# MAKING THE CASE FOR BUILDING TO ZERO CARBON

## Canada Green Building Council®

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STUDY SUPPORTERS:

Government of Canada / Gouvernement du Canada

real estate foundation British Columbia

REALPAC

NOVA SCOTIA / NOUVELLE-ÉCOSSE

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**About CaGBC**

The CaGBC (www.cagbc.org) is a not-for-profit, national organization that has been working since 2002 to advance green building and sustainable community development practices in Canada. Through its leading programs that include the Leadership in Energy and Environmental Design (LEED®) and Zero Carbon Building Standard and in collaboration for its membership of over 1,200 industry organizations involved in designing, building, and operating buildings, homes, and communities, CaGBC has made excellent inroads toward achieving its mission of reducing the environmental impact of the built environment in Canada.

**About the Researchers (WSP)**

A leading engineering professional services consulting firm, WSP is a network of technical experts and strategic advisors that includes engineers, technicians, scientists, planners, surveyors, environmental specialists, and other design, program and construction management professionals. WSP experts are problem solvers who evolve, improve, modernize and excel, constantly working toward shaping the communities of tomorrow and helping societies thrive sustainably.

**About the Real Estate Foundation of British Columbia (REFBC)**

The Real Estate Foundation of British Columbia is a philanthropic organization based in British Columbia, Canada. REFBC supports land use and real estate practices that contribute to resilient, healthy communities and natural environments. The Foundation works to transform land use attitudes and practices in two ways: through grants to support research, education and law/policy reform; and through initiatives and special projects that bridge gaps in research and collaboration.

**About REALPAC**

Founded in 1970, REALPAC is a not-for-profit institutional real estate association, dedicated to advancing the long-term vitality of Canada's investment real estate sector. The Association advocates for global accounting, tax, market, sustainability and governance best practices. Membership is comprised of large public and private companies, pension funds, banks, life insurers and fund managers. Visit us at realpac.ca.



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# 1.0 EXECUTIVE SUMMARY

The Pan-Canadian Framework on Clean Growth and Climate Change committed to by Canada's First Ministers in December 2016 established Canada's vision for meeting its international commitment of a 30% reduction of greenhouse gas (GHG) emissions below 2005 levels by 2030 — a critical objective in Canada's transition to a low-carbon future.

Canada's built environment is a significant contributor to GHG emissions, with 17% of GHGs coming from residential, commercial and institutional buildings.[1]

The standard approach for decreasing GHG emissions associated with Canada's building stock remains the reduction of energy use required to heat, cool and power buildings through energy efficiency. By investing in energy efficiency measures, and as a result of cleaner electrical grids, Canada's GHG emissions associated with buildings have trended downward.[2]

However, current projections reveal that GHG emissions associated with buildings will grow modestly by 2030 unless further action is taken.[3] To effectively reduce GHG emissions at the building level, and to help ensure Canada meets its GHG reduction commitments, both energy use and carbon emissions need to be reduced simultaneously, which can be accomplished cost effectively by taking a Zero Carbon Building (ZCB) approach.

By turning existing and new buildings into ZCBs, Canada can significantly reduce its GHG emissions, decrease the demand for carbon intensive energy, and support Canadian real estate owners in optimizing the returns and resiliency of their portfolios. ZCBs can do this because they are designed to minimize carbon emissions and then offset any remaining emissions by generating clean, renewable energy onsite or offsite, which can reduce life-cycle costs and mitigate exposure to carbon pollution pricing.

A ZCB is characterized by four key components:

1. The building demonstrates a zero-carbon balance in its operations. Over the course of a year, its operations contribute zero carbon emissions.
2. Design prioritizes reducing energy demand and meeting energy needs efficiently.
3. Onsite renewable energy is used.
4. The embodied carbon of the structural and envelope materials (primarily carbon associated with manufacturing) is evaluated as part of the design.

ZCBs are essential to supporting Canada in meeting its Pan-Canadian Framework commitments, supporting building owners and operators in future proofing their building portfolios, and contributing to achieving carbon neutrality by 2050 as recommended by the United Nations' Intergovernmental Panel on Climate Change (IPCC).

## ZERO CARBON COSTING STUDY PROCESS

ZCB is a new approach in Canada that is not yet well understood by the development and construction industry, governments, and the real-estate sector with regards to the business case and necessary considerations for their implementation.

To address this knowledge gap, the Canada Green Building Council (CaGBC) commissioned WSP, supported by A.W. Hooker and Associates, to evaluate the financial viability and impact of constructing new buildings as ZCBs. The study examined seven building archetypes across six communities (see right).

**BUILDING ARCHETYPES:**

- Low-rise office
- Mid-rise office
- Low-rise multi-unit residential
- Mid-rise multi-unit residential
- Primary school
- Big box retail
- Warehouse

**COMMUNITIES:**

- Vancouver
- Calgary
- Ottawa
- Toronto
- Montreal
- Halifax

The study applied a tailored package of carbon reduction measures across all building archetypes, including: wall and roof enhancements, window upgrades, enhanced user controls (i.e., smart controls), efficient ventilation systems, better heating and cooling delivery systems, fuel switching, and the use of onsite renewable power, such as photovoltaics (PV). The financial, energy and carbon reduction outcomes of the ZCBs were examined and compared to a baseline design that reflected the 2011 National Energy Code for Buildings.

[1] Pan-Canadian Framework on Clean Growth and Climate Change. Canada's Plan to Address Climate Change and Grow the Economy. 2016. Available at: https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework/climate-change-plan.html
[2] Environment Canada. Canada's Emissions Trends. 2014. Available at: http://publications.gc.ca/collections/collection_2014/ec/En81-18-2014-eng.pdf
[3] Pan-Canadian Framework on Clean Growth and Climate Change. Canada's Plan to Address Climate Change and Grow the Economy. 2016. Available at: https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework/climate-change-plan.html

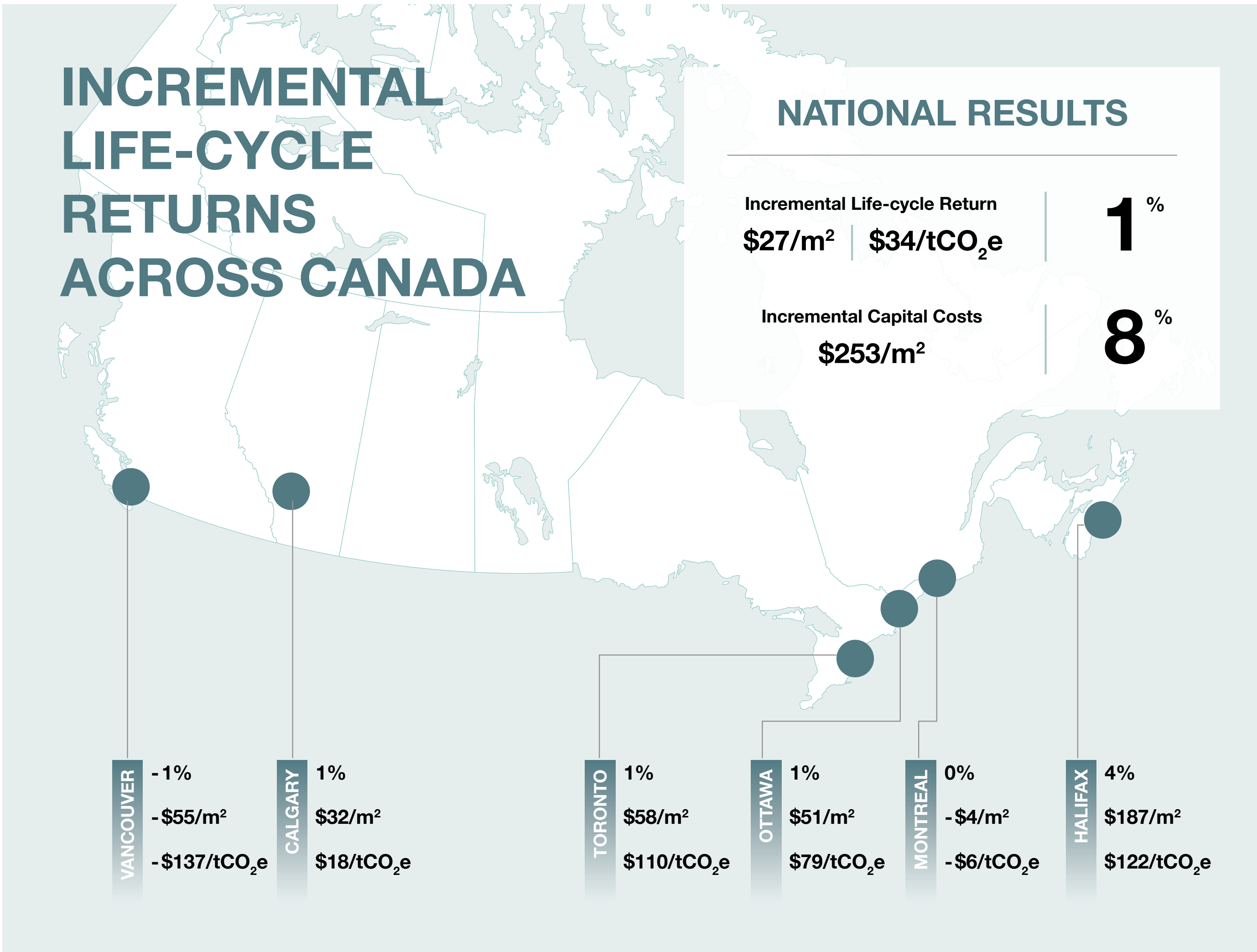



*Figure 1 – Incremental life-cycle returns across Canada*

## ZERO CARBON BUILDINGS OFFER MEANINGFUL CARBON REDUCTIONS AND POSITIVE FINANCIAL RETURNS

The study found that by 2030, over 4 million tonnes (Mt) of carbon dioxide equivalent emissions per year ($CO_2e$/yr) could be avoided cost-effectively if the building types studied are built to be ZCBs. This represents over 22% of the 20 Mt of GHG reductions that the Pan-Canadian Framework recognizes as potential savings from the buildings sector.[4] By 2050, over 12 Mt $CO_2e$/yr could be avoided.[5] The emissions reductions could be delivered at a total incremental capital cost of $3.3 billion per year, which would fund the construction of approximately 47,500 new residential units and 4,800 new commercial/institutional ZCBs annually.

This level of carbon reduction can be achieved with existing market-ready technologies and approaches for the building types evaluated. The study also confirmed that ZCBs are financially viable: on average, ZCBs can be achieved with a positive financial return of 1% over a 25-year life-cycle, inclusive of carbon pollution pricing, and require a modest 8% capital cost premium.[6] As the cost of carbon rises over time, the financial return from ZCBs will only grow.

[4] Canada's Buildings Strategy Update (2018), Energy and Mines Ministers' Conference. Available from https://www.nrcan.gc.ca/publications/11102

[5] This was determined by examining the floor area forecasted to be built for each archetype, in each province, assuming floor area grows at the same rate as the population (~26% between 2019 and 2050 ). These floor areas were then multiplied by the corresponding carbon savings per square meter per year, assuming NECB-2011 as the baseline.



Nationally, the different archetypes yielded the following financial outcomes:

- Mid-rise and low-rise offices offer the highest life-cycle returns at close to 3%.
- Warehouses and big box retail facilities can yield returns of 1-2%.
- Multi-unit residential buildings (MURBs) and primary schools are cost neutral or nearly cost neutral.

Regionally, the outcomes for ZCBs are strongest in Halifax due to the high carbon intensity of the Nova Scotia electricity grid (which results in higher carbon cost savings potential) and the relatively low cost of electricity relative to natural gas (2:1 compared to almost 5:1 in Ontario). These factors make switching from natural gas to electricity for heating and hot water more financially advantageous.

In Montreal, Ottawa, Toronto and Calgary, the outcomes for ZCBs are economically strong with any upfront capital cost premium mitigated over the life-cycle by higher operating and emissions savings.

The financial outcome of ZCBs is less strong in Vancouver because of the low-carbon intensity of the electricity grid (which results in lower carbon cost savings potential), the low cost of natural gas, and the milder climate, which reduces the demand for energy. While the current economic case in Vancouver is less favourable than in the other communities profiled in this study, the financial returns will improve over time as the cost of carbon rises, which will lead to a higher price on all types of fossil fuels, including natural gas. The closer that electricity and natural gas come in price, the stronger the economic case for ZCBs. Vancouver's milder climate also enables alternate approaches to ZCB design, such as the use of air-source heat pumps and lower levels of building envelope performance, that would yield superior financial results.

The results of the study confirmed that ZCB can be achieved using only onsite carbon reduction measures in over 70% of the scenarios evaluated. In other cases, it is necessary to offset emissions by purchasing green power generated offsite. In this study, offsite green power is assumed to take the form of renewable energy credits (RECs). Where required, the financial impact of purchasing RECs is modest.

## AVOIDED COSTS OF BUILDING TO ZERO CARBON

The economic case for ZCBs presented above is further strengthened by the costs that are avoided by building to zero carbon, including:

| Avoided Cost | Explanation |
|---|---|
| Costly future retrofits | Buildings that are not designed at the outset to be ZCBs can expect to undergo more costly retrofits. These retrofits are likely to be disruptive, resulting in adverse economic impacts such as lost rent, or in the case of owner-operator buildings, displacement of staff. Life-cycle economic analyses need to account for these future retrofits. |
| Reduced service life of buildings | Although some of the carbon reduction measures evaluated for this study were not always cost-effective, such as window frames and additional wall insulation, their service lives exceed the 25-year time frame used for this study, extending their energy cost savings. |
| Reduced resilience and value impairment | ZCBs can help insulate owner-operators from future energy and carbon cost risks. There is the potential that the cost of carbon emissions in the period 2030-2050 will be higher than assumed in this study. It is also possible that the price for electricity and natural gas will rise faster than presumed. Additionally, ZCBs that incorporate low-powered systems and onsite green power generation will further support buildings to withstand, respond and recover from prolonged power outages and other impacts of extreme weather events. |

[6] Over 25 years, the averaged cost of carbon pollution used for this study was $150/tonne. The starting cost was $50/tonne and an annual increase of $8/year was applied over 25 years.

## UNLOCKING THE POTENTIAL OF ZERO CARBON BUILDINGS

There are immediate opportunities for owner-operators, design teams and policy decision-makers to benefit from undertaking ZCB development, and to support the development of a ZCB marketplace.

### OWNER-OPERATORS AND DESIGN TEAMS

The business case for building owner-operators is strong, as they often pay both capital and operating costs over the entire life-cycle and are likely to have broader carbon reduction targets and commitments for their organizations. Furthermore, the incremental capital cost for developing ZCBs is expected to come down over time as building codes are strengthened and the price of carbon pollution increases. To unlock the value of ZCBs, building owner-operators and their design teams are encouraged to:

1. **Evaluate ZCB options to maximize carbon reductions and associated carbon costs today:** It is important to consider the risk of escalating carbon pollution pricing in the years ahead. Owner-operators should use life-cycle costing that factors in tightening building codes and increasing carbon pollution pricing as a tool to make future-proofing decisions early in the building development cycle.
2. **Use existing financial incentives to achieve a ZCB design:** There is a wide range of incentives and capital improvement grant opportunities to draw on to advance the development of ZCBs. Owner-operators can inform governments and utilities that they are willing to go beyond code - even going carbon neutral now – with the support of incentives targeted at the uptake of effective carbon reduction measures.
3. **Accept the challenge to be innovative:** Following an integrated design, construction and commissioning process can optimize carbon savings relative to capital costs and deliver a building that achieves its targets (including savings) during operation. The carbon reduction approaches and bundles evaluated for each archetype in this study could be further optimized through a properly leveraged integrated design process that includes early interaction with cost and construction experts.

Owner-operators can seek to maximize opportunities for carbon reduction measures and the benefits of an integrated design, especially at the bid development and contracting stages. Owner-operators can also recognize and promote the non-financial benefits of ZCBs to tenants/occupants and market peers, such as improved occupant comfort and increased resiliency.

### POLICY DECISION-MAKERS

The establishment of a robust ZCB marketplace can be accelerated by a range of pricing mechanisms, procurement and partnership models, and regulations that address the known impediments. To unlock the value of ZCBs, government policy-makers are encouraged to:

1. **Continue to incrementally raise the price for carbon pollution to achieve alignment with the IPCC target of carbon neutrality by 2050:** All users should see and pay the full real costs of carbon pollution from energy use. An incrementally rising cost on carbon causes conventional fossil fuel sources used for electricity and heating to gradually rise in cost based on their direct environmental impact. This helps re-enforce the business case for ZCBs and spurs innovation. An increasing price on carbon pollution is a critical measure for advancing GHG emissions reductions from Canada's buildings.
2. **Support time of use pricing for electricity, the use of renewable energy generation and storage, and net-metering:** Electricity pricing regimes can exert a strong influence on energy conservation and carbon reduction efforts. For example, if the commercial and mid-rise residential archetypes evaluated in this study were subject to time-of-use pricing (as are low-rise residential buildings in Ontario), building owner-operators could use demand reduction and demand response actions to achieve significant reductions in the cost of electricity, which would greatly support the uptake and viability of ZCBs. The use of distributed renewable energy generation, such as PV, and energy storage at the building site level can be instrumental to ZCB. The use of net metering, including virtual net metering, offers building owner-operators opportunities to benefit from the use of renewable energy generation and energy storage technologies, and avoid the potential need to use RECs.



3. **Incentivize capital based on carbon reduction potential:** Due to capital costs accruing to the owners/developers and energy cost savings to the tenant, referred to as the split incentive, there is a market barrier to considering the long-term benefit of carbon reductions. To address this, private investment can be incented by making ZCBs a new capital cost allowance class with an accelerated depreciation rate. This would allow owners to mitigate the capital cost premiums associated with ZCBs and support government efforts to reduce carbon emissions. Creating this new capital cost allowance class is an opportunity to direct the investment of capital to building projects that achieve carbon reductions.
4. **Demonstrate leadership through public building portfolios:** Governments are encouraged to demonstrate leadership by making it policy that any new buildings be constructed and operated as a ZCB. Federal, provincial, and municipal governments and their agencies own significant portfolios that can be levered to demonstrate the business case for ZCBs. This should also extend to buildings leased by government. In addition, federal-provincial infrastructure agreements should make ZCBs a key criterion for social infrastructure projects (e.g., affordable and social housing, education and training institutions, and healthcare facilities) funded under these bi-lateral agreements, including agreeing to fully fund any capital cost premium associated with ZCBs.
5. **Move the market to zero carbon and provide training to accomplish it:** Governments across Canada are introducing updated performance-based building codes that are placing increased emphasis on energy efficiency and the opportunity for renewable energy. As more stringent building codes are introduced, the most cost-effective measures for energy efficiency and carbon reduction will become business as usual. This will decrease the incremental capital costs required to achieve ZCBs, but it will also decrease the energy savings available and therefore make it harder to justify the investments needed. To address this, more progressive and targeted incentives and financing mechanisms that adapt to evolving building codes will be needed to support both public and private sector owner-operators in achieving ZCBs. In addition, a wide range of new skills and capabilities are needed for trades and other members of the construction workforce. Governments will need to invest in green building training, education and apprenticeship programs that target low carbon skills for tradespeople.

## ACCELERATING TO ZERO

The need for climate action is growing. In its recent report on limiting global temperature rise to 1.5°C, the United Nations' Intergovernmental Panel on Climate Change (IPCC) updated their recommended targets to 50% GHG emissions reduction by 2030 and 100% reduction by 2050.[7] The latest recommendations require accelerated reductions between now and 2030.

This study demonstrates that Canada can significantly and economically advance its current targets and those advised by the IPCC by taking a ZCB approach in the real estate sector, achieving up to 22% of the building sector's 20 Mt GHG reduction potential recognized in the Pan-Canadian Framework.[8]

The cost of not adopting a ZCB approach increases with each passing day. Every building built today that is not designed to achieve near-zero carbon emissions is contributing to a continued increase in carbon emissions. Buildings not built to be ZCBs will require major investments in retrofits of mechanical equipment, ventilation systems and building envelopes (walls, roofs, and windows) by 2050 to meet Canada's targets. These retrofits will be costly and disruptive to building owner-operators and tenants, and will likely need to occur before the normal 25 to 40-year cycle of re-investment in major equipment and building upgrades.

CaGBC has worked with its members and industry stakeholders to develop a ZCB Standard for new and existing buildings. Supported by the insights of this study, the ZCB Standard is a made-in-Canada solution to achieving our climate change commitments, providing a path for buildings to reach zero carbon and contributing to the clean growth economy.[10]

Working together, Canada's building owner-operators, their design teams, and governments at every level can demonstrate leadership in proving the economic case for ZCBs and normalizing the processes and technologies that will make ZCBs the Canadian industry standard for value and resilience.

