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# Simulation Study for Working Group-Costing: PCF1527 – Impact Analysis

Author(s): Edward Vuong, Mariana Barssoum, Iain Macdonald and  
Adam Wills

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# Simulation Study for Working Group- Costing: PCF1527 - Impact Analysis

Author

  
Edward Vuong, MASC

Approved

  
Alexandra J.L. Thompson, PhD  
High Performance Buildings  
NRC Construction Research Centre

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## Executive Summary

The Standing Committee on Energy Efficiency established the Working Group on Costing to evaluate the impact of adopting the proposed performance Tiers in the Proposed Change Form (PCF) 1527, “Tiered Energy Code for NECB”. The proposal introduces four Tiers of elevated building energy performance, relative to the National Energy Code of Canada for Buildings’ (NECB’s) minimum performance. In PCF 1527, the energy performance level of Tier 1 is equal to the enforced edition of the NECB, Tier 2 requires a 25% energy reduction relative to (or maximum 75% annual energy consumption of) the code, Tier 3 requires a 50% reduction, and Tier 4 specifies a 60% reduction. For this study, NECB 2017 (Codes Canada, 2017) was used as the baseline to evaluate the impact of the proposed changes.

An energy simulation study was undertaken to demonstrate the technical feasibility of these Tiers and estimate the associated cost impact. The Working Group on Costing is currently focussing on six archetype buildings in six locations (each location is a representative city for climate zones 4-8). An engineering approach was taken whereby the models were analyzed and the principle contributors to energy use were addressed (e.g. if heat loss through the envelope was dominating the energy consumption, then the wall insulation levels, window performance and air-tightness were improved and the efficacy of these changes evaluated). The simulation results show that all three Tiers of elevated energy performance are achievable using current technology (see Figure 1 to Figure 3).

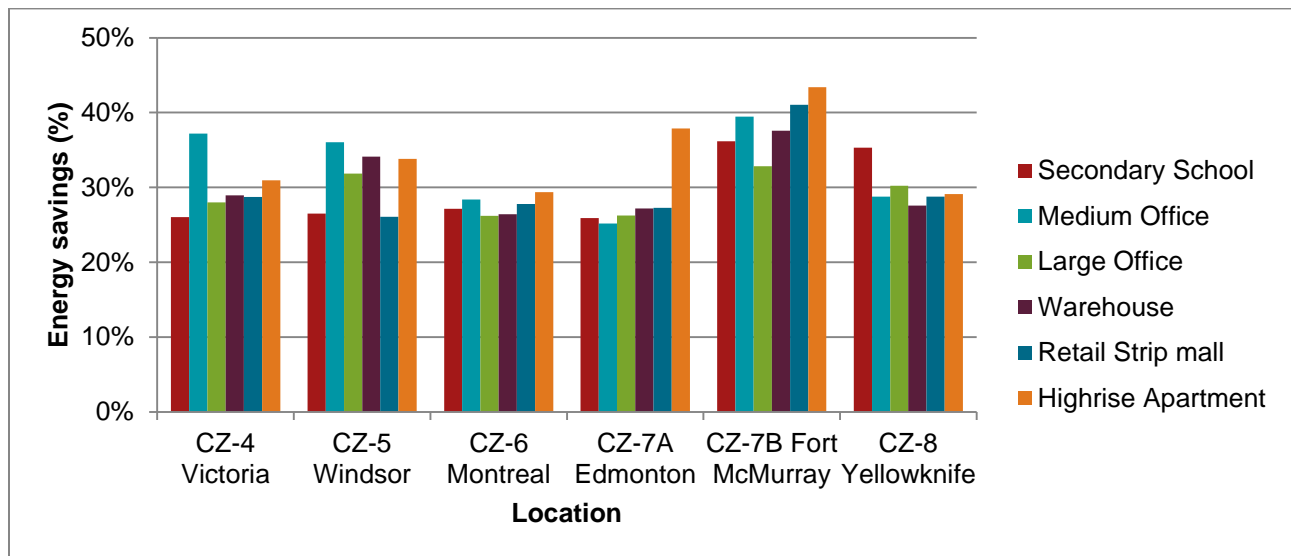


Figure 1. Tier 2 Compliant Archetype Energy Reductions.



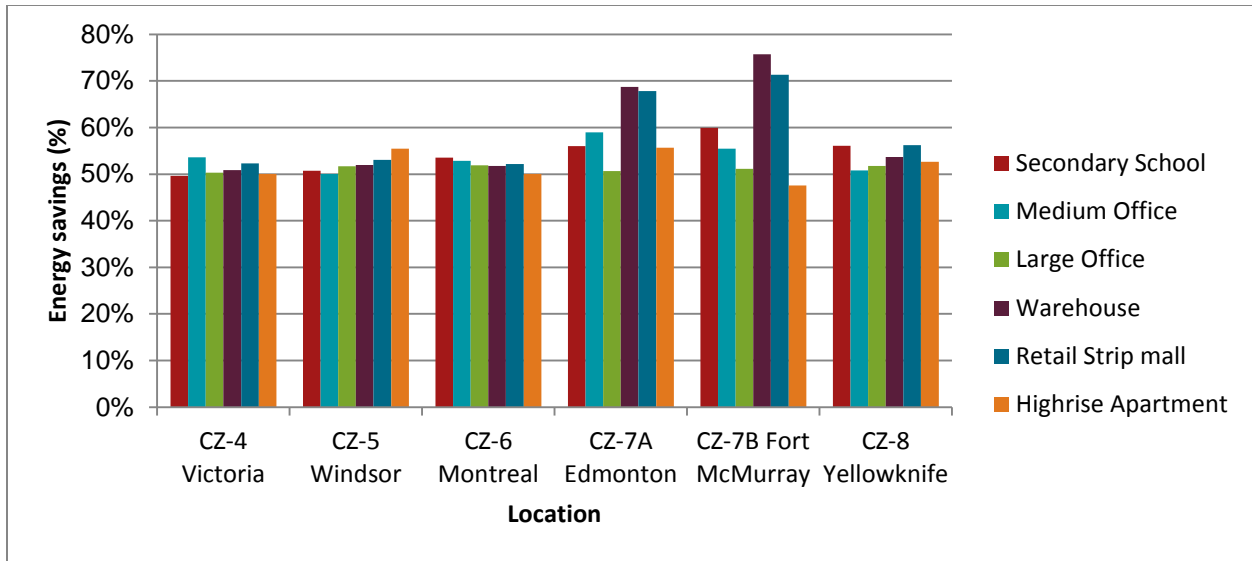


Figure 2. Tier 3 Compliant Archetype Energy Reductions.

