to track energy savings. In doing so, it helps to address the uncertain risk profile of retrofit projects. The Canada Infrastructure Bank adopted ICP as part of its technical due diligence requirements under its retrofit financing program.

High Loan Transaction Costs

Most real estate lending is for the construction, purchase, or refinancing of a building. The size of the loans is often for a substantial portion of the value of the building. The amount of financing required for even a substantial energy or carbon retrofit project will be modest in comparison. Yet, the transaction costs may be as high or higher than for larger, standard loans – this makes financing energy or carbon efficiency projects comparatively less attractive for all parties.

Availability of Secured, On-Balance Sheet Debt

Buildings have balance sheets showing their assets relative to their liabilities. The lower the debt on a building, the better its cash flow (since there is less loan to service), the more room there is for additional borrowing, and the better its borrowing rates.

Typical loans show up on the balance sheet, and so are less attractive to owners. Whether an energy or low-carbon retrofit loan is rolled into a building's larger mortgage, added as a second or third mortgage, or is a lien on equipment, it will increase the building's leverage (debt to equity) ratio. Such loans will compete with the building's core business and decrease net cash flow.

6.2 – Deep Retrofit Strategies – Implementation and Procurement Solutions for Building Owners and Operators

Effective implementation and procurement strategies for building owners and operators can help overcome some of the barriers to deep carbon retrofit projects. The benefits of these approaches can include no up-front payments, off-balance sheet debt treatment, passing along some of the costs to tenants, and guaranteed performance. These implementation pathways each provide a different level of flexibility, capital requirement, risk, benefits, and contract duration and can have a profound impact on the business case by:

- Reducing administrative burden and addressing lack of knowledge and capacity
- Reducing project transaction and capital costs and increasing access to attractive financing
- Reducing building owner risk
- Addressing split incentives

It is important to keep in mind that up to now the retrofit industry has been geared mostly towards 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 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.

Since low and mid-rise office buildings built in 1970s in Halifax and Toronto have the lowest payback period (see Table 12), they are particularly well suited for the approaches presented in this section. Additionally, when owners control their own financing, such as traditional financing, commercial property-assessed clean energy (C-PACE), and on-bill financing (OBF), they will have more flexibility to invest as they see fit (though OBF-funded measures typically must meet an energy reduction cost effectiveness test). In comparison, the depth of energy performance contract (EPC), energy service agreement (ESA), and managed energy service agreement (MESA) projects will be limited by the financial returns for the providers, which will depend on their cost of capital and cost of performance insurance.

Table 13 provides a comparison between the different methods and financing tools. One notable missing consideration in the Table is whether costs can be passed along to tenants. Since this is dependent on the tenant's lease, it is hard to generalize on this issue. However, costs from C-PACE, On-Bill-Financing, and MESAs are considered easier to pass on to tenants because they are paid via property taxes and utility payments, expense items that are commonly passed to tenants.

Table 13: Comparison of Project Financing and Project Delivery Combinations

	Characteristic	Traditional Owner Financing	Innovative Owner Financing		Pay for Performance		Other [37]
		Out of Pocket or Borrowing	Commercial Property Assessed Clean Energy (C-PACE)	Property On-Bill Financing / Repayment	Energy Services Agreement	Managed Energy Services Agreement	Energy Performance Contract
Core Attributes	Project Delivery Method	Typically Design-Bid-Build	Typically Design-Bid-Build	Typically Design-Bid-Build	DBOM	DBOM	Energy Performance Contract
	Performance Risk	Borne by owner	Borne by owner	Borne by owner	Borne by provider	Borne by provider	Borne by provider
	Typical Project Size	Any	Small to large	Small to medium	Large to very large	Large to very large	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 multi-unit residential buildings (MURBs)	Not suited for large projects	Typically, only viable in leased space if contract term does not exceed the lease term	Typically, only viable in leased space if contract term does not exceed the lease term	Typically, only viable in leased space if contract term does not exceed the lease term

[37] While Energy Performance Contract is a project delivery mechanism, occasionally energy service companies (ESCOs) facilitate financing if required by the client. The retrofit provider may directly fund the project or offer support in accessing other funds and subsidies to defray the improvement costs.

	Characteristic	Traditional Owner Financing	Innovative Owner Financing		Pay for Performance		Other [37]
		Out of Pocket or Borrowing	Commercial Property Assessed Clean Energy (C-PACE)	Property On-Bill Financing / Repayment	Energy Services Agreement	Managed Energy Services Agreement	Energy Performance Contract
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	Fixed payments (if savings minimum achieved)
	Collateral	Building	Tax assessment lien	Equipment; service termination	Equipment	Equipment	Depends on financing
	Typical Balance Sheet Treatment	On balance sheet	Inconclusive; potentially some off-balance sheet treatment	Inconclusive; potentially some off-balance sheet treatment	Off balance sheet [38]	Off balance sheet	On balance sheet
	Typical Duration	Varies	10-20 years	2-15 years	5-15 years	5-15 years	5-20 years
Administration	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)

[38] It should be noted that off balance sheet treatment is not permissible in Quebec and may not be permissible in other provinces.

6.2.1 – Steps for Implementing and Procuring Deep Carbon Retrofits

There is no “one size fits all” solution for implementing and procuring a deep carbon retrofit project for the building archetypes discussed in this report. But there is a common best-practices approach that all building owners and operators should follow to help ensure success.

This approach can be divided into 6 key steps, outlined in Figure 132. This Section provides guidance to building owners by highlighting these steps and by helping them understand the applicability of the different procurement pathways and options available considering their specificities and cost-effectiveness. A particular emphasis is given to project delivery and financing methods due to the importance of understanding these alternatives in the decision-making process.

Figure 132. Steps for Achieving Deep Carbon Retrofits

NRCan Major Energy Retrofit Guidelines

NRCan has developed guidelines for implementing deep energy retrofits. The goal of the “Major Energy Retrofit Guidelines” modules is to provide an overview to identifying and implementing a major retrofit depending on the building type.

Step 1. Establish Goals

An essential element of any complex building project is to establish clear, measurable goals. This step provides direction and ensures that all parties, including senior management, staff responsible for energy and sustainability, accounting, and consultants all work towards the same objectives.

These goals should reflect organizational values and operational realities and it should define key target metrics including (1) specific carbon reduction targets (short-term and long-term), (2) financing and return on investment boundaries and (3) standards to evaluate performance.

Owners might choose to follow pre-established goals such as the Zero Carbon Building Standard or to develop more bespoke goals following an analysis of their portfolio.

Net Zero Carbon Buildings Commitment

Organizations that control over 32 million square meters of building spaces have signed onto the World Green Building Council's Net Zero Carbon Buildings Commitment. Signatories, including 109 businesses and organizations, commit to operating at net zero for all assets under their direct control.

Step 2. Understand Current Building Operations

For existing buildings, any deep carbon retrofit should be based on a thorough knowledge of the building's current conditions including site specificities, building systems, occupant use patterns, on-site solar PV potential, and planned infrastructure renewal schedules. While the archetypes studied are representative of common construction, systems, and practices across Canada, each building is unique and requires individual assessment.

Owners should first ensure that all relevant building information is collected and that building operational parameters that can affect energy use are carefully tracked. Once completed, owners can track building energy use and carbon emissions and compare them to buildings within or outside of their portfolio. Benchmarking for commercial and institutional buildings, such as offices, multi-unit residential buildings (MURBs), and schools is typically accomplished using the ENERGY STAR Portfolio Manager benchmarking tool.

Building owners still new to energy management best practices can benefit from onsite Energy Managers. Energy Managers are becoming more common in Canada, their role is to take a strategic approach to meet the company climate goal objectives and provide benefits to the company by identifying key energy savings opportunities. They also improve the internal practices of occupants by engaging with them on a regular basis.

Step 3. Develop a Zero Carbon Transition Plan

Implementing deep carbon retrofits cost-effectively requires careful planning. Sophisticated owners already plan for replacement of major building systems and opportunities for efficiency, but long-term deep retrofit plans remain rare and seldom include carbon reduction objectives. Achieving deep carbon savings relies on having a zero carbon transition plan in place for the building that outlines a series of building improvements and the situations that may trigger them, whether lease turnover or major equipment replacement. This way, there is a pre-defined set of retrofit actions to follow various triggers that an owner can draw from and point their contractors to.

Zero Carbon Building Standard

The Zero Carbon Building Standard, developed by the CaGBC, offers pathways for buildings to reach zero carbon and is specifically designed to meet the needs of Canada's real estate industry. The certification covers both new and existing buildings and is applicable to all buildings except homes and small multi-family residential buildings.

Key components of an effective zero carbon transition plan can include:

- **Align retrofits with key building system renewal cycles** to reduce incremental capital costs and increase operational savings. As described in Section 2, there are major milestones that directly impact the cost-effectiveness of retrofits, which is the reason why this study specifically targeted these trigger events. These decisive moments must be clearly identified in the zero carbon transition plan to make sure that the building owner is ready when the time comes.

- **Plan for proper sequencing of CRMs**. As described in this report, any HVAC upgrades, especially high-capital carbon-reduction measures, should always be preceded by measures that can reduce energy loads if possible, including improving building envelopes, lighting upgrades, and plug load reduction.

- **Management & ownership cycles impacts should also be considered**. While there is an ideal flow for carbon reduction measures based on system service life, in practice the timing of a retrofit sometimes has little to do with operational considerations. Instead, the biggest opportunities for carbon savings can arise during major events in building management and ownership, including tenant turnover, sale, or re-positioning of a building, or non-energy building refurbishment.

Step 4. Define Delivery Methods

Owners need to determine how they will design, implement, and finance the retrofit. There are many ways for an owner to procure carbon retrofits through different combinations of contracting (or "project delivery") and financing methods. Procurement approaches can have a profound impact on the business case, with different levels of risk, capital requirements, benefits, and balance sheet treatment. The first step is to choose the delivery method best tailored to the project characteristics, including owner willingness to take on project risks, project costs, funding and complexity, scheduling needs, and the required level of expertise.

There are several methods to deliver construction projects, but the most common ones for energy/carbon reduction retrofits can be divided into the following three methods:

- **Design-Bid-Build.** This represents the traditional approach to construction: owners first hire a design firm to create project designs and then bid out the work for a contractor to implement the design.
- **Design-Build and Design-Build-Operate-Maintain (DBOM).** These are turnkey project delivery methods that combine traditionally separate services under one fixed-fee contract. A single entity is responsible for project design and construction (Design-Build) and in some cases subsequently operates and maintains the building systems (DBOM).
- **Energy Performance Contracts.** Design-Build or DBOM turnkey project delivery can be combined with an energy performance guarantee. The value of energy savings is shared between the building owner and retrofit provider, with energy cost savings over time expected to be greater than the "loan" amount to pay for the work. If the project fails to achieve the minimum savings the provider pays the difference to the client. Since the EPC financing model is based on financial savings from energy consumption, EPCs do not translate directly to GHG savings as greater GHG savings may not provide the greatest financial savings. However, GHG savings requirements could be built into the project's requirement at the RFP stage, forcing energy service companies (ESCOs) to find the most cost-effective ways to reach the required GHG reductions. Including GHG emissions reduction requirements within EPC contracts would help to align ESCO financial motivations with carbon reductions.

While design-bid-build is suitable to any project, design-build and DBOM typically target larger projects such as the modelled mid-rise office and MURB archetypes. For contractors to take on the risk of cost overruns and design changes under design-build and DBOM, they tend to seek larger projects that can warrant the greater analysis and transaction costs entailed. For similar reasons, EPCs are typically only seen in larger projects, even though other factors impact the appropriateness of EPCs. In the future, with policy supports and other mechanisms, design-build and DBOM providers may be able to target smaller buildings with similar characteristics as well.

The advantages and disadvantages of these project delivery methods are summarized below in Table 14.

Table 14: Key Pros and Cons of Project Delivery Methods

	Design Bid Build	Design Build and Design Build Operate Maintain	Energy Performance Contract
Responsibility for Cost Overruns	Owner	Provider	Provider
Responsibility for Energy Performance Risk	Owner	Owner	Provider
Lower Cost	◒	○	○
Faster Schedule	○	●	●
Greater Choice of Providers	●	◒	○
Fewer Change Orders	○	●	●
Ease to Optimize for GHG Rather Than Energy Reductions	●	●	◒

● Always present
◒ Sometimes present
○ Absent

Step 5. Explore Project Financing Options

The project delivery methods discussed above can be combined with different forms of financing. Owners who arrange their own financing can pay out of pocket (business-as-usual) or take advantage of emerging innovative financing options. Providers of turnkey contracts can take the concept of the performance guarantee in an EPC one step further by financing retrofits entirely through energy savings with no up-front costs or risk to owners (Energy Savings Agreements and Managed Energy Savings Agreements). Some financing options are listed and further detailed below:

- **Traditional Owner Financing:** Out of Pocket or Traditional Borrowing.
- **Innovative Owner Financing:** Commercial Property Assessed Clean Energy (C-PACE) & On-Bill Financing / Repayment (OBF/OBR).
- **Pay for Performance:** Energy Services Agreements (ESA) and Managed Energy Services Agreements (MESA).

Table 15 summarizes the relative applicability of project financing methods and EPCs.

Table 15: Applicable Markets for Project Financing Methods and EPCs

Building Features	Traditional Owner Financing	Innovative Owner Financing		Energy Performance Contract		Pay for Performance
	Out of Pocket or Traditional Borrowing	**C-PACE**	**On-Bill Financing / Repayment**	**Energy Performance Contract**	**Energy Services Agreement**	**Managed Energy Services Agreement**
Large	●	●	○	●	●	●
Small	●	○	●	○	○	○
Owner-Occupied	●	●	●	●	●	●
Leased	●	●	◒	◒	◒	◒
Public	●	○	○	●	●	●
Private	●	●	●	●	●	●

● Possible, with many existing programs
◒ Possible, with few existing programs
○ Theoretically possible

Canada Infrastructure Bank: A New, Transformative Retrofit Investor

In March 2021, the Canada Infrastructure Bank (CIB) launched the Building Retrofit Initiative, which includes a stream for privately-owned commercial buildings and a stream for publicly owned buildings. The CIB offers long-term, below market interest rate loans for building retrofits that substantially reduce GHG emissions. Financing is available for large individual projects, or a pool of projects from retrofit aggregators like energy service companies (ESCOs).

The program requires that all projects target a minimum of 30% GHG savings, while offering more favourable financing terms (cheaper capital and longer payback periods) for projects that target deeper savings. Based on the analysis in this report, savings much greater than 30% are possible, indicating that projects should be able to obtain favorable financing terms.

With a minimum deal size of $25 million, most owners will likely participate in the initiative indirectly through retrofit project aggregators like ESCOs and Super ESCOs.

1. Traditional Owner Financing

Owners typically pay for energy retrofits out of pocket or will sometimes incorporate costs into broader, standard financing when the retrofit is substantial or part of a larger building renovation. For whole-building retrofits, owners may seek a construction bridge loan.

> **VanCity Community Investment Bank**
>
> Unusual among lenders, VanCity offers dedicated commercial financing for building energy efficiency retrofits, renewable energy and storage, and geoexchange heating and cooling systems.

Some banks and credit unions offer lending specifically for energy savings projects. In the future, more of these products may emerge, spurred by the growing commitment of banks to directly support climate change mitigation action and greater levels of climate risk disclosure. In addition, the Canada Infrastructure Bank offers a financing route to owners with very large projects (at least $25 million).

Traditional owner financing can be combined with any project delivery mechanism.

Pros

- With out-of-pocket cash, no time is lost securing financing and there are no new contracts or encumbrances on the building.
- With financing rolled into a mortgage, owner can typically access lower financing rates.
- Limited complexity in comparison to innovative project financing methods.

Cons

- Retrofit project is competing with other, often more attractive owner priorities for cash and debt.
- Project size is limited by owner's available cash and debt ceiling.

2. Innovative Owner Financing

Whether owners use design-bid-build or a turnkey approach to procurement, they can also tap innovative financing options such as C-PACE and OBR.

C-PACE offers long term low interest financing that is repaid through a special assessment applied to the municipal property tax bill, a cost that is passed along to tenants under typical leases. The source of capital can be either public with government loan capital or private via a third-party loan capital.

OBR is another highly secure repayment mechanism, where loans are repaid though the energy utility bill. With On-Bill Financing, utilities offer financing that uses the existing billing systems for loan servicing and collections. On-Bill Repayment only differs in that the source of funds is not the utility but a third-party, while the payment mechanism remains the same.

Building owners should consider C-PACE for projects that call for very deep savings or where GHG savings do not align well with energy cost savings (e.g., Ontario). In this situation, there may not be sufficient financial savings to compensate a pay-for-performance provider. The owner is presumably motivated by something other than ROI from direct energy savings, such as attracting marquee tenants, corporate social responsibility, or assumptions about the future of the real estate market. C-PACE is also particularly adapted if the owner wants long-term financing (>10 years) with lower monthly payments and the ability to transfer financing obligations at the time of sale.

Toronto High-Rise Retrofit Improvement Support Program (Hi-RIS)

Hi-RIS is a financing option offered by the City of Toronto for energy efficiency improvements to rental apartment buildings. A low interest loan is provided to eligible buildings for up to 100% of the retrofit cost and is paid back via a charge on the property tax bill. The loan is transferrable as it is tied to the property, not the owner.

Efficiency Nova Scotia

The Small Business Solutions offers small business customers financing through third-party. The interest-free on bill financing is available for up to 24 months for a range of energy saving opportunities.

Owners may also find on-bill financing (OBF) and on-bill repayment (OBR) appealing for projects where owners want a simple financing option with convenient repayments for implementation of specific measures and where owners pay their utility bills. However, OBF programs might not be applicable to deep carbon savings projects because these programs apply a cost-effectiveness test to financed measures.

Pros

- No up-front cost to building owner.
- May be possible to structure for off-balance sheet treatment.
- Potential to tap into Canada Infrastructure Bank funding.
- C-PACE costs can typically be passed along to tenants (addressing the problem of "split incentives"); same for OBF depending on lease terms and how it is structured.
- C-PACE repayment obligation stays with the building upon resale; same for OBF if structured as a tariff.

Cons

- C-PACE: For buildings with a mortgage, consent is usually required by the mortgage lender.
- OBF: Since it comes via utilities, OBF has a cost-effectiveness test and focus on energy efficiency that may preclude deep carbon retrofit projects.
- To be available, requires enabling legislation (C-PACE) or utility regulator policy decision (OBF).

3. Pay for Performance

Building owners should consider pay for performance models (EPCs, ESAs, and MESAs) for projects where building owners want (1) retrofits without spending their own capital, (2) a third-party to take on performance risk or (3) a third-party to provide energy management and/or maintenance and operation services. Due to their transaction costs, these models are particularly well-suited for large, ideally owner-occupied buildings or bundled smaller projects.

Energy as a service (EaaS) is a pay-for-performance, off-balance sheet solution that is relatively new but is becoming more and more common in the commercial sector. Under these agreements the vendor designs the scope of the project and pays for the entire project equipment and installation costs.

Energy services agreements (ESA) are the most common type of EaaS arrangements. Under an ESA, the building owner makes payments only for realized savings, while the ESA provider typically designs, implements, finances, owns, and operates the energy efficiency measures and equipment. The owner will pay the ESA per unit of energy savings at or below the owner's utility rate. ESAs are also known as Energy Service Performance Agreements (ESPAs). The provider can also sign an energy performance contract (EPC) with a contractor or ESCO to install and maintain the installed equipment and guarantees performance until the end of the contract. Generally, an EaaS vendor will assume the entire performance risk while an ESCO will only guarantee a portion of the savings.

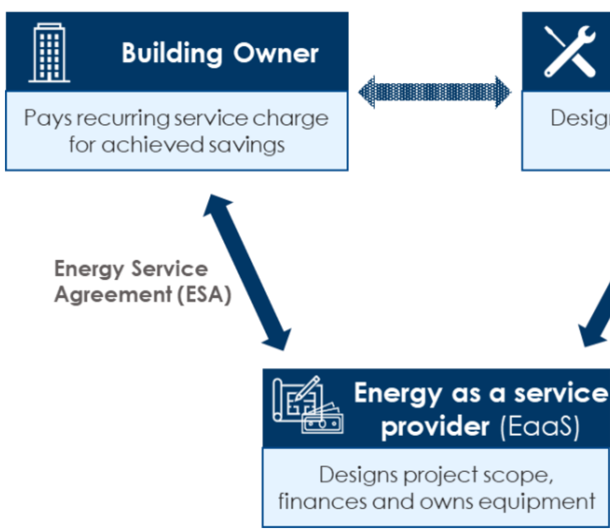


Figure 133. ESA Model

While EPCs and ESA agreements are both solutions to guarantee savings by assuming some equipment performance risk, there are significant variations between them. ESA models are designed to provide financing to the commercial private sector with limited capital and ESCOs tend to better address the public sector. One key difference is that the building owner provides the capital and owns the installed equipment (an ESCO may sometimes offer financing support). With an ESA provider, the provider takes on the financial and performance risk and generally owns the newly installed equipment.