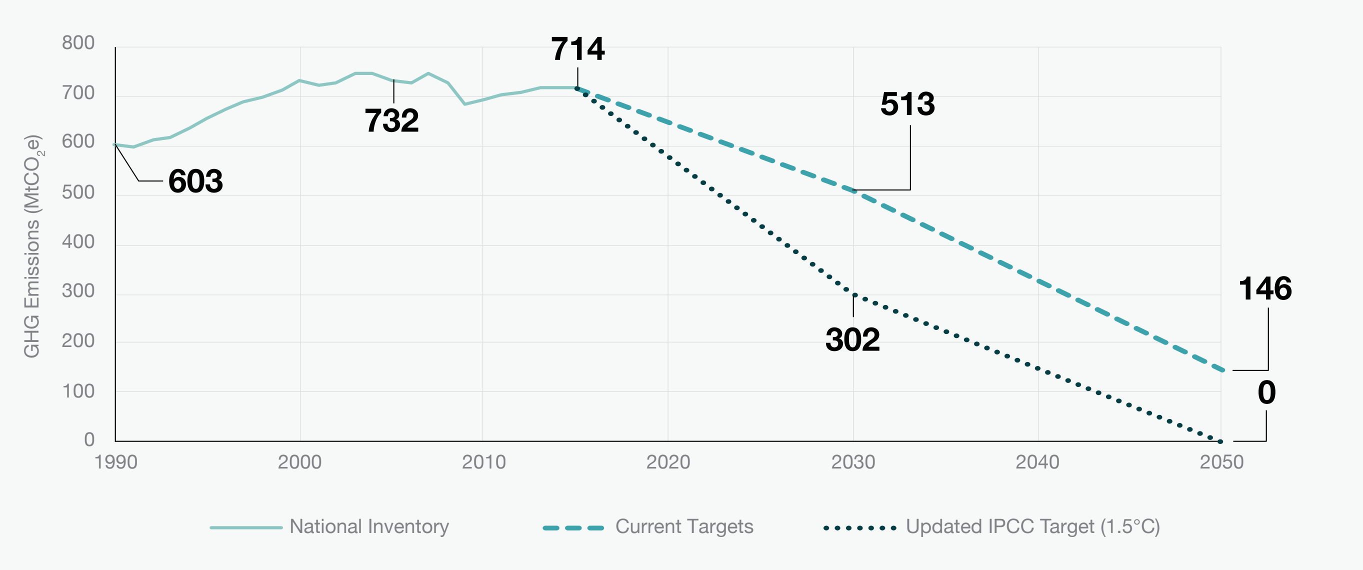
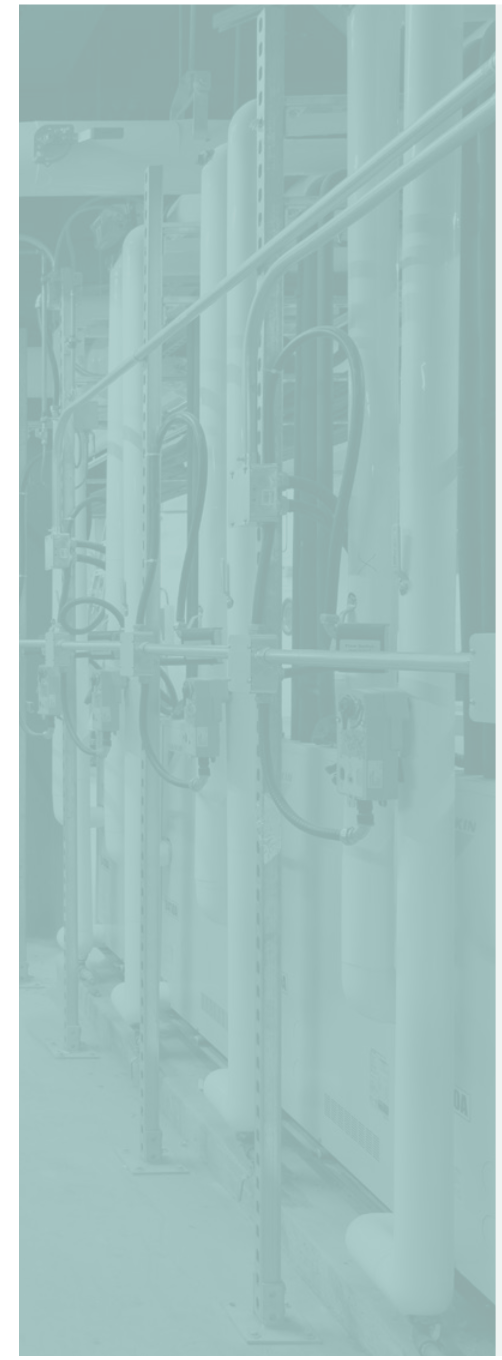



*Figure 2 – Historical and targeted GHG emissions for Canada[9]*

[7] Intergovernmental Panel on Climate Change (2018). Global Warming of 1.5°C. Available from http://www.ipcc.ch/report/sr15/
[8] Canada's Buildings Strategy Update (2018), Energy and Mines Ministers' Conference. Available from https://www.nrcan.gc.ca/publications/11102
[9] Data from Canada's National GHG Inventory Report (2017), available at https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html
[10] CaGBC's Zero Carbon Building Standard is available at https://www.cagbc.org/zerocarbon





Buildings not built to be ZCBs will require major investments in retrofits of mechanical equipment, ventilation systems and building envelopes by 2050 to meet Canada's targets.

# INTRODUCTION



## 2.0 INTRODUCTION

With the approval of the Pan-Canadian Framework on Clean Growth and Climate Change, announced by Canada's First Ministers in 2016, Canada committed to a greenhouse gas (GHG) emissions reduction target of 80% by 2050, with an interim target of 30% by 2030 (relative to 2005 levels).

One-third of the Pan-Canadian Framework emissions reductions required by 2030 are anticipated to be achieved through ambitious energy efficiency measures from the buildings, industrial and transportation sectors. Currently, 17% of GHG emissions in Canada are associated with residential, commercial and institutional buildings.[11]

In a recent report on the potential benefits of limiting global temperature rise to 1.5°C, the United Nations' Intergovernmental Panel on Climate Change (IPCC) updated their recommended targets to 50% GHG emissions reduction by 2030 and 100% reduction by 2050.[12] As shown in Figure 3, the latest recommendations require significantly faster reductions between now and 2030

This study demonstrates that Canada can significantly and economically advance its current GHG reduction targets and those advised by the IPCC by taking a Zero Carbon Building (ZCB) approach in the real estate sector.

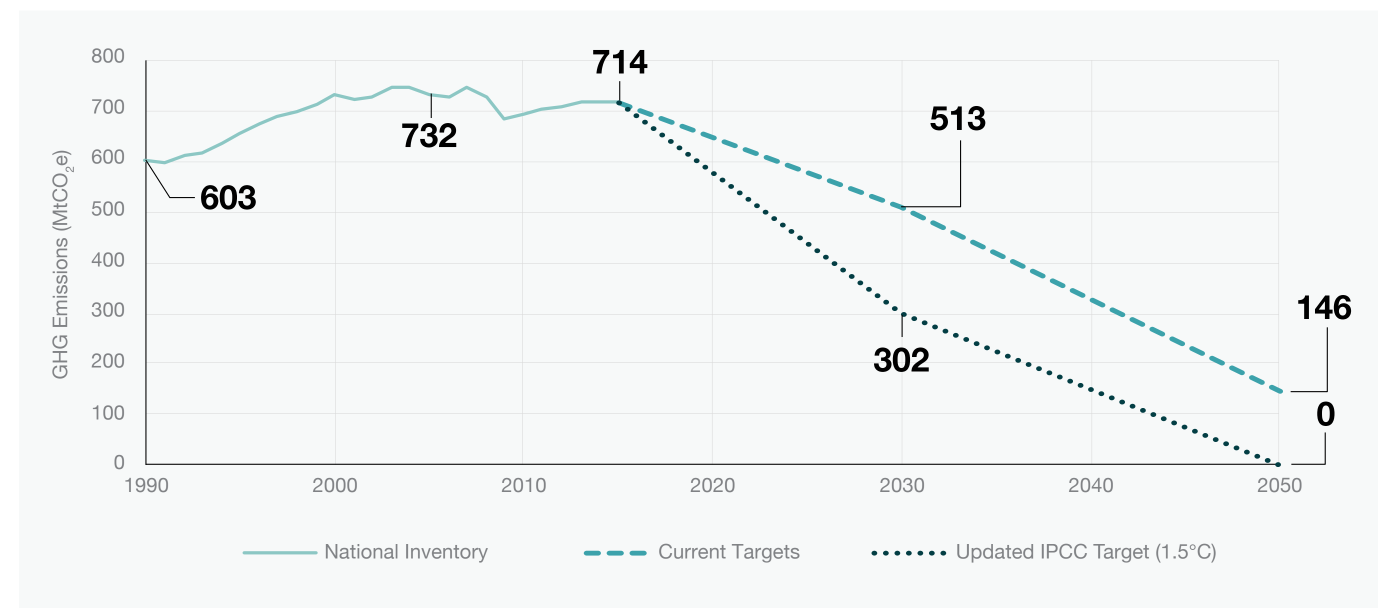



*Figure 3 – Historical and targeted GHG emissions for Canada*[13]

[11] Pan-Canadian Framework on Clean Growth and Climate Change. Canada's Plan to Address Climate Change and Grow the Economy. 2016. Available at: https://www.canada.ca/en/services/environment/weather/climatechange/pan-canadian-framework/climate-change-plan.html

[12] Intergovernmental Panel on Climate Change (2018). Global Warming of 1.5°C. Available from http://www.ipcc.ch/report/sr15/

[13] Data from Canada's National GHG Inventory Report (2017)

By turning existing and new buildings into ZCBs Canada can reduce its carbon emissions, decrease the demand for carbon intensive energy, and support Canadian real estate owners in optimizing the returns and resiliency of their portfolios. ZCBs can do this because they are designed to minimize carbon emissions and then offset any remaining emissions by generating clean, renewable energy onsite or offsite, which reduces life-cycle costs and mitigates exposure to carbon pollution pricing.

A ZCB is characterized by four key components:

1. The building demonstrates a zero-carbon balance in its operations.
2. Design prioritizes reducing energy demand and meeting energy needs efficiently.
3. Onsite renewable energy is used.
4. The embodied carbon of the structural and envelope materials (primarily carbon associated with manufacturing) is evaluated as part of the design.

It is important to note that every building built today that is not designed to achieve near-zero carbon emissions is only contributing to a continued increase in carbon emissions. Buildings not built to be near-zero carbon emissions will require major investments in retrofits of mechanical equipment, ventilation systems and building envelopes (walls, roofs, and windows) by 2050 to meet Canada's targets. These retrofits will be costly and disruptive to building owner-operators and their tenants. Furthermore, they will likely need to occur before the normal 25 to 40-year cycle of re-investment in major equipment and building upgrades.

ZCB is a new approach in Canada that is not yet well understood by the development and construction industry, governments, or the real-estate sector with regards to the business case and necessary considerations for their implementation.

To address this knowledge gap, the Canada Green Building Council (CaGBC) commissioned WSP, supported by A.W. Hooker and Associates, to evaluate the financial viability and impact of constructing new buildings as ZCBs. A future study will investigate the viability and impact of retrofitting existing buildings to achieve zero carbon.

The study undertook to:

1. Provide an understanding of the financial implications of pursuing a variety of ZCB archetypes in communities across Canada.
2. Examine the key barriers to the adoption of zero carbon building design and construction, including the uncertainty associated with capital and life-cycle costs, and the uncertainty associated with the benefits and costs of specific technologies and design strategies.
3. Convey to owner-managers, design teams, and policy decision-makers the key considerations for implementing ZCB development and accelerating the growth of a ZCB marketplace.

The report begins with a brief introduction to the process undertaken, and greater detail can be found in the appendices. The results section starts by providing national-level takeaways before looking at the whole-building level findings by archetype and community, and finally examining in detail the costs and impacts of the various carbon reduction measures , which provides critical insights for designers. A brief discussion of the broader benefits of ZCBs is provided, and the report concludes with actionable recommendations for both owner-operators and policy decision-makers.



ZCBs can help reduce carbon emissions, decrease the demand for carbon intensive energy, and support Canadian real estate owners in optimizing the returns and resiliency of their portfolios.

# METHODOLOGY

## 3.0 METHODOLOGY

This study evaluated new commercial, institutional and multi-unit residential buildings (MURBs), which represent 40% of the building floor area across Canada[14], and 46.5% of carbon emissions from the building sector, amounting to 51 million tonnes (Mt) of carbon dioxide equivalent ($CO_2e$) or 10% of Canadian carbon emissions associated with energy use.[15] The study did not evaluate the potential contribution of buildings that fall under Part 9 of the building code (mainly single-family homes, which represent 49% of all building carbon emissions), energy-intensive retail facilities (e.g., restaurants) or healthcare facilities (which represent 4.5-6% of building carbon emissions).[16]

A synopsis of the study's approach is provided below, and a complete methodology is provided in Appendix A-1 through A-5.

1. Develop a tailored set of carbon reduction measures and deploy them on seven building types in six communities representing diverse climatic conditions[17] and the bulk of new commercial, institutional and multi-unit residential building construction.

   **BUILDING ARCHETYPES:**

   Low-rise office
   Mid-rise office
   Low-rise multi-unit residential
   Mid-rise multi-unit residential
   Primary school
   Big box retail
   Warehouse

   **COMMUNITIES:**

   Vancouver (climate zone 4)
   Calgary (climate zone 6)
   Ottawa (climate zone 6)
   Toronto (climate zone 5)
   Montrea (climate zone 6)
   Halifax (climate zone 6)

2. Develop 25-year life-cycle costing of the onsite carbon reduction measures for each archetype, taking into account:
   - Capital costs
   - Utility costs and escalation
   - Operational and maintenance costs
   - Carbon taxes (including progressive escalation aligned with climate change targets)

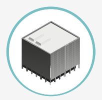
3. Analyze the financial impact of offsite green power purchases, in the form of renewable energy certificates (RECs), where onsite carbon reduction measures are not adequate to achieve zero carbon operations.

4. Examine the cost-effectiveness of individual carbon reduction measures to understand the reasons why ZCB can be achieved more cost-effectively in particular archetypes and locations.

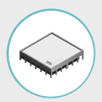
[14] See Appendix A-5 - National Building Stock for national area, population growth and component estimates.
[15] National Inventory Report 1990–2015: Greenhouse Gas Sources and Sinks in Canada (2017). GHG emissions associated with energy use account for approximately 70% of total emissions; other sources include non-energy use (feedstock), energy losses (conversions), producer consumption and pipeline energy use (Natural Resources Canada (2013). Energy Efficiency Trends in Canada 1990-2013. Available from https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/trends2013.pdf)
[16] While experience indicates that healthcare facilities would experience life-cycle cost outcomes similar to those of the archetypes studied, the carbon reduction measures would need to be substantially different from those applied in this study. Part 9 buildings were excluded for similar reasons.
[17] While no communities in climate zone 7 (such as Edmonton or Winnipeg) were included in this study, experience indicates the life-cycle cost outcomes would be similar or better than those in the communities studied, although the carbon reduction measures would be applied differently.

## 3.1 BUILDING ARCHETYPES

Seven building types were selected for this study, representing approximately 40% of the national building stock by floor area.[18] A description of the seven archetypes is provided below.[19]



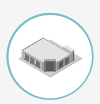
**Mid-rise Office:**
500,000 ft² (46,350 m²), 12-storey office building with a window-to-wall area ratio of 40%. Such a large area over 12 storey results in a relatively deep floor plate.



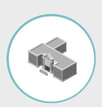
**Low-rise Office:**
53,620 ft² (4,982 m²), 3-storey roughly-square building with a window-to-wall ratio of 33%.

**Mid-rise Multi-Unit Residential Building (MURB):**
84,350 ft² (7,830 m²), 10-storey building with window-to-wall ratio of 40%.

**Low-rise Multi-Unit Residential Building (MURB):**
33,750 ft² (3,135 m²), 4-storey square building with 8 residential units and window-to-wall ratio of 20%.



**Big Box Retail (Retail):**
24,689 ft² (2,294 m²) stand-alone, big-box style retail facility with a window-to-wall ratio of 7.2%.



**Primary School (School):**
73,932 ft² (6,871 m²) 1-storey primary school with a window-to-wall ratio of 35%, heated and cooled year-round, which is representative of the average, but not all, educational buildings.

**Warehouse:**
49,500 ft² (4,600 m²) 1-storey building. The building contains an office area that is 5% of the total area. The building has a window-to-wall ratio of less than 1% and 68 m² of skylights. The warehouse is heated and cooled to reflect the market-wide blend of heated-only, heated/cooled and refrigerated warehouse facilities.

For a more detailed description of the seven building archetypes, see Appendix A-1.

[18] See Appendix A-5 - National Building Stock for national area, population growth and component estimates.

[19] An archetype, as used in this report, is a building incorporating several specific characteristics such as building type/use, total floor area, number of storeys, and window-to-wall ratio.



## 3.2 BASELINE

The study drew on the National Energy Code of Canada for Buildings 2011 (NECB-2011) to develop the comparable reference model (referred to as the baseline). The NECB-2011 is illustrative of the building code requirements currently in place across Canada. Some jurisdictions have requirements that are more stringent and can therefore expect the incremental capital costs for achieving ZCBs to be lower than those identified in this study.

## 3.3 COST ESTIMATES

A class D capital cost estimate was prepared by A.W. Hooker based on assumptions and equipment sizing information provided by WSP for both the baseline and ZCB models for each archetype. Hooker developed detailed pricing for Toronto, then used regional cost adjustment factors for sub-components of the pricing to derive pricing for the other markets. The summary of all capital cost estimates by region and archetype are included in Appendix C.

Detailed costing for individual building components (e.g. boilers, air handlers, and wall constructions) was also provided (though not included in Appendix C) so that service life estimates and residual value of different building components could be analyzed more accurately over the life-cycle.

Life-cycle costs were assessed over 25 years, a commonly accepted timeframe roughly representing the minimum period between significant re-investments in building infrastructure, especially HVAC systems. Escalation factors were applied to the costs of energy and carbon. Maintenance and replacement costs were considered, and any residual value for equipment (at the end of the 25 years) was recognized. A discount rate of 2.5% per year was used, reflecting the cost of government bonds (or similar investment).

An average carbon cost of $150/tonne was used, reflecting an initial cost of $50/tonne and annual cost increases of $8/year over the course of 25 years. Note that the rising cost of carbon means that any future 25-year life-cycle cost analysis will have an average carbon cost greater than $150/tonne, improving the financial outcomes. For example, a life-cycle cost study evaluating the 2025-2050 period will have better financial outcomes than one evaluating the 2020-2045 period.

For a detailed description of financial assumptions and the life-cycle costing process, see Appendix A-3.

In most provinces the marginal emissions factor is higher than the average emissions factor, as peak electricity demand is generally met with natural gas fired power generation

## 3.4 CARBON ACCOUNTING

The study applied the carbon emissions accounting methodology defined in CaGBC's ZCB Standard[20]. Direct, indirect and biomass emissions must be offset by avoided emissions, which are provided by green power (electricity from renewable sources) generated onsite (such as from photovoltaic systems) or offsite.

In conformance with the CaGBC's ZCB Standard, electricity production from onsite renewable energy systems was calculated on an hourly basis, and any power in excess of the building demand was treated as an export to the electricity grid. Exported electricity was assumed to displace the electricity generated by the last facility activated to meet peak demand, on the assumption that peak-demand facilities are most readily ramped up and down and consequently will absorb the impact of additional renewable energy production. Therefore, the carbon intensity of the last facility, known as the "marginal emissions factor", was applied to any onsite renewable energy exported into the electricity grid. See Appendix A-3 for more detail on how exported power was analyzed.

As shown in Figure 5, in most provinces the marginal emissions factor is higher than the average emissions factor, as peak electricity demand is generally met with natural gas fired power generation, whereas low-carbon power generation facilities (e.g., nuclear, hydroelectric, wind, PV) provide much of the power the rest of the time. The exceptions are Alberta, where much of the overall electricity demand is met with coal and oil-fired power generation, and to a lesser extent Nova Scotia.


*Figure 4 – Summary of ZCB carbon balance*

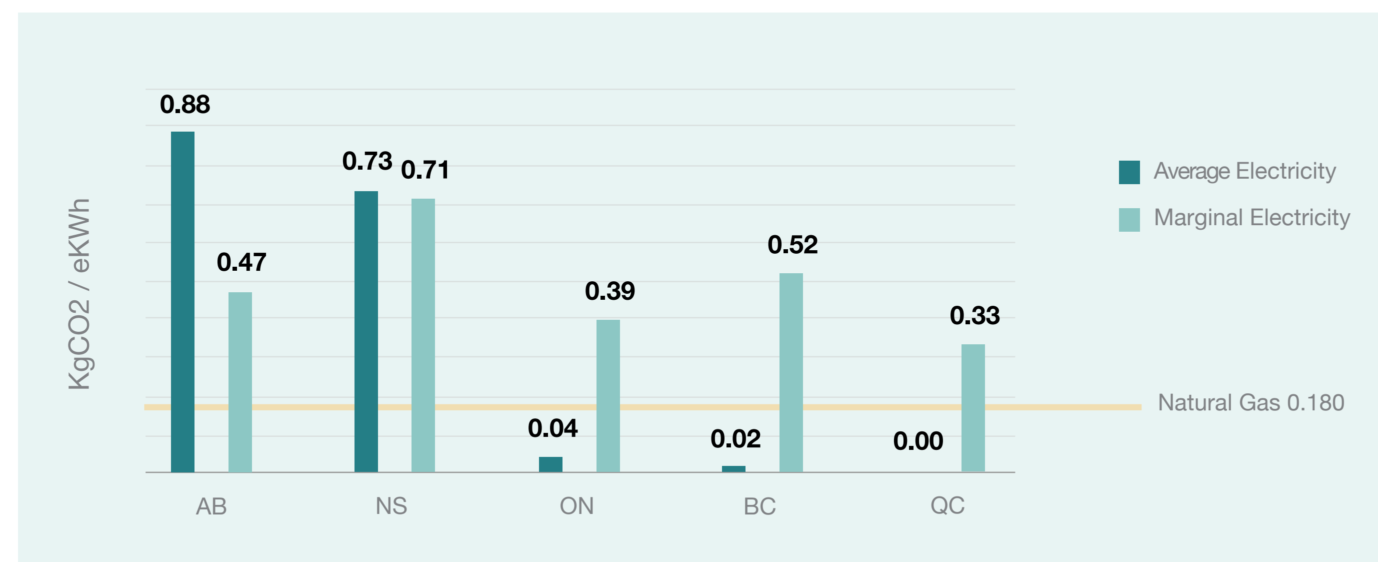



*Figure 5 – Carbon emissions factors for electricity. See Appendix A-4 for further details.*

[20] CaGBC's Zero Carbon Building Standard is available at https://www.cagbc.org/zerocarbon

## 3.5 METRICS ANALYZED

Seven key metrics were used to describe and evaluate the performance of the building archetypes.

**Energy Use Intensity (EUI):** A building's total operational energy use, including all heating, cooling, ventilation, lighting, plug and process loads. It is typically reported in kilowatt-hours per square meter (kWh/m²). Onsite renewable energy generation can be included in EUI (which may then be referred to as total or net EUI). This study provides EUI results with and without onsite renewable energy.

**Thermal Energy Demand Intensity (TEDI):** The annual heat delivered by the building's heating system, reflecting the performance of enclosure, ventilation and heating delivery systems.[21] Decreasing the thermal energy demand intensity increases thermal comfort as cold surfaces, drafts, temperature differences and fluctuations over time are reduced. Targeting a low TEDI also ensures that building designers focus on minimizing a building's demand for energy before producing or procuring renewable energy. Finally, a low TEDI allows smaller, more cost-effective, high-performance HVAC designs to be used. The current TEDI targets for CaGBC's ZCB-Design certification are provided to the right.