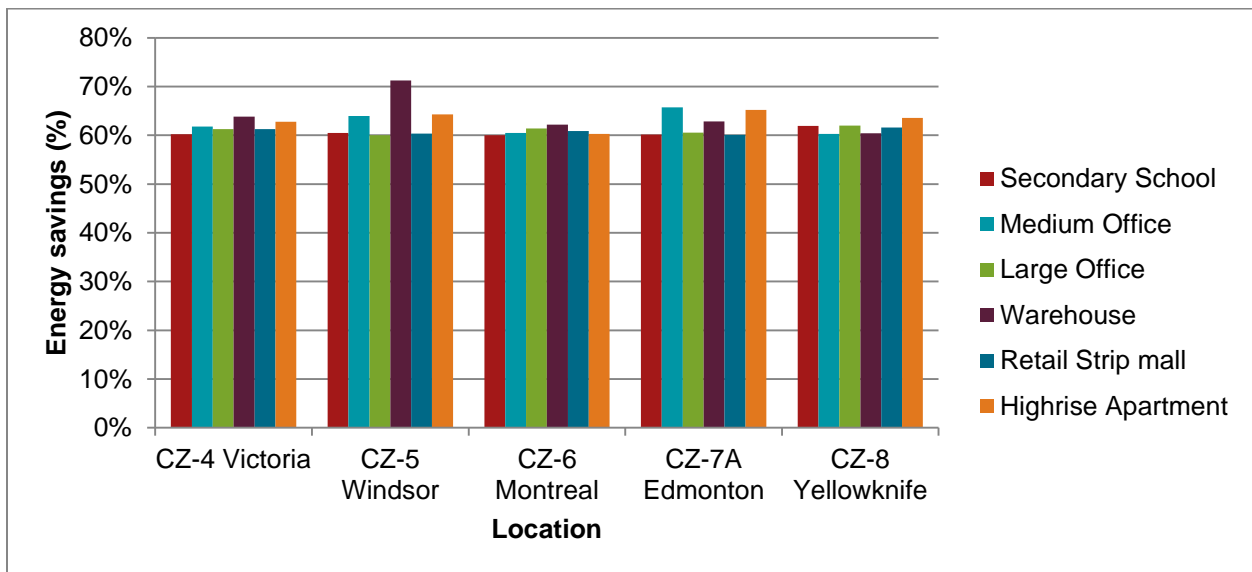


Figure 3. Tier 4 Compliant Archetype Energy Reductions.

Table 1 shows a comparison of two building archetypes’ expected total energy use intensity (TEUI), for several locations (climate zones 4-8), adhering to NECB 2017, the proposed Tier 4 target, and the ASHRAE design guide targets (ASHRAE, AIA, IES, USGBC, US-DOE, 2018, 2019). It can be seen that the PCF 1527’s proposed Tier 4 target generally results in the archetypes to meet or exceed ASHRAE’s targets for net zero energy performance. This shows that although the NECB performance path is based on a relative performance criteria for demonstrating compliance (i.e. reference vs proposed), the resulting Tier 4 targets are in-line with industry best practice.

Table 1. Baseline NECB 2017 energy performance, Tier 4 target, and ASHRAE net zero design target TEUI.

Archetype	Performance level	TEUI (kWh/m <sup>2</sup> )
Secondary School	NECB 2017 (Baseline)	115-198
	Tier 4 target (60% reduction from NECB 2017)	46-79
	ASHRAE net zero energy design guide target	55-75
Medium Office	NECB 2017 (Baseline)	122-146
	Tier 4 target (60% reduction from NECB 2017)	49-58
	ASHRAE net zero energy design guide target	55-114

The costing analysis was sub-contracted to a cost consultant (Hanscomb Quantity Surveyors). The total costs of each archetype in each location only comprise of the envelope and HVAC cost components (labour, equipment, material, subcontractor overhead, profit). The total costs (per area basis) for Tier 2 and 3 for Edmonton are shown in Table 2 (Tier 4 is only shown for comparative purposes); costs of Tiered archetypes that are lower than NECB 2017 costs are bolded. To calculate the normalized costs for the other locations in Tier 2 and 3, the location cost factors presented in Table 3 can be used. Note that since each archetype/location has a unique set of energy conservation measures applied, applying these factors onto the Tier 2/3 costs in Table 2 will only provide an estimated cost of the same particular Edmonton building in the other locations. However, the estimate obtained can still be used to infer the magnitude of cost for the archetype in general to reach Tier 2 or Tier 3 in other location. For Tier 4, five locations were fully costed and the results presented in Table 4.

Table 2. Baseline, Tier 2, 3 and 4 Envelope and HVAC Costs Normalised by Floor Area (\$/m<sup>2</sup>) - Edmonton.

Archetype	NECB 2017	Tier 2	Tier 3	Tier 4
<b>Secondary School</b>	\$758	\$841	\$816	\$816
<b>Medium Office</b>	\$929	<b>\$877</b>	<b>\$764</b>	<b>\$755</b>
<b>Large Office</b>	\$555	<b>\$530</b>	<b>\$460</b>	<b>\$502</b>
<b>Warehouse</b>	\$1,104	\$1,161	\$1,152	\$1,156
<b>Retail Strip mall</b>	\$1,240	\$1,292	\$1,256	\$1,310
<b>Highrise MURB</b>	\$649	\$667	\$683	\$685

Table 3. Location Cost Factors (for Tiers 2 and 3 only).

Location	Cost Factor
Victoria	105
Windsor	98
Edmonton	100
Yellowknife	115
Montreal	97

Table 4. Tier 4 Envelope and HVAC Costs Normalised by Floor Area (\$/m<sup>2</sup>) – 5 locations.

Building	Victoria	Windsor	Montreal	Edmonton	Yellowknife
Secondary School	\$767	\$775	\$763	\$816	\$936
Medium Office	<b>\$738</b>	<b>\$731</b>	<b>\$694</b>	<b>\$755</b>	<b>\$902</b>
Large Office	<b>\$450</b>	<b>\$446</b>	<b>\$495</b>	<b>\$502</b>	<b>\$560</b>
Warehouse	\$1,076	\$1,158	\$1,057	\$1,156	\$1,366
Retail Strip mall	\$1,235	\$1,177	\$1,188	\$1,310	<b>\$1,462</b>
Highrise MURB	\$661	\$633	\$594	\$685	<b>\$726</b>

The results show some archetypes (Medium and Large Offices) have a lower cost at higher Tiers compared to NECB 2017; the total envelope and HVAC costs of these archetypes are bolded in Table 4. This is attributed to the decrease in fenestration area (reduced window-wall ratios; no skylights) and reduced HVAC capacities (more efficient envelope and mechanical equipment reduces heating/cooling capacities and air flows). A more comprehensive and detailed analysis will be required to fully understand these differences. These results are consistent with other studies, e.g. CaGBC's (Canada Green Building Council, 2019), where the increased costs for some components are offset with significant reductions elsewhere.

From previous cost analyses for codes adoption (e.g. British Columbia Step Code), it should be noted that multiple solutions exist for each performance Tier, each with a unique cost (Energy Step Code Council and BC Housing, 2017). Thus, there may be less expensive solutions and more expensive solutions to achieve the Tier targets than presented. Future work should investigate alternative solutions and complete more detailed cost studies.

# 1 Introduction

The Standing Committee for Energy Efficiency (SC-EE) created the Working Group on Costing (WG-Costing) to develop the impact analysis for PCF 1527. This report gathers evidence to support the decision making of the WG-Costing and SC-EE. PCF 1527 proposes the inclusion of a Tiered Code system for the National Energy Code of Canada for Buildings (NECB); a total of four Tiers, are to be introduced and reflect different levels of building energy performance. Tier 1 will be the then current version of the NECB; Tier 2, 3, and 4 will require a 25%, 50%, and 60% energy reduction relative to the NECB (the baseline of this study). The WG-Costing identified a set of six NECB compliant archetypes located in six climate zones (CZs) to be used in the analysis. The analysis was conducted in two stages: 1) Identify solutions to the Tiers; 2) Quantify costs associated with the solutions. This report details the measures taken to achieve the Tiered targets and associated cost implications.

## 2 Objectives

Using the selected archetype models determine:

- 1) If the energy performance targets are achievable;
- 2) Identify costs associated with achieving the targets.

## 3 Methodology

To quantify the changes required and costs associated with building to higher performance levels across Canada, a set of six representative archetypes were selected in consultation with the WG-Costing. The archetypes were simulated using OpenStudio in six representative locations (one for each climate zone 4-8). This is a similar approach to previous impact analyses used to support code changes.