Table 16: Key Differences between ESA and EPC [39]

	ESA	EPC
Ownership	Often ESA provider	Often customer
Performance Risk	ESA provider	Split between customer/ESCO
Up-front Costs	ESA provider	Often customer
Off-balance Sheet Financing	Yes, in some jurisdictions	No
Flexibility to add retrofit during contract period	Yes	Yes

A Managed Energy Services Agreements (MESA) is a variation of an ESA. The provider's role is expanded as it performs all the roles encompassed by an ESA but also assumes overall responsibility for the broader building energy management including utility bills (therefore, the provider directly receives the energy savings associated with the retrofit). In exchange, the customer makes fixed pre-defined payments based on their historic energy use. With the MESA provider taking responsibility for the utility bills, customers are also protected from any unexpected energy rates increase.

Throughout the term of the ESA or MESA, the provider typically retains ownership of the equipment. At the end of the contract, the customer can purchase the equipment, extend the contract, or return the equipment.

Pros

- No up-front costs or underperformance risk for the owner.
- Can be structured to pass costs along to tenants (in particular MESAs since MESA sub-charges can be added to tenants on their energy bill rather than a separate individual service charge).
- May be possible to structure for off-balance sheet treatment.
- Potential to tap into Canada Infrastructure Bank funding.

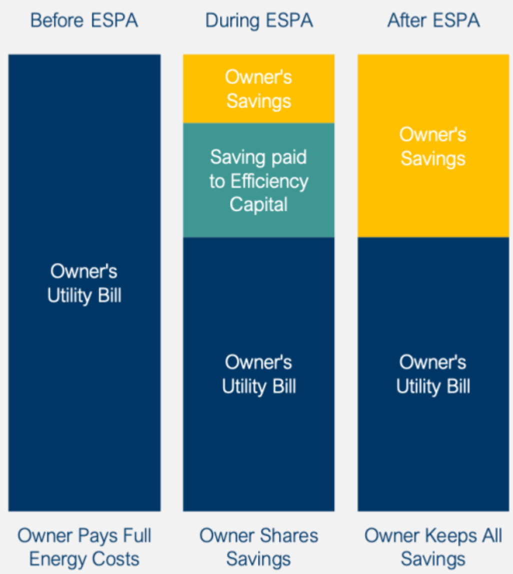
Cons

- Provider owns the equipment, which owners may view as an encumbrance on sale of the property.
- Since the financing model is based on financial savings from energy consumption, ESAs and MESAs do not translate directly to GHG savings (greater GHG savings may not provide the greatest financial savings).
- Like EPCs, ESAs and MESAs are more challenging in leased spaces and typically only workable if the EPC contract term does not exceed the lease term.

[39] Not possible in some jurisdictions such as Quebec.

Efficiency Capital

Efficiency Capital, supported by The Atmospheric Fund (TAF), offers an energy savings performance agreement (ESPA) for up to 10 years that covers the cost of energy and water retrofit projects for multifamily, commercial, industrial, and institutional buildings. They take care of the building audit, project costs, project implementation, and measurement and verification. The owner pays no up-front capital. Efficiency Capital is repaid through a share of the building's utility savings during the contract term; afterwards all savings go to the building.



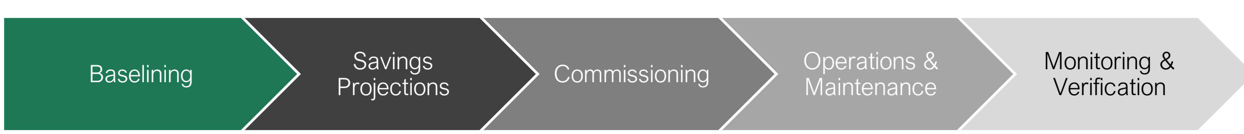
Graph Credit: TAF

Investor Ready Energy Efficiency certification

No matter the financing method, Investor Ready Energy Efficiency (IREE) certification can bring significant benefits.

IREE certification is a project development due diligence assurance certification that is achieved prior to project implementation. It signals to investors that projects were developed by qualified project developers and meet the requirements of the Investor Confidence Project (ICP) Protocols. The certification's protocols provide investors with a consistent roadmap for assessing risk and comparing retrofit project investment opportunities, supporting a more streamlined project approval process.

Having a clear and consistent process allows project teams, investors, and owners to have confidence that their project will be setting itself up for success. The ICP protocols create a framework that ensures best practices in the five crucial elements that make up successful energy efficiency projects:



As part of its retrofit financing program due-diligence requirements, the Canada Infrastructure Bank requires that all projects comply with IREE certification.

Step 6. Measure and Verify Achievements

Following the implementation of retrofits, it is important to measure and verify savings that occurred and compare them against the targeted goals and specific metrics.

IREE certification provides a standard framework for collecting and reporting retrofit data, allowing for consistent measurement, and benchmarking across different retrofit projects and portfolios. Standardized data collection and reporting is critical for attracting private capital to the market and allows building owners and policy makers to report on progress towards meeting climate targets. It may also be important in future markets where building owners can sell carbon credits.

6.2.2 – Key findings

Building owners and operators will need support to implement the CRMs presented in this study. The level of support will vary by building location, characteristics, owner risk tolerance, access to capital and other time and financial constraints. Since one of the key drivers for implementation is the estimated payback period of retrofits, a few observations can already be made based on the results from the financial analysis. These implementation observations are grouped based on building type and/or discounted payback period and are presented in Table 17.

Table 17. Best Fit Procurement Methods to Building Typologies

	Vancouver	Edmonton	Toronto	Montréal	Halifax
Low-rise Office 1970	3	2	2	3	1
Low-rise Office 1990	3	3	3	3	3
Mid-rise Office 1970	3	3	2	3	2
Mid-rise Office 1990	3	3	3	3	3
Low-rise MURB 1970	3	3	3	3	3
Low-rise MURB 1990	3	3	3	3	3
Mid-rise MURB 1970	3	3	3	3	3
Mid-rise MURB 1990	3	3	3	3	3
Primary School	4	4	4	4	4

1 Option 1: Turnkey project delivery

These deep retrofits are highly cost-effective, which makes them financially interesting for building owners. A turnkey project delivery method will be ideal to implement the project. Design Build are common in

Canada, and it can be used for buildings of all sizes and types, even though it is generally used for larger projects. Owners is this category do not especially need external financing tools for financing them. This delivery model is most applicable to the 1970s low-rise office Halifax building archetype.

2 Option 2: Turnkey project delivery with a pay for performance financing model (EPCs, ESAs, or MESAs) OR Design-bid-build project delivery with OBF/OBR or C-PACE financing

These retrofits can achieve great financial savings despite longer payback periods. Projects under this category do not face cost-effectiveness barriers but with paybacks between 5 and 15 years, building owners tend to be reluctant to implement voluntary retrofits. These projects could highly benefit from some financing tools:

- **To reduce upfront costs, OBF/OBR and C-PACE are particularly attractive options** since the financial arrangements are tied to the property. They can also align incentives for landlord and tenants as both the tax assessment and financial savings can be shared with tenants under some lease structures. Owners more interested in simple financing options with convenient repayments can be more attracted to OBF financing tools.

- **To limit the hassle of implementing those retrofits, pay for performance options are the best solution.** Building owners can select the contract type that is more relevant for them and in leased buildings, they have the flexibility to pass the costs to the tenants. To increase investors interest and reduce initial set up burden. smaller buildings should be bundled into a larger building portfolio when possible. Although, it is important to note that pay-for-performance can be challenging for the condo industry.

The summarized Option 2 delivery models are most applicable to the 1970s low-rise office archetypes in Edmonton and Toronto, as well as the 1970s mid-rise office archetypes in Halifax and Toronto.

3 Option 3: Design-bid-build project delivery with OBF/OBR or C-PACE financing combined with financial incentives.

Implementing the deep retrofits that offer much longer paybacks, or that are not cost-effective, can be very challenging. These projects will still benefit from the delivery and financing options presented under Option 2, but further financial incentives will be needed to support these retrofits. Mechanical upgrades are the largest incremental capital cost (ICC) driver for most of these archetypes, typically representing over 75% of the total ICC for retrofits to 1970s buildings and over 90% for retrofits to 1990s buildings. Therefore, additional financing incentives targeting specific mechanical upgrades could make a difference. As summarized in Table 17, most building archetypes studied would benefit from these delivery model considerations.

4 Option 4: Pay for performance models

Schools are particularly attracted by performance guarantee options and scalability potential, and they rarely change ownership, which makes it convenient for longer term investment. Also, portfolios of schools usually include many older buildings that have the potential for larger savings. This delivery model would be most beneficial for the primary school archetypes studied.

6.3 – Deep Retrofit Strategies: Policy and Support Options

Policy and other government support initiatives can play a key role in overcoming barriers to retrofits. In some cases, policies are needed to improve the financial viability of projects. However even with a strong business case and effective implementation and procurement solutions, the case for deep carbon retrofits is still a challenge for most building owners. Across all building archetypes modelling for this study, retrofits are unlikely to accelerate at the pace needed to meet climate targets without significant policy support to address economic, market and financing barriers.

Fortunately, there are many policy tools available. Some have been deployed broadly in jurisdictions across North America and Europe, while others are just emerging. The number and variation of barriers to implementing these deep carbon retrofits means that no single policy 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. This section offers an overview and descriptions of these key strategies, including:

Regulatory Mechanisms	Financing Mechanisms	Other Supporting Measures
• Incentives and Rebates • Carbon Pricing • Local Requirements and Incentives • Energy Rating & Disclosure • Retrofit Codes and Performance Requirements • Net-metering and Other Distributed Energy Policies	• Repayment mechanisms (e.g., commercial property-assessed clean energy (C-PACE) and utility on-bill financing (OBF) • Credit enhancements (loan loss reserve, loan guarantee and interest rate buy-downs)	• Public Procurement • Demonstration Projects • Retrofit Support Services • Education & Training

The following tables summarize the potential impact of regulatory, financing, and other strategies on the market barriers (Table 18) and financing barriers (Table 19) discussed in Section 5.1.

Table 18: Potential Impact of Strategies on Market Barriers

		Lack of Energy or Carbon Awareness	Return & Hassle	Split Incentives	Performance Skepticism	First Mover Disadvantage	Cost Effectiveness
Regulatory Mechanisms	Incentives	○	◒	◒	◒	◒	◒
	Local Requirements & Incentives	●	●	○	◒	◒	◒
	Energy Rating & Disclosure	●	◔	○	◔	○	○
	Performance Requirements	●	●	○	○	○	○
	Carbon Pricing	●	●	○	○	○	●
Financing Mechanisms	C-PACE	○	◒	●	○	○	○
	On-Bill Financing	○	◒	◒	○	○	○
	Credit Enhancements	○	◒	○	○	○	◒
Other Strategies	Public Procurement	◒	○	○	◒	◒	○
	Demonstration Projects	◒	○	○	◒	●	○
	Retrofit Support Services	○	●	○	○	◒	○
	Education & Training	◒	○	○	◒	○	○

● Substantial potential impact
◒ Moderate potential impact
◔ Low potential impact
○ Little or no potential impact

Table 19: Potential Impact of Strategies on Financing Barriers

		Access to Attractive Financing	Uncertain Risk Profile	High Loan Transaction Costs	Secured, On Balance Sheet Debt
Regulatory	Incentives	○	○	○	○
	Carbon Pricing	○	○	○	○
	Local Requirements & Incentives	○	○	○	○
	Energy Rating & Disclosure	○	○	○	○
	Performance Requirements	○	○	○	○
Financing	C-PACE	●	○	●	◒
	On-Bill Financing	●	○	●	◒
	Credit Enhancements	●	◒	○	○
Other Strategies	Public Procurement	○	○	○	○
	Demonstration Projects	○	◒	○	○
	Retrofit Support Services	◒	○	○	○
	Education & Training	○	◒	○	○

● Substantial potential impact
◒ Modest potential impact
○ Little or no potential impact

6.3.1 – Regulatory Mechanisms

Government policies and regulations can advance energy and carbon retrofits through requirements, incentives, and taxes. This section provides an overview of the following:

- Incentives and Rebates
- Carbon Pricing
- Local Requirements and Incentives
- Energy Rating & Disclosure
- Retrofit Codes
- Performance Requirements
- Net-metering and Other Distributed Energy Policies

Incentives and Rebates

Clean BC Custom GHG Incentives

Unlike typical efficiency incentives, Clean BC's Custom and Custom-Lite programs are neither energy savings incentives nor equipment rebates. Instead, they are incentives for **reducing building carbon emissions.**

Clean BC's **Facilities Electrification Fund** is available to fuel switching projects that reduce emissions and helps to reduce the cost of connecting into BC Hydro's clean electricity grid.

Financial incentives and rebates can be effective in improving the financial viability of retrofit projects by lowering the cost of carbon reduction measures (CRMs). They can take the form of grants, discounts and rebates, tax credits, and free or subsidized technical services like audits. Incentives can also be offered to cover the cost of fuel switching, including the cost to upgrade the existing electricity service.

However, most incentives programs are tied to energy rather than carbon savings and typically focus on single measure upgrades, rather than whole building retrofits. Furthermore, the cost of scaling incentive programs to all buildings would be prohibitive. For these reasons, incentives must be paired with other policies to be most effective in driving significant increases to retrofit activity.

Carbon Pricing

Carbon pricing also improves the business case for deep carbon retrofits. Carbon pricing works by levying a cost per tonne of carbon emitted. It does not directly require any changes to behaviour. Instead, it makes it more expensive to undertake carbon-intensive activities, for example coal power generation or heating a building with natural gas. As discussed in Section 2.3.3, this study includes a carbon price that ramps up to $170 per tonne by 2030.

Greenhouse Gas Pollution Pricing Act

Canada has a national carbon tax on fuels and emissions from large industrial emitters. In 2020, The Government of Canada announced that the price of carbon will increase from the $30 per ton to $170 per ton in 2030.

Energy Rating and Disclosure

Ontario Energy and Water Reporting and Benchmarking

Most buildings in Ontario over 100,000 square feet (50,000 square feet starting 2023) are required to report their annual energy and water consumption through Portfolio Manager. Utilities are required to make whole-building data available to owners.

Energy rating and disclosure programs encourage or require tracking and reporting of the energy performance of homes and buildings. They promote retrofits by making building owners, their stakeholders (tenants, buyers, and investors), energy specialists, and policy makers aware of the relative energy usage of buildings. They can be mandatory or voluntary and apply at any time or in a particular period of building ownership (such as when listing a home for sale). The data collected can be used by potential buyers as they are considering a property with high or low energy operating costs. While rating and disclosure policies have traditionally focussed on energy and water reporting, they can easily be adapted to include carbon emissions. For example, the city of Boston enacted their Building Energy Reporting and Disclosure Ordinance (BERDO) in 2013 requiring large buildings to report their annual energy and water use and greenhouse gas emissions to the city.

Local Requirements & Incentives

Local governments commonly oversee building permitting and zoning, which places several policy tools at their disposal to support retrofits by including them as a condition of zoning approvals. Examples include density bonuses, reductions in development-related charges, or expedited approvals.

Retrofit Codes

Until very recently, building energy usage (and indirectly, building carbon emissions) has only been regulated during periods of new construction or major renovation. Retrofit codes typically follow the same approach by requiring energy efficiency and carbon reduction measures following an owner's voluntary changes to a building.

National Code for Alterations to Existing Buildings

The Pan-Canadian Framework has committed signatories to the development of a national model code for existing buildings.

The province of B.C. is currently developing a retrofit code to address energy, carbon, and resiliency. The Government of Canada has committed to developing a national model code for existing buildings, projected to be in place by 2025.

Performance Requirements

An alternative to retrofit codes is a regulated energy and/or carbon emissions performance target for existing buildings, such as under development by the City of Vancouver (see sidebar). The key challenges with performance metrics are the difficulty in establishing appropriate targets and substantial penalties that may be needed to achieve high compliance rates. When it comes to regulating carbon, a performance metric must also consider the carbon intensity of the electrical grid, which varies across provinces and over time.

Ultimately, policy makers considering performance limits for existing buildings need to balance various trade-offs, including:

City of Vancouver Carbon Pollution Limits

In November 2020, Vancouver approved a Climate Emergency Action Plan that includes annual carbon pollution limits for existing buildings. Initially, limits will only apply for detached homes and large commercial buildings, with targets that must be achieved by 2025. The carbon limits will be set so as to only impact the 10-20% worst performing buildings, with the intent that they can be met with simple, low-cost and high-savings measures.

- To what extent should performance targets take into account differences in building usage, including building type and occupant behavior?
- Is there sufficient data on building usage and consumption to establish the desired targets?
- Should assumptions of the carbon intensity of electricity be based on the grid today (maximizing reductions today) or the grid as it will or is planned to be (maximizing reductions in the future)?

Net-metering and other distributed energy policies

Governments and utilities can introduce policies to encourage the addition of distributed energy resources such as solar PV to reduce building energy demand and emissions. Net-metering is one example, along with feed-in tariffs. These programs often have restrictions on project size, as discussed in Section 2.1.4.

6.3.2 – Financing Mechanisms

Financing initiatives can also play an important role in enabling retrofits. Governments can support financing through innovative repayment mechanisms such as C-PACE and Utility On-Bill Financing and credit enhancements.

Repayment Mechanisms

As explained in Section 5.2, repayment mechanisms can be powerful tools to overcome financing barriers.

Commercial Property Assessed Clean Energy (C-PACE) financing and On-Bill Financing can be developed and managed by municipalities with support from provincial or federal governments to offer guarantees on those programs. C-PACE programs enable repayment via property taxes and can typically be passed along to tenants while On-Bill Financing utilizes the utility billing system for loan servicing and collection.

Credit Enhancements

Credit enhancements encourage lenders to offer longer term financing and/or lower interest rates than they otherwise would have, or to offer financing in situations where uncertain credit risk may be a barrier. These tools have been used primarily for small residential buildings and low-income multi-residential buildings. Forms of credit enhancements include:

- **Loan Loss Reserve:** A fund to cover a portion of losses incurred by lenders due to borrower defaults. With these reserves (typically 10%-20% of the loan portfolio), energy efficiency loans become more attractive to private lenders because the government is absorbing some or most of the performance risk.

- **Loan Guarantee:** A government partial or full guarantee of loans to private citizens or companies. The reduced risk for lenders enables them to offer longer term loans and / or lower interest rates, or financing to customers who would otherwise be considered un-credit-worthy.

- **Interest Rate Buy-Down:** Subsidizes the interest rate of private loans. This makes loans more affordable and improves the business case for building owners.

Clean BC Better Homes Low-Interest Financing Program

This program provides low interest loans to single family homes, duplexes and side by side row houses, for switching from a fossil fuel (oil, propane, or natural gas) heating system to a heat pump. The program offers reduced interest rates via a private financial institution, as an alternative to accessing heat pump rebates.

6.3.3 – Other Measures

In addition to regulatory and financing mechanisms, there are many other programmatic strategies that governments can employ to advance retrofits, including:

- Public Procurement
- Demonstration Projects
- Retrofit Support Services
- Education & Training

Public Procurement

The rise of standards like LEED was facilitated by government policies for their own procurements and facilities. Governments can likewise lead by example by retrofitting public buildings. By doing so, they send a strong signal to the market about what is important and what skills and expertise need to be cultivated. Additionally, since governments are one of the biggest building owners across the country, retrofits of these buildings could lead to significant GHG reductions, as well as support market transformation by promoting retrofit best practices and standardized public reporting.

Transitions Énergétique Québec

The TEQ Master Plan establishes 2022-23 and 2029-30 energy consumption targets for existing public buildings. It also calls for public buildings to phase out heating with fuel oil by 2023, with certain exceptions.

Demonstration Projects

As discussed in the barriers section, building owners typically seek approaches and practices that are tried and true. They do not want to use their buildings to experiment with new technology and approaches. Successful deep energy retrofits are currently a rarity, and deep carbon retrofits are an emerging concept. Data from successful projects is not widely available and there is a lack of consistency in reporting on performance, making comparison across projects challenging. Governments can help address this challenge by supporting the implementation of demonstration projects and promoting their results.

Retrofit Support Services

Many owners do not have the staff capacity and expertise to evaluate and manage retrofit projects. These owners will require some form of third-party assistance to do so effectively.

Government programs can help fill the support gap. Some jurisdictions provide free project-management services to either all or low-income owners, or at times to small business participants. Services may include energy audits, assistance with interpreting audits, bidding out projects, selecting contractors, and post-installation measurement and verification.