*Table 1 – TEDI targets for ZCB-Design certification*

| Climate Zone | TEDI Targets kWh/m²/year |
|---|---|
| 4 | 30 |
| 5 | 32 |
| 6 | 34 |
| 7 | 36 |
| 8 | 40 |

**Greenhouse Gas Intensity (GHGI):** The total greenhouse gas emissions associated with energy use on the building site. It is reported in kilograms of $CO_2$-equivalent per square meter ($kgCO_2e/m^2$) and includes emissions associated with provincial electricity generation.[22]

**Incremental Capital Cost Per Square Meter (ICC/m²):** The increase or decrease in the cost of construction per square meter for achieving zero carbon, relative to the NECB-2011 baseline.

**Incremental Capital Cost Per Tonne $CO_2$-equivalent Saved ($ICC/tCO_2e$):** The increase or decrease in the cost of construction per tonne of $CO_2$-equivalent saved for achieving zero carbon, relative to the NECB-2011 baseline.

**Incremental Life-Cycle Cost Per Square Meter (ILCC/m²):** The net present value (NPV) of the increase or decrease in total costs per square meter for construction, operation and maintenance over 25 years for achieving ZCBs, relative to the NECB-2011 baseline.

**Incremental Life-Cycle Cost Per Tonne $CO_2$-equivalent Saved ($ILCC/tCO_2e$):** The NPV of the increase or decrease in total costs per tonne of $CO_2$-equivalent saved for construction, operation and maintenance over 25 years for achieving ZCBs, relative to the NECB-2011 baseline.

[21] TEDI arguably excludes energy delivered by the heating system related to humidification and dehumidification, however they were included in this study. The impact of humidity management is minor, however, given the scope of the study.

[22] The ZCB Standard was used to define the carbon intensity of provincial electricity generation. The study did not take into account anticipated changes in the carbon intensity of electricity generation (e.g., reduction in reliance on coal in Alberta). The impact of the anticipated changes is discussed in the body of the report; for example, reduced reliance on coal in Alberta will bring about a net-carbon reduction from heating with electrically-driven heat pumps rather than natural gas. See Appendix A-3 for more details.



## 3.6 CARBON REDUCTION MEASURES

The carbon reduction measures applied to achieve ZCB include energy efficiency measures, fuel-switching technologies, and onsite renewable energy generation systems. Importantly, all the measures used for the study represent established, readily available products and technologies. The carbon reduction measures were selected based on WSP's extensive project experience and an efficiency-first mindset; that is, energy efficiency measures were maximized before considering fuel-switching or onsite renewable energy generation.

The same carbon reduction measures were applied to all archetypes. Further refinements were necessary for retail and warehouses to ensure the carbon reduction measures were appropriate for these archetypes. Specifically, the window, heating/cooling delivery, and fuel switching bundles were removed and the amount of onsite photovoltaics (PV) was increased to take greater advantage of the roof space available.

For each archetype, the set of carbon reduction measures was applied the same way in each community, meaning they were not optimized to reflect differences in weather and electricity grid carbon intensity.

The carbon reduction approaches and measures evaluated for this report were not optimized for each archetype and location. For any real-world project, a client-supported integrated design process and optimization tools such as parametric analysis could yield improved results.

| ENCLOSURE – WALLS & ROOF | ENCLOSURE – WINDOWS | USER-CONTROLLED LOADS | VENTILATION | HEATING/COOLING DELIVERY | FUEL-SWITCHING | RENEWABLE ELECTRICITY |
|---|---|---|---|---|---|---|
| The opaque (non-window) components of the building enclosure (including ground-contact surfaces and floors above unconditioned spaces) separate the building from its surroundings. Insulation and air sealing systems prevent heat loss/gain and air infiltration/exfiltration. | Windows and skylights allow light into the building, but typically increase heat loss. Solar gains can help reduce heating requirements but may increase cooling loads and associated equipment size. | Users interact with lighting, plugged in equipment (e.g., appliances and computers) and water fixtures throughout the facility. This equipment has a significant impact on both the HVAC load and energy use of the facility. | All building codes in Canada require compliance with ventilation standards (typically, ASHRAE 62.1) in commercial buildings and MURBs. In most buildings, providing ventilation is a significant source of energy demand, especially heating energy. | Commercial buildings have dedicated systems to provide heating and cooling (and humification and dehumidification) to spaces, typically for the comfortof lightly-active occupants (21-24°C, 25-60% relative humidity) or for specific processes like conditioned storage, data centres, or food retailing. | Natural gas, though less carbon intensive than other fossil fuels, is more carbon intensive than electricity (for most of the Canadian electrical grid system) and low-carbon biofuels. | The electrical energy needs of each building must be met by offsite (grid) and onsite sources. In a zero-carbon future, all electricity must be generated from sources that do not contribute carbon to the atmosphere. |
| **BASELINE CRITIQUE** | | | | | | |
| Insulation R-values (typically called “nominal R-values”) in current codes are significantly reduced by thermal bridging at intersections between major systems (i.e. walls and roof, walls and windows, etc.). | Typical construction uses excellent double-glazed windows (e.g., argon filled, warm edge-spacers) but with only modest thermal breaks in frames. Also, window to wall ratios in commercial developments are typically over 50%. | Code requirements for lighting power are being lowered, but they do not maximize the control benefits of LED technologies. Similarly, computers, appliances and water fixture efficiency have steadily increased, but the best-in-class offer significant, low-cost improvements. | Though increasingly required by code, heat recovery and demand-control are limited in effectiveness due to ventilation systems being entangled with the delivery of heating and cooling. | Variable flow systems and condensing boilers are increasingly being used, but because of large peak loads driving costs up, systems typically involve large, centralized fan systems and small reheat/baseboard coils at zonal levels, which demand high-temperature water. | Heating is most often provided by natural gas, due to its cost-effectiveness. Although most code-compliant natural gas boiler systems must include modulation and be up to 85% efficient, they are still responsible for significant emissions. | Buildings already benefit from Canada’s generally low-carbon electricity grids. However, building codes do not require onsite renewable electricity generation to help meet increasing demand across the building, transportation and other sectors. |
| **ZERO CARBON SOLUTION:** | | | | | | |
| True R-30 (walls) to R-40 (roof) performance with low air leakage is achievable with a systems approach and **excellent detailing** at all intersections. | Triple-glazed windows in matched, thermally-broken frames double system performance relative to baseline. Window-to-wall ratio and window treatments are designed to **balance solar gain with heat loss and internal gains**. | **Smart building** controls and scheduling can help the user match their lighting, plug and hot water loads to their usage. Selecting the lowest power equipment (e.g., laptops, heat-pump dryers) and using ultra-low-flow fixtures and drain water heat recovery also offers important benefits, especially in MURBs. | **Dedicated Outdoor Air System (DOAS)** ventilation couples well with displacement ventilation and occupancy-driven controls and maximizes the benefit of demand-control and heat recovery. | With very low loads and an occupant-controlled DOAS for ventilation, zonal heating and cooling can be delivered with minimal fan power and **low-exergy** systems, enabling more efficiency at the HVAC-plant and increased use of low-grade sources of heating/cooling (e.g., direct from solar hot water panels and ground heat exchanger). | Electrifying heating systems using modulating or variable refrigerant flow (VRF) heat pumps, especially with geo-exchange (though air-source heat pumps can be more cost effective in some instances), minimizes both energy and carbon emissions. To address any remaining (possibly high-temperature) heating needs, **sustainable biofuel** should be used. | Installing onsite solar photovoltaics (PV) (i.e., solar-power) and other low-carbon sources of electricity (with energy storage, where possible) and procuring offsite renewable energy using RECs can provide demand reduction during peak electricity times to help **decarbonize the grid** and improve the building’s resilience to fluctuations in the electricity grid (e.g., extreme weather-driven brownouts and blackouts). |
| **THE IMPORTANCE OF DETAILING** | **BALANCING SOLAR GAIN WITH HEAT LOSS AND INTERNAL GAINS** | **WHAT IS A SMART BUILDING?** | **WHAT IS A DOAS?** | **WHAT DOES LOW-EXERGY MEAN?** | **WHAT IS SUSTAINABLE BIOFUEL?** | **HOW CAN WE DECARBONIZE THE GRID?** |
| Excellent detailing results in an enclosure that has a more consistent R-value over the entire area. It includes ensuring continuity and/or overlap of insulation and air sealing systems at all intersections between major enclosure components. Two-dimensional modeling/calculation is often necessary to properly capture the effect of thermal bridges, unless excellent detailing has allowed for sufficient, continuous insulation at all major intersections. | Windows serve three purposes: (i) offering views for occupants, (ii) providing daylight to the space, and (iii) controlling for heat loss and/or solar heat gain. These functions can be achieved for almost any space with a window-to-wall ratio of 40% (or less) if the loads in the space and from the glass are studied alongside the relative need for daylight in the space. Windows can also be segmented and treated differently to perform different functions. | A smart building that contributes to carbon reductions generally has interconnected building control systems that can: (i) sense occupancy and use that information to deliver services efficiently and effectively; (ii) manage system performance with knowledge of interconnections and future conditions (i.e., weather, grid state); and (iii) engage occupants to understand their impact and act to reduce energy use. | A Dedicated Outdoor Air System (DOAS) separates, to varying degrees, ventilation from heating and cooling. Most common heating and cooling approaches offer a way to transform the ventilation channel(s) into a DOAS configuration. DOAS offers simpler controls that are easier to commission and pair well with heat recovery technology. DOAS also minimizes heating and cooling by allowing these systems to ramp down or turn off entirely when only ventilation is required. | The exergy of a system is the effective work that can be done between the current state and the dead or ambient state. Heating water delivered at a higher temperature (or cooling water delivered at a colder temperature) has a higher exergy, but low-exergy systems are preferable because they enable higher central plant efficiencies and maximize the use of carbon-free sources of low-grade heating and cooling (e.g. direct solar heated or ground-cooled water). | Biofuel is any non-fossil organic substance that can be used as a combustion fuel, such as biogas (renewable natural gas) or biomass. There is an indirect carbon footprint associated with manufacturing, transportation and onsite processing of biofuel. The CaGBC’s ZCB Standard has specific rules on what qualifies as zero emissions biofuel, and how to account for biofuel that is not zero emissions. | Renewable electricity can reduce demand on the electricity grid, while energy storage allows reductions to be timed with peaks in the demand for electricity. Peak power is often provided by natural gas fueled power plants. Electricity storage also helps extend the length of time that power plants operate, allowing them to operate at higher efficiencies and avoid losses from short operation cycles. |

*Figure 6 – Carbon reduction measures*

# FROM HERE TO THERE

This comparative schematic illustrates how design strategies can change when pursuing Zero Carbon Buildings. An office is represented; however, similar approaches can be applied across other archetypes. Some measures, such as battery storage and reduced window size, are not included in the study.

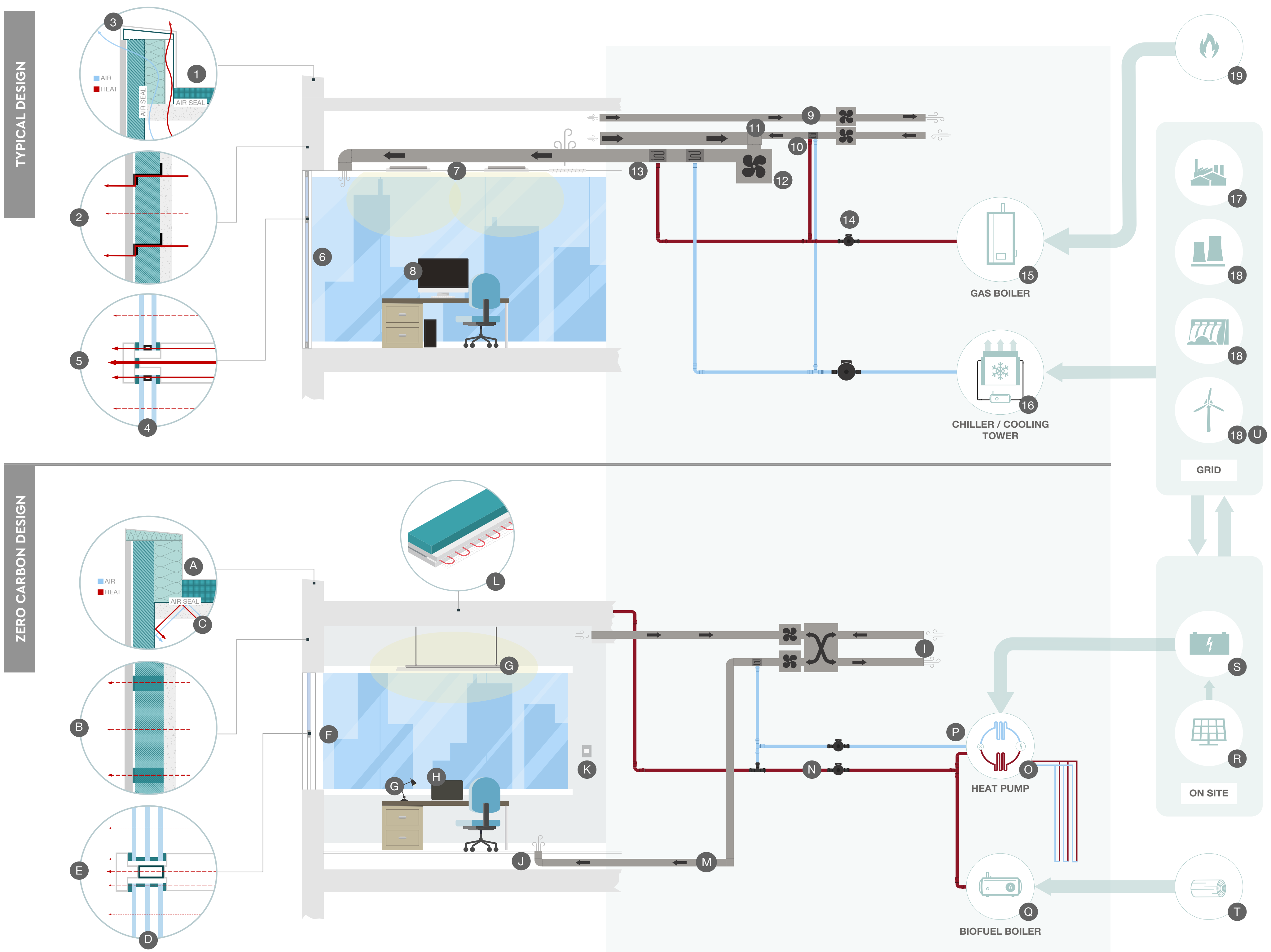
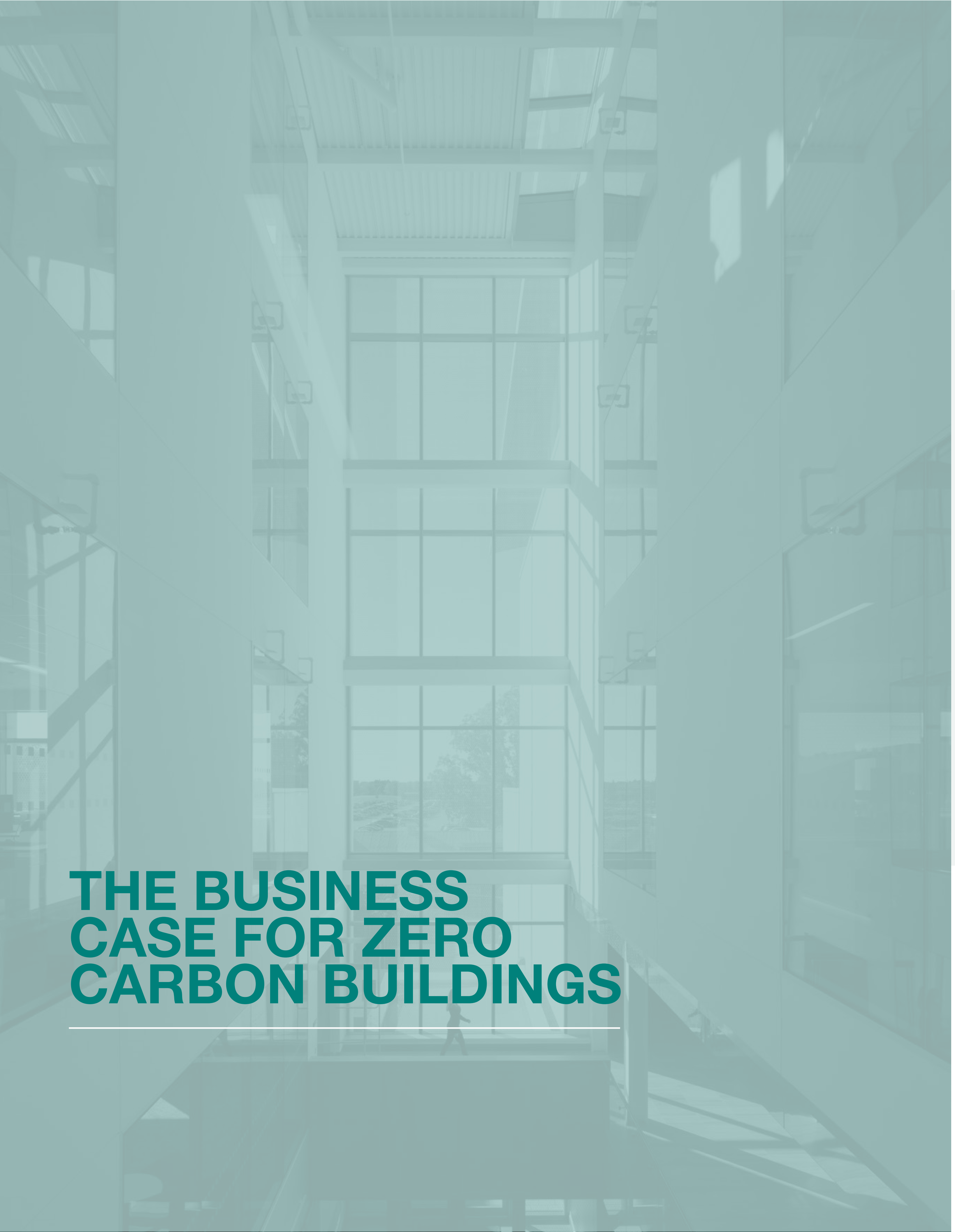



*Figure 7 – How design strategies can change when pursuing Zero Carbon Buildings*

| TYPICAL DESIGN | | ZERO CARBON DESIGN | |
|---|---|---|---|
| **Enclosure - Walls & Roof** | | | |
| 1 | R-30 nominal, R-25 actual from heat loss at intersections (~20% reduction) | A | R-40 actual with full, overlapping insulation |
| 2 | R-20 nominal, R-8 actual because of thermal bridges (~60% reduction) | B | R-30 actual using non-metal supports/clips or other methods |
| 3 | Intersection (e.g., at parapet) air leakage and vapour permeation risk | C | Proper air/vapour seal location avoids leakage and prolongs assembly life |
| **Enclosure - Windows** | | | |
| 4 | Double-glazed, low-energy, argon | D | Triple-glazed, two low-energy coatings, possible solar control (e.g. overhangs) |
| 5 | Overall ~R-2.5, typical frames with minimal thermal break | E | Overall ~R-5, best-in-class frames |
| 6 | Floor to ceiling glass (>50%) glazing is used in many building types | F | Dedicated daylighting and visible sections; total 30-40% glazing |
| **User-controlled Loads** | | | |
| 7 | Lighting operated on schedule at peak power | G | Task lighting and smart controls (e.g., occupancy and daylight controls) |
| 8 | Desktop equipment with high standing power | H | Laptops, best-in-class appliances |
| **Ventilation** | | | |
| 9 | No heat recovered from distributed exhaust points | I | Full heat recovery from exhaust points connected to dedicated outdoor air system |
| 10 | Significant outdoor air heating typically required | J | Supply temperature from Energy Recovery Ventilator almost perfect for displacement delivery |
| 11 | Heating/cooling energy higher due to variable are volume system delivering more air (at minimum) than required for good air quality | K | Occupancy sensing matches outdoor air to demand |
| **Heating/cooling Delivery** | | | |
| 12 | Fans needed to deliver both heating and cooling. | L | Heated/Chilled surface is close to room temperature |
| 13 | Extra re-heat when large central fan serves spaces that need heating and cooling at the same time | M | Larger dedicated outdoor air system can provide extra cooling, if needed (especially in core areas) |
| 14 | Water temperature selected to minimize equipment size/cost, restricting low-carbon central plant options | N | Variable-speed motors with efficient operation at part-load |
| **Fuel Switching** | | | |
| 15 | Modulating gas boiler, near-condensing (85% efficient) | O | Central heat pump with geo-exchange (where available) achieves 400-650% efficiency; even better at fractional loads |
| 16 | Typical chiller (500-600% efficient) | P | Takes advantage of simultaneous heating and cooling. |
| | | Q | Supplementary biofuel heating (85% efficient) |
| **Renewable Electricity** | | | |
| 17 | Fossil fuel generation (300-800 g $CO_2$e/kWh) | R | PV, especially for low-rise / sub-urban (0 g $CO_2$e/kWh) |
| 18 | Existing low-carbon generation (~0 g CO2e/kWh) | S | Energy storage to manage electricity demand |
| 19 | Natural gas heating (180 g $CO_2$e/kWh) | T | Sustainable biofuel - (~0 g CO2e/kWh) |
| | | U | RECs (0 g $CO_2$e/kWh), ~$25/MWh |



# THE BUSINESS CASE FOR ZERO CARBON BUILDINGS



## 4.0 THE BUSINESS CASE FOR ZERO CARBON BUILDINGS

A comprehensive assessment was undertaken to explore the economic and financial viability of Zero Carbon Buildings (ZCBs) across Canada. Seven building archetypes were examined in six communities, resulting in forty-two archetype/community combinations. For each combination, an NECB-2011 compliant baseline design was created as well as a design that minimized carbon emissions from building operations. Section 4.1 provides high-level observations and conclusions based on the modeled designs, while Section 4.2 outlines in detail the benefits achieved from each of the carbon reduction bundles examined. For the full set of results, see Appendix B.