To manage the simulation process, the baseline archetypes were generated using the Building Technology Assessment Platform (BTAP), an add-on to OpenStudio. BTAP supports the automated generation of NECB 2017 compliant archetypes (BTAP, 2019). The energy performance of these models was first improved using a common set of energy conservation measures (ECMs or measures) based on expectations of technology improvements. The models were then independently refined using an iterative Hill-Climbing approach, i.e., the largest contributors to energy demand were targeted for improvement first. Solutions were thus generated for the three performance levels.

The ECMs applied in this study were selected from several sources:

- ASHRAE's Achieving Zero Energy Advanced Energy Design Guides (ASHRAE, AIA, IES, USGBC, & US-DOE, 2018, 2019)
- CaGBC's report on "Making the case for Building to Zero Carbon" (Canada Green Building Council, 2019), and
- the authors' experience/guidance from the WG-Costing;

Additional ECMs used in the study were developed as scripts by the authors.

Once solutions were found to each Tier, the associated costs of the archetypes were estimated by a third party cost consulting firm, Hanscomb Quantity Surveyors. The costs are an order of

magnitude estimate of achieving the energy performance Tiers; the costs reflect the envelope and HVAC components. The costing data was also compared to similar studies.

### 3.1 Simulations

Six archetypes (Secondary School, Medium Office, Large Office, Warehouse, Retail Strip mall, and Highrise) (BTAP, 2019) were simulated in six locations for each of the NECB CZs, shown in Table 5. These locations were also used for the cost estimates. Thus, for the energy analysis there are 36 data points for each Tier, excluding Tier 4 which only has 30 data points because the results for Fort McMurray were not obtained due to time constraints. However, this does not diminish the value of the analysis overall since the results for CZ-7A and CZ-8 bound CZ-7B; thus, both the feasibility and cost to reach Tier 4 can be inferred.

Table 5. Representative locations.

Climate Zone	4	5	6	7A	7B	8
Heating Degree Day Range	<3000	3000 to 3999	4000 to 4999	5000 to 5999	6000 to 6999	≥ 7000
Representative location	Victoria	Windsor	Montreal	Edmonton	Fort McMurray	Yellowknife
Location heating degree days	2650	3400	4400	5120	6250	8170

### 3.2 Energy Conservation Measures

Table 6 through Table 11 presents the ECMs, and its range of inputs, utilized in the study. The baseline (NECB 2017) parameters and systems are shown as a reference; the differences of the Tiers from the baseline input or components (e.g. level of insulation) are presented in bold. Certain ECMs were found to be effective for select archetypes but not for all; thus, the ECMs are grouped as follows,

Tier 2 ECMs applied to the

- Secondary School, Warehouse, and Retail Strip mall are presented in Table 6;
- Highrise MURB, Medium Office, and Large Office are presented in Table 7.

Similarly, for Tier 3, the ECMs are presented in the same manner in Table 8 and Table 9, respectively. Lastly, for Tier 4, the ECMS for the

- Secondary School, Warehouse, Highrise MURB and Retail Strip mall are presented in Table 10;
- Medium and Large Offices are presented in Table 11.

While these tables represent the ranges of values used in the study, it should be noted that each archetype/location (data point) in each Tier has a unique solution within the ranges given. A detailed set of ECMs applied onto the Edmonton Medium Office archetype is presented in Appendix A as an example. It should also be noted that detailed design was not carried out for wall/roof solutions – the study was only concerned with energy performance and did not consider other functions of the envelope (e.g., management of condensation risk or mould

index).

Table 6. Tier 2 Energy Conservation Measures for Secondary School, Warehouse, and Retail Strip mall.

Baseline Description	Tier 2 Description
<p>Envelope</p> <ul style="list-style-type: none"> <li>• Walls: R18 – R31</li> <li>• Roofs: R30 – R47</li> <li>• Windows: 2.1 – 1.4 (W/m<sup>2</sup>K)</li> <li>• FDWR (Fenestration, door, wall ratio): 0.4 – 0.2</li> <li>• Air Leakage: 1.45 L/sm<sup>2</sup> @ 75Pa</li> <li>• Shading: N/A</li> </ul>	<p>Envelope</p> <ul style="list-style-type: none"> <li>• <b>Walls: R19 – R32</b></li> <li>• <b>Roofs: R35 – R50</b></li> <li>• <b>Windows: 1.9 – 1.4 (W/m<sup>2</sup>K); skylights removed</b></li> <li>• <b>FDWR: 0.33 – 0.2</b></li> <li>• <b>Air Leakage: 0.725 -1.45 L/sm<sup>2</sup> @ 75Pa</b></li> <li>• <b>Shading: horizontal, 30% of window length</b></li> </ul>
<p>Air Handling Unit</p> <ul style="list-style-type: none"> <li>• Make up units (Const. Volume - CAV)</li> <li>• Single zone rooftop unit (CAV)</li> </ul> <p>Heating &amp; Cooling</p> <ul style="list-style-type: none"> <li>• Electric/gas heating</li> <li>• DX cooling</li> <li>• Baseboard heaters</li> <li>• Boilers (location specific) : ~83%-86%</li> <li>• Fans (30%-55% efficient)</li> <li>• Water pumps (80%-90% efficient)</li> </ul> <p>Service Water Heating</p> <ul style="list-style-type: none"> <li>• Water tank</li> </ul>	<p>Air Handling Unit</p> <ul style="list-style-type: none"> <li>• <b>Through wall DOAS-ERV (50%-70% efficient)</b></li> <li>• <b>Fan coil units (VAV)</b></li> </ul> <p>Heating &amp; Cooling</p> <ul style="list-style-type: none"> <li>• Electric/gas heating</li> <li>• DX cooling</li> <li>• Baseboard heaters</li> <li>• <b>Boiler: 88% efficient</b></li> <li>• <b>More efficient fans (up to 75% efficient)</b></li> <li>• Water pumps (80%-90% efficient)</li> </ul> <p>Service Water Heating</p> <ul style="list-style-type: none"> <li>• Water tank</li> </ul>
<p>Lighting</p> <ul style="list-style-type: none"> <li>• NECB 2017</li> </ul>	<p>Lighting</p> <ul style="list-style-type: none"> <li>• <b>Up to 30% reduction on NECB 2017 values</b></li> </ul>
<p>Electrical Equipment</p> <ul style="list-style-type: none"> <li>• NECB 2017 Table A-8.4.3.2.(1) and Table A-8.4.3.2.(2)</li> </ul>	<p>Electrical Equipment</p> <ul style="list-style-type: none"> <li>• <b>Up to 30% reduction on NECB 2017 values</b></li> </ul>

Table 7. Tier 2 Energy Conservation Measures for Highrise MURB, Medium Office, and Large Office.