How Much Change Will Result from Information and Voluntary Measures?

New York City has had mandatory building energy reporting and disclosure (BERD), audits, retro-commissioning, and retrofit support services (started later) in place since 2010. During that time, energy use and carbon emissions in benchmarked buildings declined 8.5% and 23%, respectively. But only about 1/3 of that reduction was due to energy efficiency rather than fuel switching (fuel oil to natural gas) and grid efficiencies. City policy makers concluded that mandatory solutions were required to bolster these efforts, leading to limits to building carbon emissions under Local Law 97.

Education & Training

Deep carbon retrofits require a trained workforce to deliver them, including knowledgeable owners and property managers, architects, engineers, contractors, and building trades. Building professionals can gain hands-on experience working on government and demonstration projects, which is how many in the building industry first learned how to design and construct LEED buildings. They can also learn through education and training programs, tapping into robust, existing delivery channels.

Some building professionals, notably construction trades, have the additional challenge of just recruiting sufficient new workers to meet projected demand. The Canada Green Building Council (CaGBC) estimates that the number of green building jobs will

American Institute of Architects New York, "Retrofit Now!"

16-hour trainings designed specifically for architects on their role in energy retrofit projects to comply with Local Law 97, including incremental retrofits during building system replacement.

double or triple by 2030, depending on the extent of government climate policy. The industry will need to hire and train about 500,000 to 1 million new skilled works.[40]

[40] Canada Green Building Council, *Canada's Green Building Engine* (2020).

6.3.4 – Summary of Current Strategies Across Canada

The existing ecosystem of policies and support measures to support retrofits differs among Canada's provinces, as summarised in Table 20.

While most provinces have adopted at least one voluntary mechanism to advance retrofits, **mandatory mechanisms 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 forthcoming in BC, Quebec and at the national level.

British Columbia, Ontario, Quebec, and Nova Scotia are the regions with the highest readiness for financing carbon retrofits. It should be noted however, that even in provinces with PACE-enabling legislation, C-PACE has only been adopted by the city of Toronto for now and is therefore not yet widely available. OBF and OBR programs are primarily focused on residential customers and offers to large commercial, institutional, and industrial buildings are nonexistent.

At the federal level, the CIB's $2 billion Building Retrofit Initiative has the potential to transform the retrofit market by providing large-scale financing for the archetypes in the report, encouraging new innovative business models, crowding in private capital, and helping to establish retrofits as a distinct asset class.

It is also worth noting that most of the current provincial policies are still primarily focussed on energy efficiency measures rather than specifically targeting carbon emissions.

Table 20: Key Policy & Financing Mechanisms and Ecosystem Maturity Level by Province and Territory

	Efficiency Canada Score [41]	EE/RE Rebates [42]	C PACE Programs [43]	OBF Programs [44]	BERD	Code & Performance Requirements	Ecosystem Maturity [45]
BC	58	High	Planned PACE-enabled legislation	Voluntary program	Voluntary program	Planned Mandatory program	High
AB	24	Low / Mid	PACE-enabled legislation		Voluntary program		Mid / High
SK	17	Low	PACE-enabled legislation				Low
MB	29	Mid		Voluntary program	Voluntary program		Mid
ON	45	High	Voluntary program		Mandatory program		High
QC	52	Mid / High			Voluntary program	Planned Mandatory program	Mid / High
NB	27	Low / Mid					Low / Mid
NS	49	Mid	PACE-enabled legislation	Voluntary program	Voluntary program		Mid / High
NL	17	Mid		Voluntary program			Low / Mid
PE	37	Mid	PACE-enabled legislation				Low / Mid

- Mandatory program
- Voluntary program
- PACE-enabled legislation
- Planned Mandatory program
- Planned Voluntary program
- Planned PACE-enabled legislation

[41] From Efficiency Canada Provincial Energy Efficiency Scorecard 2020. Provinces receive a total score out of 100 across five policy areas: energy efficiency programs, enabling policies, buildings, transportation and industry.

[42] High/Medium/Low EE/RE rebates offering. Data collected via: https://www.nrcan.gc.ca/energy-efficiency/energy-efficiency-homes/financial-incentive-province/4947

[43] Pembina Institute, 2020. Property Assessed Clean Energy in Canada. Ontario is the only province with an active municipal C-PACE programs (Hi-RIS Toronto).

[44] Circles denote jurisdictions where on-bill financing (OBF) programs have taken place. Note that enabling legislation may not be required to launch OBF programs, as it may already be permitted. Further research is required to in jurisdictions without precedence.

Program precedence from: Efficiency Canada. Energy Efficiency Policy Database. Support for Financing. (May 2021). Accessed at: https://database.efficiencycanada.org/policies/

[45] Qualitatively assessed as low, medium, high

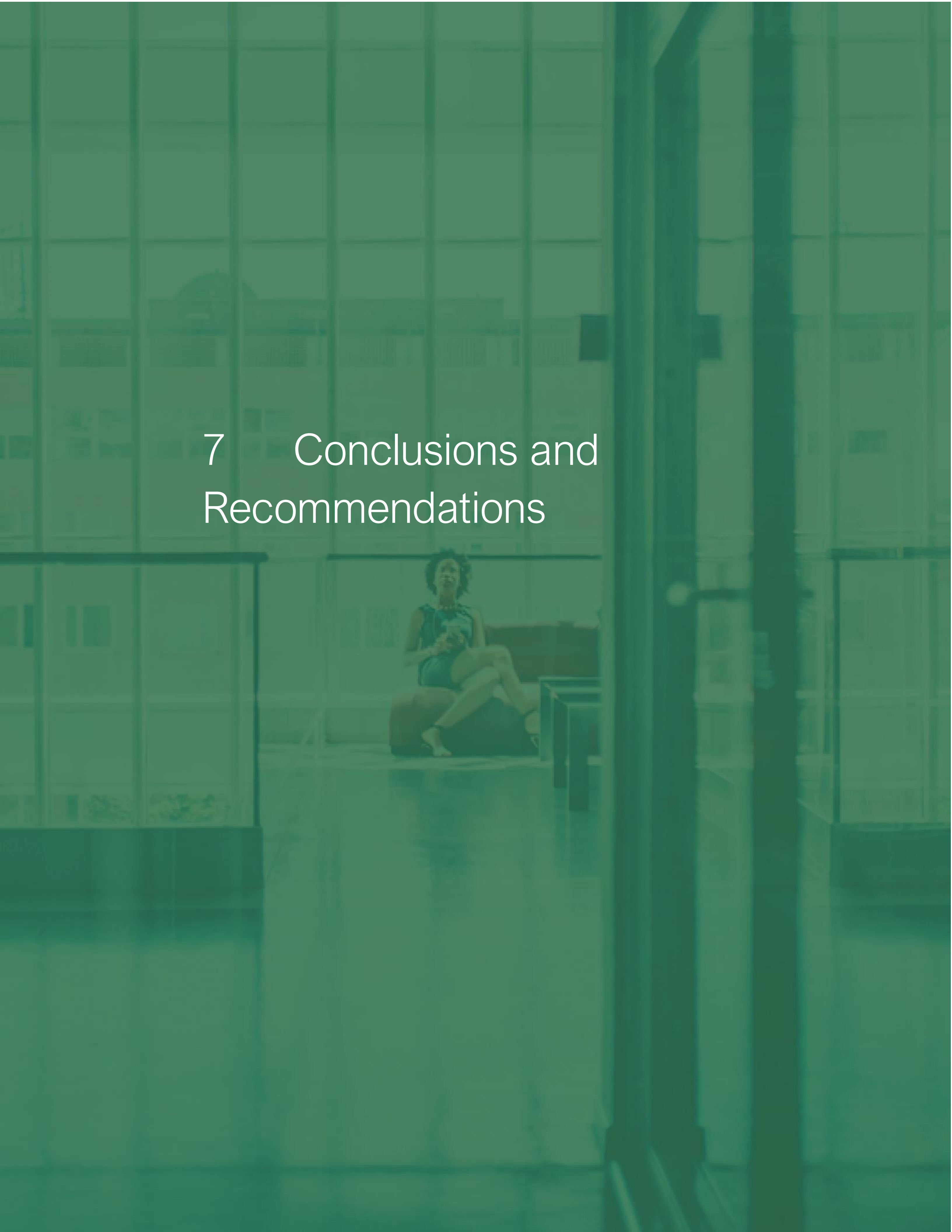
6.3.5 – Key Findings

To create a strong decarbonization market with sufficient capacity to help meet 2050 GHG targets, a combination of policies is necessary. Table 21 provides further guidance for policy makers interested in deploying a strategy in response to a specific objective. To meet 2050 climate goals, all provinces need to improve their current readiness levels for all modelled archetypes.

Table 21: Policy Goals and Approaches

Policy makers wishing to...	...should consider the following policy approaches
1. Increase owner and tenant awareness of building energy consumption and carbon emissions	1- BERD policies 2- Carbon pricing, performance incentives
2. Improve the business case for retrofits	1- Carbon pricing and performance-based requirements 2- Incentives, financing mechanisms, and carbon cost drivers 3- Retrofit support services
3. Reduce the gap between financial savings from energy efficiency and from carbon reductions	1- Carbon pricing 2- Incentives 3- Retrofit support services
4. Make it easier for owners to manage and pay for retrofits	1- Financing mechanisms and retrofit support services 2- BERD policies
5. Create examples for the private sector to follow	1- Demonstration projects and public procurement 2- BERD policies
6. Ensure there is an educated workforce to deliver retrofits	1- Education and training
7. Accelerate the transformation of industry practices	1- Carbon performance requirements and code alterations 2- Education and training and demonstration projects 3- Retrofit support services

7 Conclusions and Recommendations



Conclusions and Recommendations

A described in this report, **retrofit planning decisions are guided by technical and non-technical** considerations. Our study reveals that it is technically possible to achieve full decarbonization by 2050 for all studied building archetypes. The transition to zero carbon operations for all buildings will happen by combining careful staging of key carbon reduction measures with (1) additional mechanical replacements to eliminate any residual fossil fuel use, (2) upgrading of enclosures not yet slated for renewals, and (3) further decarbonization of grid electricity.

Even though it is technically possible, and financially viable in some cases, there are still a range of additional barriers that make retrofits a tough sell for many building owners. Policy and other support mechanisms are therefore critical to accelerating the pace and depth of retrofits to reach Canada's climate change goals.

7.1 – Recommendations for Policy-makers and Building Owners

To achieve Canada's climate goals, a combination of strategies is required. As discussed in Section 5.3, while some jurisdictions have made more progress than others on policy and programs to encourage deep retrofits, further action is required to provide deeper support across all jurisdictions in Canada.

While every strategy focuses on specific objectives, each one brings the market one step closer to becoming more active and focused on decarbonization activities to help meet 2050 GHG targets. Below are the key strategies that are fundamental to success. Ideally, the real estate sector and governments would implement these mechanisms in a coordinated manner, but the urgency of climate action is now overwhelming. All these support mechanisms should be developed now, and implemented simultaneously, to support retrofit market transformation.

Objectives	Clear Technical Pathways	Informed Market	Workforce and Industry Capacity	Implementation Support	Accelerate the Pace
Actions	Leveraging infrastructure renewal events Strategic sequencing of upgrade measures On-site renewable energy Mitigate peak electricity demand	Mandatory rating and disclosure policies Standardization and reporting Demonstration projects	Education and training programs Collaborate with industry and manufacturers	Carbon pricing mechanisms Financial incentives targeting CRMs Financing mechanisms (C-PACE, credit enhancement) Procurement solutions	GHG operational performance requirements and building retrofit codes
Outcomes	Technical Solutions	Market Awareness and Confidence	Market Readiness	Attractiveness for Building Owner	Demand for Decarbonization Retrofits

Figure 134. Steps towards zero carbon buildings

7.1.1 – Pursue Technical Pathways to Deep Carbon Retrofits

If Canada is to cut built-environment emissions at the needed scope, scale, and speed, stakeholders must shift their mindset from energy savings to carbon reductions. This means looking beyond individual measures to consider systemic improvement – such as replacing major building systems and/or structural components. To enable this, the following specific strategies and actions are recommended to be implemented.

1. **Owners must pursue the right measures at the appropriate times.** Building owners must develop zero carbon transition plans for each asset to ensure they schedule and sequence their deep carbon reduction measures (CRMs) with care. Deep carbon retrofits require replacing major building systems and/or structural components. These are expensive investments, and not always cost-effective over the operational lifetime of the new equipment or system. To improve the numbers and capture deep carbon reductions, building owners should align CRMs with regularly scheduled building renewals, and follow proper sequencing, like working on energy demand measures before upgrading mechanical systems, if possible

2. **Governments must support on-site renewable electricity**, especially in provinces with more carbon intensive grids. Policies to support distributed renewable generation can play a key role in reducing emissions. There should be no arbitrary limits on energy system size to help maximize renewable system inputs and reduce energy grid management challenges long term.

3. **Owners should mitigate electricity peak demand.** Demand reduction will be crucial to help offset needed electrification measures across all sectors of the economy. Except for the office archetypes, this study found that the electrification of space heating and service hot water systems results in an increase in annual peak electricity demand. This points to the critical importance of demand reduction strategies, such as enclosure upgrades and heat recovery. Onsite renewable energy, thermal and battery storage, as well as demand response programs, may be options to help harness energy when it is available and mitigate high peak demand on the grid. The study found that increases in peak demand were greater for the 1990s archetypes, which did not include enclosure upgrades - highlighting the importance of these upgrades whenever feasible.

7.1.2 – Get Your Data House in Order

To support the market's transformation to zero carbon, building owners, investors, policy-makers and other stakeholders need better data. Improved data quality that is consistent and transparent will help increase awareness of decarbonization opportunities within buildings, property portfolios, and even cities. To this end, we recommend the following:

1. **Governments must implement mandatory energy and emissions benchmarking.** Energy rating and disclosure programs – and requirements for commercial and institutional buildings – are powerful tools for increasing awareness of deep carbon retrofit opportunities and driving results. Building owners will be far more informed and motivated to develop and implement deep carbon retrofits if they can better understand a building's performance and potential savings as compared to its peers. Supporting increased benchmarking and providing relevant retrofit references can move the needle on Canada's retrofit economy.

2. **Governments and owners must help standardize the deep carbon retrofit market.** Standardized approaches to developing, implementing, measuring, and reporting on deep carbon retrofit projects can reduce investment risk and transaction costs. Governments and owners can support this standardization by leveraging programs like the Investor Confidence Project (ICP) protocols and achieving Investor Ready Energy Efficiency (IREE) certification, similar to the CIB's Commercial Building Retrofits Initiative's due-diligence requirements.

3. **Governments and industry leaders must lead by example.** Demonstration projects or case studies address the "first-mover disadvantage" barrier and provide evidence that deep carbon retrofits work. They are especially important when it comes to new and emerging carbon reduction measures and technologies. Governments should lead by example by committing to zero carbon operations in existing public buildings, and by following best practices when implementing and reporting on deep carbon retrofit projects. Industry leaders should prioritize and implement deep retrofit projects and utilize innovative approaches that can be scaled up within a portfolio of buildings or by a building sector, as well as share their experience and retrofit project data more readily.

7.1.3 – Grow the Deep Carbon Retrofit Workforce and Boost Industry Capacity

Canada must retrofit hundreds of millions of square meters of floor space. To do so, our industry needs to build workforce capacity with new hires and training to deliver zero-carbon performance. To ensure this occurs, we recommend the following:

1. **Develop retrofit support services, education, and training.** Governments, building owners, industry associations, and educational institutions need to ramp up their efforts to build capacity and support services. We propose a range of supportive actions to do so:

    - **Leverage industry associations and existing training opportunities.** Many associations representing building owners and property managers offer educational programs. For example, CaGBC offers a course on Zero Carbon Transition Plans. Likewise, the Building Owners and Managers Association (BOMA) offers an online eEnergyTraining course for building operators, engineers, and facility managers. Government should prioritize supports to the development of collaborative platforms and industry partnership initiatives that address siloed approach to skills development, such as Workforce 2030.
    - **Incorporate deep carbon retrofit training into continuing education training requirements for architects and engineers.** Schools have the opportunity to modify their accreditation standards to ensure their curriculum addresses energy and carbon reduction. There may also be an opportunity for architectural and engineering schools to establish programs or schools dedicated to carbon reduction retrofits of buildings.
    - **Invest in building-related retrofit training programs.** Many unions and colleges run training programs for incumbent trades and apprentices. The federal and provincial government

typically fund these types of programs and could encourage further building retrofit training through them.

- **Collaborate with manufacturers.** Manufacturers could incorporate deep carbon retrofit considerations as part of their client training and system support. This is one of the main routes available to reach retrofit contractors, and improve industry buy-in.

7.1.4 – Tweak Incentives and Support Innovation

Financial incentives and financing programs can work with different procurement approaches to improve the business case for deep carbon retrofits.

1. **Broaden incentives to include carbon reductions and target markets that have limited cost-effectiveness.** We recommend governments and utilities include fuel switching and other carbon reduction measures in incentive programs. Incentives are needed to close the gap and create a positive business case – especially for multi-unit residential buildings (MURBs), which are typically less cost-effective than the other archetypes modelled. Similarly, deep carbon retrofits in 1970s and 1990s low-rise office buildings in Vancouver are less cost-effective than in other provinces, given their already relatively high efficiency values and lower carbon emissions.

2. **Support business model innovation for market transformation.** New and innovative business models, such as Super ESCOs, are needed to deliver deep carbon retrofits at scale across the country.[46] While ESCOs exist in Canada, they have historically focused on traditional energy savings targets and public buildings.

7.1.5 – Along with the Carrots, Bring out the Sticks

With less than a decade remaining to cut carbon emissions by 40 to 45 per cent, we cannot afford to wait any longer for significant action. After decades of carrots, the time has come for governments to enact carbon performance requirements and codes for existing buildings.

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. Retrofit codes and performance requirements are under development in BC and Quebec, yet most of the deployed provincial policies are still primarily focused on energy efficiency measures rather than specifically targeting carbon emissions

[46] Governments or public-private partnerships can establish a specialized energy saving company ("Super ESCO") to serve as a liaison between the government, a building owner, and a traditional ESCOs on a school, library, hospital, or similar challenging public-sector energy efficiency project.

The federal government has committed to developing a model code for existing buildings by 2025, which will be crucial to help drive activity and improvements. However, progress to date has been slow, and implementation is not close on the horizon.[47]

It is imperative that key federal departments step up and move quickly to finalize the code and ensure that carbon performance requirements are a core focus. Provinces should move quickly to adopt the model code or pursue their own mandatory performance requirements.

7.1.6 – The Imperative of an All-Hands-on-Deck Approach

To scale up deep carbon retrofits, governments will need to effectively integrate and align policies and initiatives. Many of the policies described in this report are complementary. For example, building rating and disclosure policies can easily integrate performance requirements, and governments and utilities can roll together financing with incentives to offer building owners a seamless experience.

With efforts underway at the local, regional, provincial, and federal levels, policy decision makers will need to coordinate and collaborate to avoid introducing a patchwork of policies across different jurisdictions.

[47] "We need a national retrofit code sooner, rather than later." Kevin Lockhart. Efficiency Canada. September 29, 2021. Retrieved from https://www.efficiencycanada.org/national-retrofit-code-sooner/.

7.2 – The Path Forward

The owners and operators of Canada's larger buildings are critical actors in Canada's climate emergency; their actions in the coming decades will help to determine whether or not Canada meets its emission reduction goals.

The research summarized in this report demonstrates how they can pursue deep carbon retrofits to significantly reduce their carbon footprints and support Canada's climate mitigation targets. Prompt action on this front will also provide added benefits such as healthier indoor environments for building tenants and occupants, as well as upgraded assets that will help to ensure the long-term profitability and security of building-related investments. Governments will also play a critical role in lowering barriers to action, including improving the business case and enabling innovative financing where needed. Working with all stakeholders, private sector leaders should leverage their considerable influence to ask for what they need to pursue the recommended actions shared here.

With this study, building owners and operators have a viable pathway to zero. We've presented concrete steps that can be taken today to move toward the goal of decarbonizing Canada's large buildings. Knowing how high the stakes are, it is clear that we need an all-hands-on deck approach if we are to succeed in meeting our decarbonization goal.

Appendices

Appendix A - Baseline Building Characteristics

The enclosure and HVAC assumptions are unique to the location and age category. The baseline building assumptions are summarized below for each location and vintage. A detailed list of the baseline building modelling assumptions is provided in the Technical Report.