## 4.1 CRITICAL INSIGHTS

### 4.1.1 NATIONAL PERSPECTIVE

This study identified that by 2030 over 4 Mt of $CO_2$-equivalent emissions per year could be avoided cost-effectively if the building types studied are built to be ZCBs. This represents over 22% of the 20 Mt of GHG reductions that the Pan-Canadian Framework recognizes as potential savings from the buildings sector.[23] By 2050, over 12 Mt $CO_2$e/yr could be avoided.[24] The emissions reductions could be delivered at a total incremental capital cost of $3.3 billion per year, which would enable the ZCB construction of approximately 47,500 residential units and 4,800 commercial/institutional buildings annually.

### 4.1.2 ENERGY AND CARBON METRICS

Important high-level insights that are consistent across all archetypes include the following:

- The archetypes achieve an average 72% reduction in EUI before the use of PV. Variation from this average is minimal except for the big box retail and warehouse archetypes, which rely more heavily on PV to achieve ZCB and demonstrate lower EUI reductions before PV is accounted for.
- Once PV is accounted for, the EUI can reach zero (or lower), as in the cases of Calgary and Halifax.
- Most archetypes demonstrate the potential for a 40% or greater improvement in TEDI performance, and significantly exceed the ZCB Standard's TEDI targets, with any differences largely a function of location (colder climates proving more challenging than warmer climates). The exceptions are the big box retail and warehouse archetypes, which rely less on measures that improve TEDI and more on PV.
- The EUI, TEDI and GHGI results (other than for retail and warehouses) align with the high-performance tiers of the Toronto Green Standard, City of Vancouver Rezoning Bylaw, and BC Step Code.
- The relationship between energy savings and carbon emissions has to do with the electricity grid.
    - o High-carbon grids: the percentage reduction in carbon is lower than the percentage of energy savings because the electricity used for heating the zero carbon archetypes is currently very carbon intensive. As identified in Section 4.2.2, it is anticipated that the carbon intensity of the electrical grids will decrease over time.
    - o Medium-carbon and low-carbon grids: the percentage reduction in carbon is significantly more than energy savings since fuel switching to electricity virtually removes the need for natural gas, which is responsible for the majority of the baseline archetype emissions.
- Almost all low-rise buildings can offset carbon emissions with onsite PV generation in all locations, as shown in the GHGI portion of Figure 8. The mid-rise buildings studied can balance 20% of annual usage with onsite PV, despite having a relatively small roof to floor area ratio. Taller buildings (>12 storeys) face increasing challenges meeting a significant portion of demand with onsite PV.

Figure 8 illustrates the results for low-rise multi-unit residential buildings, which are typical of other archetypes. The three graphs show the baseline and ZCB results side-by-side. For both the EUI and GHGI graphs, results before and after PV are shown and the values indicated represent the results after PV. For example, the EUI of the ZCB in Calgary is -2 kWh/m² and the GHGI is 11 $kgCO_2e/m^2$. The performance of all the ZCB archetypes is provided in Appendix B-1.

[23] Canada's Buildings Strategy Update (2018), Energy and Mines Ministers' Conference. Available from https://www.nrcan.gc.ca/publications/11102

[24] This was determined by examining the floor area forecasted to be built for each archetype, in each province, assuming floor area grows at the same rate as the population (~26% between 2019 and 2050). These floor areas were then multiplied by the corresponding carbon savings per square meter per year, assuming NECB-2011 as the baseline. See Appendix A-5 for details.



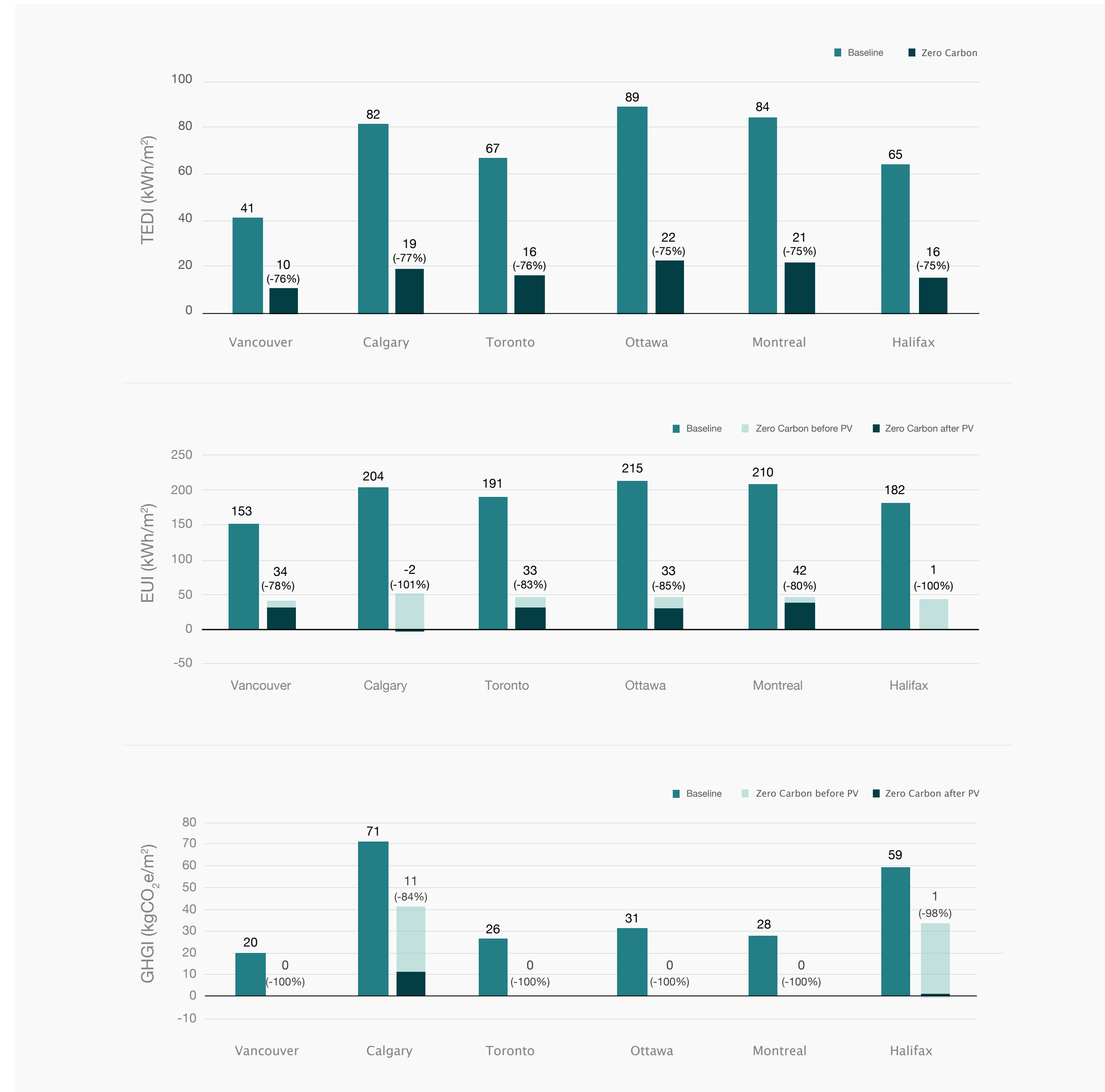



*Figure 8 – TEDI, EUI, GHGI results for low-rise MURB, typical of other archetypes*

Among the critical insights this study identified was the amount of PV required to achieve ZCBs across Canada. To illustrate the variation across archetypes and locations, Figure 9 shows the percentage of total energy use that is met with onsite PV in the ZCB archetypes for mid-rise offices, low-rise MURBs, and primary schools in Calgary, Halifax and Montreal. The reductions in GHG and energy use intensities are shown to illustrate the outcomes of the ZCB designs.

High-level conclusions include:

- Taller buildings generally need to max out their PV potential, which is limited by the roof area, except in low carbon electricity grids. For example, the mid-rise office in Calgary incorporated the maximum amount of PV possible, which enabled it to produce 20% of its energy using onsite PV; however, this only reduced the GHG intensity of the building by about 50%, meaning that offsite renewable green power is required to achieve a ZCB. On the other hand, the mid-rise office in Montreal only needs to produce 9% of its energy using onsite PV in order to achieve a ZCB.

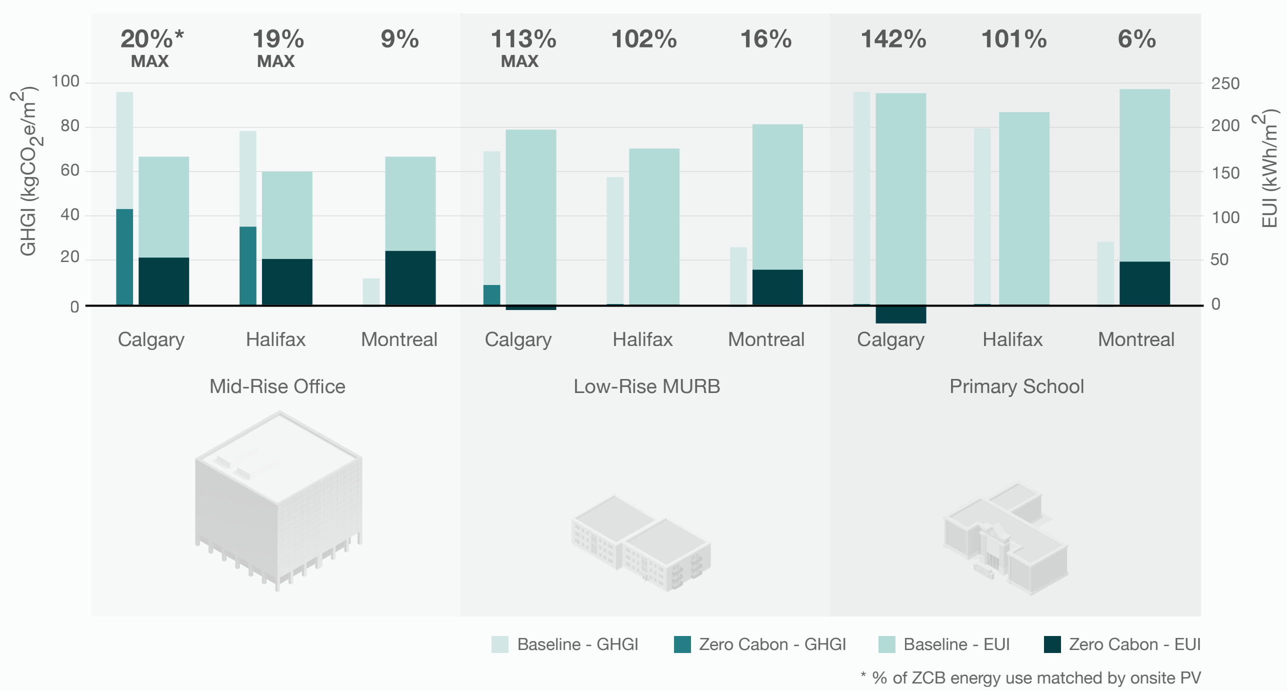



*Figure 9 – Comparison of EUI and GHGI resulting from different PV requirements*



- In low carbon electricity grids, very little PV is required because emissions are low to begin with and only a small amount of marginal electricity grid emission reduction is required (i.e., only a few hours a year where electricity is exported) to offset total emissions. For example, in Montreal the mid-rise office, low-rise MURB and primary school were all able to achieve ZCB using only onsite measures, and the fraction of total energy use that had to be met with PV was only 9%, 16% and 6% respectively.
- In Halifax, where marginal grid emissions are currently equal to average emissions, the ZCB archetypes tend to have as much PV as is required to balance energy use (i.e., ZCB = net zero energy[25]) provided there is sufficient roof space. For example, the low-rise MURB and primary school achieved ZCB and net zero energy, while the mid-rise office did not have sufficient PV to achieve ZCB or net zero energy with onsite measures alone.
- In Calgary, where marginal grid emissions are currently better than average emissions, the ZCB archetypes must sometimes produce more onsite renewable electricity than they consume; that is, they must be net exporters of green power (see the Calgary low-rise MURB and primary school results in Figure 9). This feature of the grid in Alberta may promote more behind-the-meter solutions for PV (including energy storage) until additional renewable energy generation and the conversion of coal-fired electricity generation facilities to natural gas drops the average grid emission intensity.

### 4.1.3 FINANCIAL RESULTS

The study found that ZCBs are both technologically feasible and financially viable. The ZCB archetypes studied, when evaluated over a 25-year life-cycle, can provide a positive financial return of 1%, and require a modest 8% capital cost premium. As the cost of carbon pollution rises over time, the financial return from ZCBs will improve.

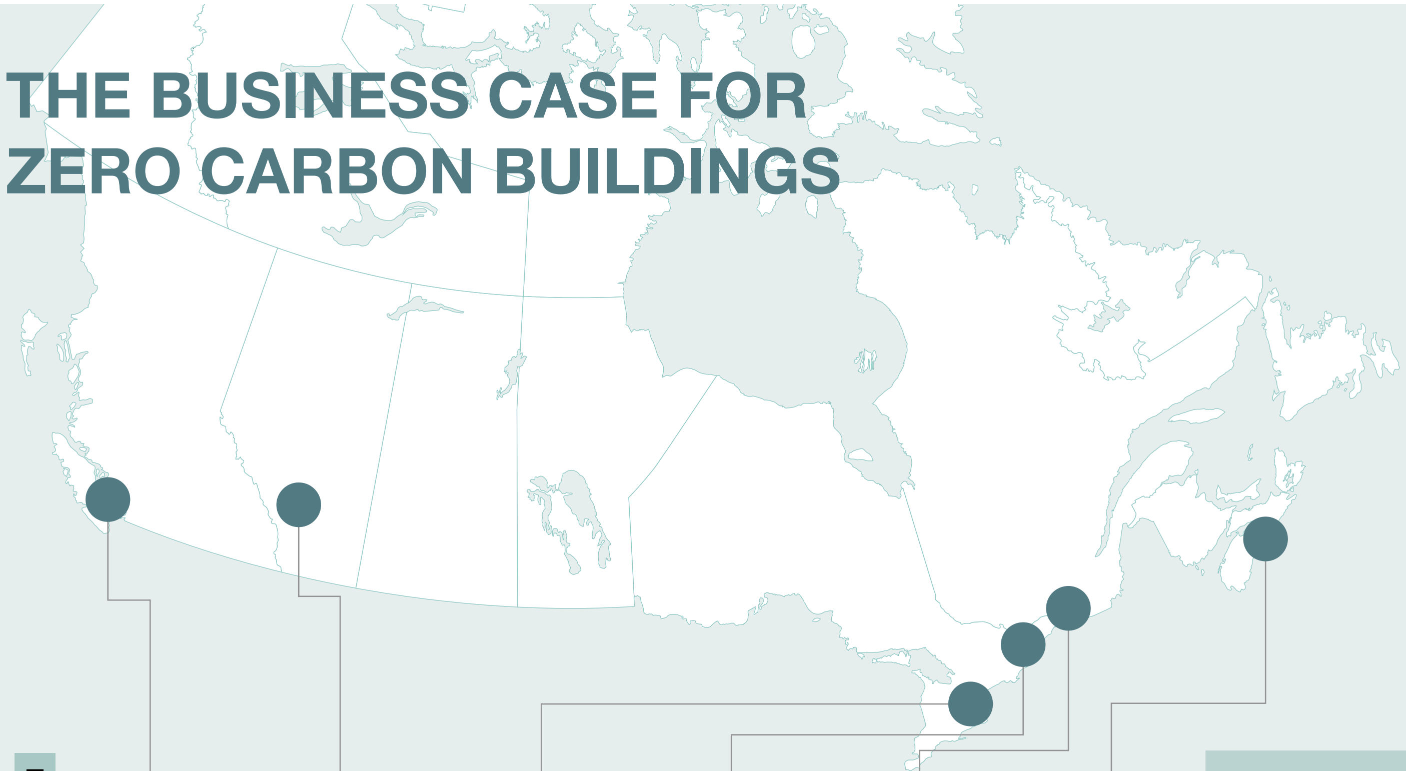
**Low-rise and mid-rise offices:** ZCB low-rise and mid-rise office archetypes can both yield incremental life-cycle returns of 3%, averaged nationally. Much of the life-cycle cost benefit comes from the fact that incremental capital costs are low, owing to the benefit of switching to radiant, dedicated outside air system (DOAS) approaches and away from more complex variable air volume (VAV) with reheat strategies. The lower delivery system costs leave room for additional investment in fuel switching and PV.

**Retail and warehouses:** ZCB warehouses and big box retail archetypes can yield incremental life-cycle returns of 2% and 1% respectively. As noted in section 3.6, the warehouse and retail archetypes benefited from large roofs, which enabled greater use of PV and allowed investment in other carbon reduction measures to be scaled back.

**Schools, low-rise and mid-rise MURBs:** ZCB schools, low-rise and mid-rise MURB archetypes can be achieved for an incremental life-cycle cost of 1%, 1% and 0% respectively, averaged nationally. These archetypes do not benefit as much as offices from reduced capital costs for the HVAC delivery system, and electricity savings are not as significant. Nonetheless, the significant reduction in energy use (largely due to improved ventilation and enclosure systems) offers significant operational cost savings. Capital costs for the mid-rise MURBs are proportionately lower than for low-rise MURBs due to economies of scale.

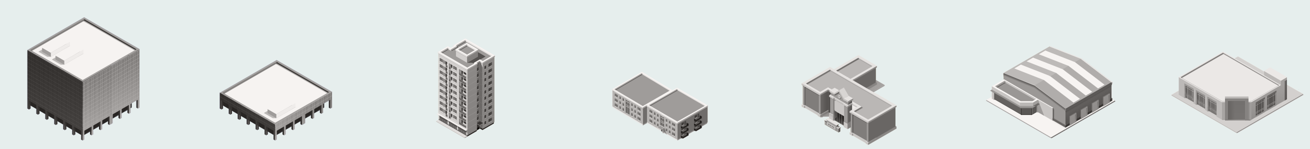
[25] Over the course of a year, a net zero energy building produces as much energy onsite as it consumes, using renewable energy systems such as PV. At certain times, the building produces more energy than it requires, and at other times it relies on electricity from the grid.

# THE BUSINESS CASE FOR ZERO CARBON BUILDINGS



## NATIONAL RESULTS

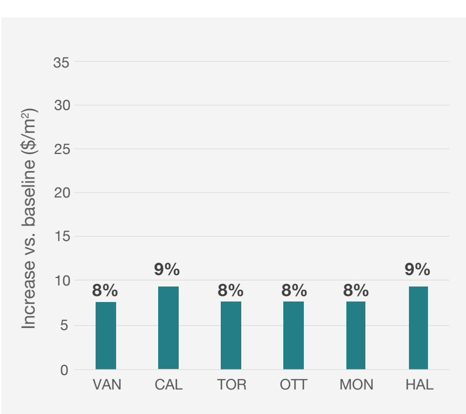
| | | | |
|---|---|---|---|
| **Incremental Life-cycle Return** $27/m² \| $34/tCO$_2$e | **1** % | **Annual Operating Savings** $17/m² | **24** % |
| **Incremental Capital Costs** $253/m² | **8** % | **Emission Savings from Onsite Measures** 31 kgCO$_2$e/m²/yr | **91** %* |



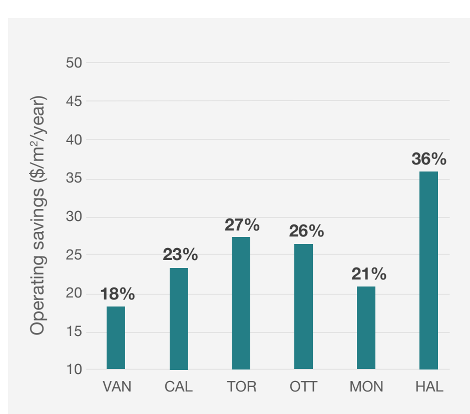
| Geographical | Vancouver | Calgary | Toronto | Ottawa | Montreal | Halifax | Incremental Life-cycle Return | Mid-Rise Office | Low-Rise Office | Mid-Rise MURB | Low-Rise MURB | Primary School | Warehouse | Big-Box Retail | Archetype |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | -1% | 1% | 1% | 1% | 0% | 4% | % vs Baseline | 3% | 3% | 0% | -1% | -1% | 2% | 1% | |
| | -55 | 32 | 58 | 51 | -4 | 187 | $/m² | 107 | 120 | 20 | -51 | -45 | 42 | 37 | |
| | -137 | 18 | 110 | 79 | -6 | 122 | $/tCO$_2$e | 208 | -166 | 27 | -63 | -44 | 64 | 34 | |

## GEOGRAPHICAL RESULTS

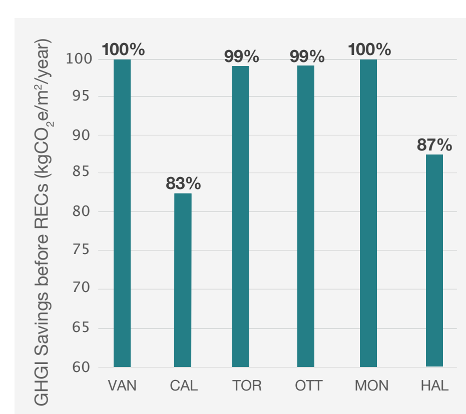
### Incremental Capital Costs




### Annual Operating Savings

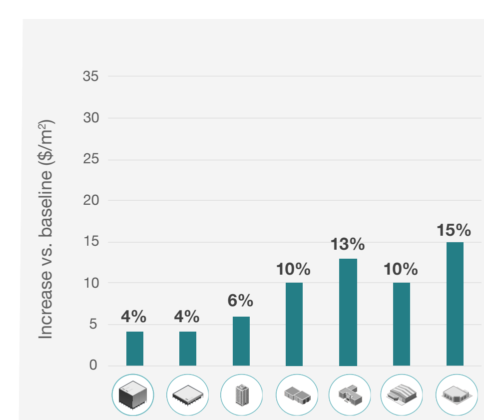



### Annual Emissions Savings

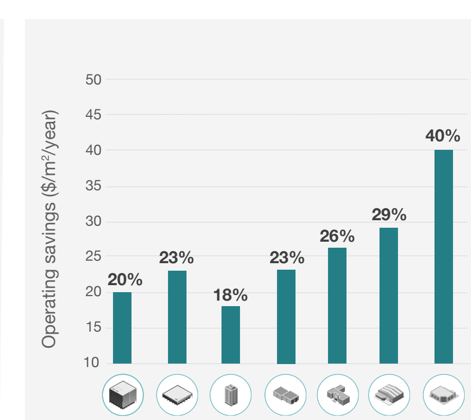



## ARCHETYPE RESULTS

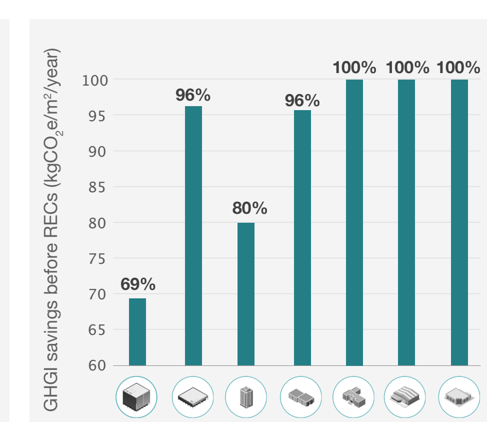
### Incremental Capital Cost




### Annual Operating Savings




### Annual Emissions Savings




* All values are area-weighted averages. Life-cycle costs are assessed over 25 years. Results reflect onsite carbon reduction measures. NECB-2011 serves as the baseline. In certain communities, some archetypes require offsite green power to achieve Zero Carbon Building. Nationally, the average incremental life-cycle cost rises from 0.7% to 1.3% when offsite green power (in the form of Renewable Energy Certificates) is included.