Baseline Description	Tier 2 Description
Envelope <ul style="list-style-type: none"> <li>• Walls: R18 – R31</li> <li>• Roofs: R30 – R47</li> <li>• Windows: 2.1 – 1.4 (W/m<sup>2</sup>K)</li> <li>• FDWR (Fenestration, door, wall ratio): 0.4 – 0.2</li> <li>• Air Leakage: 1.45 L/sm<sup>2</sup> @ 75Pa</li> <li>• Shading: N/A</li> </ul>	Envelope <ul style="list-style-type: none"> <li>• <b>Walls: R20 – R32</b></li> <li>• <b>Roofs: R35 – R50</b></li> <li>• <b>Windows: 1.9 – 1.4 (W/m<sup>2</sup>K); skylights removed</b></li> <li>• <b>FDWR: 0.33 – 0.15</b></li> <li>• <b>Air Leakage: 0.725 -1.45 L/sm<sup>2</sup> @ 75Pa</b></li> <li>• <b>Shading: horizontal, 30% of window length</b></li> </ul>
Air Handling Unit <ul style="list-style-type: none"> <li>• Multizone VAV</li> <li>• Make up units (constant volume)</li> </ul> Heating & Cooling <ul style="list-style-type: none"> <li>• Electric/gas heating</li> <li>• Baseboard heaters</li> <li>• Boilers (location specific) : ~83%-86%</li> <li>• Fans (30%-55% efficient)</li> <li>• Chiller + Cooling Tower</li> <li>• Packaged air conditioners (Highrise only)</li> <li>• Water pumps (80%-90% efficient)</li> </ul> Service Water Heating <ul style="list-style-type: none"> <li>• Water tank</li> </ul>	Air Handling Unit <ul style="list-style-type: none"> <li>• Multizone VAV</li> <li>• <b>Fan coil units (VAV)</b></li> <li>• <b>Through wall DOAS-ERV (50%-70% efficient)</b></li> </ul> Heating & Cooling <ul style="list-style-type: none"> <li>• Electric/gas heating</li> <li>• Baseboard heaters</li> <li>• <b>Boiler: 88% efficient</b></li> <li>• <b>More efficient fans (up to 75%)</b></li> <li>• Chiller + Cooling Tower</li> <li>• <b>Packaged air conditioners removed</b></li> <li>• Water pumps (80%-90% efficient)</li> </ul> Service Water Heating <ul style="list-style-type: none"> <li>• Water tank</li> </ul>
Lighting <ul style="list-style-type: none"> <li>• NECB 2017</li> </ul>	Lighting <ul style="list-style-type: none"> <li>• <b>Up to 30% reduction on NECB 2017 values</b></li> </ul>
Electrical Equipment <ul style="list-style-type: none"> <li>• NECB 2017 Table A-8.4.3.2.(1) and Table A-8.4.3.2.(2)</li> </ul>	Electrical Equipment <ul style="list-style-type: none"> <li>• <b>Up to 30% reduction on NECB 2017 values</b></li> </ul>

Table 8. Tier 3 Energy Conservation Measures for Secondary School, Warehouse, and Retail Strip mall.

Baseline Description	Tier 3 Description
Envelope <ul style="list-style-type: none"> <li>Walls: R18 – R31</li> <li>Roofs: R30 – R47</li> <li>Windows: 2.1 – 1.4 (W/m<sup>2</sup>K)</li> <li>FDWR (Fenestration, door, wall ratio): 0.4 – 0.2</li> <li>Air Leakage: 1.45 L/sm<sup>2</sup> @ 75Pa</li> <li>Shading: N/A</li> </ul>	Envelope <ul style="list-style-type: none"> <li><b>Walls: R37 – R52</b></li> <li><b>Roofs: R45 – R48</b></li> <li><b>Windows: 0.7 (W/m<sup>2</sup>K); skylights removed</b></li> <li><b>FDWR: 0.26 - 0.08</b></li> <li><b>Air Leakage: 0.2 - 0.8 L/sm<sup>2</sup> @ 75Pa</b></li> <li><b>Shading: horizontal, 30% of window length</b></li> </ul>
Air Handling Unit <ul style="list-style-type: none"> <li>Make up units (Const. Volume - CAV)</li> <li>Single zone rooftop unit (CAV)</li> </ul> Heating & Cooling <ul style="list-style-type: none"> <li>Electric/gas heating</li> <li>DX cooling</li> <li>Baseboard heaters</li> <li>Boilers (location specific) : ~83%-86%</li> <li>Fans (30%-55% efficient)</li> <li>Water pumps (80%-90% efficient)</li> </ul> Service Water Heating <ul style="list-style-type: none"> <li>Water tank</li> </ul>	Air Handling Unit <ul style="list-style-type: none"> <li><b>Through wall DOAS-ERV (70%-90% efficient)</b></li> <li><b>Fan coil units (VAV)</b></li> </ul> Heating & Cooling <ul style="list-style-type: none"> <li>Electric/gas heating</li> <li><b>Baseboard heaters (eliminated in some)</b></li> <li><b>Boiler: 96% efficient</b></li> <li><b>More efficient fans (up to 75%)</b></li> <li><b>More efficient pumps (91%)</b></li> </ul> Service Water Heating <ul style="list-style-type: none"> <li><b>Zone air + outdoor air mix - Air source heat pump water heater + back up electric element</b></li> </ul>
Lighting <ul style="list-style-type: none"> <li>NECB 2017</li> </ul>	Lighting <ul style="list-style-type: none"> <li><b>42%-87% reduction from NECB 2017</b></li> </ul>
Electrical Equipment <ul style="list-style-type: none"> <li>NECB 2017 Table A-8.4.3.2.(1) and Table A-8.4.3.2.(2)</li> </ul>	Electrical Equipment <ul style="list-style-type: none"> <li><b>40% reduction from NECB 2017</b></li> </ul>



Table 9. Tier 3 Energy Conservation Measures for Highrise MURB, Medium Office, and Large Office.

Baseline Description	Tier 3 Description
Envelope <ul style="list-style-type: none"> <li>Walls: R18 – R31</li> <li>Roofs: R30 – R47</li> <li>Windows: 2.1 – 1.4 (W/m<sup>2</sup>K)</li> <li>FDWR (Fenestration, door, wall ratio): 0.4 – 0.2</li> <li>Air Leakage: 1.45 L/sm<sup>2</sup> @ 75Pa</li> <li>Shading: N/A</li> </ul>	Envelope <ul style="list-style-type: none"> <li><b>Walls: R32 – R47</b></li> <li><b>Roofs: R45 – R50</b></li> <li><b>Windows: 1.9 (W/m<sup>2</sup>K); skylights removed</b></li> <li><b>FDWR: 0.15 - 0.08</b></li> <li><b>Air Leakage: 0.2 - 0.8 L/sm<sup>2</sup> @ 75Pa</b></li> <li><b>Shading: horizontal, 30% of window length</b></li> </ul>
Air Handling Unit <ul style="list-style-type: none"> <li>Multizone VAV</li> <li>Make up units (constant volume)</li> </ul> Heating & Cooling <ul style="list-style-type: none"> <li>Electric/gas heating</li> <li>Baseboard heaters</li> <li>Boilers (location specific) : ~83%-86%</li> <li>Fans (30%-55% efficient)</li> <li>Chiller + Cooling Tower</li> <li>Packaged air conditioners (Highrise only)</li> <li>Water pumps (80%-90% efficient)</li> </ul> Service Water Heating <ul style="list-style-type: none"> <li>Water tank</li> </ul>	Air Handling Unit <ul style="list-style-type: none"> <li><b>DOAS AHU (ERV 80% - 90%) (chiller + electric/gas heating)</b></li> </ul> Heating & Cooling <ul style="list-style-type: none"> <li><b>Air source Variable Refrigerant Flow system</b></li> <li>Baseboard heaters</li> <li><b>Boiler: 96% efficient</b></li> <li><b>More efficient fans (up to 75%)</b></li> <li><b>More efficient pumps (91%)</b></li> </ul> Service Water Heating <ul style="list-style-type: none"> <li><b>Zone air + outdoor air mix - air source heat pump water heater + back up electric element</b></li> </ul>
Lighting <ul style="list-style-type: none"> <li>NECB 2017</li> </ul>	Lighting <ul style="list-style-type: none"> <li><b>43%-85 reduction from NECB 2017</b></li> </ul>
Electrical Equipment <ul style="list-style-type: none"> <li>NECB 2017 Table A-8.4.3.2.(1) and Table A-8.4.3.2.(2)</li> </ul>	Electrical Equipment <ul style="list-style-type: none"> <li><b>40%-85 reduction from NECB 2017</b></li> </ul>

Table 10. Tier 4 Energy Conservation Measures for Secondary School, Warehouse, Highrise MURB, and Retail Strip mall.