Low-rise Office

Table 22 Baseline building assumptions for low-rise office archetype in Vancouver

	1970s	1990s
Enclosure		
Walls	Steel stud walls w/batt insulation, effective overall RSI-0.70 m^2-K/W.	Steel stud walls w/batt insulation, effective overall RSI-0.70 m^2-K/W.
Windows	Single glazed, non-thermally broken aluminum frames, USI – 5.68 W/m^2-K, SHGC-0.80.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC-0.66.
Window-to-wall ratio	40%	65%
Mechanical		
HVAC	Gas-fired (80% efficient*), constant volume make-up air units ducting ventilation to distributed units. Distributed water-to-air heat pumps for zone heating (COP-3.3) and cooling (COP-2.7).	Gas-fired (80% efficient) constant volume make-up air units ducting ventilation to distributed units. Four-pipe fan coil units connected to gas-fired boiler (80% efficient) and air-cooled chiller (COP-2.5).
Service Hot Water (SHW)	Central gas-fired boiler (80% efficient*).	Central gas-fired boiler (80% efficient*).

* The mechanical system has been upgraded since original construction.

Table 23 Baseline building assumptions for low-rise office archetype in Edmonton

	1970s	1990s
Enclosure		
Walls	Steel stud wall w/batt insulation, effective overall RSI-2.11 m^2-K/W.	Steel stud wall w/batt insulation, effective overall RSI-2.11 m^2-K/W.
Windows	Single glazed, non-thermally broken aluminum frames, USI – 5.68 W/m^2-K, SHGC-0.80.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC-0.66.
Window-to-wall ratio	40%	65%
Mechanical		
HVAC	Constant volume rooftop units with hydronic heating coil for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient*), and air-cooled chiller (COP-2.5).	Variable air volume rooftop units with hydronic heating coil for pre-heat and cooling coil. Hydronic baseboards and reheat coils. Gas-fired boiler (80% efficient), and air-cooled chiller (COP-2.5).
Service Hot Water (SHW)	Central gas-fired boiler (80% efficient*).	Central gas-fired boiler (80% efficient*).

* The mechanical system has been upgraded since original construction.

Table 24 Baseline building assumptions for low-rise office archetype in Toronto

	1970s	1990s
Enclosure		
Walls	Steel stud wall w/batt insulation, effective overall RSI-2.11 m^2-K/W.	Steel stud wall w/batt insulation, effective overall RSI-2.11 m^2-K/W.
Windows	Single glazed, non-thermally broken aluminum frames, USI – 5.68 W/m^2-K, SHGC-0.80.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC-0.66.
Window-to-wall ratio	40%	65%
Mechanical		
HVAC	Constant volume rooftop units with hydronic heating coil for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient*) and air-cooled chiller (COP-2.5).	Variable air volume and temperature (VVT) rooftop units with gas-fired heating coil (80% efficient) and DX cooling coil (COP-2.5).
Service Hot Water (SHW)	Central gas-fired boiler (80% efficient*).	Central gas-fired boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 25 Baseline building assumptions for low-rise office archetype in Montreal

	1970s	1990s
Enclosure		
Walls	Steel stud wall w/batt insulation, effective overall RSI-2.11 m^2-K/W.	Steel stud wall w/batt insulation, effective overall RSI-2.11 m^2-K/W.
Windows	Single glazed, non-thermally broken aluminum frames, USI – 5.68 W/m^2-K, SHGC-0.80.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC-0.66.
Window-to-wall ratio	40%	65%
Mechanical		
HVAC	Constant volume rooftop units with hydronic heating coil for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient*) and air-cooled chiller (COP-2.5).	Constant volume rooftop units with gas-fired heating coils (80% efficient) for pre-heat and DX cooling coil (EER-8.5). Hydronic baseboard convectors connected to gas-fired boiler (80% efficient) and reheat coils at zone level. Gas-fired boiler (80% efficient)
Service Hot Water (SHW)	Central gas-fired boiler (80% efficient*).	Central gas-fired boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 26 Baseline building assumptions for low-rise office archetype in Halifax

	1970s	1990s
Enclosure		
Walls	Steel stud wall w/batt insulation, effective overall RSI-2.11 m^2-K/W.	Steel stud wall w/batt insulation, effective overall RSI-2.11 m^2-K/W.
Windows	Single glazed, non-thermally broken aluminum frames, USI – 5.68 W/m^2-K, SHGC-0.80.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC-0.66.
Window-to-wall ratio	40%	65%
Mechanical		
HVAC	Dual duct variable air volume (VAV) rooftop units with hydronic heating and cooling coil. Gas-fired boiler (80% efficient*) and water-cooled chiller (COP-5.2).	Variable air volume (VAV) rooftop units with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Oil-fired boiler (80% efficient) and air-cooled chiller (COP-2.5).
Service Hot Water (SHW)	Central gas-fired boiler (80% efficient*).	Central oil-fired boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Baseline Building Consumption

Figure 135 and Figure 136 show the total energy use intensity (TEUI) and end-use breakdown, respectively, for the 1970s and 1990s low-rise office baseline building archetypes in each region.

The TEUI range from 213 to 925 kWh/m²/yr for the 1970s archetype, and from 222 to 830 kWh/m²/yr for the 1990s archetype. The highest total energy use intensity is seen in the 1970s Halifax baseline building archetype followed by the 1970s Edmonton baseline building archetype. The office archetypes have a wide variety of HVAC systems, which contributes to the wide range in energy performance.

The 1970s Vancouver archetype show higher electricity consumption and lower natural gas consumption compared to the 1990s archetype. This is because the 1970s Vancouver low-rise baseline building archetype is partially heated by distributed water-to-air heat pumps. Although the distributed water-to-air heat pumps units are connected to a gas boiler and fluid chiller, the local heat pump units provide additional heating or cooling as needed, which results in a slightly higher electricity load.

Although the Vancouver low-rise office baseline building archetypes have worse performing enclosure in comparison to the other locations (R-4 exterior wall instead of R-12), they show lower energy consumption. This is mainly due to the difference in ventilation systems. For the Vancouver archetypes, tempered outdoor air (100 per cent) is delivered via single zone constant volume gas-fired make-up air units; the air is then heated (and cooled) as needed at zone level.

For all other locations (except 1970s Halifax), the ventilation system consists of multizone recirculating rooftop units (1/floor) with re-heat coils that provide cooling through their central air handlers, which also provide ventilation. To cool the interior zones that require year-round cooling, these systems provide mixed air at 12°C (55°F), the air is then re-heated as needed in the perimeter spaces to 35°C (95°F) via hydronic coils. The net effect is that there are periods of cooling provided by the central air handler and reheat in the perimeter spaces increasing heating energy consumption beyond what is needed for ventilation and enclosure heating demand. This system type results in higher fan and heating energy compared to the DOAS make-up air units.

The 1970s Halifax baseline building archetype is assumed to have a dual-duct ventilation system; this system type results in high fan, heating and cooling energy as it also supplies heating and cooling at the same time.

The 1990s Edmonton, Toronto, and Halifax archetypes show improvement in TEUI compared to the 1970s archetypes in the same locations. The improvement in energy performance is mainly due to the change from constant to variable speed for the ventilation system, and improved enclosure thermal performance. The conversion of these multi-zone recirculating ventilation and cooling air handlers to variable speed significantly reduces, but does not eliminate, reheat in the perimeter spaces.

The 1970s multizone recirculating ventilation systems are assumed to operate at constant speed whereas the 1990s Edmonton, Toronto, and Halifax multizone recirculating ventilation systems are variable speed, which results in reduced fan and heating energy. The non-recirculating DOAS ventilation system for the 1990s Vancouver baseline building archetypes are assumed to stay constant.

Further, it is assumed that the window-to-wall ratio increases from 40 per cent to 65 per cent between the two age categories. On the other hand, the thermal performance of the 1990s windows is better than the 1970s window, and the overall thermal performance for the above grade walls and windows is better for the 1990s archetypes.

Note that the 1990s Halifax low-rise office baseline building archetype is heated with oil, whereas all other archetypes use natural gas.

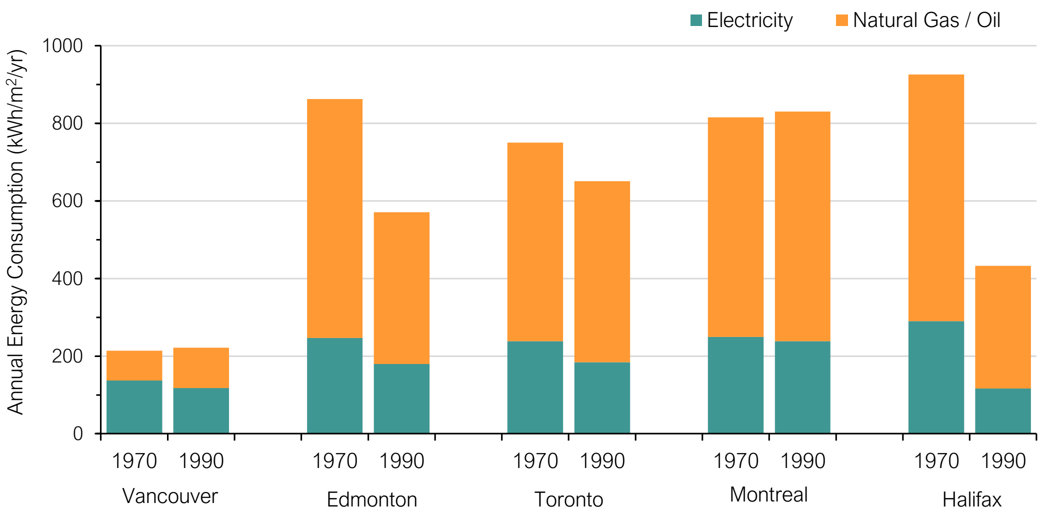
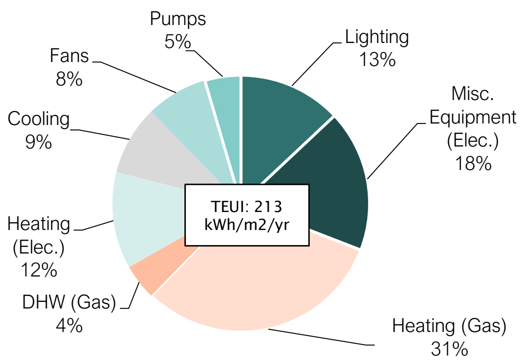
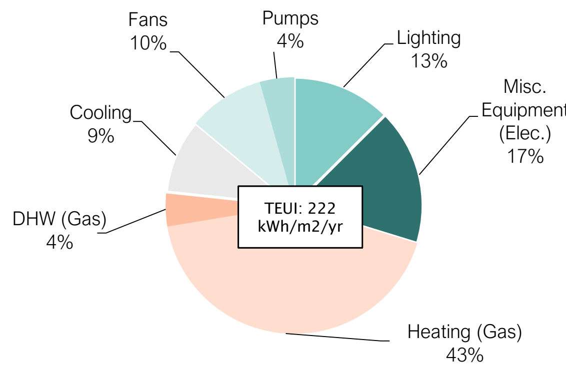


Figure 135. Total energy use intensity (TEUI) for the 1970s and 1990s low-rise office baseline building archetypes presented by region.

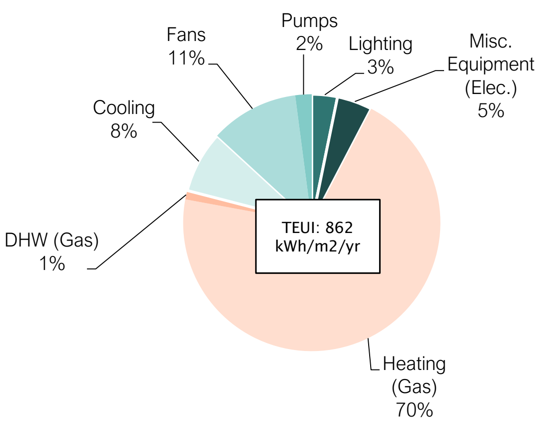
The dominant energy end use for the low-rise office archetypes in all locations is space heating. The CRMs chosen for this archetype focus on space heating demand reduction as well as improving system efficiency to reduce energy consumption.



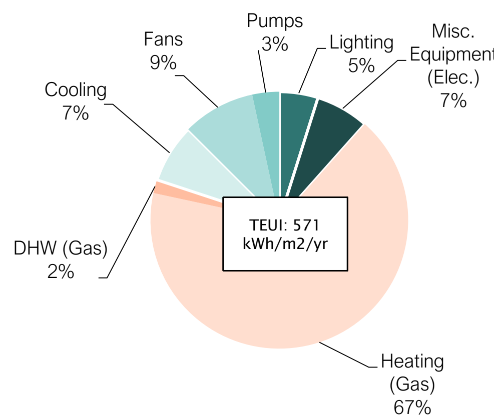
Vancouver 1970



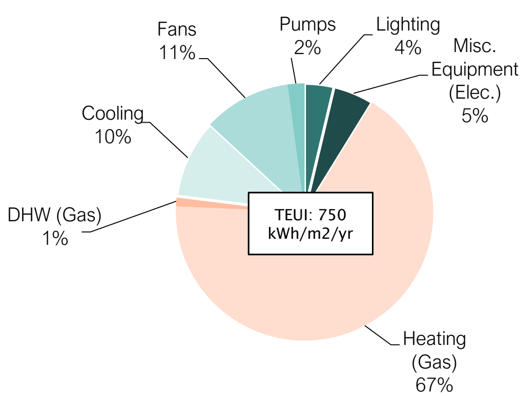
Vancouver 1990



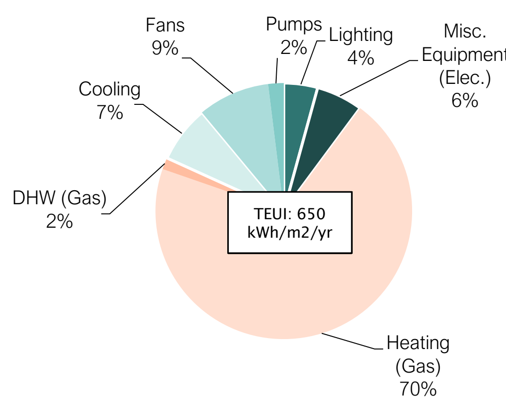
Edmonton
1990



Edmonton
1990



Toronto
1970



Toronto
1990

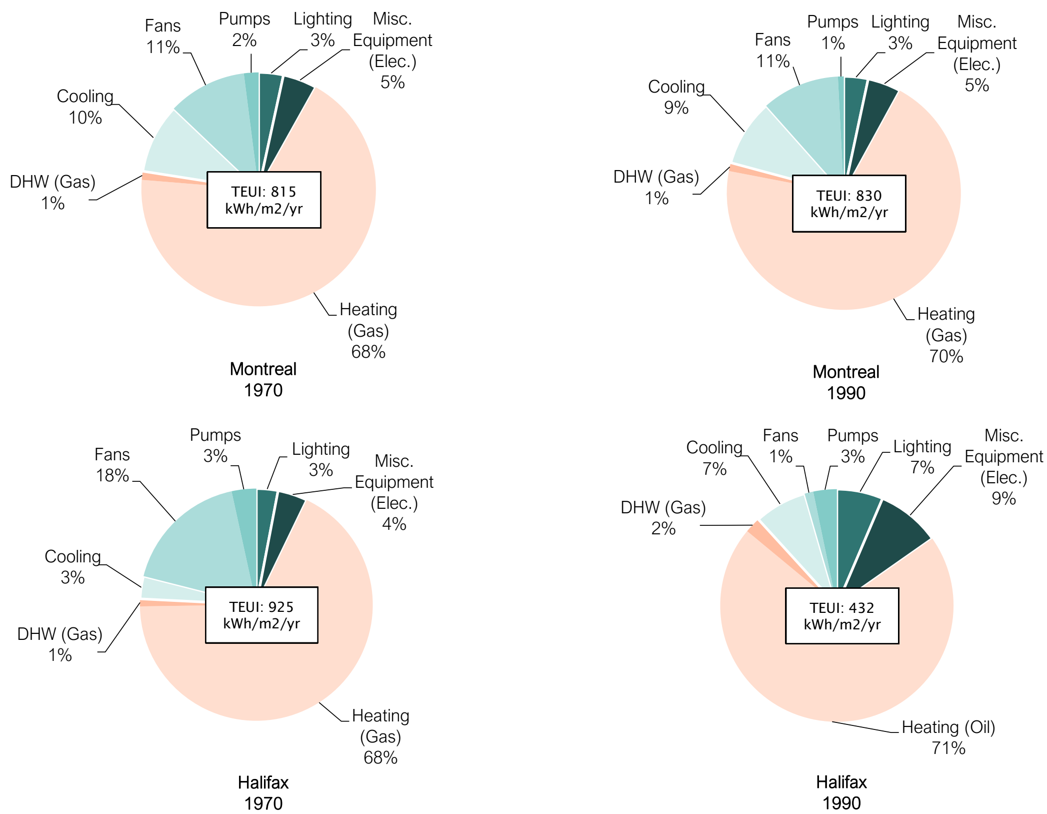


Figure 136 Energy end-use breakdown for the low-rise office baseline building archetypes.

Figure 137 shows the annual greenhouse gas intensity (GHGI) for the 1970s and 1990s low-rise office baseline building archetypes, with the GHGI range from 15 to 312 $kgCO_2eq/m^2/yr$ for the 1970s vintage building, and from 20 to 205 $kgCO_2eq/m^2/yr$ for the 1990s vintage building.

With the exception of Vancouver, 1970s low-rise office baseline building archetypes all had relatively similar total energy consumption. On the other hand, there is significant variation in greenhouse gas intensities from location to location. This is due to the difference in the carbon intensity of electricity in each region. Figure 137 highlights how the carbon emissions associated with electricity are very low in Vancouver, Toronto, and Montreal, whereas in Edmonton and Halifax electricity related carbon emissions are greater than the emissions from natural gas or oil.

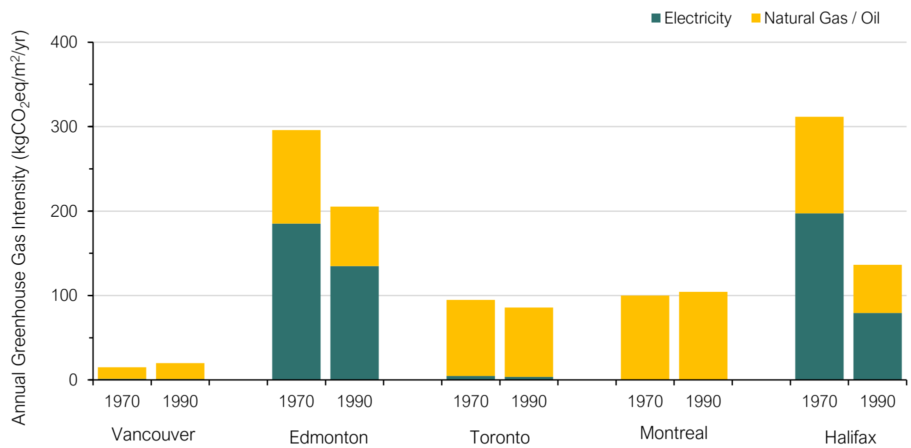


Figure 137 Greenhouse gas intensity (GHGI) for the 1970s and 1990s low-rise office baseline building archetypes presented by region.

The 1970s and 1990s low-rise office baseline building energy and GHGI results are summarized in Table 27 by fuel type.