**Halifax:** Regionally, the outcomes for ZCBs are strongest in Halifax due to the high carbon intensity of the Nova Scotia electricity grid (which results in higher carbon cost savings potential) and the relatively low cost of electricity relative to natural gas (2:1 compared to almost 5:1 in Ontario). This second factor makes switching from natural gas to electricity for heating and hot water more financially advantageous.

**Montreal, Ottawa, Toronto and Calgary:** In these communities, the outcomes for ZCBs are economically strong with any upfront capital cost premium mitigated over the life-cycle by higher operating and emissions savings.

**Vancouver:** The financial outcome of ZCBs is less strong in Vancouver because of the low carbon intensity of the electricity grid (which results in lower carbon cost savings potential), the low cost of natural gas, and the milder climate, which reduces the demand for energy. While the current economic case in Vancouver is less favourable than in the other communities in this study, the financial returns will improve over time as the cost of carbon rises, which will lead to a higher price on all types of fossil fuels, including natural gas. The closer that electricity and natural gas come in price, the stronger the economic case for ZCBs. Vancouver's milder climate also enables alternate approaches to ZCB design, such as the use of air-source heat pumps and lower levels of building envelope performance, that would yield superior financial results.

### 4.1.4 SENSITIVITY ANALYSIS

A sensitivity analysis was performed to determine the relative impact that changes in initial capital costs, baseline and ZCB energy costs (consumption and price), and the cost of carbon have on the life-cycle cost. Mid-rise office and low-rise MURB archetypes were examined in three different communities. The parameters were increased by 25% for the purposes of this analysis.

Figure 10 illustrate the results for each archetype. The X-axis shows how much each parameter contributes to the variability of life-cycle costs; it does not have any units, but rather presents a relative indication of the strength of the contribution of each parameter.

Key insights include:

- For mid-rise offices, and likely for other larger buildings or buildings with higher energy costs, life-cycle costs are much more sensitive, overall, to energy costs than to either capital costs or the cost of carbon.
- For smaller buildings, or those that have lower energy costs (as with the low-rise MURB), capital costs become more important. The cost of energy also remains important, especially in markets with higher energy costs such as Toronto.
- The cost of carbon has a small impact in low-carbon grids, but a much more meaningful impact in higher-carbon grids where emissions are substantially higher. In fact, the cost of carbon is almost as important as the energy cost of the baseline building in both Calgary cases shown.
- The closer to net-zero energy the ZCB is (i.e. the more onsite renewable energy is generated), the less sensitive the life-cycle costs are to energy costs. For example, the ZCB low-rise MURB in Calgary exports as much renewable energy as it purchases from the electricity grid, and therefore shows no sensitivity to the cost of energy.
- When sensitivity to energy costs decreases, sensitivity to capital cost rises. This is illustrated by the heightened sensitivity to capital costs in the low-rise MURB, as compared to in the mid-rise office.
- Likewise, when the baseline building's energy cost decreases, sensitivity to capital costs rises. Toronto has higher energy costs than Vancouver, and as a result both Toronto archetypes show greater sensitivity to baseline energy cost; conversely, the higher cost of energy decreases the sensitivity to changes in capital costs.

Since the results vary significantly between archetypes and locations, an important conclusion of the sensitivity analysis is that a similar exercise should be repeated on all projects when making long-term economic decisions. It would also be prudent to explore different variation ranges for different factors. For example, a higher range of variability could be considered for energy costs than for capital, since the ability to achieve the desired capital cost is more under the control of the design-build team than the future price of energy.



Details of the methodology can be found in Appendix A-4, and detailed results of the sensitivity analysis are in Appendix B-3.


*Figure 10 – Sensitivity analysis, mid-rise office and low-rise MURB in Toronto*

## 4.1.5 FINANCIAL IMPACT OF OFFSITE GREEN POWER PURCHASES

The analysis of life-cycle and capital costs focused on onsite measures to eliminate carbon emissions. In over 70% of the scenarios studied, ZCBs were achieved through onsite measures. For example, primary school, retail building and warehouse archetypes achieve zero carbon in all locations using only onsite measures. Low-rise MURBs and low-rise offices are also able to achieve zero carbon using only onsite measures in all locations, except for Calgary. Even mid-rise MURBs and mid-rise offices are able to achieve ZCB using only onsite measures in two communities, Montreal and Vancouver, due to the very low carbon electricity grids and relatively high marginal emissions factors in these regions.

Where buildings are not able to achieve zero carbon through onsite measures, they may achieve it through the purchase of green power generated offsite. This study assumes that offsite green power, where needed, takes the form of renewable energy certificates (RECs), at an average cost of \$25/MWh[26]. The impact of purchasing offsite green power, where needed, is presented in Table 2.

The impact of adding RECs to fully offset carbon emissions is generally modest. One exception is the mid-rise office building in Calgary, where the savings drop from \$95/t$CO_2$e to \$52/t$CO_2$e due to an annual REC cost of ~\$107,000. This is only an increase in estimated annual O&M of 4%, but almost doubles the total annual energy cost for the facility.

Owners and managers may wish to focus on onsite measures until the average emissions of the electricity grid in Alberta decreases as new renewable and natural gas power generation replaces coal. The onsite measures should, however, recognize the ongoing transition in the electricity grid; for example, electrical heating solutions should still be pursued as this will decrease emissions over the life of the HVAC system and avoid costly retrofits.

*Table 2 – Life-cycle cost per tonne $CO_2$e with RECs relative to without RECs.*

| | Mid-Rise Office | Mid-Rise MURB | Low-Rise MURB | Low-Rise Office | Primary School | Big Box Retail | Warehouse |
|---|---|---|---|---|---|---|---|
| CALGARY | 43 | 38 | 8 | 5 | – | – | – |
| HALIFAX | 29 | 23 | – | – | – | – | – |
| OTTAWA | 6 | 2 | – | – | – | – | – |
| TORONTO | 6 | 1 | – | – | – | – | – |
| VANCOUVER | 1 | – | – | – | – | – | – |
| MONTREAL | – | – | – | – | – | – | – |

*Note: "-" indicates no RECs are required to achieve Zero Carbon Building.*

[26] This cost of RECs reflects the average price for EcoLogo-certified RECs across the country. See Appendix A-4 for more discussion of these points.



## 4.1.6 FINANCIAL RESULTS PER TONNE OF CARBON ABATED

Comparing the incremental capital costs per tonne $CO_2$e against the incremental life-cycle costs per tonne $CO_2$e of the ZCB designs gives a broad understanding of cost implications for achieving ZCB. Figure 11 is a bubble graph depicting all the archetypes and three locations: Vancouver, Toronto and Calgary. The centre of each bubble is the financial performance, and the size of the bubble is the relative carbon emissions saved.

Some important high-level conclusions that are clear when viewing the results in this manner include:

- The incremental capital cost per tonne varies significantly from ~\$70/tonne to as much as ~\$700/tonne.
- In most scenarios, the incremental life-cycle cost of building zero carbon is less than the expected cost of carbon, which is estimated at an average of \$150/tonne over the next 25 years.
- The carbon emissions, illustrated by the size of the bubbles, are somewhat higher in Calgary than they are in Toronto and significantly larger than those in Vancouver. This reflects the significantly higher carbon intensity of electricity in Alberta relative to the low-carbon grids in Ontario and BC. Simultaneously, it illustrates the impact of the total floor area of buildings: Ontario emissions are significantly larger than those in Vancouver because the total floor area of buildings in Ontario is 50% greater than the floor areas of both Alberta and BC combined.

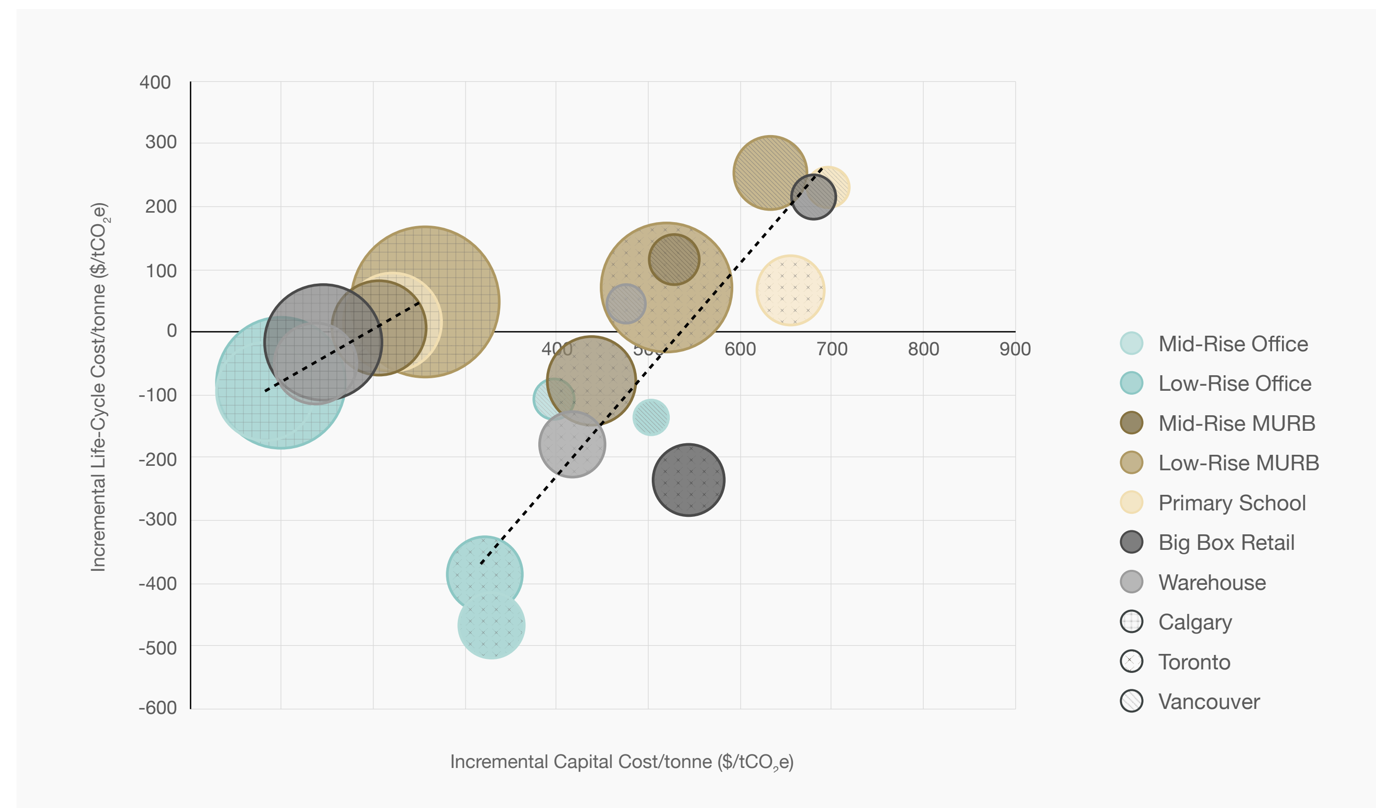



*Figure 11 – ILCC/t$CO_2$e vs. ICC/t$CO_2$e with bubble size as carbon reduction for each archetype and location*

The average incremental life-cycle cost per tonne is -$34/ $tCO_2e$ (i.e. an average savings) when weighted by the contribution of each archetype/location to the national building stock.

The wide variation in incremental capital cost per tonne is primarily driven by differences in the denominator (tonnes of carbon reductions), which is most heavily impacted by heating demand and the carbon intensity of the electricity grid. The results consistently show Vancouver as the costliest and Calgary as the least costly of the three locations, despite the average cost of construction in each market showing the inverse (i.e. Calgary as most costly, Vancouver as least).

The most interesting observation from Figure 11 is that there appears to be two distinct near-linear clusters of results. The first cluster is all the Calgary facilities. These scenarios are all near zero incremental life-cycle cost and are positioned on the left-hand (i.e. low incremental capital cost per tonne) side of the graph. The narrow range of results is caused by the large amount of carbon savings in Calgary (at least three times that of other locations), which increases the denominator (tonnes of carbon reductions) and consequently compresses both the life-cycle and capital results.

The second linear cluster is the rest of the facilities, starting with the Toronto offices (bottom-left) and ending with the grouping of Vancouver low-rise MURB, primary school and retail. The smaller potential for carbon reductions in Toronto and Vancouver decreases the denominator used, which increases capital costs per tonne (horizontal axis) and the variability in both capital and life-cycle costs per tonne. In the second cluster, the low-rise MURB performs the worst because it has among the highest capital cost increases and, although it has higher carbon savings potential than offices, most of those savings are in heating energy which saves on the cheapest fuel: natural gas. On the other hand, the offices perform well because they have low incremental capital costs and save on electricity and natural gas more evenly.

Also of note is how PV drives down the life-cycle costs of some of the better outliers (e.g. retail in Toronto) by contributing pure electricity cost savings and delivering carbon reductions at the marginal carbon intensity of the grid (as discussed earlier).

Important conclusions include:

1. Life-cycle cost per tonne is roughly linearly related to capital cost per tonne for a given grid and climate. The more support there is for capital costs, the more likely an owner-operators and developer is to take action.
2. The more carbon intensive the electricity grid, the more similar (and reliable) the financial performance of ZCB projects will be.



## 4.2 ANALYSIS OF CARBON REDUCTION MEASURES

An analysis was conducted to help understand the cost-effectiveness of the different carbon reduction measures. As described in Section 3.6, the measures are grouped into seven carbon reduction bundles. For the purpose of this analysis, the fuel switching bundle was broken-out to show the ground-source heat pump (GSHP) separately from the peaking biomass boiler. The latter was used in the mid-rise office and mid-rise MURB archetypes, where additional heating was required because the limited site areas restricted the number of boreholes for the geo-exchange system. Biogas may also be considered in such situations.

To further simplify, only three of the archetypes explored in this study are used for this analysis. Archetypes were selected to represent a MURB (mid-rise MURB); an office (mid-rise office); and an archetype with more unique operating conditions and reflecting lower-cost construction (big-box retail). To allow a more complete comparison all the bundles were applied to the big box retail archetype.

### 4.2.1 IMPACT OF MEASURES ON ENERGY AND GREENHOUSE GAS METRICS

Figures 12 through 14 show the overall TEDI, EUI and GHGI results associated with the various bundles of carbon abatement (i.e., reduction) measures. Each graph shows all three studied archetypes. The individual bundles are assessed in a cascaded manner, meaning that the impact of each bundle is assessed on the assumption that all the bundles listed previously (i.e., to the left) have been installed already. For example, the cost, size and performance of a GSHP installed on a building using typical construction will be significantly different than that of a GSHP installed on a building where the insulation and windows have been improved and heating and cooling are delivered through an efficient delivery system with dedicated outdoor air and energy recovery systems. The bundles are cascaded in a sequence that prioritizes reductions in demand first, followed by efficiency in meeting energy demand, then fuel switching and finally renewable energy.

## IMPACT ON TEDI

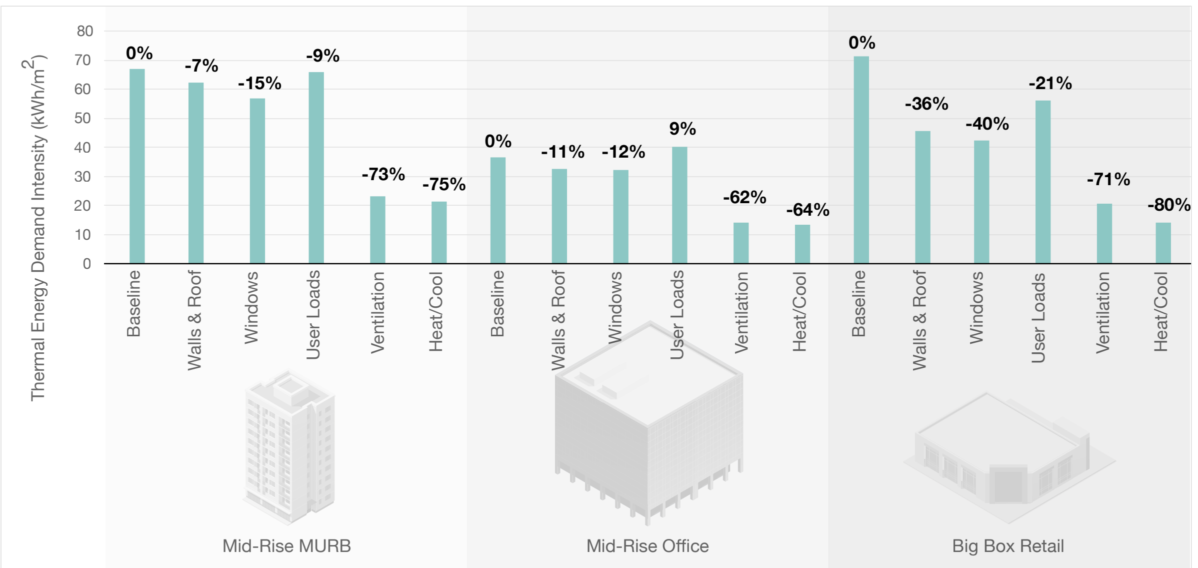



*Figure 12 – Cascaded TEDI of each bundle, 3 archetypes in Calgary*

TEDI results are largely consistent across all locations, so only results for Calgary are shown. The most useful observations are:

- The impact of improving walls varies across the three archetypes, with the greatest benefit being for smaller buildings with larger ratios of wall and roof area to floor area.
- For retail, improving walls has a larger impact on heating loads due to the relatively low window area of these buildings. Similar results would be seen for the primary school and warehouse archetypes.
- Reducing user-controlled loads increases TEDI because savings in lighting and plug loads increase demand for heating. This effect is most prominent in office and retail archetypes, where lighting and plug loads are much higher than in MURBs.
- Switching the ventilation system to a dedicated outdoor air system (DOAS) with excellent heat recovery (by way of an energy recovery ventilator, or ERV) and demand-control ventilation (DCV) significantly improves TEDI for all archetypes and locations. Even half the heat recovery performance would be enough to achieve the CaGBC ZCB Standard target for many of the larger buildings.
- Mid-rise MURBs are particularly affected by this DOAS/ERV/DCV bundle of measures, with huge improvements shown over a more conventional design where no heat recovery is provided and fresh outdoor air is supplied into the building corridors rather than directly into residential units.
- Improvements to heating and cooling delivery systems offer a modest improvement to TEDI, in the same range as window and wall improvements.
- The remaining carbon reduction measures (GSHPs, biomass and PV) have minimal impact on TEDI, as they do not impact thermal energy demand.



## IMPACT ON EUI

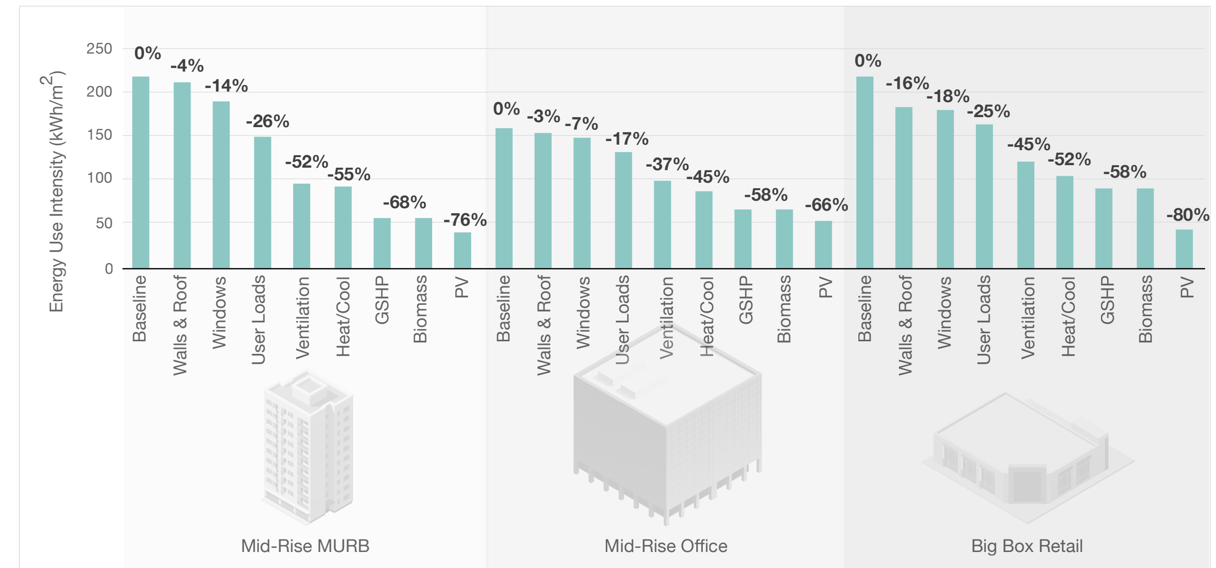



*Figure 13 – Cascaded EUI of each bundle, three archetypes in Calgary*

The overall EUI does not vary much between locations either. Each bundle of carbon abatement measures shows a positive contribution towards energy savings (except for biomass[27]). Important observations include:

- Contributions from each bundle are more evenly distributed in mid-rise offices than they are for mid-rise MURB or big box retail archetypes, reflecting the fact that energy consumption in offices tends to be more balanced across end-uses. For the mid-rise MURB archetype, energy savings are most closely tied to reductions in ventilation loads (as with TEDI).
- GSHPs provide heat approximately four times more efficiently than gas boilers. However, the average energy efficiency benefit after all other improvements have already been made is around 14% when calculated as a fraction of the total reduction from baseline. These cascaded results differ significantly from the individual measured results, which are discussed in the next section.
- For the retail archetype, where there is ample roof space, PV can contribute significantly to energy (and carbon) savings.