Baseline Description	Tier 3 Description
<p>Envelope</p> <ul style="list-style-type: none"> <li>• Walls: R18 – R31</li> <li>• Roofs: R30 – R47</li> <li>• Windows: 2.1 – 1.4 (W/m<sup>2</sup>K)</li> <li>• FDWR (Fenestration, door, wall ratio): 0.4 – 0.2</li> <li>• Air Leakage: 1.45 L/sm<sup>2</sup> @ 75Pa</li> <li>• Shading: N/A</li> </ul>	<p>Envelope</p> <ul style="list-style-type: none"> <li>• <b>Walls: R36 – R57</b></li> <li>• <b>Roofs: R40 – R57</b></li> <li>• <b>Windows: 1.2 – 0.7 (W/m<sup>2</sup>K); skylights removed</b></li> <li>• <b>FDWR: 0.26 - 0.08</b></li> <li>• <b>Air Leakage: 0.2 - 0.8 L/sm<sup>2</sup> @ 75Pa</b></li> <li>• <b>Shading: horizontal, 30% of window length</b></li> </ul>
<p>Air Handling Unit</p> <ul style="list-style-type: none"> <li>• Make up units (Const. Volume - CAV)</li> <li>• Single zone rooftop unit (CAV)</li> </ul> <p>Heating &amp; Cooling</p> <ul style="list-style-type: none"> <li>• Electric/gas heating</li> <li>• DX cooling</li> <li>• Baseboard heaters</li> <li>• Boilers (location specific) : ~83%-86%</li> <li>• Fans (30%-55% efficient)</li> <li>• Water pumps (80%-90% efficient)</li> </ul> <p>Service Water Heating</p> <ul style="list-style-type: none"> <li>• Water tank</li> </ul>	<p>Air Handling Unit</p> <ul style="list-style-type: none"> <li>• <b>Through wall DOAS-ERV (80%-90% efficient)</b></li> <li>• <b>Fan coil units (VAV)</b></li> </ul> <p>Heating &amp; Cooling</p> <ul style="list-style-type: none"> <li>• Electric/gas heating</li> <li>• <b>Baseboard heaters (eliminated in some)</b></li> <li>• <b>Boiler: 96% efficient</b></li> <li>• <b>More efficient fans (up to 76%)</b></li> <li>• <b>More efficient pumps (92%)</b></li> </ul> <p>Service Water Heating</p> <ul style="list-style-type: none"> <li>• <b>Zone air + outdoor air mix - Air source heat pump water heater + back up electric element</b></li> </ul>
<p>Lighting</p> <ul style="list-style-type: none"> <li>• NECB 2017</li> </ul>	<p>Lighting</p> <ul style="list-style-type: none"> <li>• <b>70%-85% reduction from NECB 2017</b></li> </ul>
<p>Electrical Equipment</p> <ul style="list-style-type: none"> <li>• NECB 2017 Table A-8.4.3.2.(1) and Table A-8.4.3.2.(2)</li> </ul>	<p>Electrical Equipment</p> <ul style="list-style-type: none"> <li>• <b>70%-85% reduction from NECB 2017</b></li> </ul>

Table 11. Tier 4 Energy Conservation Measures for the Medium Office, and Large Office.

Baseline Description	Tier 3 Description
Envelope <ul style="list-style-type: none"> <li>Walls: R18 – R31</li> <li>Roofs: R30 – R47</li> <li>Windows: 2.1 – 1.4 (W/m<sup>2</sup>K)</li> <li>FDWR (Fenestration, door, wall ratio): 0.4 – 0.2</li> <li>Air Leakage: 1.45 L/sm<sup>2</sup> @ 75Pa</li> <li>Shading: N/A</li> </ul>	Envelope <ul style="list-style-type: none"> <li><b>Walls: R26 – R77</b></li> <li><b>Roofs: R35 – R75</b></li> <li><b>Windows: 1.1 – 0.7 (W/m<sup>2</sup>K); skylights removed</b></li> <li><b>FDWR: 0.15 - 0.05</b></li> <li><b>Air Leakage: 0.2 - 0.8 L/sm<sup>2</sup> @ 75Pa</b></li> <li><b>Shading: horizontal, 30% of window length</b></li> </ul>
Air Handling Unit <ul style="list-style-type: none"> <li>Multizone VAV</li> <li>Make up units (constant volume)</li> </ul> Heating & Cooling <ul style="list-style-type: none"> <li>Electric/gas heating</li> <li>Baseboard heaters</li> <li>Boilers (location specific) : ~83%-86%</li> <li>Fans (30%-55% efficient)</li> <li>Chiller + Cooling Tower</li> <li>Packaged air conditioners (Highrise only)</li> <li>Water pumps (80%-90% efficient)</li> </ul> Service Water Heating <ul style="list-style-type: none"> <li>Water tank</li> </ul>	Air Handling Unit <ul style="list-style-type: none"> <li><b>DOAS AIR HANDLING UNIT (AHU) (ERV 80% - 90%) (chiller + electric/gas heating)</b></li> </ul> Heating & Cooling <ul style="list-style-type: none"> <li><b>Air source Variable Refrigerant Flow system</b></li> <li>Baseboard heaters</li> <li><b>Boiler: 96% efficient</b></li> <li><b>More efficient fans (up to 76%)</b></li> <li><b>More efficient pumps (93%)</b></li> </ul> Service Water Heating <ul style="list-style-type: none"> <li><b>Zone air + outdoor air mix - Air source heat pump water heater + back up electric element</b></li> </ul>
Lighting <ul style="list-style-type: none"> <li>NECB 2017</li> </ul>	Lighting <ul style="list-style-type: none"> <li><b>70%-85% reduction from NECB 2017</b></li> </ul>
Electrical Equipment <ul style="list-style-type: none"> <li>NECB 2017 Table A-8.4.3.2.(1) and Table A-8.4.3.2.(2)</li> </ul>	Electrical Equipment <ul style="list-style-type: none"> <li><b>70%-85% reduction from NECB 2017</b></li> </ul>

### 3.3 Costing

Hanscomb Quantity Surveyors established the total cost increments by costing NECB 2017 and the individual Tiers. These estimates are comprised of two cost components: building envelope and HVAC. Envelope costs are based on fenestration, wall, and roof areas, as well as its construction (studs, incremental layers of EPS for increased R-values); less expensive solutions may exist for an alternative construction. These envelope costs do not include other structural components/wiring. The cost estimates are predicated on competitive bidding and is intended to be a fair market value. Lastly, the cost elements include equipment, labour and material, subcontractor's overhead and profit. Tier 2 and 3 costs were estimated for Edmonton only; location cost factors for other locations are provided for the reader. For Tier 4, five locations were fully costed in detail.

## 4 Results

### 4.1 Energy Performance

Simulation results for Tier 2, Tier 3, and Tier 4 are presented in Figure 4-Figure 6, respectively. Compliant solutions were found for each of the archetypes in each of the representative locations. In Tier 4, the energy results were not evaluated for Fort McMurray due to time constraints; but the energy results for CZ-7A and CZ-8 bound CZ-7B. The fact that Tier 4 was met in both zones, demonstrates the feasibility to meet Tier 4 in CZ-7B. It should be noted that in some cases the performance achieved exceeds the minimum specified by the Tier by a large margin as a result of the iterative search. The ECMs applied are presented in Table 6 to Table 11; an example set of the specific ECMs applied to the Edmonton Medium Office archetype is provided in Appendix A.