Table 27: Low-rise office baseline building TEUI and GHGI results

	Total energy use intensity (TEUI), kWh/m²/yr			Greenhouse gas intensity (GHGI), $kgCO_2e/m^2/yr$		
	Electricity	Natural gas	Total	Electricity	Natural gas	Total
Low-Rise Office 1970s						
Vancouver	137	77	214	1	14	15
Edmonton	247	616	863	185	111	296
Toronto	239	512	751	5	90	95
Montreal	250	566	816	0	100	100
Halifax	290	636	926	197	114	311
Low-Rise Office 1990s						
Vancouver	118	104	222	1	19	20
Edmonton	180	391	571	135	70	205
Toronto	184	466	650	4	82	86
Montreal	239	591	830	0	104	104
Halifax	117	316	433	79	57	136

Mid-rise Office

Table 28 Baseline building assumptions for mid-rise office archetype in Vancouver

	1970s	1990s
Enclosure		
Walls	Steel stud walls w/batt insulation, effective overall RSI-0.70 m^2-K/W.	Steel stud walls w/batt insulation, effective overall RSI-0.70 m^2-K/W.
Windows	Single glazed, non-thermally broken aluminum frames, USI – 5.68 W/m^2-K, SHGC-0.80.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	40%	60%
Mechanical		
HVAC	Constant volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient*) and water-cooled chiller (COP-5.5).	Variable air volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient) and water-cooled chiller (COP-5.2).
Service Hot Water (SHW)	Central gas-fired boiler (80% efficient*).	Central gas-fired boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 29 Baseline building assumptions for mid-rise office archetype in Edmonton

	1970s	1990s
Enclosure		
Walls	Precast concrete walls, steel stud w/batt insulation, effective overall RSI-1.06 m^2-K/W.	Steel stud wall w/batt insulation, effective overall RSI-1.4 m^2-K/W.
Windows	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	40%	40%
Mechanical		
HVAC	Core: Constant volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Reheat coils at zone level. Perimeter: Dedicated outdoor air system (constant volume) with hydronic heating and cooling coil. Four-pipe induction coils. Hydronic heating coils connected to gas-fired boiler (80 per cent efficiency*) and cooling coils connected to water-cooled chiller (COP-5.5).	Variable air volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient) and water-cooled chiller (COP-5.2).
Service Hot Water (SHW)	Central gas-fired boiler (80% efficient*).	Central gas-fired boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 30 Baseline building assumptions for mid-rise office archetype in Toronto

<table>
<tr><th colspan="3"></th></tr>
<tr><td></td><td>1970s</td><td>1990s</td></tr>
<tr><td colspan="3">Enclosure</td></tr>
<tr><td>Walls</td><td>Steel stud wall w/batt insulation, effective overall RSI-1.4 m^2-K/W.</td><td rowspan="3">Reinforced concrete frame with double glazed, thermally broken curtain wall, USI – 3.42 W/m^2-K, SHGC– 0.62, and spandrel panel, USI – 0.76 W/m^2-K.</td></tr>
<tr><td>Windows</td><td>Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.</td></tr>
<tr><td>Window-to-wall ratio</td><td>40%</td></tr>
<tr><td colspan="3">Mechanical</td></tr>
<tr><td>HVAC</td><td>Constant volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient*) and water-cooled chiller (COP-5.2).</td><td>Variable air volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient) and water-cooled chiller (COP-5.2).</td></tr>
<tr><td>Service Hot Water (SHW)</td><td>Central gas-fired boiler (80% efficient*).</td><td>Central gas-fired boiler (80% efficient).</td></tr>
</table>

* The mechanical system has been upgraded since original construction.

Table 31 Baseline building assumptions for mid-rise office archetype in Montreal

	1970s	1990s
Enclosure		
Walls	Steel stud wall w/batt insulation, effective overall RSI-1.4 m^2-K/W.	Reinforced concrete frame with double glazed, thermally broken curtain wall, USI – 3.42 W/m^2-K, SHGC– 0.62, and spandrel panel, USI – 1.32 W/m^2-K.
Windows	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.	
Window-to-wall ratio	40%	
Mechanical		
HVAC	Variable air volume air handling units (AHUs) with hydronic heating coil for pre-heat and cooling coil. Steam radiators at zone level. Gas-fired steam boiler (80% efficient*) and water-cooled chiller (COP-5.2).	Variable air volume air-handling units (AHUs) with hydronic heating for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient) and water-cooled chiller (COP-5.2).
Service Hot Water (SHW)	Central gas-fired boiler (80% efficient*).	Central gas-fired boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 32 Baseline building assumptions for mid-rise office archetype in Halifax

	1970s	1990s
Enclosure		
Walls	Steel stud wall w/batt insulation, effective overall RSI-1.4 m²-K/W.	Steel stud wall w/batt insulation, effective overall RSI-1.05 m²-K/W.
Windows	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	40%	40%
Mechanical		
HVAC	Dual duct variable air volume with hydronic heating and cooling coils. Gas-fired boiler (80% efficient*) and water-cooled chiller (COP-5.2).	Variable air volume air handling units (AHUs) with hydronic heating coil for pre-heat and cooling coil. Hydronic baseboards and reheat coils at zone level. Gas-fired boiler (80% efficient) and water-cooled chiller (COP-5.2).
Service Hot Water (SHW)	Central gas-fired boiler (80% efficient*).	Central gas-fired boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Baseline Building Consumption

Figure 138 shows the total energy use intensity (TEUI) for the 1970s and 1990s mid-rise office baseline building archetypes presented by region. Figure 139 shows a summary of the TEUI and end-use breakdown, respectively, for the 1970s and 1990s mid-rise office baseline building archetypes in each region.

The TEUI ranges from 388 to 750 kWh/m²/yr for the 1970s archetype, and from 439 to 667 kWh/m²/yr for the 1990s archetype. The office archetypes have a wide variety of HVAC systems, which contributes to the wide range in energy performance.

The 1990s Montreal show higher energy use compared to the 1970s archetypes in the same locations. This is mainly because the 1990s Montreal exterior walls consist of spandrel panel and curtainwall, and the overall thermal performance of the enclosure is worse compared to the 1970s archetype.

This change in enclosure is seen for the 1970s and 1990s Toronto archetypes as well, though the 1990s Toronto baseline building results in a lower TEUI than the 1970s archetype. The 1990s Toronto ventilation system is improved to a variable air volume system, from a constant air volume in the 1970s baseline building, which results in reduced heating and fan energy. This change in ventilation system is not seen for the Montreal archetypes.

The Vancouver mid-rise office performs worse than the Vancouver low-rise office. The mid-rise office consists of compartmentalized air-handling units (1/floor) and re-heat coils. This system type results in significantly higher fan and heating energy compared to the DOAS make-up air units in the Vancouver low-rise office.

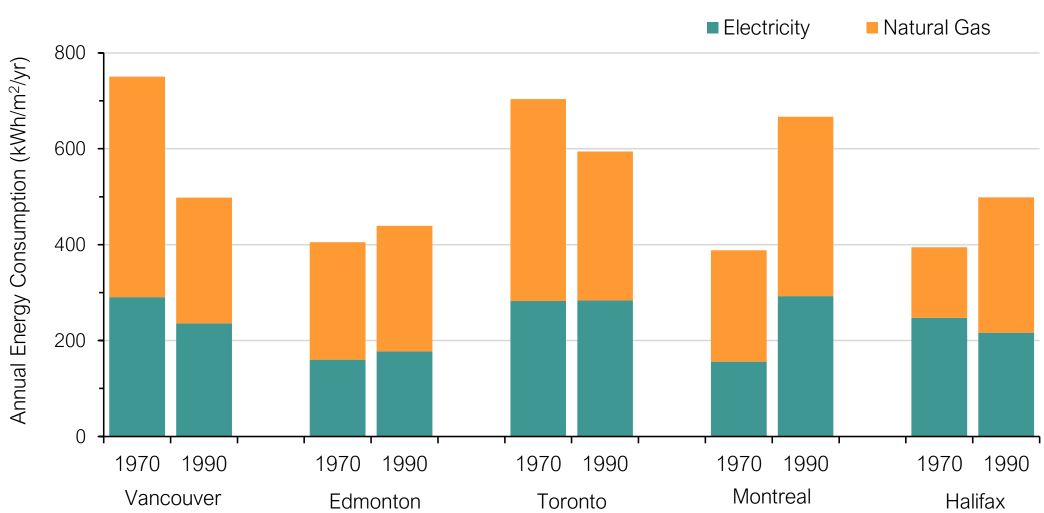
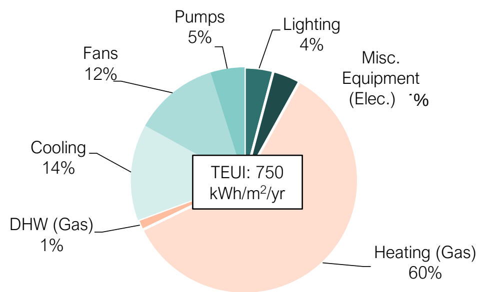
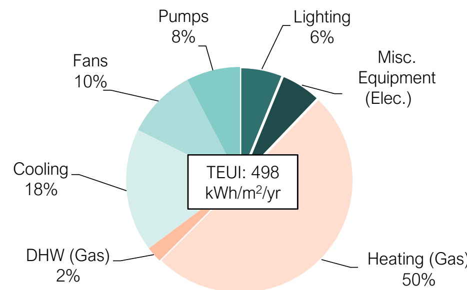


Figure 138 Total energy use intensity (TEUI) for the 1970s and 1990s mid-rise office baseline building archetypes presented by region.

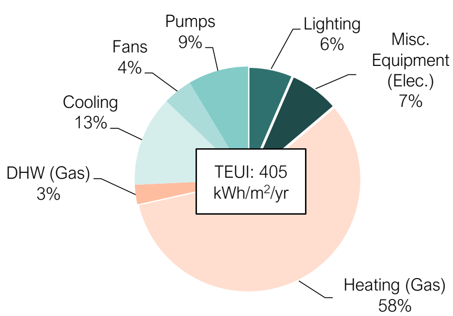
The dominant energy end use for the mid-rise office archetypes in all locations is space heating. CRMs chosen for this archetype focus on space heating demand reduction as well as improving system efficiency to reduce energy consumption.



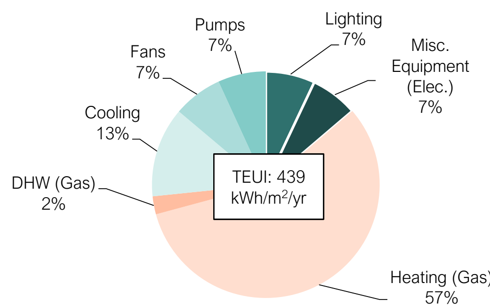
Vancouver
1970



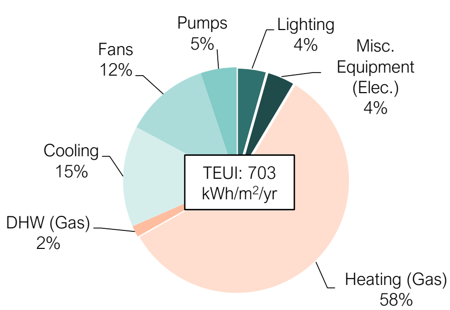
Vancouver
1990



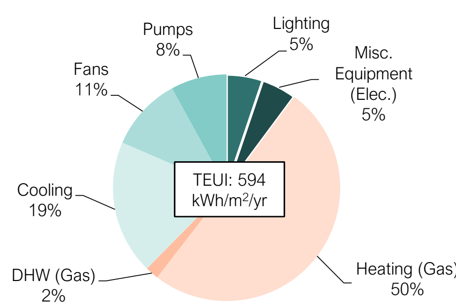
Edmonton
1970



Edmonton
1990



Toronto
o1970



Toronto
1990

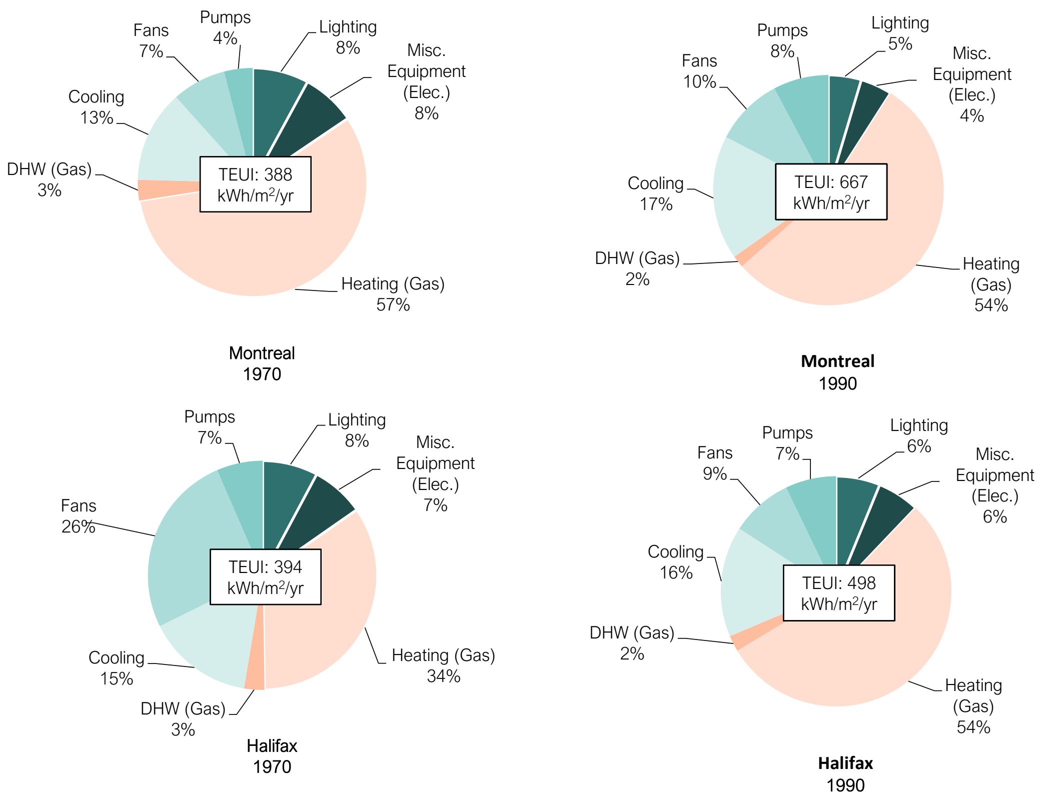


Figure 139 Energy end-use breakdown for the mid-rise office baseline building archetypes.

Figure 140 shows the annual GHGI for the 1970s and 1990s mid-rise office baseline building archetypes, with the GHGI ranging from 41 to 195 $kgCO_2eq/m^2/yr$ for the 1970s archetype, and from 49 to 198 $kgCO_2eq/m^2/yr$ for the 1990s archetype.

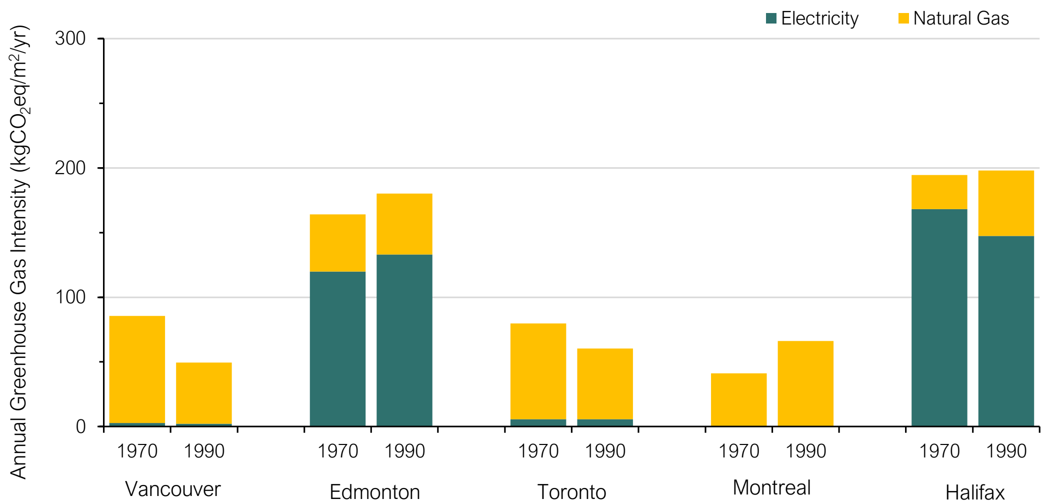


Figure 140 Total greenhouse gas intensity (GHGI) for the 1970s and 1990s mid-rise office archetypes presented by region.

The 1970s and 1990s mid-rise office baseline building energy and GHGI results are summarized in Table 33.

Table 33 Mid-rise office baseline building TEUI and GHGI[48]

	Total energy use intensity (TEUI), kWh/m²/yr			Greenhouse gas intensity (GHGI), $kgCO_2e/m^2/yr$		
	Electricity	Natural gas	Total	Electricity	Natural gas	Total
Mid-Rise Office 1970s						
Vancouver	290	460	750	3	83	86
Edmonton	160	245	405	120	44	164
Toronto	282	421	703	6	74	80
Montreal	156	233	389	0	41	41
Halifax	247	147	394	168	26	194
Mid-Rise Office 1990s						
Vancouver	236	262	498	2	47	49
Edmonton	177	262	439	133	47	180
Toronto	284	310	594	6	55	61
Montreal	293	374	667	0	66	66
Halifax	217	282	499	147	51	198

[48] Additive discrepancies are due to rounding.

Low-rise MURB

Table 34 Baseline building assumptions for low-rise MURB archetype in Vancouver

	1970s	1990s
Enclosure		
Walls	Wood frame (2x4) w/batt insulation, no balconies, effective RSI-1.40 m^2-K/W.	Wood frame (2x4) w/batt insulation, balconies (insulated between joists), effective RSI-1.76 m^2-K/W.
Windows	Single glazed[2)], non-thermally broken aluminum frames, USI – 5.68 W/m^2-K, SHGC – 0.80.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	20%	30%
Mechanical		
HVAC	Constant volume unheated make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient[1]).	Constant volume gas-fired (80% efficient) make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient).
Service Hot Water (SHW)	Central gas-fired water heater (80% efficient[1]).	Central gas-fired water heater (80% efficient).

1) The mechanical system has been upgraded since original construction.

2) The 1970s vintage low-rise MURB assumes no window upgrades have occurred. Market assessment of RDH data from depreciation reports and building enclosure condition assessments indicates that there is approximately 50/50 split between single-glazed and upgraded double-glazed windows for MURBs of this era.

Table 35 Baseline building assumptions for low-rise MURB archetype in Edmonton

	1970s	1990s
Enclosure		
Walls	Woof frame (2x4) w/batt insulation, no balconies, effective RSI-1.76 m^2-K/W.	Wood frame (2x4) w/batt insulation, balconies (insulated between joists), effective RSI-1.76 m^2-K/W.
Windows	Single glazed, non-thermally broken aluminum frames, USI – 5.68 W/m^2-K, SHGC – 0.80.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	20%	30%
Mechanical		
HVAC	Constant volume gas-fired (80% efficient) make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient*).	Constant volume gas-fired (80% efficient) make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient).
Service Hot Water (SHW)	Central gas-fired water heater (80% efficient*).	Central gas-fired water heater (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 36 Baseline building assumptions for low-rise MURB archetype in Toronto

	1970s	1990s
Enclosure		
Walls	Wood frame (2x4) w/batt insulation and brick veneer, effective RSI-1.76 m²K/W.	Wood frame (2x6) w/batt insulation, effective RSI-2.11 m²K/W.
Windows	Double glazed, non-thermally broken aluminum frames with single glazed sliders (x2) for operators, USI – 3.97 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	20%	30%
Mechanical		
HVAC	Constant volume gas-fired (80% efficient, upgraded) make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient*). 75 per cent of suites use window installed A/C units.	Constant volume gas-fired (80% efficient) make-up air units. Two-pipe fan coil units connected to gas-fired boiler (80% efficient).
Service Hot Water (SHW)	Central gas-fired water heater (80% efficient*).	Central gas-fired water heater (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 37 Baseline building assumptions for low-rise MURB archetype in Montreal

	1970s	1990s
Enclosure		
Walls	Wood frame (2x4) w/batt insulation and brick veneer, effective RSI-1.76 m²K/W.	Wood frame (2x4) w/batt insulation and brick veneer, effective RSI-1.76 m²K/W.
Windows	Double glazed, non-thermally broken aluminum frames with single glazed sliders (x2) for operators, USI – 3.97 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	20%	30%
Mechanical		
HVAC	Bathroom exhaust (no make-up air). Hydronic baseboard convectors connected to oil-fired boiler (80% efficient*), 50 per cent of suites use window installed A/C units.	Gas-fired (80% efficient) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient), 50 per cent of suites use window installed A/C units. Gas-fired boiler (80% efficient).
Service Hot Water (SHW)	Central oil-fired water heater (80% efficient*)	Central gas-fired water heater (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 38 Baseline building assumptions for low-rise MURB archetype in Halifax

	1970s	1990s
Enclosure		
Walls	Wood frame (2x4) w/batt insulation, effective RSI-1.76 m^2-K/W.	Wood frame (2x6) w/batt insulation, effective RSI-2.11 m^2-K/W.
Windows	Double glazed, non-thermally broken aluminum frames with single glazed sliders (x2) for operators, USI – 3.97 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	20%	30%
Mechanical		
HVAC	Gas-fired (80% efficient, upgraded) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient*), 40 per cent of suites use window installed A/C units.	Oil-fired (80% efficient) constant volume make-up air units. Hydronic baseboard convectors connected to oil-fired boiler (80% efficient), 40 per cent of suites use window installed A/C units.
Service Hot Water (SHW)	Central gas-fired water heater (80% efficient*).	Central oil-fired water heater (80% efficient).

* The mechanical system has been upgraded since original construction.

Baseline Building Consumption

Figure 141 and Figure 142 show a summary of TEUI and the end-use breakdown, respectively, for the 1970s and 1990s low-rise MURB baseline building archetypes in each region.