[27] Biomass boilers are roughly as efficient as non-condensing natural gas boilers and so do not improve EUI.

## IMPACT ON GHGI

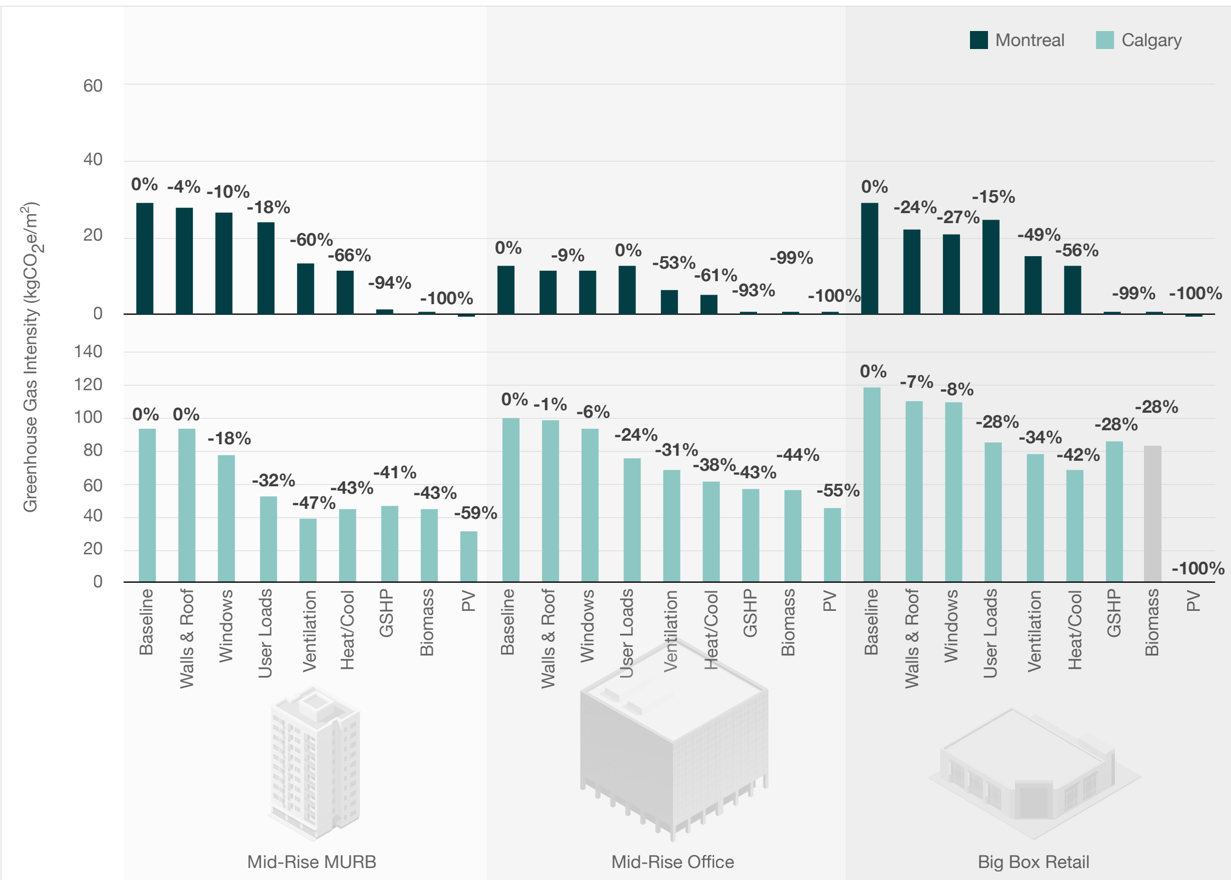



*Figure 14 – Cascaded GHGI of each bundle, three archetypes in Montreal and Calgary*

The GHGI results tell the most varied story due to the range of electricity grid emission factors (illustrated in Figure 14). To illustrate the breadth of the differences, results for Montreal and Calgary are presented, representing the two extremes for grid electricity emissions.

Key observations include:

- Even with all the onsite carbon reduction measures, in a minority of situations, ZCB cannot be achieved without RECs (see Section 4.1.2). For example, in Calgary, the mid-rise MURB and mid-rise office archetypes do not achieve zero carbon using only onsite measures.
- With lower window-to-wall ratios, window improvements can often save more on cooling than heating, therefore impacting electricity use more than natural gas consumption. As a result, window improvements have an enhanced benefit in high-carbon grids. This is discussed in greater detail in Section 4.2.2.
- Measures to reduce user-controlled loads drive down electricity demand, which may increase heating demand and natural gas use. As a result, user-controlled load reductions often have a negative impact on GHGI in low-carbon grids (see the mid-rise office and retail archetypes in Montreal). This is not the case for MURB archetypes because of their large baseline demand for domestic hot water, which is a component of user-controlled loads. The significant savings potential from reducing domestic hot water demand greatly increases the overall benefit of user-controlled load reductions. The mid-rise MURB archetype illustrates this point.



- The ventilation bundle provides benefit for all electricity grids but has an enhanced benefit in low-carbon electricity grids because it saves mostly heating energy, which is delivered by natural gas boilers in the baseline buildings.
- Low-exergy, low fan-power approaches to heating and cooling save natural gas and electricity almost equally, resulting in similar benefits across all locations.
- GSHP have significant benefits in low-carbon electricity grids. However, in high-carbon electricity grids where electricity can be more carbon intensive than natural gas, the benefit is less clear and can currently be negative, as seen in the Calgary retail and mid-rise MURB archetypes. Across Canada, it is expected that the carbon intensity of high-carbon electricity grids will continue to fall as coal-fired electricity generation is phased out. As a result, it can be expected that GSHPs will provide carbon reduction benefits in the most carbon-intensive provinces within just a few years and they should be considered in new construction today to ensure optimal performance over the life-cycle of the buildings.[28]
- Biomass systems reduce emissions related to heating. As with the ventilation bundle, the benefit is much more prominent in low-carbon electricity grids where total emissions are dominated by natural gas use.
- The benefits of PV vary significantly across building archetypes and locations due to variations in carbon intensity of the electricity grid. For example, PV does not contribute meaningfully to the GHGI of the archetypes in Montreal as the GHGI has already fallen to near-zero before PV is added to the set of carbon reduction measures. On the other hand, the GHGI of retail buildings in Calgary relies on PV for more than 50% of its zero-carbon performance (as illustrated by the drop from ~80 $kgCO_2e/m^2$ after geo-exchange to 0 $kgCO_2e/m^2$ after PV).

### 4.2.2 COST-EFFECTIVENESS OF MEASURES

The cost-effectiveness of the carbon reduction bundles was examined by creating abatement curves that illustrate the life-cycle cost per tonne of carbon abated (vertical axis) and the carbon abatement potential (horizontal axis) of each bundle (Figures 15 and 16). The bundles are arranged left-to-right from the most to the least cost-effective.

Separate graphs are shown for the mid-rise office, mid-rise MURB and retail building archetypes, which were selected to illustrate the range of results.

Figure 15 (on the next page) illustrates the cascaded abatement curves: the carbon reduction bundles are assessed in the context of the ZCB, which incorporates all the bundles. Each vertical bar represents a 1% reduction in carbon emissions, and the carbon abatement of all the bundles equals 100% as these ZCB designs have no associated emissions.

Figure 16 (on page 47) illustrates the abatement curves for the bundles of measures, if they were implemented individually on a baseline NECB-2011 compliant building. Life-cycle costs are lower and carbon abatement is greater when an individual bundle is implemented on its own: the NECB-2011 building has higher energy use and associated emissions, which increases the emissions reduction potential of implementing any one carbon reduction bundle. For the same reason, the total carbon abatement of the individual measures is greater than 100% of the emissions of the baseline building. The incremental life-cycle cost and 100% carbon emissions reduction of the ZCB design is represented by the translucent yellow overlay for comparison.[29]

The full set of results for all archetypes and communities is provided, in a slightly altered form, in Appendices B-2 and B-4.

[28] CaGBC's A Roadmap for Retrofits in Canada: Charting a Path Forward for Large Buildings report (2017) indicated that electricity grids would be clean enough to justify using air-source heat pumps by 2027, based on forecasts by the National Energy Board of Canada (see page 18 of the report). GSHPs are approximately twice as efficient as air-source heat pumps and will reduce emissions in provinces with the dirtiest of grids within the next few years. Available at https://www.cagbc.org/CAGBC/Advocacy/A_Roadmap_for_Retrofits_in_Canada.aspx.

[29] The carbon reduction measures implemented were kept consistent across all archetypes for the purposes of this analysis. Therefore, the life-cycle cost for retail shown in Figure 16 is significantly worse than the result provided in Section 4.1.3, as the latter is considered a more cost-optimal design.

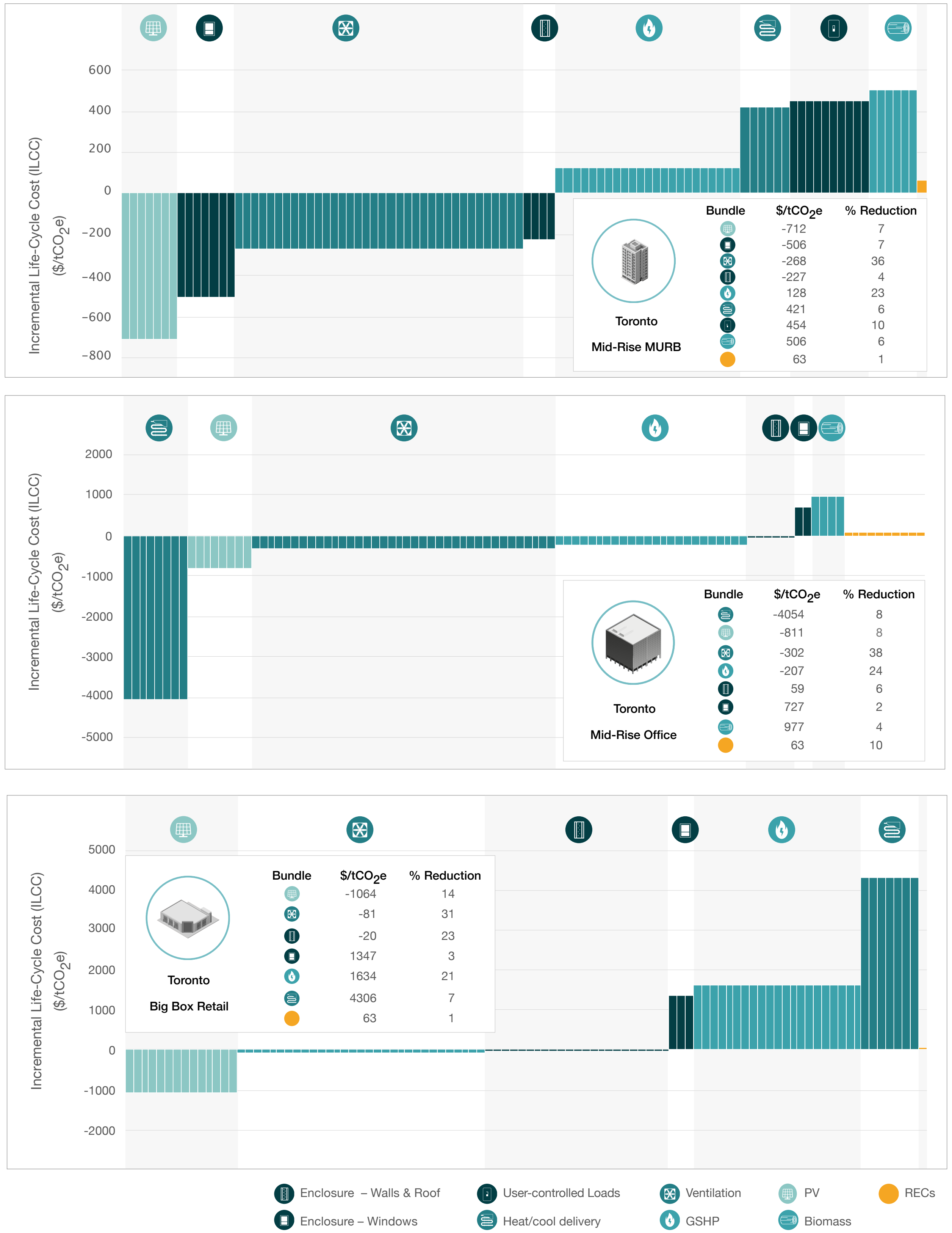



*Figure 15 – Carbon abatement cost curves of cascading measures in Toronto for mid-rise office, mid-rise MURB and retail*



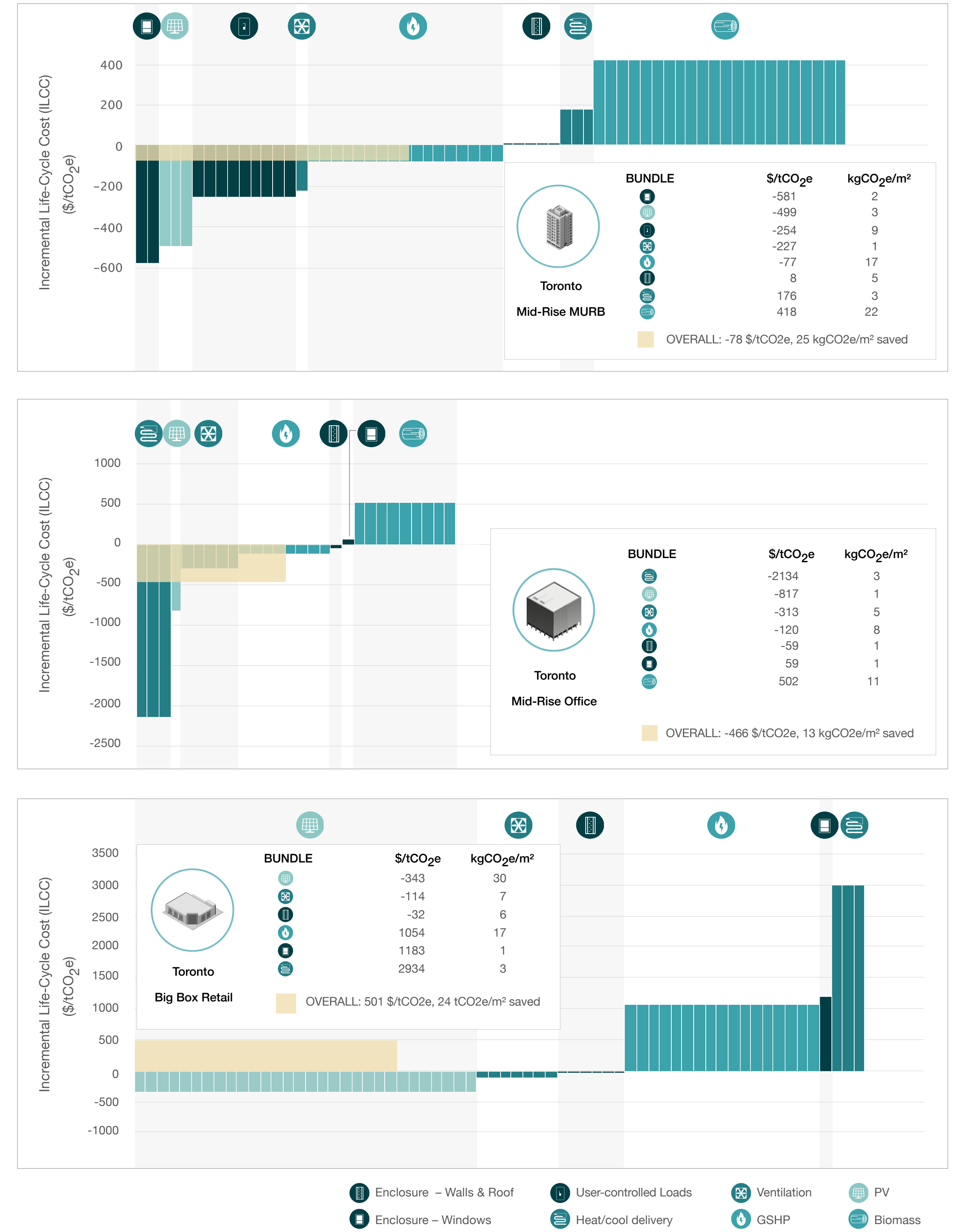



*Figure 16 – Carbon abatement cost curves of individual measures in Toronto for mid-rise office, mid-rise MURB and retail*

Discussions of each bundle are provided below in order of increasing complexity.

## FUEL SWITCHING – PEAKING BIOMASS

The biomass boiler has a consistent and relatively high life-cycle cost per tonne of $CO_2$-equivalent abated, which is due to the increased cost of biomass fuel for the same overall system efficiency as in the base case (biomass boilers being of similar efficiency as non-condensing natural gas boilers). Results are better when biomass systems are considered as an individual measure since carbon reductions can be much higher in a building with only a biomass boiler for heating as compared to a building where the biomass boiler is used to supplement a GSHP system. For example, in the mid-rise office, biomass has a cost of nearly \$1000/t$CO_2$e when all the other measures are implemented, whereas it has a cost of approximately \$500/t$CO_2$e when considered as a standalone measure. Even at a cost of \$500/t$CO_2$e, capital constrained projects may consider provisioning for this technology but not installing it fully due to the relatively high costs.

## USER-CONTROLLED LOADS

Measures that focus on lighting and plug loads achieve electricity savings at the cost of raising heating demand. Since lighting and plug load improvements are assessed before fuel switching, the improvements increase natural gas consumption, which greatly reduces the carbon emission savings potential, or even increases emissions in locations with low carbon electricity grids. This effect is seen in the figures for mid-rise office and big-box retail archetypes, which do not contain results for user-controlled loads since they do not save carbon. While user-controlled load reduction measures implemented on their own may not seem to reduce carbon in low-carbon grids, when they are implemented as part of the full set of measures they contribute positively to cost-effectiveness. User-controlled load measures are also critical to reducing and controlling electricity and cooling demand, which supports decarbonization of the electricity grid.

In high carbon electricity grids, the decision is much easier - the energy cost savings from user-controlled load improvements have a significant life-cycle cost benefit and provide significant carbon emission reductions. In fact, user-controlled loads contribute a great deal to the improved performance of the high-carbon grid life-cycle cost results discussed above.

As previously mentioned, user-controlled loads in MURBs archetypes also show benefit, because they include demand for domestic hot water, which is a significant use of natural gas in the baseline MURB.

## VENTILATION SYSTEMS

The switch to DOAS (including the use of displacement ventilation[30] where applicable) with high-efficiency energy recovery had some of the strongest results both as an individual and as a cascaded measure:

- For the mid-rise MURB archetype, the switch carried a relatively small capital cost increase compared to the large energy and carbon savings. The additional cost of adding return ductwork was partially offset by the removal of an in-suite exhaust system.
- The mid-rise office archetype shows similar life-cycle cost benefits, with the capital cost of more complex central air-handling units (AHUs) partly offset by the removal of the floor-by-floor compartment units.
- For big-box retail archetypes, improved ventilation systems are less cost-effective, but contribute significantly to reducing emissions and are recommended on their own for any project, regardless of performance.

Overall, the improved ventilation bundle yields the best combination of carbon reduction and cost-effectiveness of all the bundles studied and should be included in any ZCB design.

## ENCLOSURE

Wall and roof insulation, glazing, air sealing and other envelope measures are critical to achieving ZCBs. However, their added contribution often diminishes with each additional level of investment.

[30] Displacement ventilation involves slightly warmer air being delivered low and slow at the floor and exhausted from above, allowing ventilation air to be delivered more effectively into the breathing zone.

In the cascaded results shown for Toronto, wall and roof improvements do show a life-cycle cost benefit and carbon reduction across all archetypes studied. In warmer climates or in archetypes where walls are less important to heat loss, this performance does not hold, and savings do not outweigh costs (for example, see the Vancouver office results in Appendix B-2). Targeting a level of wall insulation that is life-cycle cost per tonne neutral may be prudent, respecting additional comments below.

Window performance is a key component of the overall carbon reduction in high-carbon electricity grids, where reductions in cooling demand (and the associated electricity) contributes just as much (or more) when compared to reductions in natural gas heating. However, window improvements at the level included in the study (i.e., triple-glazed with best-in-class aluminum frames) have a high capital cost relative to their abatement potential for most archetypes, with the notable exception of the MURB archetype. In the MURB archetype, the window-to-wall ratio is high, and heating energy is significant, so improved windows play an important role and are a cost-effective choice.

Improved enclosure performance is vital for reasons other than carbon reduction. First and foremost, good enclosure design enables smaller (i.e., more cost-effective) low-exergy / low-fan-power HVAC designs. Some HVAC configurations (such as radiant heating/cooling) only become feasible with a sufficiently well-insulated enclosure. As illustrated in Figure 17, a cost-effective VRF system that does not require ducting air to the windows to counter drafts is only possible when the peak heating is below 18 BTU/hr-ft2 (~60 W/m²), which requires an overall R-11 for the walls and windows in a corner office. It is also important to note that retrofits of building envelopes are very costly and disruptive.