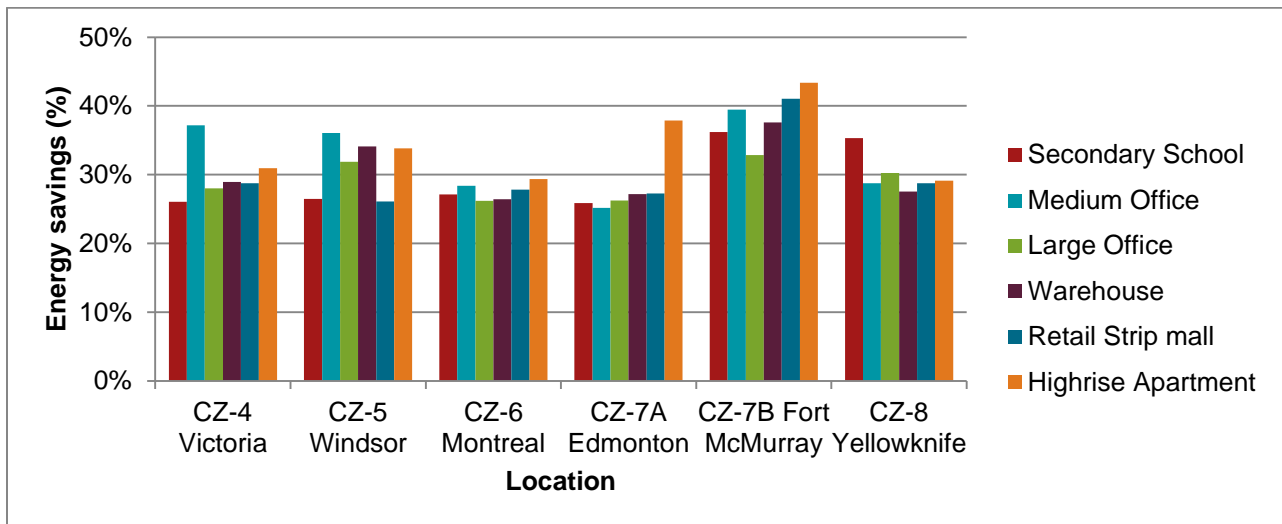


Figure 4. Tier 2 Compliant Archetype Energy Reductions.

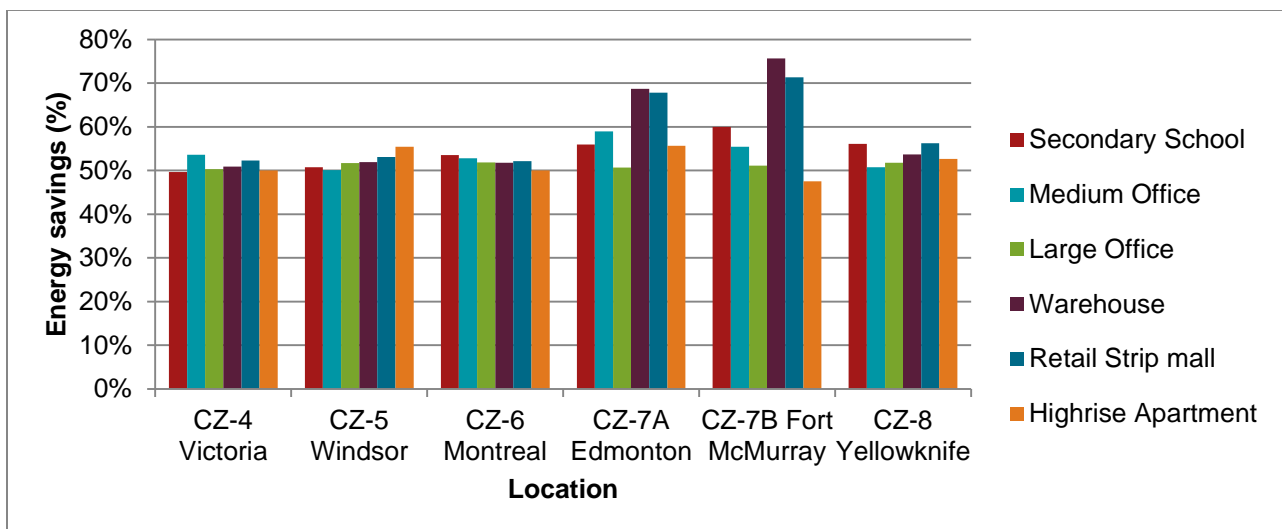


Figure 5. Tier 3 Compliant Archetype Energy Reductions.

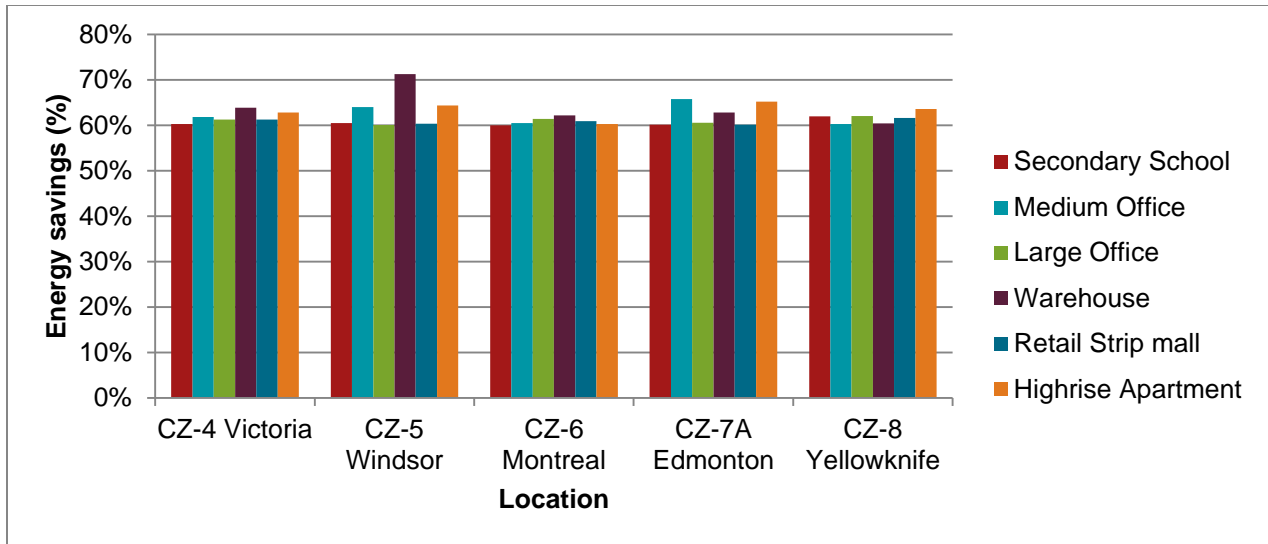


Figure 6. Tier 4 Compliant Archetype Energy Reductions.

## 4.2 Cost Estimates

For Tier 2 and Tier 3, only the total costs associated with Edmonton were directly evaluated and are presented Table 12 and

Table 13, respectively; a detailed breakdown of the envelope and mechanical equipment costs for the baseline and Tiers are presented in Appendix B. An estimate of the Tier 2 and Tier 3 costs for other locations can be inferred by using the set of location cost factors provided by the cost consultants in Table 14. Applying these cost factors to the estimates in Table 12 and

Table 13 provides the cost of the Edmonton building in other locations and not the actual cost of the archetypes in other locations; nevertheless, this cost can still be used to infer an indicative estimate of the cost, to achieve Tier 2 or 3 in the other locations. The results in Table 12 and

Table 13, show is variability in the cost increments; in some cases, the estimated total cost of the Tiers are actually lower than that of NECB 2017.