The TEUI ranges from 185 to 343 kWh/m²/yr for the 1970s archetype, and from 213 to 333 kWh/m²/yr for the 1990s archetype.

The TEUI are relatively similar between the 1970s and 1990s baseline building archetypes, except for in Montreal. The results suggest that the energy efficiency of typical low-rise MURBs has not improved significantly between the two age categories. This is consistent with previous studies such as the *Energy Consumption in Low-Rise Multi-Family Residential Buildings in British Columbia*[49].

The 1990s Montreal low-rise MURB archetype shows higher TEUI than the 1970s low-rise MURB. This is mainly because the 1990s archetype has gas-fired make-up air units that provide tempered air to the corridors (100 cfm outdoor air/suite). The 1970s Montreal baseline building does not have a mechanical ventilation system, instead it has bathroom exhaust which is balanced with infiltration (60 cfm outdoor air per suite). Since the 1990s archetype supplies more outdoor air, the heating demand is higher for this archetype.

Note that the 1970s Montreal baseline building archetype uses oil for heating, and the 1990s Halifax baseline building uses oil for heating and service hot water.

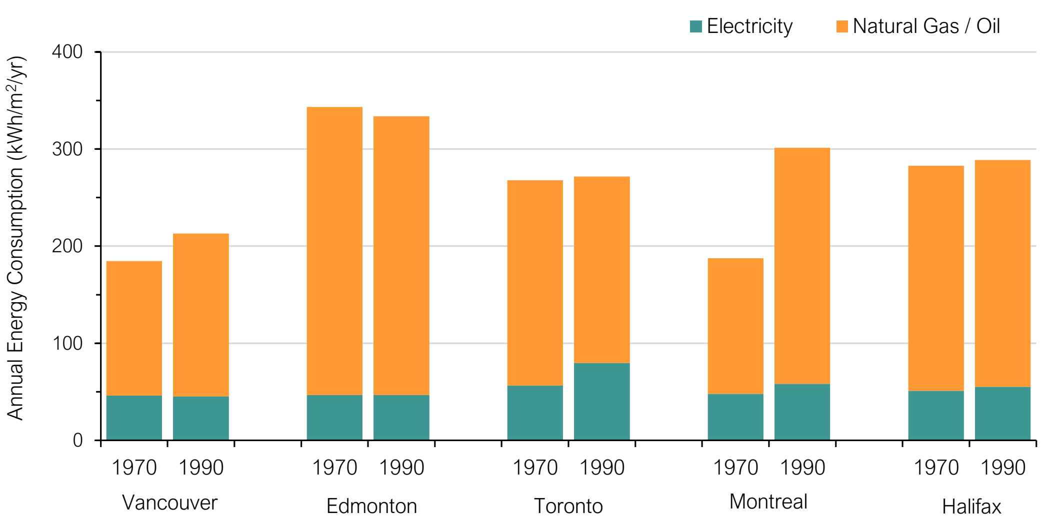
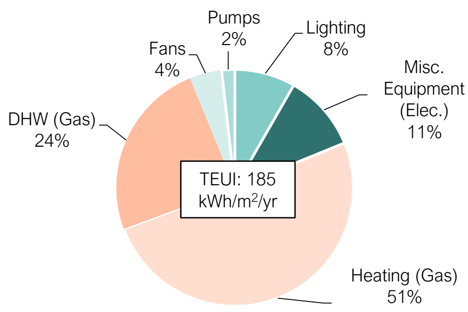


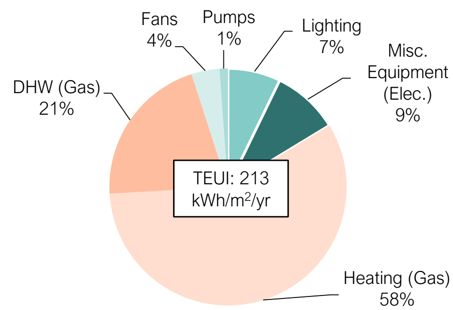
Figure 141 Total energy use intensity (TEUI) for the 1970s and 1990s mid-rise MURB baseline building archetypes presented by region.

[49] Energy Consumption in Low-Rise Multi-Family Residential Buildings in British Columbia, authored by RDH, May 2017

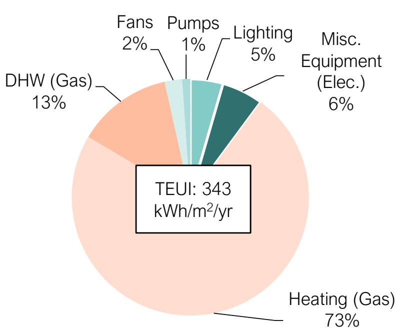
The dominant energy end use for all low-rise MURB in all locations is space heating. The CRMs chosen for this archetype focus on space heating demand reduction as well as improving system efficiency to reduce energy consumption.



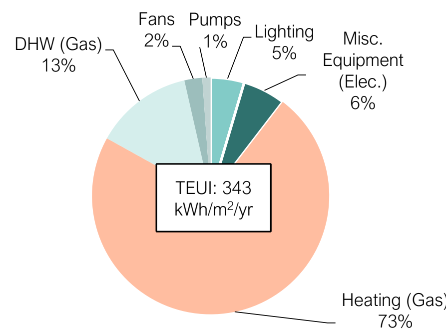
Vancouver
1970



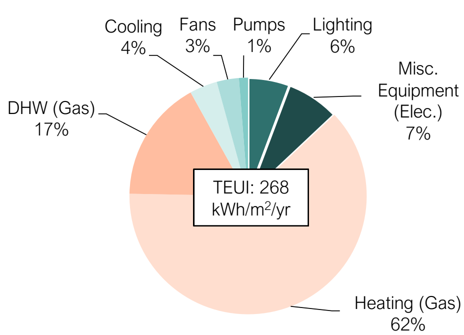
Vancouver
1990



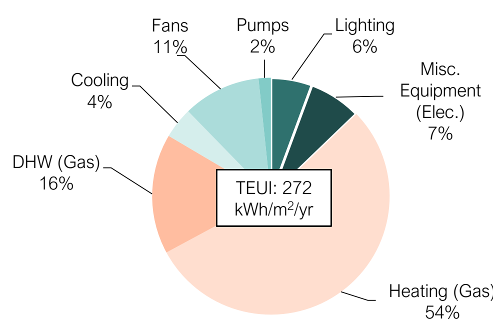
Edmonton
1970



Edmonton
1990



Toronto
1970



Toronto
1990

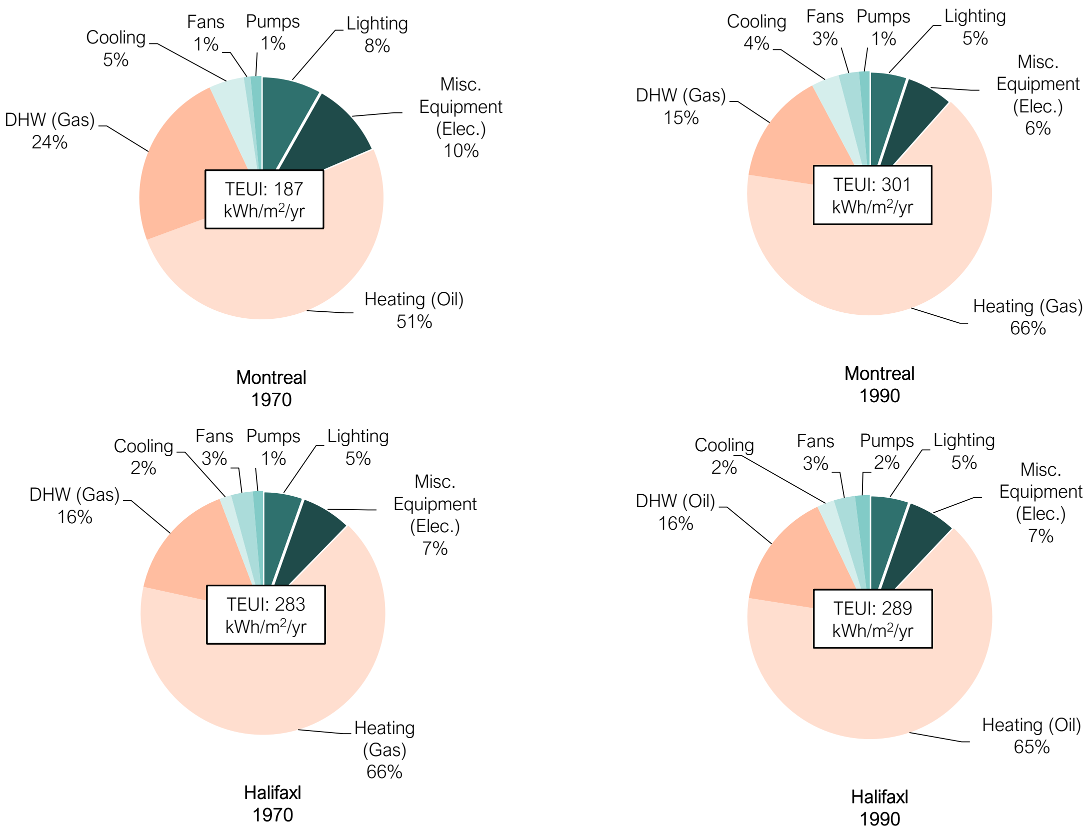


Figure 142 End-use breakdown for low-rise MURB 1970s and 1990s baseline building archetypes.

Figure 143 shows the annual GHGI for the 1970s and 1990s low-rise MURB baseline building archetypes, with the GHGI ranging from 25 to 88 $kgCO_2eq/m^2/yr$ for the 1970s archetype, and from 31 to 87 $kgCO_2eq/m^2/yr$ for the 1990s archetype.

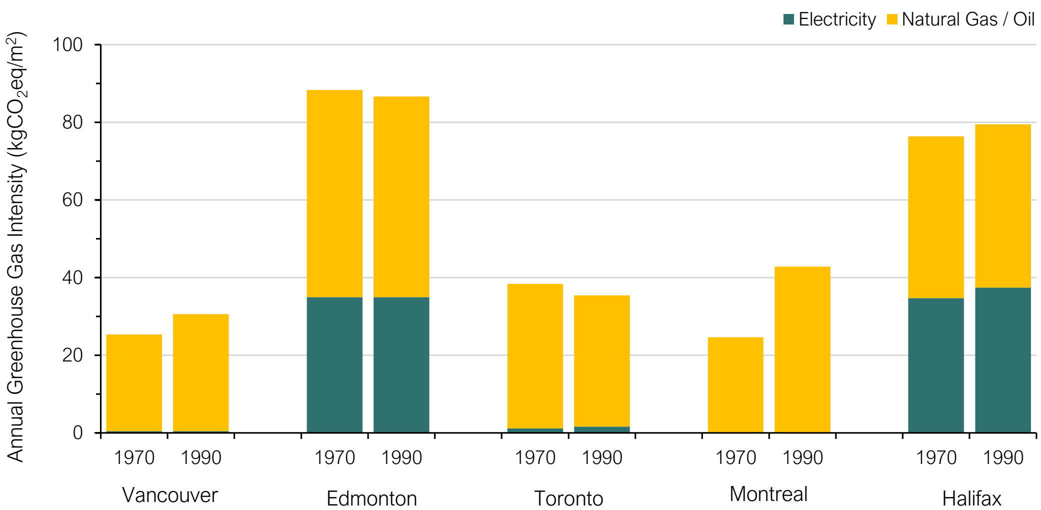


Figure 143 Total greenhouse gas intensity (GHGI) for the 1970s and 1990s low-rise MURB baseline archetypes presented by region.

The 1970s and 1990s low-rise MURB baseline building energy and GHGI results are summarized below by fuel type.

Table 39 Low-rise MURB baseline building TEUI and GHGI[50]

	Total energy use intensity (TEUI), kWh/m²/yr			Greenhouse gas intensity (GHGI), $kgCO_2e/m^2/yr$		
	Electricity	Natural gas	Total	Electricity	Natural gas	Total
Low-Rise MURB 1970s						
Vancouver	46	139	185	0	25	25
Edmonton	47	297	344	35	53	88
Toronto	56	212	268	1	37	38
Montreal	48	139	187	0	25	25
Halifax	51	232	283	35	42	76
Low-Rise MURB 1990s						
Vancouver	45	168	213	0	30	30
Edmonton	47	287	334	35	52	87
Toronto	80	192	272	2	34	36
Montreal	58	243	301	0	43	43
Halifax	55	234	289	37	42	79

[50] Additive discrepancies are due to rounding.

Mid-rise MURB

Table 40 Baseline building assumptions for mid-rise MURB archetype in Vancouver

	1970s	1990s
Enclosure		
Walls	Exposed concrete walls w/interior insulation, uninsulated slab edges, non-thermally broken balconies, effective overall RSI-0.70 m^2-K/W.	Exposed concrete walls w/interior insulation, uninsulated slab edges, non-thermally broken balconies, effective overall RSI-0.70 m^2-K/W.
Windows	Single glazed, non-thermally broken aluminum frames, USI – 5.68 W/m^2-K, SHGC – 0.80.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	40%	60%
Mechanical		
HVAC	Gas-fired (80% efficient*) constant volume make-up air units. Hybrid baseboard convectors connected to gas-fired boiler (80% efficient*).	Gas-fired (80% efficient) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient). Gas-fired boiler (80% efficient).
Service Hot Water (SHW)	Central gas-fired water heater (80% efficient*).	Central gas-fired water heater (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 41 Baseline building assumptions for mid-rise MURB archetype in Edmonton

	1970s	1990s
Enclosure		
Walls	Exposed concrete walls w/interior insulation, uninsulated slab edges, non-thermally broken balconies, effective overall RSI-0.70 m^2-K/W.	Exposed concrete walls w/interior insulation, uninsulated slab edges, non-thermally broken balconies, effective overall RSI-0.70 m^2-K/W.
Windows	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	30%	50%
Mechanical		
HVAC	Gas-fired (80% efficient*) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient*).	Gas-fired (80% efficient) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient).
Service Hot Water (SHW)	Central gas-fired water heater (80% efficient*).	Central gas-fired water heater (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 42 Baseline building assumptions for mid-rise MURB archetype in Toronto

	1970s	1990s
Enclosure		
Walls	Exposed concrete walls w/interior insulation, uninsulated slab edges, non-thermally broken balconies, effective overall RSI-0.70 m²K/W.	Exposed concrete walls w/interior insulation, uninsulated slab edges, non-thermally broken balconies, effective overall RSI-0.70 m²K/W.
Windows	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	30%	40%
Mechanical		
HVAC	Gas-fired (80% efficient*) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient*), 75 per cent of suites use window installed A/C units.	Gas-fired (80% efficient) constant volume make-up air units. Two-pipe fan coil units, heating coil connected to gas-fired boiler (80% efficient) and cooling coil connected to water-cooled chiller (COP-4.2).
Service Hot Water (SHW)	Central gas-fired water heater (80% efficient*).	Central gas-fired water heater (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 43 Baseline building assumptions for mid-rise MURB archetype in Montreal

	1970s	1990s
Enclosure		
Walls	Exposed concrete walls w/interior insulation, uninsulated slab edges, non-thermally broken balconies, effective overall RSI-0.70 m^2-K/W.	Exposed concrete walls w/interior insulation, uninsulated slab edges, non-thermally broken balconies, effective overall RSI-0.70 m^2-K/W.
Windows	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.
Window-to-wall ratio	30%	40%
Mechanical		
HVAC	Gas-fired (80% efficient*) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient*), 50 per cent of suites use window installed A/C units.	Gas-fired (80% efficient) constant volume make-up air units. Hydronic baseboard convectors connected to gas-fired boiler (80% efficient), 50 per cent of suites use window installed A/C units. Gas-fired boiler (80% efficient).
Service Hot Water (SHW)	Central gas-fired water heater (80% efficient*)	Central gas-fired water heater (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 44 Baseline building assumptions for mid-rise MURB archetype in Halifax

	1970s	1990s
Enclosure		
Walls	Exposed concrete walls w/interior insulation, uninsulated slab edges, non-thermally broken balconies, effective overall RSI-0.70 m^2K/W.	Exposed concrete walls w/interior insulation, uninsulated slab edges, non-thermally broken balconies, effective overall RSI-0.88 m^2K/W.
Windows	Double glazed, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.66.	Double glazed, low-e coating, non-thermally broken aluminum frames, USI – 3.52 W/m^2-K, SHGC – 0.45.
Window-to-wall ratio	30%	40%
Mechanical		
HVAC	Constant volume make-up air units with hydronic heating coil. Hydronic baseboard convectors. Gas-fired boiler (80% efficient*).	Constant volume make-up air units with hydronic heating coil. Hydronic baseboard convectors. Oil-fired boiler (80% efficient).
Service Hot Water (SHW)	Central gas-fired water heater (80% efficient*).	Central oil-fired water heater (80% efficient).

* The mechanical system has been upgraded since original construction.

Baseline Building Consumption

Figure 144 and Figure 145 show a summary of the total energy use intensity and end-use breakdown, respectively, for the 1970s and 1990s mid-rise MURB baseline building archetypes in each region.

The TEUI ranges from 261 to 376 kWh/m²/yr for the 1970s mid-rise MURB, and from 284 to 386 kWh/m²/yr for the 1990s mid-rise MURB.

Like the low-rise MURB, there is a small difference in TEUI between the 1970s and 1990s baseline building archetypes. There is a slight increase in TEUI for the 1990s archetypes (for all locations); this is because the 1990s archetypes have a higher window-to-wall ratio compared to the 1970s archetypes. It is assumed that there is no change in window and wall thermal performance for the 1990s archetype compared to the 1970s archetype, and therefore the higher window-to-wall ratio results in a higher overall U-value and ultimately higher heating demand. The results suggest that the energy efficiency of typical mid-rise MURBs has slightly worsened between the two age categories, this is consistent with previous studies such as the *Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia*[51].

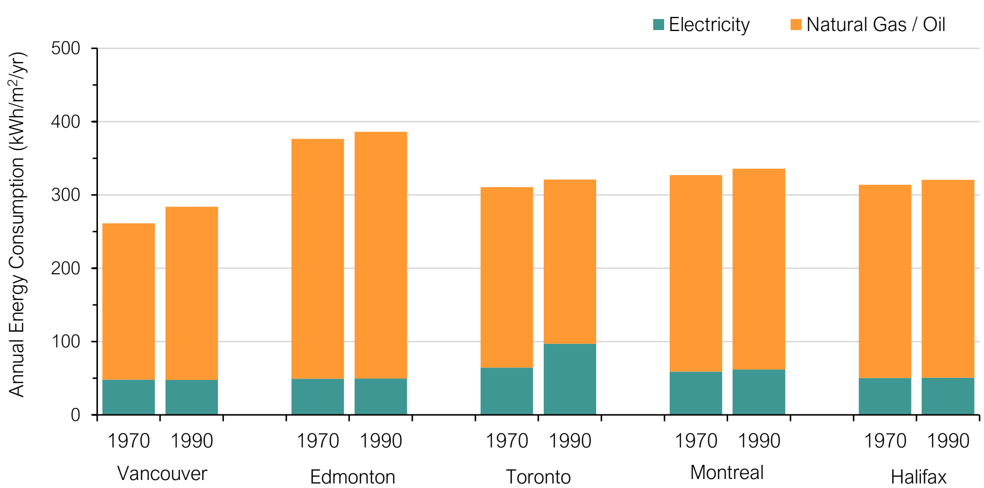
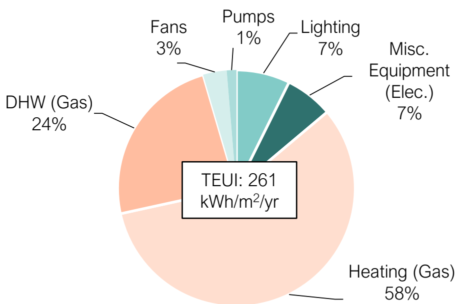


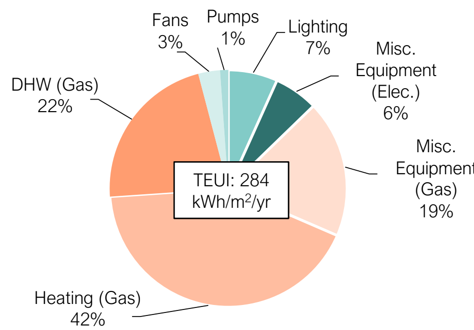
Figure 144 Total energy consumption (TEDI) for the 1970s and 1990s mid-rise MURB baseline building archetypes presented by region.

[51] Energy Consumption and Conservation in Mid- and High-Rise Residential Buildings in British Columbia, authored by RDH Building Science, February 2012.