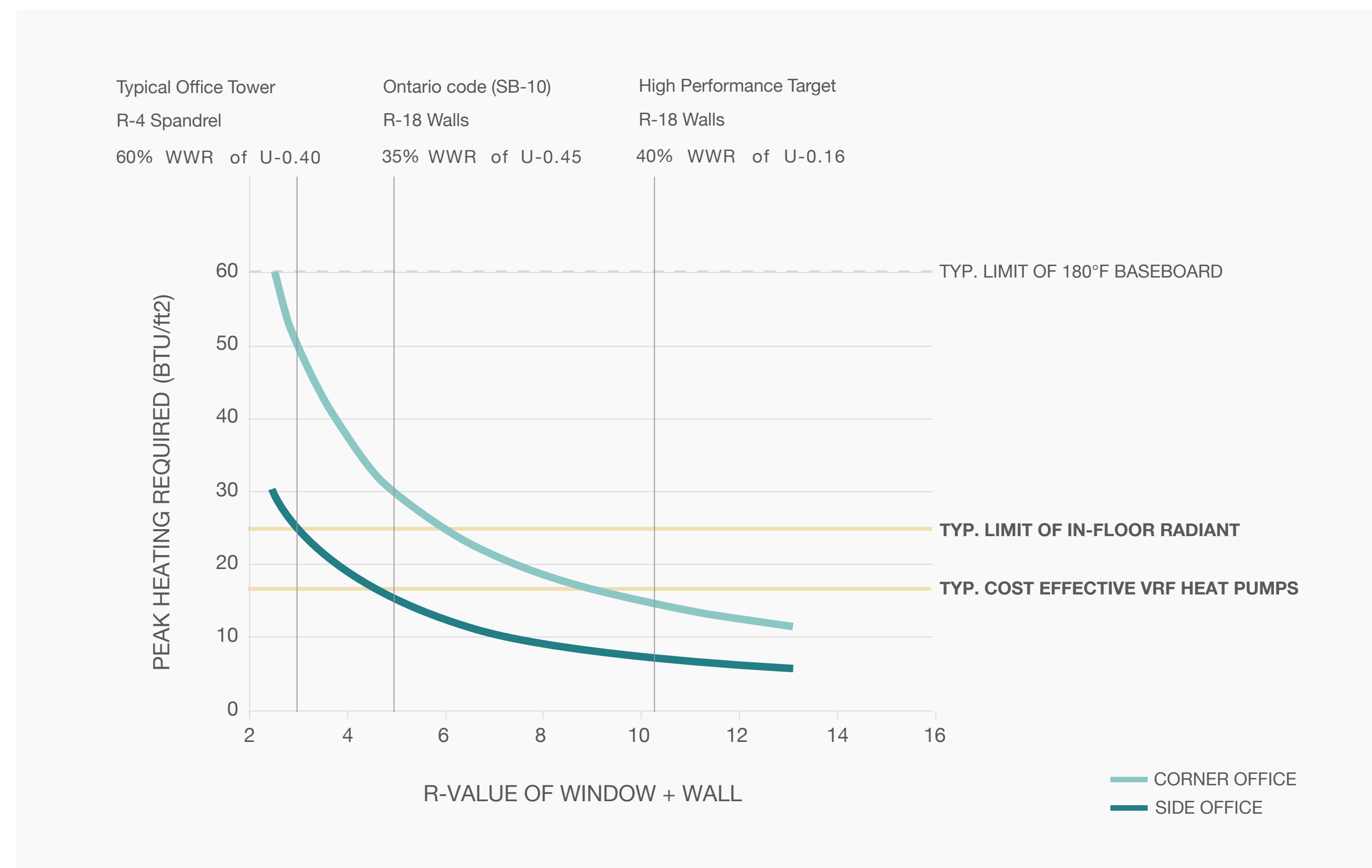



*Figure 17 – Maximum load curves for practical installation of different HVAC delivery technologies for heating.*

Improved enclosures also allow for more expensive HVAC systems to be smaller in size, and therefore cheaper. This is particularly important for geo-exchange and central heat pump systems, where equipment is sized based on the larger of heating and cooling loads (and can be larger due to an imbalance in loads). Enclosure improvements play a huge role in reducing and balancing the heating and cooling loads within buildings.

Finally, enclosures are important for occupant comfort, as well as resiliency in the face of power outages – particularly in MURBs, where power outages can quickly drive occupants to seek shelter outside their home.

## HEATING AND COOLING DELIVERY SYSTEMS

Low-exergy and low-power heating and cooling delivery systems show meaningful and consistent reductions in energy and emissions across all archetypes and locations. However, there are differences across the archetypes regarding the cost to implement these measures, resulting in different financial performances.

- The overall life-cycle benefit is clear for the mid-rise office archetype, which already has a relatively more expensive multi-zone HVAC system[31] in the baseline building. The office also has the highest use of cooling of all archetypes, resulting in additional benefit from measures that reduce cooling energy costs, such as this bundle.
- For the mid-rise MURB, low-exergy and low-fan power delivery systems are more cost-effective on their own because they bring less carbon reduction benefit in a ZCB, just as with the biomass boiler discussed above.
- For the retail archetype, heating/cooling delivery needs can be reasonably well met by relatively inexpensive and simple systems. Therefore, the relative cost-effectiveness of low-exergy and low-power systems is poor. As noted in Section 3.6, these systems were not included in the retail ZCB archetype; they are only included here for comparison.

Low-fan power improvements to HVAC systems typically provide a good financial return, since they save on electricity. Low-exergy improvements to delivery systems, however, can add to the cost (e.g., using radiant surfaces instead of coils) without seeming to save a great deal in energy costs. Similar to the enclosure discussion, the importance of low-exergy systems is their ability to enable heat pumps and other plant equipment to be more efficient. They also permit low-grade sources of energy such as solar hot water and direct-geo-exchange cooling to be used in a much larger number of operating hours.

[31] Multi-zone systems typically have both central equipment for one or more services (e.g., central cooling fans) and zonal equipment that adjusts and/or provides additional services locally (e.g., VAV boxes with zonal heating coils). Multi-zone systems offer excellent control of temperature, but at an additional cost, especially when heating and cooling need to be available in all zones all year long.



## FUEL SWITCHING - GROUND SOURCE HEAT PUMPS

Variations in the performance of heat pumps across the three studied archetypes is noteworthy. For the mid-rise office and retail building archetypes, the GSHP approach shows similar results (whether positive or negative) when applied either as an individual measure or as part of the suite of measures. For the mid-rise MURB, GSHP systems have a negative life-cycle cost when considered on their own (i.e., they bring a positive financial return), but they increase life-cycle cost when considered as part of the cascade of measures. This is because the bundles applied to the MURB before including the GSHP system have already dramatically reduced the heating loads, leaving less room for improvement from the fuel switching bundles. At the same time, the capital cost of the GSHP system in the mid-rise MURB archetype is virtually the same in both the individual and cascaded cases because the archetype has a limited site area, which restricts the number of boreholes possible. That is, additional boreholes cannot be dug to meet the increased demand for heating and cooling when the GSHP is considered as a stand-alone solution in a baseline building. Even though the ZCB design achieves better overall energy performance for the fixed number of boreholes, its only marginally better than the individual measure. This phenomenon is not the same for sites where the number of boreholes can be matched to the load, translating to a higher cost when GSHP is implemented on its own.

While location influences the cost-effectiveness of most measures (due to differences in climate, energy costs, and electricity grid emission intensity), GSHPs are particularly sensitive to these differences. GSHPs directly replace natural gas with high-efficiency electricity-based heating. This leads to an overall reduction in energy consumption. In low-carbon grids, the benefit from switching to electricity further reinforces the carbon reduction impact of the bundle. However, high-carbon electricity grids (such as Alberta and Nova Scotia) may currently have grid emissions intensities that diminish the carbon reduction potential of GSHPs.[32]

- As illustrated in Figure 18 (on page 53), higher natural gas prices can readily overcome any disadvantage posed by a high-carbon grid. Calgary and Halifax, which both have carbon-intensive electricity grids, represent the worst and best financial arguments for GSHP, respectively, reflecting the low cost of natural gas in Calgary and the significantly higher cost of natural gas in Halifax (highest amongst the communities studied).
- For the mid-rise office archetype, the significant cooling savings from GSHP systems offset the impact of high-carbon grids. In the end, the life-cycle cost results for the mid-rise office show financial benefits across all communities.
- GSHPs also demonstrate a positive financial return for mid-rise MURBs, except in Calgary (due to the low price of natural gas).
- For the retail archetype, the benefit of fuel switching is currently very poor across all regions due to the high incremental costs of the equipment. Even in Montreal, where the cost of electricity is relatively low, the performance of GSHPs in the retail case is over \$300/$tCO_2e$. Also, GSHPs result in increased emissions in both Halifax and Calgary (hence the carbon savings potential is not shown in Figure 18). This situation will reverse with the closure of coal-fired electricity generation facilities. As noted in Section 3.6, GSHP systems were not included in the retail ZCB archetype; they are only included here for comparison.

In general, fuel switching using GSHPs is recommended for most ZCBs, especially when heating and cooling loads can be balanced to minimize the number and cost of boreholes. For applications where heating or cooling heavily dominates the other, GSHPs may not be as appropriate. Instead, air-source heat pumps,[33] biomass, or a combination of various fuel switching approaches may be more appropriate.

[32] The Canada Green Building Council's A Roadmap for Retrofits in Canada: Charting a Path Forward for Large Buildings report (2017) indicated that electricity grids would be clean enough to justify using air-source heat pumps by 2027 (see page 18). GSHPs are approximately twice as efficient as air-source heat pumps and will therefore reduce emissions in provinces with dirty grids within the next few years. Available at https://www.cagbc.org/CAGBC/Advocacy/A_Roadmap_for_Retrofits_in_Canada.aspx.

[33] Air-source heat pumps (ASHP) can often meet heating demand in office buildings and offer advantages such as low-cost and ease of retrofit.

## RENEWABLE ELECTRICITY - PV

PV shows excellent performance in almost all scenarios studied, due to the low (and falling) cost of the technology and the fact that it reduces the most expensive form of energy – grid electricity. For the retail archetype, and likely for most other low-rise archetypes, ZCB can be achieved using only PV, assuming there are no regulatory constraints to the amount installed.

The life-cycle abatement cost, however, shows significant variation based on location due to the differences in average and marginal carbon emissions intensities of the electricity grids (Figure 19). As discussed in Section 3.4, in alignment with the CaGBC ZCB framework, different credit is given to electricity generated by PV based on the portion used onsite (credited at average carbon intensity of grid) and the portion exported (credited at marginal carbon intensity of grid).

For Calgary and Halifax, where electricity has higher average and marginal emissions than natural gas, the benefit of PV is clear and should be maximized wherever possible. Life-cycle returns for the communities of Toronto and Ottawa are also positive and are aided by high electricity grid prices.

In low-carbon electricity grids, reducing electricity demand does not significantly impact total carbon emissions, and therefore PV is not a cost-effective ($/tonne $CO_2e$) measure unless the system can be made large enough to provide significant exported power. The mid-rise office archetypes in Vancouver and Montreal illustrate this point, increasing life-cycle costs as shown in Figure 19. On the other hand, where space allows for more PV and greater net-export of power (such as in low-rise building archetypes), PV becomes the most beneficial measure based purely on life-cycle cost per tonne, since exported power is credited at marginal grid carbon intensity rates.

This result is particularly important for low-rise building archetypes. Instead of sizing the amount of PV to achieve ZCB, it would be financially advantageous to install more PV and export additional electricity. However, this approach is only feasible where net-export arrangements with a local utility provider and the associated provincial regulation and energy regulator permit it. The business case for PV would also be strengthened if the price of electricity were regulated to recognize the importance of reducing natural gas use for marginal (peak) power generation, such as through time-of-use pricing (discussed in Section 6).



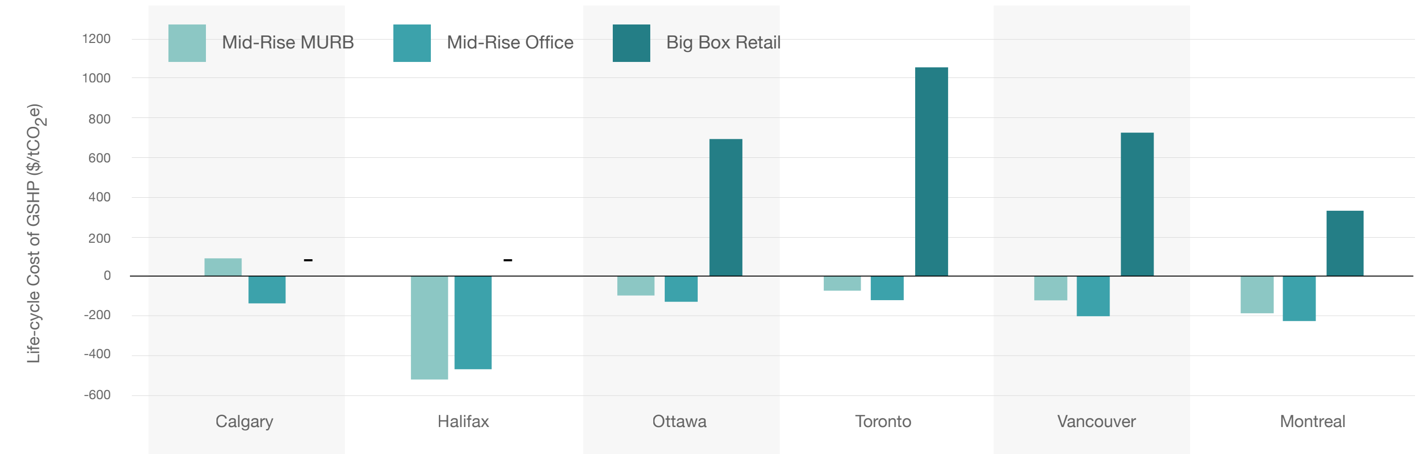



*Figure 18 – Life-cycle cost-effectiveness of GSHP as an individual measure*

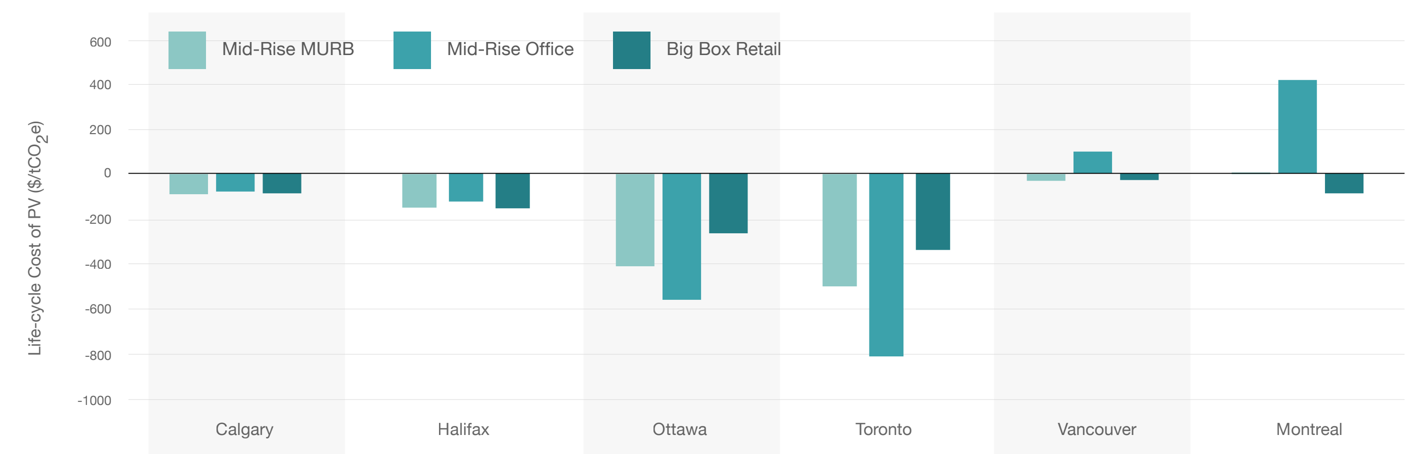
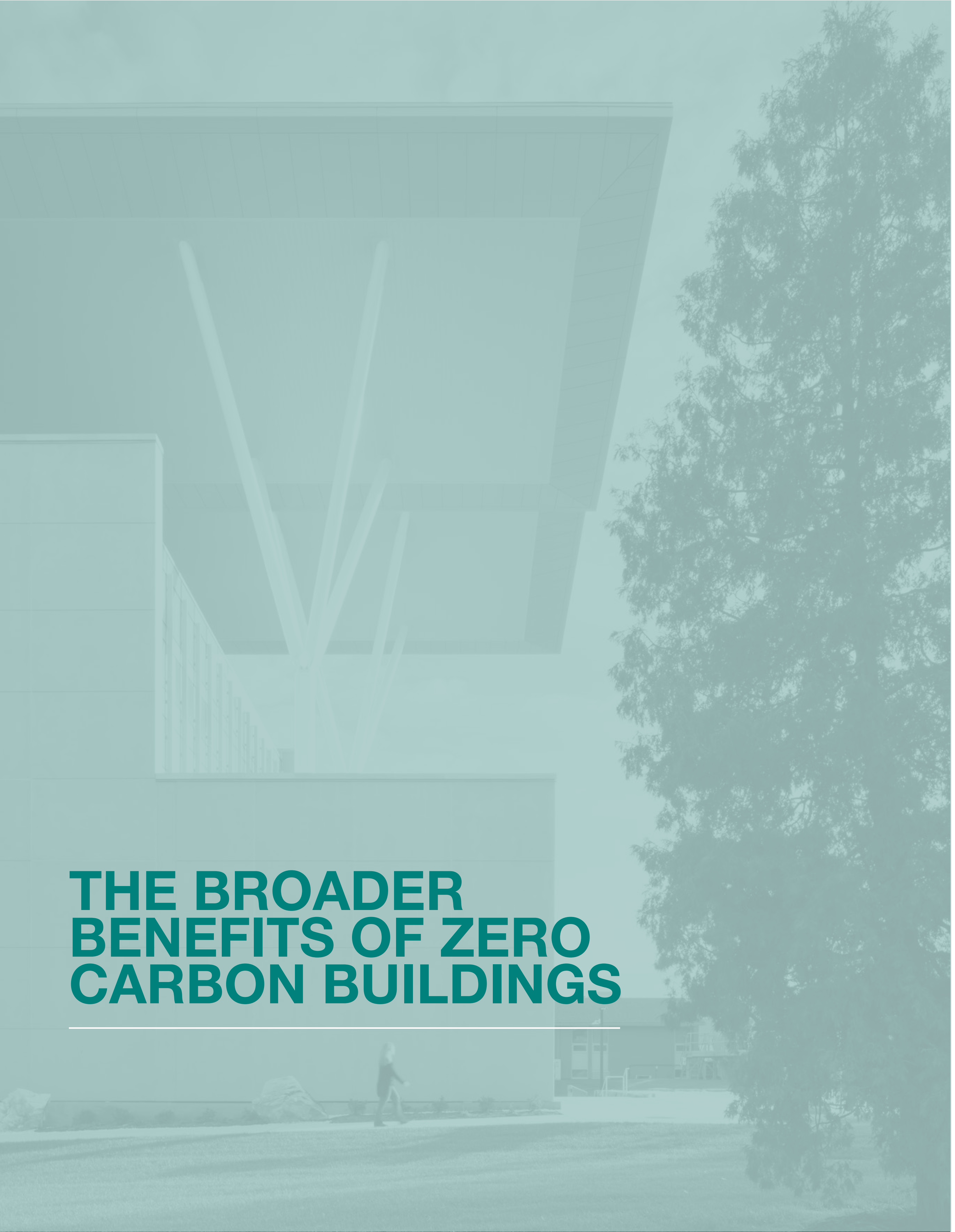



*Figure 19 – Life-cycle cost-effectiveness of PV*



# THE BROADER BENEFITS OF ZERO CARBON BUILDINGS



# 5.0 THE BROADER BENEFITS OF ZERO CARBON BUILDINGS

## 5.1 THE AVOIDED COSTS OF BUILDING TO ZERO CARBON

Implementing carbon reduction measures supports avoided costs that confer additional financial benefits that were not incorporated into the financial assessment for this study but are relevant for decision making. These avoided costs are discussed below.

### Expensive Retrofits

Buildings designed today will likely still be in operation in 2050, by which time they will have to be operating as ZCBs to meet the latest recommendations from the United Nations' IPCC. Buildings that are not designed to be zero carbon will require costly retrofits in the future. These retrofits are likely to be disruptive, resulting in the displacement of occupants and lost rent; or, in the case of owner-occupied buildings, additional costs for moving and temporarily accommodating staff elsewhere. Furthermore, retrofits will likely need to occur before the normal 25 to 40-year cycle of re-investment in major equipment and building upgrades.

A full life-cycle analysis should therefore account for the future retrofits required to achieve zero carbon. Additionally, measures to reduce the cost and disruption of future retrofits will need to be considered, such as minimizing rooftop equipment to maximize future PV potential, or designing HVAC systems for lower operating temperatures typical of heat pump systems. It is especially important that the measures that are most challenging to justify or implement as retrofits, such as improved building envelopes, be incorporated at the design stage.

### Reduced Service Life

The bundle analysis demonstrated that some enclosure, heating/cooling delivery and fuel-switching measures that contribute significantly to carbon reductions are not always the most cost-effective improvements. However, a hidden benefit of these improvements is that the measures have a service life that is much longer than the 25-year study period. For example, the following service life assumptions are common:

- Window frames: >50 years
- Additional wall insulation: >50 years
- Pipes and ductwork: >50 years
- Geo-exchange well field: >60 years

Although the residual value of many of these improvements has been included in the life-cycle cost calculations, there would be even greater financial benefit if the energy cost savings were considered over the full-life of the building.

### Maintenance Costs

Carbon reduction measures with longer service lives typically have lower (or zero) ongoing maintenance requirements (e.g., insulation). Due to the limitations of the study, it was assumed that the operating cost differences of all the measures would be negligible. However, this assumption may not be valid for longer-life measures. These "hidden" operating cost savings have an important economic benefit that should be quantified in future work.

### Asset Future Value Impairment

There is the potential that the cost of carbon emissions will be higher than assumed in this study. It is also possible that the price for electricity and natural gas will rise faster than anticipated. ZCBs can help insulate owners and operators from future energy and carbon costs.

## 5.2 SOCIETAL AND OTHER BENEFITS

In addition to the economic reasons for taking sector-wide zero carbon action now, there are additional societal and owner-operator benefits.

### Electricity Grid Benefits

Although not a core focus for the study, ZCBs do contribute to enhancing the electricity grid by helping to reduce future peak and overall electricity demand. The potential peak demand reductions for ZCBs are outlined in Table 3. By reducing the need for additional grid-based electricity, future capital, operating and maintenance costs for the grid are decreased; the customer base and floor area served by an existing electrical grid is permitted to increase; and new sources of electricity demand, such as electric vehicles, can more easily be accomodated. Reducing peak electricity demand also helps reduce the carbon emissions associated with electricity generation, as the facilities used to respond to peak electricity demand are typically more carbon intensive, such as natural gas-fired generating stations.