The area normalized total cost Tier 4 archetypes, in various locations, and the normalized incremental cost required to achieve Tier 4, relative to the baseline, are presented in Table 15 and Table 16, respectively. In Table 16, the costs increments of several archetypes-locations are actually decrements from NECB 2017, these values are bolded.

Table 12. Tier 2 Envelope and HVAC Cost Increments Compared to NECB 2017 (\$/m<sup>2</sup> floor area) - Edmonton.

Building	NECB 2017 Cost	Incremental Cost	Tier 2 Cost
<b>Secondary School</b>	\$758	\$83	\$841
<b>Medium Office</b>	\$929	<b>-\$52</b>	\$877
<b>Large Office</b>	\$555	<b>-\$25</b>	\$530
<b>Warehouse</b>	\$1,104	\$57	\$1,161
<b>Retail Strip mall</b>	\$1,240	\$52	\$1,292
<b>Highrise MURB</b>	\$649	\$18	\$667

Table 13. Tier 3 Envelope and HVAC Cost Increments Compared to NECB 2017 (\$/m<sup>2</sup> floor area) - Edmonton.

Building	NECB 2017 Cost	Incremental Cost	Tier 3 Cost
<b>Secondary School</b>	\$758	\$57	\$816
<b>Medium Office</b>	\$929	-\$164	\$765
<b>Large Office</b>	\$555	-\$94	\$461
<b>Warehouse</b>	\$1,104	\$48	\$1,152
<b>Retail Strip mall</b>	\$1,240	\$16	\$1,256
<b>Highrise MURB</b>	\$649	\$34	\$683

Table 14. Location Cost Factors (for Tiers 2 and 3 only).

Location	Cost Factor
<b>Victoria</b>	105
<b>Windsor</b>	98
<b>Edmonton</b>	100
<b>Yellowknife</b>	115
<b>Montreal</b>	97

Table 15. Tier 4 Envelope and HVAC Cost per Area (\$/m<sup>2</sup> floor area) – 5 locations.

Building	Victoria	Windsor	Montreal	Edmonton	Yellowknife
<b>Secondary School</b>	\$767	\$775	\$763	\$816	\$936
<b>Medium Office</b>	\$738	\$731	\$694	\$755	\$902
<b>Large Office</b>	\$450	\$446	\$495	\$502	\$560
<b>Warehouse</b>	\$1,076	\$1,158	\$1,057	\$1,156	\$1,366
<b>Retail Strip mall</b>	\$1,235	\$1,177	\$1,188	\$1,310	\$1,462
<b>Highrise MURB</b>	\$661	\$633	\$594	\$685	\$726

Table 16. Tier 4 Envelope and HVAC Cost Increments Relative to NECB 2017 (\$/m<sup>2</sup> floor area) – 5 locations.

Building	Victoria	Windsor	Montreal	Edmonton	Yellowknife
<b>Secondary School</b>	\$44	\$59	\$58	\$58	\$32
<b>Medium Office</b>	-\$102	-\$150	-\$162	-\$174	-\$55
<b>Large Office</b>	-\$97	-\$91	-\$29	-\$52	-\$65
<b>Warehouse</b>	\$50	\$111	\$36	\$53	\$48
<b>Retail Strip Mall</b>	\$78	\$4	\$60	\$70	-\$7
<b>Highrise MURB</b>	\$57	\$37	\$11	\$36	-\$37

## 5 Discussion

The simulation results show that all six archetypes can achieve all four Tiered targets. It should be noted that aggressive ECMs were considered for Tier 4, including: 0.2 L/(s·m<sup>2</sup>) air leakage at 75 Pa, 5% window-wall ratio (or FDWR), up to R-77 wall insulation, and VRFs (Variable Refrigerant Flow HVAC).

Although a single cost value is presented for each data point (archetype in a location), the envelope and HVAC costs associated with an actual building that meets the Tiered targets in the industry may vary greatly. For example, the cost and energy savings for commercial buildings in British Columbia (BC) are presented in Figure 7 (data supplied by the BC Government); the results show that a wide range of costs can be expected for various energy levels. Some buildings designs (data point) demonstrate energy savings are possible with decreased capital cost (incremental costs less than 0%); on the other hand, other designs can result in more than a 4% cost increment. In a different study, the CAGBC also identified cost increments of up to 7% (Canada Green Building Council, 2019). As demonstrated, achieving the Tiered targets can be accomplished under a range of costs.

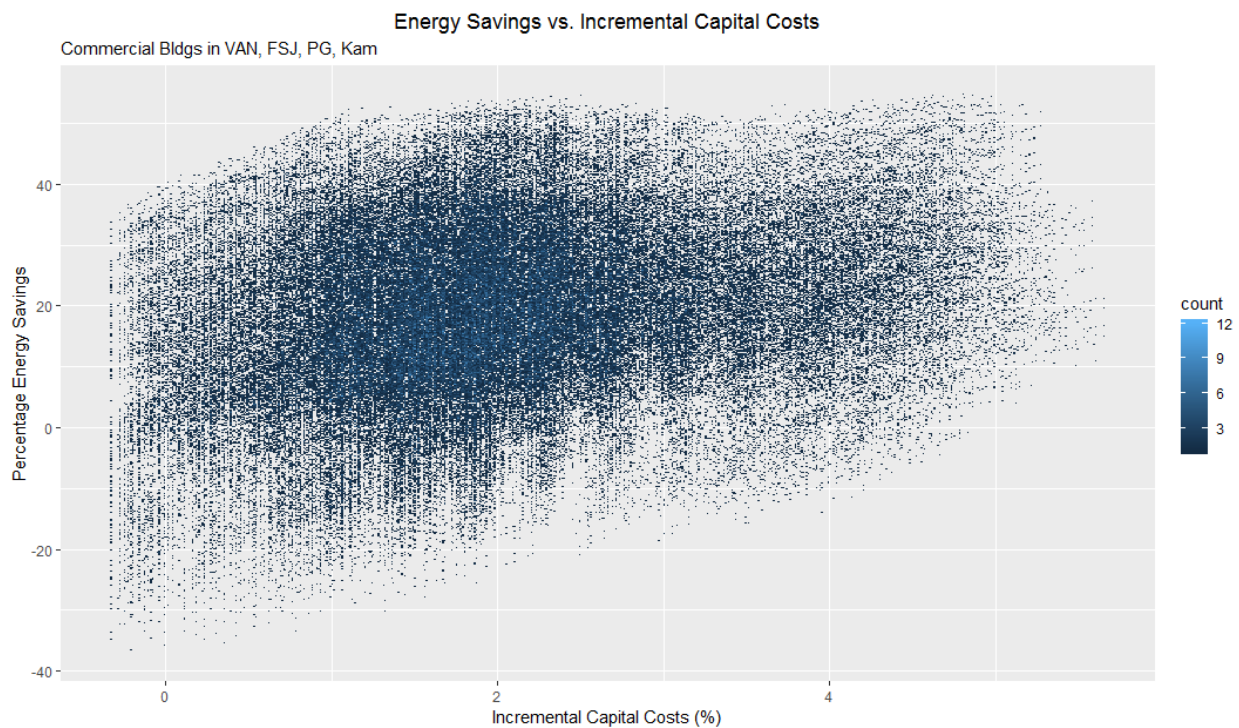


Figure 7. BC parametric cost/energy analysis data visualisation.

To better understand the level of performance achieved by adhering to the Tiered targets and to provide context to the performance, the following discussion will focus on the absolute energy consumptions of the archetypes.