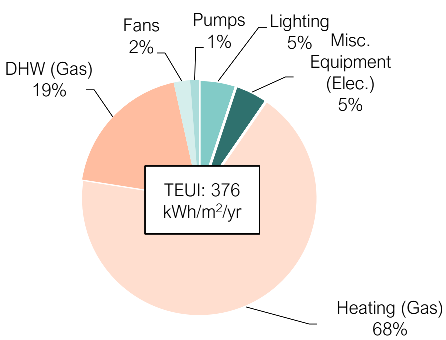
The dominant energy end use for all mid-rise MURB in all locations is space heating. The CRMs chosen for this archetype focus on space heating demand reduction as well as improving system efficiency to reduce energy consumption.



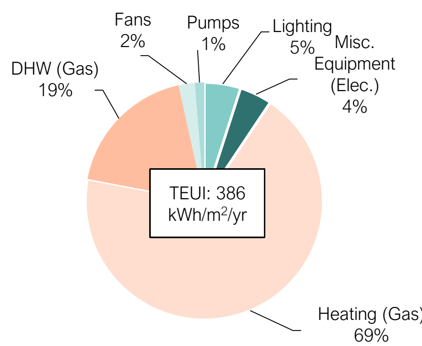
Vancouver
1970



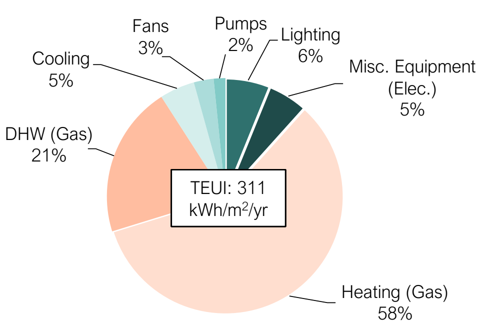
Vancouver
1990



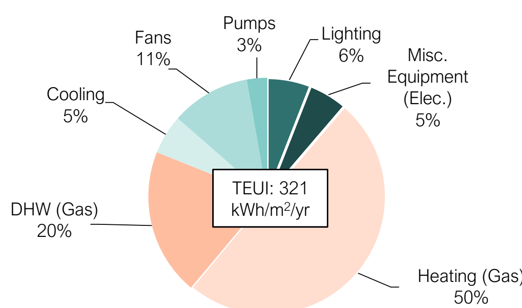
Edmonton
1970



Edmonton
1990



Toronto
1970



Torontoo
1990

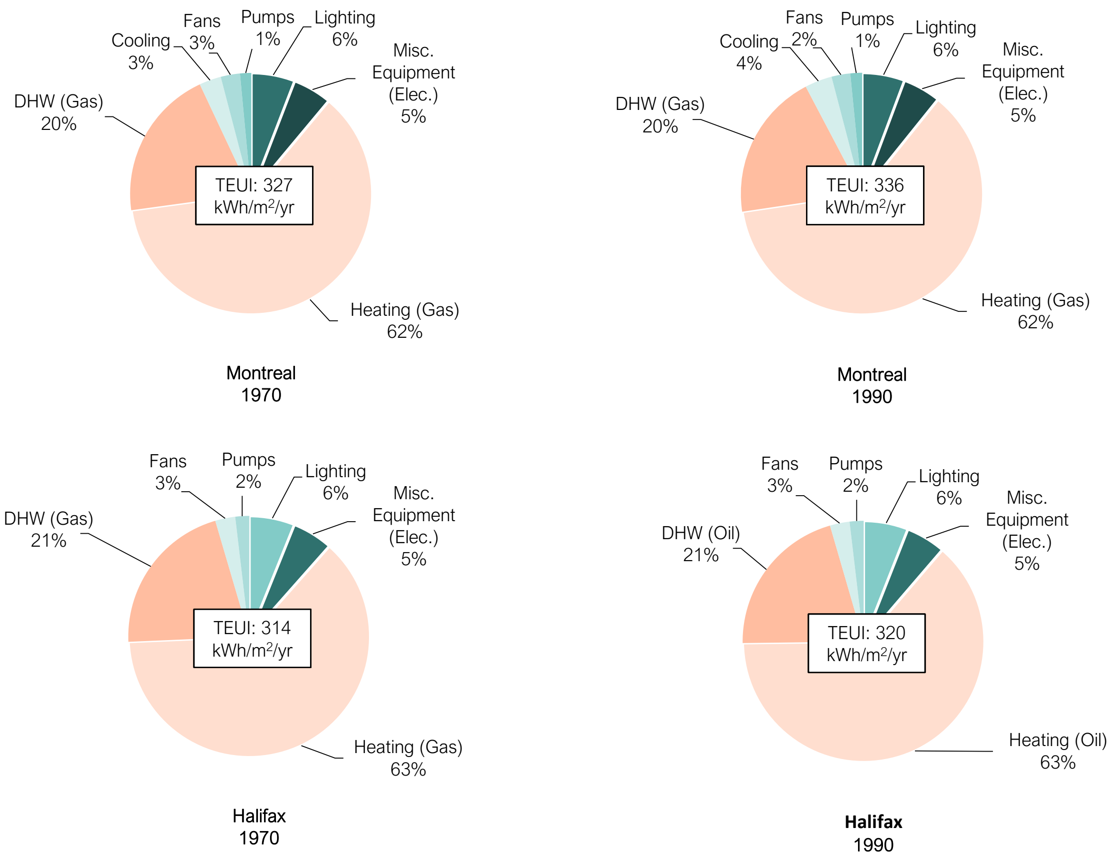


Figure 145 Energy end-use breakdown for the mid-rise MURB archetypes.

Figure 146 shows the annual GHGI for the mid-rise MURB baseline building archetypes, with the GHGI ranging from 39 and 96 $kgCO_2eq/m^2/yr$ for the 1970s mid-rise MURB, and from 41 to 98 $kgCO_2eq/m^2/yr$ for the 1990s mid-rise MURB.

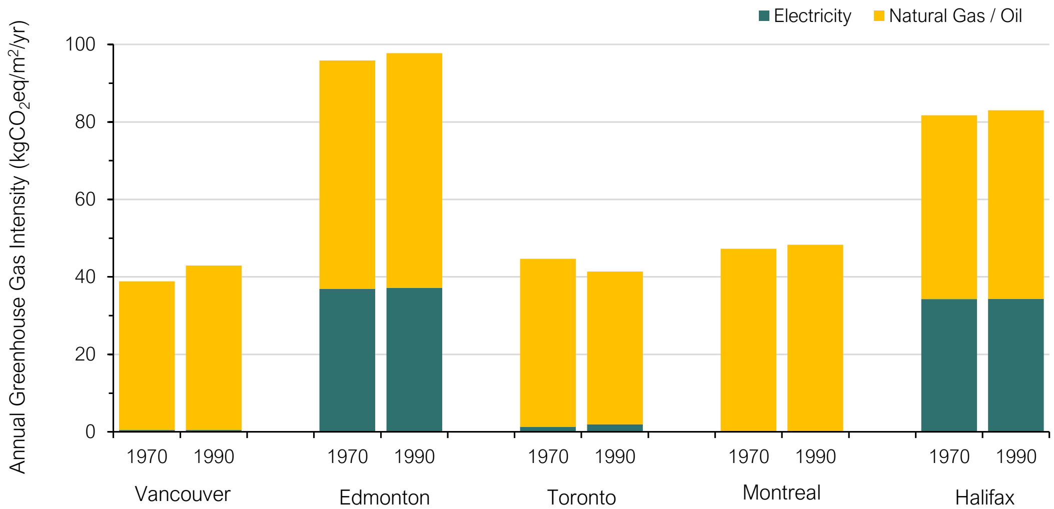


Figure 146 Total greenhouse gas intensity (GHGI) for the 1970s and 1990s mid-rise MURB baseline building archetypes presented by region.

The 1970s and 1990s mid-rise MURB baseline building energy and GHGI results are summarized below by fuel type.

Table 45 Mid-Rise MURB baseline building TEUI and GHGI[52]

	Total energy use intensity (TEUI), kWh/m²/yr			Greenhouse gas intensity (GHGI), $kgCO_2e/m^2/yr$		
	Electricity	Natural gas	Total	Electricity	Natural gas	Total
Mid-Rise MURB 1970s						
Vancouver	48	213	261	0	38	38
Edmonton	49	327	376	37	59	96
Toronto	64	246	310	1	43	44
Montreal	59	268	327	0	47	47
Halifax	50	264	314	34	47	81
Mid-Rise MURB 1990s						
Vancouver	48	236	284	0	42	42
Edmonton	50	337	387	37	61	98
Toronto	97	224	321	2	39	41
Montreal	62	274	336	0	48	48
Halifax	51	270	321	34	49	83

[52] Additive discrepancies are due to rounding.

Primary School

Table 46 Baseline building assumptions for the primary school archetype in Vancouver

	1970s	1990s
Enclosure		
Walls	Wood-frame w/batt insulation, effective RSI-1.41 m²K/W.	Steel frame w/batt insulation, effective RSI-2.11 m²K/W.
Windows	Single glazed, non-thermally broken aluminum frames, USI – 5.68 W/m^2-K SHGC – 0.80.	Single glazed, non-thermally broken aluminum frames USI – 5.68 W/m^2-K SHGC – 0.80.
Window-to-wall ratio	35%	35%
Mechanical		
HVAC	Constant volume rooftop units with hydronic heating coil for pre-heat. Single zone constant volume rooftop unit with gas-fired heating coil (80% efficient*) serving the gym. Hydronic baseboards and reheat coils connected to gas-fired boiler (80% efficient*). DX split system cooling (COP-2.5) supplying admin and computer classroom only.	Variable air volume rooftop units with hydronic heating coil for pre-heat, rooftop unit serving admin and computer classroom contains DX cooling coil (EER-8.5). Single zone constant volume rooftop unit with gas-fired heating coil (80% efficient) serving the gym. Hydronic baseboards and reheat coils. Gas-fired boiler (80% efficient).
Service Hot Water (SHW)	Supplied from building boiler (80% efficient*).	Supplied from building boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 47 Baseline building assumptions for the primary school archetype in Edmonton

	1970s	1990s
Enclosure		
Walls	Concrete structure (uninsulated), effective RSI-0.53 m²K/W.	Concrete structure w/ exterior insulation, effective RSI-1.76 m²K/W.
Windows	Double glazed, non-thermally broken aluminum frames with single glazed sliders (x2) for operators, USI – 3.97 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken frame, USI – 3.52 W/m^2-K, SHGC-0.66.
Window-to-wall ratio	25%	30%
Mechanical		
HVAC	Gas-fired (80% efficient*) constant volume make-up air units. Hydronic baseboards connected to gas-fired boiler (80% efficient*).	Gas-fired (80% efficient) constant volume make-up air units. Gas-fired (80% efficient) constant volume rooftop unit with DX cooling (EER-8.5) supplying admin area. Hydronic baseboards connected to gas-fired boiler (80% efficient).
Service Hot Water (SHW)	Supplied from building boiler (80% efficient*).	Supplied from building boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 48 Baseline building assumptions for the primary school archetype in Toronto

	1970s	1990s
Enclosure		
Walls	Concrete structure (uninsulated), effective RSI-0.53 m²K/W.	Concrete structure w/ exterior insulation, effective RSI-1.76 m²K/W.
Windows	Double glazed, non-thermally broken aluminum frames with single glazed sliders (x2) for operators, USI – 3.97 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken frame, USI – 3.52 W/m^2-K, SHGC-0.66.
Window-to-wall ratio	35%	35%
Mechanical		
HVAC	Gas-fired (80% efficient*) constant volume make-up air units. Gas-fired (80% efficient*) constant volume rooftop units with DX cooling (EER-8.5) serving admin area. Hydronic baseboards connected to gas-fired boiler (80% efficient*).	Gas-fired (80% efficient) constant volume make-up air unit ducting ventilation to distributed units. Distributed water-to-air heat pumps, heating coil (COP-3.3) and cooling coil connected to fluid cooler (COP-2.7).
Service Hot Water (SHW)	Supplied from building boiler (80% efficient*.)	Supplied from building boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 49 Baseline building assumptions for the primary school archetype in Montreal

	1970s	1990s
Enclosure		
Walls	Concrete structure (uninsulated), effective RSI-0.53 m^2K/W.	Concrete structure w/ exterior insulation, effective RSI-1.76 m^2K/W.
Windows	Double glazed, non-thermally broken aluminum frames with single glazed sliders (x2) for operators, USI – 3.97 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken frame, USI – 3.52 W/m^2-K, SHGC-0.66.
Window-to-wall ratio	35%	35%
Mechanical		
HVAC	Constant volume make-up air unit with hydronic heating coil supplying gym only. Local exhaust balanced with infiltration for remainder of building ventilation. Hydronic baseboards connected to gas-fired boiler (80% efficient*).	Constant volume rooftop units with hydronic heating coil and hydronic baseboards connected to gas-fired boiler (80% efficient).
Service Hot Water (SHW)	Supplied from building boiler (80% efficient*).	Supplied from building boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Table 50 Baseline building assumptions for the primary school archetype in Halifax

	1970s	1990s
Enclosure		
Walls	Concrete structure (uninsulated), effective RSI-0.53 m²K/W.	Concrete structure w/ exterior insulation, effective RSI-1.76 m²K/W.
Windows	Double glazed, non-thermally broken aluminum frames with single glazed sliders (x2) for operators, USI – 3.97 W/m^2-K, SHGC – 0.66.	Double glazed, non-thermally broken frame, USI – 3.52 W/m^2-K, SHGC-0.66.
Window-to-wall ratio	35%	35%
Mechanical		
HVAC	Gas-fired (80% efficient*) constant volume make-up air units. Hydronic baseboards connected to gas-fired boiler (80% efficient*).	Oil-fired constant volume make-up air units. Hydronic baseboards connected to oil-fired boiler (80% efficient).
Service Hot Water (SHW)	Supplied from building boiler (80% efficient*).	Supplied from building boiler (80% efficient).

* The mechanical system has been upgraded since original construction.

Baseline Building Consumption

Figure 147 and Figure 148 show a summary of the total energy use intensity and end-use breakdown, respectively, for the 1970s and 1990s primary school baseline building archetypes in each region.

The TEUI ranges from 388 to 623 kWh/m²/yr for the 1970s primary school archetype, and from 388 to 571 kWh/m²/yr for the 1970s primary school archetype.

Like the MURB archetypes, there is a relatively small difference in TEUI between the age categories. However, the 1990s Edmonton, Montreal and Halifax archetypes show a slightly lower TEUI than the 1970s archetypes; this is because of a better overall enclosure thermal performance.

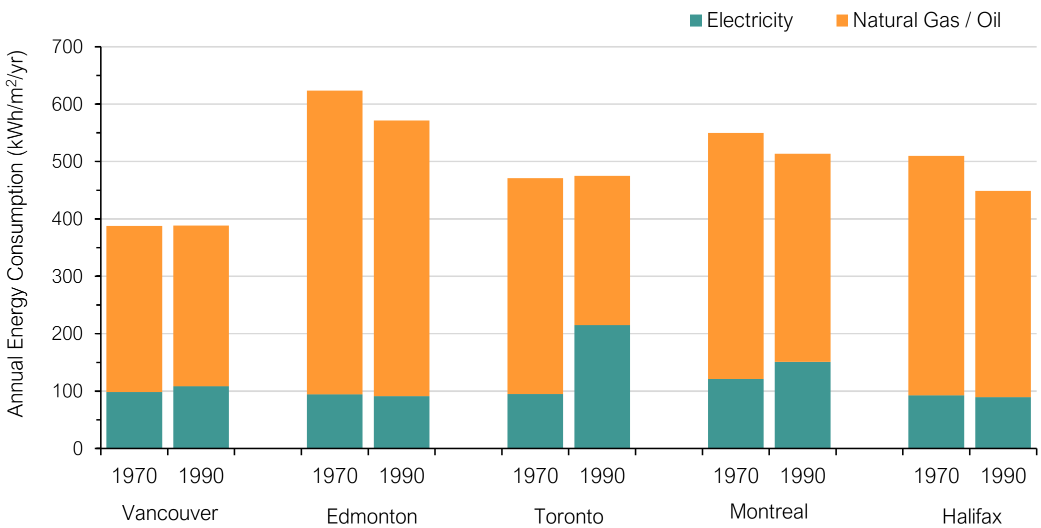
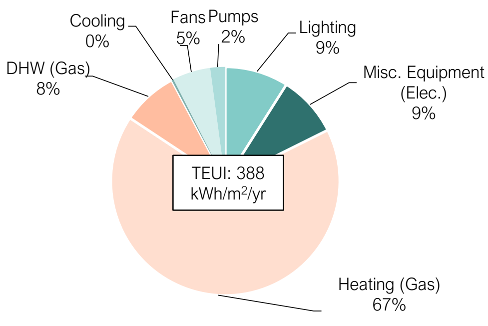
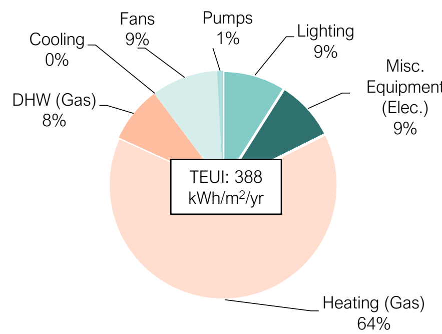


Figure 147 energy consumption (TEUI) for the 1970s and 1990s primary school baseline building archetypes presented by region.

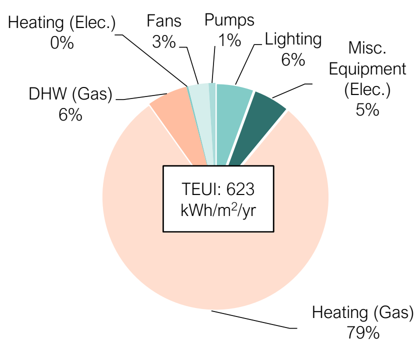
The dominant energy end use for all primary school in all locations is space heating. The CRMs chosen for this archetype focus on space heating demand reduction as well as improving system efficiency to reduce energy consumption.



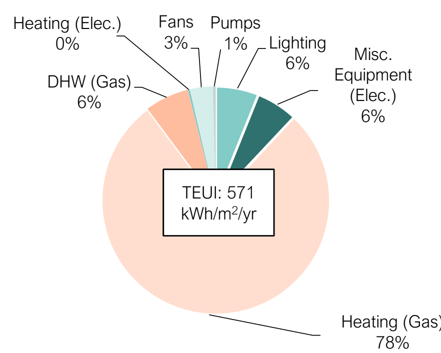
Vancouver
1970



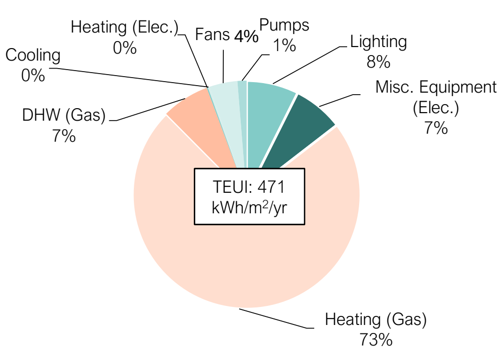
Vancouver
1990



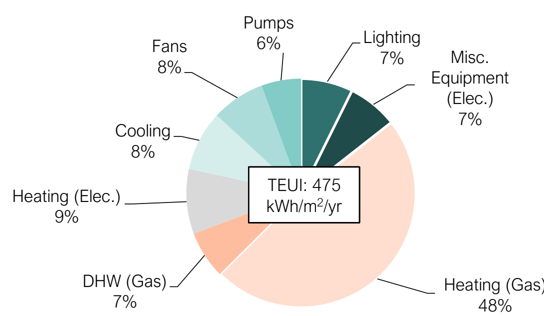
Edmonton
1970



Edmonton
1990



Toronto
1970



Toronton
1990

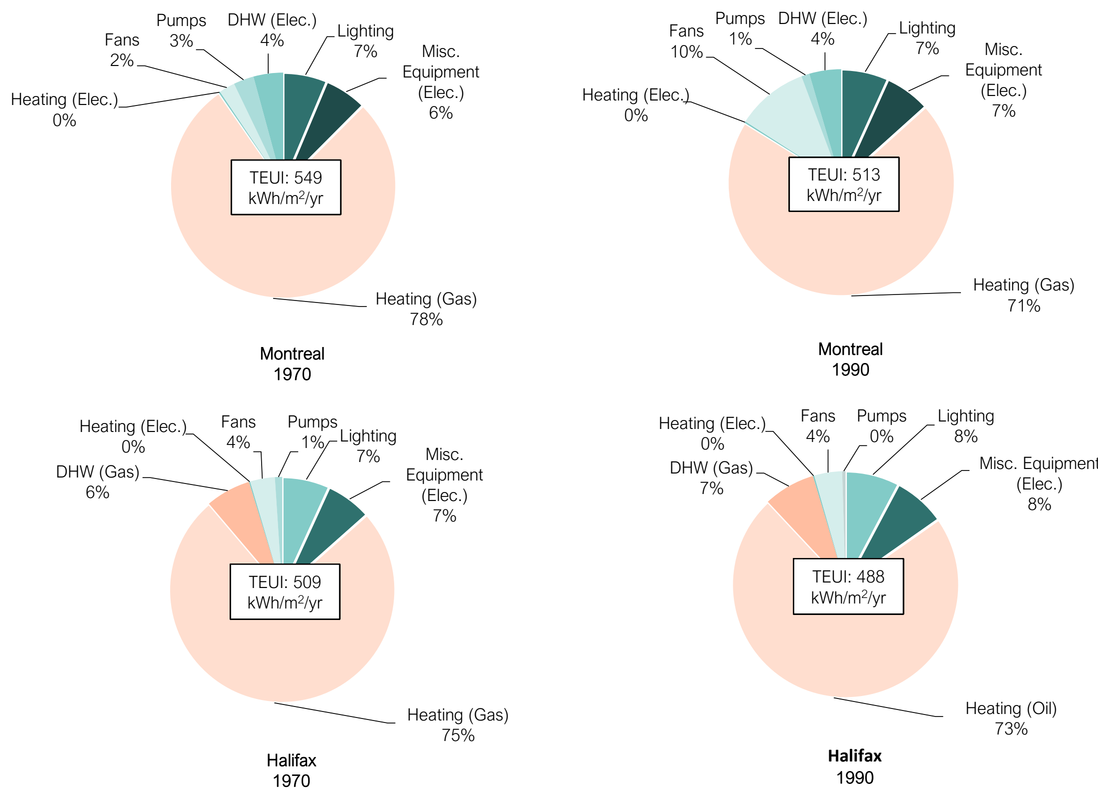


Figure 148 Energy end-use breakdown for the primary school baseline building archetypes.