Seasonal differences in peak electricity demand (i.e., summer for cooling and winter for heating) are also greatly diminished with ZCBs. By increasing ZCB, the value of existing power generation and distribution infrastructure is maximized, and costs are reduced. That is, it is more cost effective to operate facilities year-round than to have them sit idle for parts of the year.

### Decarbonizing the Electricity Grid

Reducing peak electricity demand and seasonal differences contributes to decarbonizing the electricity grid. Carbon reduction measures such as controls-based demand response and energy storage (e.g., thermal storage) also contribute more directly towards efforts to decarbonize the electricity grid. Finally, green electricity produced through onsite generation further aids in the decarbonization of the electricity grid, especially when paired with energy storage.

### Resilience

The building industry recognizes the importance of ensuring that buildings are resilient in the face of climate change. Resilient buildings are designed to better adapt to, and bounce back from, sudden shocks and chronic stresses such as more frequent and longer-lasting power outages, as well as more frequent extreme weather events. Back-up power is an example of resilient design. Carbon reduction measures such as low-powered systems and onsite green power generation reduce the size of back-up equipment and the size of fuel reserves, although larger systems may be needed when electricity is used for heating. Better building envelopes are also a carbon reduction measure that enhances resiliency, directly impacting passive survivability[35] and the ability to cope with extreme weather-related events.

*Table 3 – Demand reduction potential of archetypes*[34]

| Archetypes | Baseline | | Zero Carbon Design | | % Change | |
|---|---|---|---|---|---|---|
| | Summer Peak (kW) | Winter Peak (kW) | Summer Peak (kW) | Winter Peak (kW) | Summer Peak (kW) | Winter Peak (kW) |
| Mid-Rise Office | 1969 | 1089 | 1164 | 960 | -41% | -12% |
| Low-Rise Office | 228 | 116 | 131 | 131 | -43% | 13% |
| Mid-Rise MURB | 210 | 101 | 94 | 151 | -55% | 49% |
| Low-Rise MURB | 67 | 32 | 47 | 47 | -31% | 45% |
| Primary School | 292 | 134 | 133 | 126 | -54% | -6% |
| Big Box Retail | 91 | 49 | 84 | 84 | -7% | 71% |
| Warehouse | 96 | 49 | 47 | 145 | -50% | 193% |

[34] Results reflect archetypes before PV is considered; PV would further reduce peak demand. Retail and warehouse results reflect the implementation of carbon reduction measures.

[35] Passive survivability refers to the building's ability to maintain critical life-support conditions in the event of extended loss of power, heating fuel, or water.



### Occupant Comfort, Health and Wellbeing

Many of the strategies used to reduce carbon and improve resilience have the additional benefit of enhancing occupant comfort, health and wellbeing. A few examples include:

- Better building envelopes eliminate cold surfaces and drafts, reduce discomfort from higher heating and cooling demands, and provide views and daylighting while reducing glare and hot spots caused by thermal gain. They also ensure there are no health issues associated with moisture intrusion.
- Better distribution of heating and cooling reduces temperature differences from one area to another. Air is provided at a lower velocity and at a temperature closer to that of the ambient air.
- Ventilation systems provide adequate fresh air to all spaces, and enhanced controls adjust to fluctuating occupancy rates to maintain temperature and air quality.

While many carbon reduction measures inherently improve occupant comfort, health and wellbeing, designers must be vigilant. A more air-tight design, without adequate fresh air supply and proper distribution, may improve energy efficiency but will decrease occupant comfort and productivity, and possibly cause health issues. Occupants may also respond to design failures by taking steps that counter the intent of the design features, such as by running heaters or fans, or opening windows and doors.

# KEY CONSIDERATIONS



## 6.0 KEY CONSIDERATIONS

There are immediate opportunities for building owner-operators and policy decision-makers to benefit from undertaking Zero Carbon Building (ZCB) development and to support the development of a ZCB marketplace through effective policy, programs and incentives.

Implementing carbon reduction measures brings numerous financial benefits

## 6.1 OWNER-OPERATORS

Those who own and operate their buildings are in a unique position to demonstrate leadership to the rest of the industry, de-risk ZCB construction, accelerate the industry and normalize the processes and technologies required to build ZCBs. The business case for building owner-operators is strong, as they often pay both capital and operating costs over the entire life-cycle, and they are likely to have carbon reduction targets and commitments for their organizations. To unlock the value of ZCBs, owner-operators are encouraged to move on the following recommendations.

1. **Evaluate ZCB options to maximize carbon reductions and associated carbon costs today.**

   As buildings built to lower standards will require retrofits before 2050 to achieve zero carbon, consider using life-cycle costing as a tool to make decisions early in the development cycle. Account for the fact that buildings built below ZCB standards will be exposed to the risk of escalating carbon pollution pricing. Evaluations should also incorporate the lower maintenance costs and longer service life of some carbon reduction measures. Use the insights from this study to inform studies for building projects and to frame the potential carbon savings and financial costs within broader climate change reduction goals and business constraints.

2. **Use existing energy efficiency incentives provided by governments and local utilities to achieve a ZCB design.**

   There are a wide range of incentives and capital improvement grant opportunities to draw on to advance the development of ZCBs. Inform governments and utilities that you are willing to go beyond code - even going carbon neutral now – with the support of incentives targeted at the uptake of effective carbon reduction measures.



3. **Challenge design teams to be innovative, find efficiencies, and ensure trades are familiar with the latest technologies and practices.**

   Follow an integrated design, construction and commissioning process to optimize carbon savings versus capital costs and deliver a building that achieves its targets during operation. The carbon reduction approaches and measures evaluated for this study were not optimized for each archetype and location. A lot more can be done by an engaged, client-supported design team when the integrated design process is properly leveraged, including early interaction with cost and construction experts.

   When evaluating a range of carbon reduction measures, there is a tendency to eliminate viable options because of higher upfront capital or simple pay back considerations. Owner-operators and design teams should carefully consider how they can bundle measures to optimize financial and carbon reduction outcomes, taking into consideration the interactions between measures. Owner operators should also seek to maximize opportunities for carbon reduction measures and the benefits of an integrated design approach. This should begin at the bid development and contracting stages. A starting point can include the requirement for a full life cycle costing assessment and adhering to CaGBC's Zero Carbon Building Standard.[36]

   Owner-operators can bolster the sustainability credentials and tenant attraction of their facilities by pursing ZCB and promoting the non-financial benefits of ZCBs, such as improved occupant comfort and increased resiliency. By investing in ZCB, a strong leadership signal is sent to other owner-operators concerning the opportunity and capacity to internalize ZCB as business as usual.

   The performance of ZCBs is enhanced when trades and other members of the construction workforce have received training and have gained experience with carbon reduction measures.[37] Trades and professionals must work to stay current with the technologies and solutions available in the growing low-carbon building industry. A few interesting examples include:

   - Fibreglass window frames that can replace traditional aluminum curtainwall construction.
   - VRF systems that allow for water-based delivery of heating and cooling to zones instead of refrigerant, allowing trades to take a more typical installation approach and reduce the risk associated with refrigerant leakage.
   - Alternate geo-exchange piping configurations, drilling angles and technologies (such as standing column wells) that improve the number and efficiency of boreholes and reduce drilling costs.

[36] CaGBC's Zero Carbon Building Standard is available at https://www.cagbc.org/zerocarbon.
[37] Trading Up: Equipping Ontario Trades with the Skills of the Future. Canada Green Building Council. 2019. Available at https://www.cagbc.org/TradingUp.

## 6.2 POLICY DECISION MAKERS

The establishment of a robust ZCB marketplace can be accelerated by a range of pricing mechanisms, procurement and partnership models, and regulations. To unlock the value of ZCBs, government policy-makers are encouraged to move on the following recommendations.

1. **Continue to incrementally raise the price for carbon pollution to achieve alignment with the IPCC target of carbon neutrality by 2050.**

   The increasing cost of energy (electricity and natural gas) and the use of carbon pollution pricing is supporting the transition of the marketplace to ZCB. The uptake of ZCB can be accelerated by ensuring all stakeholders pay the full and actual costs for carbon pollution. An incrementally rising cost on carbon causes conventional fossil fuel sources used for electricity and heating to gradually rise in cost based on their direct environmental impact. The result is that carbon reduction measures, such as those evaluated for this study, become even more cost-effective. While most (62%) of the ZCB archetypes evaluated were cost effective with an escalating carbon pollution price that averaged $150/tonne over the coming 25 years, a higher average cost would be required for all ZCB archetypes to be cost effective across all of the communities studied today.[38] An increasing cost on carbon pollution is a critical measure for advancing the market change required to see wide-spread adoption of ZCB across Canada and for attaining Canada's GHG goals.

2. **Support time of use pricing for electricity, the use of renewable energy generation and storage, and net-metering.**

   Changes in pricing regimes are very influential in electricity markets, especially as it relates to energy conservation and carbon reduction efforts. For example, if the commercial and mid-rise residential archetypes evaluated in this study were subject to time-of-use pricing (as low-rise residential buildings in Ontario are), building owner-operators could use demand reduction and demand response actions to achieve significant reductions in the cost of electricity, which would greatly support the uptake and viability of ZCBs by improving the financial performance of some fuel-switching and onsite generation measures.

[38] Note that the average cost of carbon for future 25-year life-cycle cost studies will rise over time, as the starting (initial) cost will be higher. For example, the initial cost of carbon for a life-cycle cost study initiated in 2025 will be higher, increasing the average carbon cost over the subsequent 25 years.



   The use of distributed renewable energy generation, such as PV, and energy storage at the building level is expanding a decentralized and interconnected electrical distribution system. Allowing for net metering would provide building owner-operators increased opportunities to integrate renewable energy generation and energy storage technologies to achieve ZCBs. Net-metered renewable energy systems can contribute to reducing peak electricity demand and defer or avoid the need for investments in certain costly upgrades to generation and distribution infrastructure.

3. **Incentivize capital based on carbon reduction potential**

   Due to capital costs accruing to the owners/developers and energy cost savings to the tenant, referred to as the split incentive, there is a market barrier to considering the long-term benefit of carbon reductions. To address this, private investment can be incented by making ZCBs a new capital cost allowance class with an accelerated depreciation rate. This would allow owners to mitigate the capital cost premiums associated with ZCBs and support government efforts to reduce carbon emissions. Creating this new capital cost allowance class is an opportunity to direct the investment of capital to building projects that achieve carbon reductions.

4. **Demonstrate leadership through public building portfolios**

   Governments are encouraged to demonstrate leadership by making it policy that any new buildings be constructed and operated as ZCBs. Federal, provincial, and municipal governments and their agencies own significant portfolios that can be levered to demonstrate the business case for ZCBs. This should also extend to buildings leased by government. In addition, federal-provincial infrastructure agreements should make ZCB a key criterion for social infrastructure projects (e.g., affordable and social housing, education and training institutions, and healthcare facilities) funded under these bi-lateral agreements, including agreeing to fully fund any capital cost premium associated with ZCB.

5. **Move the market to zero carbon and provide training to accomplish it**

   Governments across Canada are introducing updated performance-based building codes that are placing increased emphasis on energy efficiency and the opportunity for renewable energy. As more stringent building codes are introduced, the most cost-effective measures for energy efficiency and carbon reduction will become business as usual. This will decrease the incremental capital costs required to achieve ZCBs, but it will also decrease the energy savings available and therefore make it harder to justify the needed investments. To address this, more progressive and targeted incentives and financing mechanisms that adapt to evolving building codes will be required.

   A wide range of skills and capabilities are necessary for trades and other members of the construction workforce to implement ZCBs. As codes and standards continue to evolve and new carbon reduction technologies and measures become business as usual, trades and other construction professions will require a range of options to ensure that they are equipped with the latest skills and knowledge. Governments will need to invest in green building training, education and apprenticeship programs that target low-carbon skills for tradespeople.[39]

[39] Trading Up: Equipping Ontario Trades with the Skills of the Future. Canada Green Building Council. 2019. Available at https://www.cagbc.org/TradingUp.




# 7.0 CONCLUSION

The need for climate action is growing. In its recent report on limiting global temperature rise to 1.5°C, the United Nations' IPCC called for 50% GHG emissions reduction by 2030 and 100% reduction by 2050. This study found that by 2030, more than 4 Mt of $CO_2$-equivalent emissions per year could be avoided cost-effectively if the building types studied are built to be ZCBs. This represents more than 22% of the 20 Mt of GHG reductions that the Pan-Canadian Framework recognizes as potential savings from the buildings sector. By 2050, over 12 Mt $CO_2e$/yr could be avoided.

The study demonstrates that ZCBs are not only technologically feasible using readily available technologies and practices, they are financially viable too. On average, ZCBs can be achieved with a positive financial return of 1% over a 25-year life-cycle, inclusive of carbon pollution pricing, and require a modest 8% capital cost premium. As the cost of carbon rises over time, the financial return from ZCBs will improve.

The cost of not adopting a ZCB approach increases with each passing day. Every building built today that is not designed to achieve near-zero carbon emissions is only contributing to a continued increase in carbon emissions. Buildings not built to be ZCBs will require major investments in retrofits of mechanical equipment, ventilation systems and building envelopes (walls, roofs and windows) by 2050 to meet Canada's GHG reduction targets. These retrofits will be costly and disruptive to building owner-operators and tenants, and will need to occur before the normal 25 to 40-year cycle of re-investment in major equipment and building upgrades.

Working together, Canada's building owner-operators, their design teams, and governments at every level can demonstrate leadership in proving the economic case for ZCBs and normalizing the processes and technologies that will make ZCBs the Canadian industry standard for value and resilience.




# GLOSSARY

**Archetype:** A building incorporating a number of specific characteristics such as building type/use, total floor area, number of storeys, and window-to-wall ratio.

**Average grid emissions factor:** The average global warming potential associated with electricity use in a unique electricity grid. See Appendix A-3 for more discussion.

**Baseline:** This study uses the National Energy Code of Canada for Buildings (NECB-2011) as its baseline. Performance of the various measures are related against the baseline model.

**Biomass:** As used in this study, biomass is assumed to be a wood pellet fuel meeting the requirements of the Zero Carbon Buildings Standard as a renewable energy source.

**CaGBC:** Canada Green Building Council.

**Carbon Neutral:** see Zero Carbon Building.

**Carbon pricing:** A method used to reduce GHG emissions by pricing pollution through a fee for the right to emit one tonne of CO2 into the atmosphere.

**Central plant:** Centrally-located equipment used to provide heating and cooling services to HVAC equipment throughout the facility.

**$CO_2$ equivalent ($CO_2e$):** Atmospheric impact of a greenhouse gas expressed in terms of equivalent carbon dioxide emissions, over a period.

**Condensing boiler:** Allows for additional heat from flue gases if return water temperature is sufficiently low.

**Core areas:** Central parts of the building with minimal enclosure-driven load.

**Dedicated Outdoor Air System (DOAS):** An HVAC system primarily used to deliver ventilation requirements to occupied spaces in a building, partly or wholly independent of the thermal conditioning requirements of those spaces.

**Demand control ventilation (DCV):** Delivery of outdoor air to an occupied space is adjusted based on actual demand, which can be determined using a combination of pre-programmed schedules, $CO_2$ sensors, occupancy sensors, or other means.

**Demand response:** A means of controlling building loads (typically electricity) centrally, in order to manage impact on the broader network (i.e. the grid).

**Displacement Delivery:** Low and slow supply of ventilation air at the floor, with exhaust from above.

**Double/Triple-Glazed:** Window insulated glazing units with two/three panes of glass.

**ECM:** Energy conservation measure.

**Electricity demand:** In any given moment, the amount of electric power needed. Demand is contrasted with consumption, which is the sum of all electricity used in each moment over time. Demand determines the size of the equipment needed to serve the facility and consumption determines the amount of energy needed.

**Energy Recovery Ventilator (ERV):** HVAC equipment that transfers sensible and/or latent energy from exhaust streams leaving occupied spaces to ventilation air being delivered to occupied spaces.

**Energy Use Intensity (EUI):** The total operational energy use, including all heating, cooling, ventilation, lighting, plug and process loads. It is typically reported in kWh/m$^2$.

**GHG:** Greenhouse gas.

**Green power:** Electricity generated from renewable resources, such as solar, wind, geothermal, low-impact biomass, and low-impact hydro resources. Green power is a subset of renewable energy that does not include renewable energy systems that do not produce electricity, such as solar thermal systems. "Green power" is synonymous with "renewable low-impact electricity", a term used within the CCD-003 Renewable Low-Impact Electricity Products standard from EcoLogo.

**Greenhouse Gas Intensity (GHGI):** The total greenhouse gas emissions associated with all energy use on the building site on a per area basis. It is reported in grams of CO2-equivalent per square meter (g$CO_2$e/m$^2$) and includes emissions associated with provincial electricity generation.

**Incremental Capital Cost Per Square Meter (ICC/m²):** The increase or decrease in the cost of construction per square meter, in this study the baseline is NECB-2011 and the increment is for achieving a Zero Carbon Building.

**Incremental Capital Cost Per Tonne CO2-equivalent Saved (ICC/tCO2e):** The increase or decrease in the cost of construction per tonne of CO2-equivalent saved for achieving zero carbon, relative to the NECB-2011 baseline.

**Incremental Life-cycle Cost Per Square Meter (ILCC/m²):** The net present value (NPV) of increase or decrease in total costs per square meter for construction, operation and maintenance over 25 years for achieving zero carbon, relative to the NECB-2011 baseline.

**Incremental Life-cycle Cost Per Tonne CO2-equivalent Saved (ILCC/tCO2e):** The NPV of increase or decrease in total costs per tonne of CO2-equivalent saved for construction, operation and maintenance over 25 years for achieving zero carbon, relative to the NECB-2011 baseline.

**IPCC:** Intergovernmental Panel on Climate Change.

**Lighting power (density) target:** The amount of lighting energy (per square meter) that should be achieved by a given lighting design in order to achieve a desired energy performance. The target is typically for the installed capacity of lighting which is then further modified by the benefit of controls.

**Low-e window coating:** Low emissivity window coatings reflect heat (infra-red radiation) well, but allow other types of radiation from the sun through more easily (e.g. visible light).

**Low-exergy:** The exergy of a system is the work that can be done between the current state and the dead or ambient state. In building systems, low-exergy is preferable; where the temperature of the water circulated for the purpose of heating is closer to room temperature.

**Marginal (peak) emissions factor / Marginal (peak) grid emissions:** Marginal emissions/factor reflect the GHG emissions from the generation source turned on last by the grid operator – the source that would not be required if sufficient further reduction in electricity demand was possible at peak times. See further discussion in section 3.3 of the report and in Appendix A-3.

**MURB:** Multi-unit residential building.

**NECB:** National Energy Code of Canada for Buildings. In this report, any reference to the NECB refers to the 2011 version.



**Net metering:** A system in which solar panels or other renewable energy generators are connected to a public-utility power grid and surplus power is transferred onto the grid, allowing customers to offset the cost of power drawn from the utility.

**Net-zero GHG Emissions:** see Zero Carbon.

**Part-load:** Any fraction less than full load. Designers select equipment at full load conditions to address the harshest conditions the equipment needs to serve.

**Peak demand:** The highest electrical load required by a building or by an electrical grid in a year. Peak demand for buildings is measured and reported in kW. In the report two building peak demands are discussed – one for the winter season and one for the summer season. Typically, peak demand for the electrical grid occurs in summer. Peak demand for a building will depend on the energy source used for heating and other factors.

**Renewable energy:** A source of energy that is replenished through natural process or using sustainable management policies such that it is not depleted at current levels of consumption. Air-source and ground-source (geothermal) heat pump systems do not constitute renewable energy.

**Renewable Energy Certificate (REC):** An authorized electronic or paper representation of the environmental attributes associated with the generation of 1 MWh of renewable energy.

**R-Value:** A measure of thermal resistance, defined as the amount of energy lost per unit area at a given temperature difference. R-value is reported in (ft$^2$-°F-hr/Btu).

**R-value nominal:** The R-value based on installed amount of insulation, but not considering thermal bridging.

**R-value actual:** A systemic view of heat flow, especially when considering heat loss paths at intersections of systems (e.g. at joint between wall and roof deck).

**Solar Control:** Shading of the glass, either through blinds, shades or systems built into the window itself. Solar control is usually about reducing the suns influence on heating and cooling demands within the building.

**Solar gains:** Heat gains into a building from the sun that enters through the windows. These can help improve window heating performance but also impact cooling loads and associated equipment size. Solar heat gain coefficient (SHGC) is a measure of how well a window blocks heat from the sun, expressed as a fraction of the heat from the sun that enters the window.

**TGS v3:** Toronto Green Standard version 3.

**Thermal bridging:** The part of a wall/roof assembly that allows heat to flow more easily, bypassing the insulating layer. The best example of thermal bridging is the heat loss through window frames where they connect with the wall as compared to the loss through the glass or the wall below.

**Thermal break:** An assembly modification to limit or stop thermal bridging.

**Thermal Energy Demand Intensity (TEDI):** The annual heat loss from the building envelope and ventilation. When calculated with modelling software, this is the amount of heating energy delivered to the project that is outputted from any and all types of space and ventilation heating equipment, per unit of gross floor area. TEDI is reported in kWh/m$^2$/year.

**U-Value:** A measure of the thermal conductivity of a given material or enclosure assembly, which indicates how readily heat is transferred through it (U-value is the inverse of R-value).

**VAV:** Variable-air-volume, a typical cooling/ventilation system type in office buildings.

**Virtual net metring:** A billing arrangement that allows multiple homeowners or businesses to participate in the same net metered system and share the output from a single facility that is not physically connected to their property (or their meter). The electricity conveyed into the grid from the renewable energy project creates bill credits that can be used by one or more participating customers to offset charges on their electricity bills.

**Window-to-wall ratio (WWR):** The ratio of window area to wall area for a given facade or collection of facades (sides) of a building.

**Zero Carbon Building (ZCB):** A building demonstrating net zero carbon emissions in accordance with the CaGBC's Zero Carbon Building Standard. Zero emissions biofuel: Biogas or biomass fuels considered to be net-carbon neutral as the amount of carbon released by combustion approximately equates to the carbon that would have been released by natural decomposition processes.

# APPENDIX

**A detailed Appendix to this report can be accessed separately here or online at cagbc.org/MakingtheCase.**

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Every Building Greener
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