Figure 149 shows the annual GHGI for the 1970s and 1990s primary school baseline building archetypes, with the GHGI ranges from 53 and 166 kgCO_2eq/m²/yr for the 1970s primary school, and from 50 to 155 kgCO_2eq/m²/yr for the 1990s primary school.

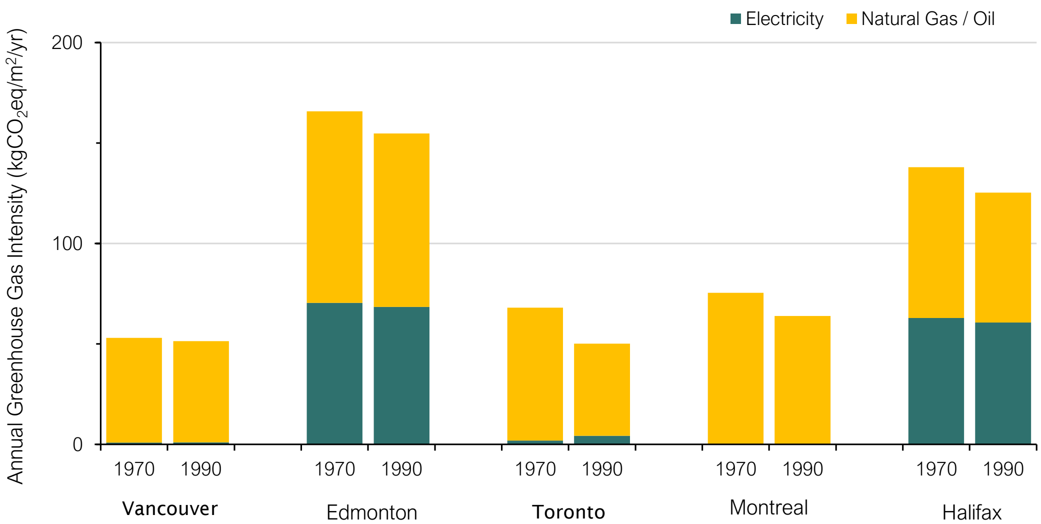


Figure 149 Total greenhouse gas intensity (GHGI) for the 1970s and 1990s primary school baseline archetypes presented by region.

The 1970s and 1990s primary school baseline building energy and GHGI results are summarized below by fuel type.

Table 51 Primary school baseline building TEUI and GHGI[53]

	Total energy use intensity (TEUI), kWh/m²/yr			Greenhouse gas intensity (GHGI), $kgCO_2e/m^2/yr$		
	Electricity	Natural gas	Total	Electricity	Natural gas	Total
Primary School 1970s						
Vancouver	99	289	388	1	52	53
Edmonton	94	530	624	71	95	166
Toronto	95	376	471	2	66	68
Montreal	121	428	549	0	75	75
Halifax	93	417	510	63	75	138
Primary School 1990s						
Vancouver	108	280	388	1	50	51
Edmonton	91	480	571	68	86	154
Toronto	215	261	476	4	46	50
Montreal	151	362	513	0	64	64
Halifax	89	360	449	61	65	126

[53] Additive discrepancies are due to rounding.

Appendix B - Additional Study Metrics

Typical Replacement/Renewal Cycle

It is most cost-effective to implement upgrades at the time of regularly scheduled building renewals. The table below summarizes typical replacement/renewal cycles for mechanical and enclosure systems. The CRMs for consideration in this analysis were selected and packaged together based on these timelines and the age of the archetypes.

Table 52 Typical renewal cycle for mechanical and enclosure systems

Building System	Building Sub-System	Replacement / Renewal
Lighting System	Lamps	10 to 15 years, driven by improved lamps
	Fixtures	15 to 20 years, driven by redesigning lighting system to best take advantage of improved lamps
HVAC	Minor HVAC Equipment e.g., fans and pumps	10 to 15 years
	Primary HVAC Equipment e.g., boilers, chiller, and rooftop units	15 to 25 years
	HVAC Distribution e.g., hydronic piping, ductwork and terminal heating/cooling, control valves and dampers	40 to 60 years
Enclosure	Windows	20 to 50 years
	Opaque Enclosure – Roofs	20 to 30 years
	Opaque Enclosure – Vertical	50 to 100 years
Structure		100+ years

Additional Considerations not Evaluated

The above CRMs were assumed to be applicable to the archetype buildings given the indicated constraints. However, it must be recognized that not all buildings in each location would be able to apply the CRMs as described due to various unique circumstances. Further, there are many CRMs that specific buildings may be able to apply that are not included in this analysis. The following examples highlight other challenges and opportunities that specific buildings could face when considering implementing deep carbon retrofit measures.

- **Structural challenge of triple glazed windows:** Triple glazed window can be 50% heavier than the double-glazed windows that they replace, primarily due to the third pane of glass in the insulating glazing unit (IGU). The additional weight, in some circumstances, may challenge the existing enclosure structural support. Some projects can mitigate the additional weight by using mylar films (e.g., Heat Mirror™) as the middle glazing in a triple glazed IGU.
- **Maintenance and condition issues with 1970s hydronic systems:** For the purposes of this study, it was assumed that the hydronic distributions systems would be retained for all the projects and as a result CRMs that take advantage of this existing infrastructure were selected. However, some building operators of 1970s vintage buildings may not have maintained their hydronic systems properly, and they may indeed be considering replacement of their piping systems due to increasing frequency of piping failures. This would increase the capital cost of their renewal project leading to a greater financial barrier to apply additional upgrade measures.
- **Over or under ventilation:** Conditioning and ventilation is one of the largest energy uses in buildings. Many existing buildings may be over or even under ventilating with respect to current ventilation codes. Ventilation codes define minimum ventilation rates, which designers and owners can elect to exceed. As little to no information is available on existing ventilation rates compared to current ventilation codes, we have assumed that ventilation rates for both the existing and post retrofit buildings meet current minimum ventilation rates.
- **Beneficial fluctuations in electricity grid carbon intensity:** The carbon intensity of electrical grids fluctuate diurnally and seasonally. While there are CRMs that can take advantage of these fluctuations using energy storage, they were not included in this analysis.

Appendix C – Summary of Costing and Financial Analysis Results

Table 53 Summary of Costing and Financial Analysis Results for Low-Rise Office

	Incremental Capital Cost (ICC), ($/m²)		Net Present Value (NPV), ($/m²)		Internal Rate of Return (IRR), %		Discounted Payback Period (Years)		Cost of Carbon Abatement, ($/tCO₂e)
	High	Low	High	Low	High	Low	High	Low	
1970s									
Vancouver Elec+Encl	$100	$70	$10	-$10	6.0%	4.2%	33	>40	$0
Vancouver Elec+Encl+Mech	$380	$260	-$100	-$220	2.4%	0.6%	>40	>40	$374
Edmonton Elec+Encl	$100	$70	$460	$420	29.2%	23.0%	5	7	$0
Edmonton Elec+Encl+Mech	$480	$300	$710	$530	15.1%	10.3%	10	16	$0
Toronto Elec+Encl	$100	$70	$380	$340	29.9%	20.9%	5	7	$0
Toronto Elec+Encl+Mech	$530	$310	$650	$430	14.8%	9.2%	10	19	$0
Montreal Elec+Encl	$90	$60	$270	$230	23.4%	16.6%	6	9	$0
Montreal Elec+Encl+Mech	$420	$260	$260	$100	10.1%	6.3%	17	31	$0
Halifax Elec+Encl	$90	$60	$1,060	$1030	70.1%	48.6%	2	3	$0
Halifax Elec+Encl+Mech	$280	$180	$1,830	$1,740	42.3%	29.7%	3	5	$0
1990s									
Vancouver Elec	$20	$20	-$10	-$20	1.5%	-0.3%	>40	>40	$0
Vancouver Elec+Mech	$530	$350	-$170	-$340	1.5%	-0.3%	>40	>40	$377
Edmonton Elec	$20	$20	$0	-$10	5.2%	3.0%	>40	>40	$37
Edmonton Elec+Mech	$1,060	$710	-$110	-$460	4.1%	2.0%	>40	>40	$63
Toronto Elec	$30	$20	-$110	-$170	-	-	>40	>40	$0
Toronto Elec+Mech	$500	$340	$400	$230	10.9%	7.5%	16	25	$0
Montreal Elec	$20	$20	-$90	-$140	-	-	>40	>40	$0
Montreal Elec+Mech	$1,030	$690	$0	-$340	5.0%	2.8%	>40	>40	$45
Halifax Elec	$20	$20	-$110	-$170	-	-	>40	>40	$500
Halifax Elec+Mech	$780	$520	-$120	-$390	3.5%	1.4%	>40	>40	$116

Table 54 Summary of Costing and Financial Analysis Results for Mid-Rise Office Archetype

	Incremental Capital Cost (ICC), (\$/m²)		Net Present Value (NPV), (\$/m²)		Internal Rate of Return (IRR), %		Discounted Payback Period (Years)		Cost of Carbon Abatement, (\$/tCO_2e)
	High	Low	High	Low	High	Low	High	Low	
1970s									
Vancouver Elec+Encl	$70	$50	$200	$170	21.9%	16.1%	7	9	$0
Vancouver Elec+Encl+Mech	$410	$250	$290	$130	10.8%	6.8%	16	28	$0
Edmonton Elec+Encl	$70	$50	$150	$120	18.3%	13.1%	9	12	$0
Edmonton Elec+Encl+Mech	$530	$350	$680	-$90	6.3%	3.9%	31	>40	$2
Toronto Elec+Encl	$70	$40	$290	$260	32.8%	22.3%	4	7	$0
Toronto Elec+Encl+Mech	$400	$270	$630	$490	16.0%	11.2%	9	15	$0
Montreal Elec+Encl	$60	$40	$40	$10	9.8%	5.6%	16	38	$0
Montreal Elec+Encl+Mech	$570	$380	-$100	-$290	3.3%	1.3%	>40	>40	$169
Halifax Elec+Encl	$60	$40	$160	$130	21.3%	14.7%	8	11	$0
Halifax Elec+Encl+Mech	$300	$200	$490	$390	15.8%	11.3%	10	15	$0
1990s									
Vancouver Elec	$20	$20	$0	-$10	4.4%	2.2%	>40	>40	$0
Vancouver Elec+Mech	$590	$390	$200	$10	7.9%	5.1%	23	>40	$0
Edmonton Elec	$20	$20	-$20	-$40	-1.6%	-6.4%	>40	>40	$174
Edmonton Elec+Mech	$700	$470	$230	$0	7.6%	5.0%	24	>40	$0
Toronto Elec	$20	$20	-$20	-$40	-2.1%	-7.1%	>40	>40	$0
Toronto Elec+Mech	$870	$580	$560	$270	10.1%	6.8%	17	28	$0
Montreal Elec	$20	$20	-$20	-$40	-7.0%	-10.6%	>40	>40	$0
Montreal Elec+Mech	$830	$550	$50	-$220	5.6%	3.2%	>40	>40	$41
Halifax Elec	$20	$20	-$10	-$30	2.3%	-3.2%	>40	>40	$110
Halifax Elec+Mech	$610	$410	$670	$470	12.7%	8.9%	20	20	$0

Table 55 Summary of Costing and Financial Analysis Results for Low-Rise MURB Archetype

	Incremental Capital Cost (ICC), ($/m²)		Net Present Value (NPV), ($/m²)		Internal Rate of Return (IRR), %		Discounted Payback Period (Years)		Cost of Carbon Abatement, ($/t$CO_2$e)
	High	Low	High	Low	High	Low	High	Low	
1970s									
Vancouver Elec+Encl	$50	$40	$20	$10	8.4%	6.2%	21	32	$0
Vancouver Elec+Encl+Mech	$340	$220	-$110	-$220	1.6%	-0.3%	>40	>40	$252
Edmonton Elec+Encl	$50	$40	$10	-$30	6.1%	-0.8%	>40	>40	$21
Edmonton Elec+Encl+Mech	$400	$260	-$70	-$210	3.4%	1.3%	>40	>40	$78
Toronto Elec+Encl	$50	$30	-$40	-$110	-	-	>40	>40	$216
Toronto Elec+Encl+Mech	$440	$270	-$80	-$250	3.1%	0.7%	>40	>40	$140
Montreal Elec+Encl	$50	$30	-$80	-$150	-	-	>40	>40	$324
Montreal Elec+Encl+Mech	$370	$230	-$160	-$300	-0.81.0%	-2.5%	>40	>40	$378
Halifax Elec+Encl	$50	$30	$30	-$10	14.0%	1.6%	8	>40	$0
Halifax Elec+Encl+Mech	$380	$240	$100	-$30	7.4%	4.5%	25	>40	$0
1990s									
Vancouver Elec	$10	$10	$0	$0	4.3%	2.0%	>40	>40	$0
Vancouver Elec+Mech	$450	$300	-$170	-$320	0.9%	-0.8%	>40	>40	$248
Edmonton Elec	$10	$10	-$10	-$20	6.5%	7.4%	>40	>40	$170
Edmonton Elec+Mech	$650	$430	-$330	-$550	-1.8%	-3.3%	>40	>40	$3771
Toronto Elec	$10	$10	-$90	-$150	-	-	>40	>40	$0
Toronto Elec+Mech	$340	$230	-$20	-$140	4.4%	2.3%	>40	>40	$68
Montreal Elec	$10	$10	-$110	-$170	-	-	>40	>40	$0
Montreal Elec+Mech	$630	$420	-$260	-$470	0.3%	-1.4%	>40	>40	$260
Halifax Elec	$10	$10	-$50	-$90	-	-	>40	>40	$500
Halifax Elec+Mech	$580	$390	-$90	-$280	3.4%	1.4%	>40	>40	$156

Table 56 Summary of Costing and Financial Analysis Results for Mid-Rise MURB Archetype

	Incremental Capital Cost (ICC), ($/m²)		Net Present Value (NPV), ($/m²)		Internal Rate of Return (IRR), %		Discounted Payback Period (Years)		Cost of Carbon Abatement, ($/t$CO_2$e)
	High	Low	High	Low	High	Low	High	Low	
1970s									
Vancouver Elec+Encl	$60	$40	$40	$20	9.3%	6.6%	19	29	$0
Vancouver Elec+Encl+Mech	$350	$230	-$50	-$170	3.6%	1.5%	>40	>40	$109
Edmonton Elec+Encl	$50	$30	$80	$70	15.5%	11.8%	10	14	$0
Edmonton Elec+Encl+Mech	$360	$230	-$40	-$160	4.1%	1.8%	>40	>40	$74
Toronto Elec+Encl	$50	$40	$70	$50	14.%	10.0%	11	17	$0
Toronto Elec+Encl+Mech	$420	$250	-$90	-$250	2.7%	0.4%	>40	>40	$136
Montreal Elec+Encl	$40	$30	$60	$50	14.5%	10.4%	11	16	$0
Montreal Elec+Encl+Mech	$330	$210	$0	-$120	4.9%	2.5%	>40	>40	$45
Halifax Elec+Encl	$40	$30	$130	$120	24.3%	17.3%	6	9	$0
Halifax Elec+Encl+Mech	$350	$220	$200	$80	9.7%	6.2%	18	32	$0
1990s									
Vancouver Elec	$10	$10	$0	$0	6.9%	4.2%	28	>40	$0
Vancouver Elec+Mech	$510	$340	-$160	-$330	1.6%	-0.2%	>40	>40	$211
Edmonton Elec	$10	$10	$10	$10	13.3%	9.4%	12	18	$0
Edmonton Elec+Mech	$710	$480	-$400	-$640	-3.1%	-4.5%	>40	>40	>$500
Toronto Elec	$10	$10	$10	$10	16.4%	11.3%	9	14	$0
Toronto Elec+Mech	$320	$210	-$10	-$110	4.9%	2.7%	>40	>40	$48
Montreal Elec	$10	$10	$0	$0	5.6%	3.1%	38	>40	$0
Montreal Elec+Mech	$620	$410	-$240	-$450	0.6%	-1.0%	>40	>40	$230
Halifax Elec	$10	$10	$10	$10	12.7%	9.0%	13	20	$0
Halifax Elec+Mech	$580	$390	-$70	-$270	3.8%	1.7%	>40	>40	$166

Table 57 Summary of Costing and Financial Analysis Results for Primary School Archetype

	Incremental Capital Cost (ICC), ($/m²)		Net Present Value (NPV), ($/m²)		Internal Rate of Return (IRR), %		Discounted Payback Period (Years)		Cost of Carbon Abatement, ($/$tCO_2$e)
	High	Low	High	Low	High	Low	High	Low	
1970s									
Vancouver Elec+Encl	$120	$90	$0	-$30	5.1%	3.6%	>40	>40	$25
Vancouver Elec+Encl+Mech	$430	$290	-$20	-$150	4.6%	2.6%	>40	>40	$52
Edmonton Elec+Encl	$130	$100	$120	$90	10.9%	8.8%	15	20	$0
Edmonton Elec+Encl+Mech	$450	$310	$280	$140	9.3%	6.7%	19	29	$0
Toronto Elec+Encl	$130	$80	$80	$40	9.9%	6.8%	17	28	$0
Toronto Elec+Encl+Mech	$630	$420	$90	-$120	6.2%	3.8%	32	>40	$6
Montreal Elec+Encl	$120	$80	$90	$50	10.4%	.72%	16	26	$0
Montreal Elec+Encl+Mech	$550	$370	-$10	-$190	4.8%	2.6%	>40	>40	$41
Halifax Elec+Encl	$110	$70	$170	$130	15.3%	10.9%	10	15	$0
Halifax Elec+Encl+Mech	$510	$340	$220	$50	8.5%	5.6%	21	37	$0
1990s									
Vancouver Elec	$30	$20	-$10	-$20	0.6%	-1.1%	>40	>40	$0
Vancouver Elec+Mech	$360	$240	$10	-$110	5.3%	3.0%	>40	>40	$29
Edmonton Elec	$30	$20	$0	-$10	5.0%	2.8%	>40	>40	$46
Edmonton Elec+Mech	$650	$430	-$50	-$270	4.2%	2.2%	>40	>40	$29
Toronto Elec	$30	$20	$10	$0	7.4%	4.6%	25	>40	$0
Toronto Elec+Mech	$840	$560	$290	$10	7.9%	5.1%	23	>40	$0
Montreal Elec	$30	$20	-$10	-$20	0.1%	-1.6%	>40	>40	$0
Montreal Elec+Mech	$600	$400	-$150	-$350	2.4%	0.5%	>40	>40	$120
Halifax Elec	$30	$20	$0	-$10	5.5%	3.2%	>40	>40	$34
Halifax Elec+Mech	$660	$440	-$100	-$330	3.5%	1.5%	>40	>40	$48