Table 17 shows the total energy use intensity (TEUI) of the baseline archetypes in each location (i.e. the NECB 2017 performance levels). These figures show that buildings designed to NECB 2017 are relatively energy efficient (compared to other standards/design guides described below). The Tier 4 archetype TEUIs are shown in

Table 18.

Table 17. Baseline NECB 2017 Archetype TEUI (kWh/m<sup>2</sup>).

Archetype	Location (Climate Zones)					
	Victoria (CZ 4)	Windsor (CZ 5)	Montreal (CZ 6)	Edmonton (CZ 7A)	Fort McMurray (CZ 7B)	Yellowknife (CZ 8)
<b>Secondary School</b>	115	155	141	174	191	198
<b>Medium Office</b>	123	142	126	146	139	122
<b>Large Office</b>	98	112	104	109	110	105
<b>Warehouse</b>	78	106	101	116	114	124
<b>Retail Strip mall</b>	154	187	177	200	206	221
<b>Highrise MURB</b>	142	186	166	220	224	236

Table 18. Tier 4 Archetype TEUI (kWh/m<sup>2</sup>).

Archetype	Location (Climate Zones)				
	Victoria (Climate Zone 4)	Windsor (Climate Zone 5)	Montreal (Climate Zone 6)	Edmonton (Climate Zone 7A)	Yellowknife (Climate Zone 8)
<b>Secondary School</b>	46	61	56	70	75
<b>Medium Office</b>	47	51	50	51	48
<b>Large Office</b>	38	45	40	43	40
<b>Warehouse</b>	28	31	38	43	49
<b>Retail Strip mall</b>	60	74	69	80	85
<b>Highrise MURB</b>	53	66	66	76	86

To place the TEUI targets calculated in

Table 18 into context, several other low energy/net zero design standards and guides are described. Table 19 shows the EUI targets from ASHRAE's Achieving Zero Energy Advanced Energy Design Guide (ASHRAE, AIA, IES, USGBC, US-DOE, 2018, 2019), which lists target EUI for net zero energy designs based on their climate zones – these targets are provided for school and office buildings. For climate zones 4C and above (i.e., those most applicable to Canada), the target EUIs range from 55 to 114 kWh/m<sup>2</sup>. These targets are generally less stringent than the TEUI of the Tier 4 archetypes in

Table 18, suggesting that the 60% target improvement over NECB 2017 is an appropriate target to achieve net zero ready performance.



Table 19. ASHRAE AEDG Net Zero Energy Design Target EUI.

ASHRAE Climate Zone	ASHRAE Small to Medium Office EUI Targets (kWh/m <sup>2</sup> )	ASHRAE K-12 School EUI Targets (kWh/m <sup>2</sup> )
4A	69	60
4B	65	58
4C	55	56
5A	73	60
5B	72	60
5C	55	56
6A	87	65
6B	78	62
7	96	68
8	114	75

Similarly, the Toronto Green Standard (a standard which focuses on sustainable design requirements; near zero emission) (City of Toronto, 2018) lists a range of 90-100 kWh/m<sup>2</sup> for their Tier 3 TEUI target and their most stringent Tier 4 requires a 65-75 kWh/m<sup>2</sup> TEUI (see Table 20). The most stringent BC Energy Step Code equipment and systems TEUI targets for Part 3 buildings are 100 kWh/m<sup>2</sup> for MURBS and 170 kWh/m<sup>2</sup> for other buildings (Energy Step Code Council and BC Safety Standards Branch, 2017).

Despite technical differences between the various guidelines, standards and regulations identified above, the observation is that the proposed Tier 4 target in PCF 1527 generally results in net zero energy ready performance for most buildings in most climate zones.

Table 20. Toronto Green Standard Energy Efficiency Targets for Tier 3 and 4 (City of Toronto, 2018).

Building Type	Total Energy Use Intensity (KWh/m <sup>2</sup> )		Thermal Energy Demand Intensity (KWh/m <sup>2</sup> )		Greenhouse Gas Intensity (kg/m <sup>2</sup> )	
	Tier 3	Tier 4	Tier 3	Tier 4	Tier 3	Tier 4
Multi-unit Residential Buildings (≥4 Storeys)	100	75	30	15	10	5
Multi-unit Residential Buildings (≤ 6 Storey wood frame construction)	100	70	25	15	10	5
Commercial Office Buildings	100	65	22	15	8	4
Commercial Retail Buildings	90	70	25	15	5	3
Mixed Use Buildings (90% residential, 5% retail, 5% commercial)	100	74	29	15	10	5

The total cost increments of the Medium and Large Offices to meet the proposed NECB Tiers (Table 12 to Table 16) (and two other Yellowknife archetypes in Table 16) on a cost per m<sup>2</sup> basis, are lower than the baseline costs. This is attributed to lower window-wall ratios (reduced window, no skylights) and reduced HVAC capacities/flowrates. Although the envelope insulation of the archetypes were enhanced, the simultaneous reduction in window area (as an ECM) resulted in overall cost savings, since windows generally cost more per area than walls. On the other hand, the introduction of dedicated outdoor air systems (DOAS) and fan coil units in some of the archetypes greatly reduced the required flowrates and capacities of the heating/cooling systems, which allowed for cost savings after the introduction of a VRF system. Thus, overall cost savings were realized. This trend of reduced HVAC costs in energy efficient buildings was also found in CaGBC's report (Canada Green Building Council, 2019) where highly efficient envelope and HVAC systems resulted in greatly reduced heating/cooling equipment capacities and resulted in reduced capital costs compared to their baseline.

## 6 Conclusions

The analysis shows that the archetypes can reach the energy performance levels specified for Tiers 2, 3, and 4 in PCF 1527 and that the cost impacts will generally be low, or actually reduce capital cost. Although the energy performance of the buildings have been demonstrated, some functions of the building envelope were not explored in this study (e.g., durability, condensation risk). Comparisons to other published targets show that PCF 1527's Tier 4 60% energy reduction target satisfies the target EUI of existing design guides for net zero energy status for most buildings and locations.

## Acknowledgments

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## Appendix A - Edmonton Medium Office ECMs Applied

Table 21. Edmonton Medium Office Applied ECMs and Building Parameters

Building Component	Baseline	Tier 2	Tier 3	Tier 4
<b>Envelope/Lighting</b>				
<b>Storey</b>	3 (No basement)			
<b>Wall R-Value ((h °F ft<sup>2</sup>)/BTU)</b>	27	29	32	37
<b>Roof R-Value ((h °F ft<sup>2</sup>)/BTU)</b>	41	42	45	45
<b>Window U-value (W/m<sup>2</sup>K)</b>	1.9	1.5	1.9	1
<b>Wall Area (m<sup>2</sup>)</b>	1335	1384	1483	1780
<b>Roof Area (m<sup>2</sup>)</b>	1661			
<b>Window Area (m<sup>2</sup>)</b>	643	593	494	198
<b>Fenestration, Door, Window Ratio (FDWR)</b>	0.325	0.3	0.25	0.1
<b>Floor Area (m<sup>2</sup>)</b>	4982			
<b>Airtightness (L/(s·m<sup>2</sup>) at 75 Pa)</b>	1.45	0.4	0.6	0.3
<b>Annual Total Energy Usage Intensity (TEUI) (kWh/(m<sup>2</sup> year))</b>	146	112	61	51
<b>Annual Lighting Energy Usage Intensity (kWh/(m<sup>2</sup> year))</b>	25	14	12	11
<b>Mechanical Equipment</b>				
<b>Air Handling</b>	Multizone VAV Reheat with ERV	Multizone VAV Reheat with ERV (Reduced air flowrate)	Fan Coil Unit (Further reduced air flowrate)	Fan Coil Unit (Further reduced air flowrate)
<b>Heating/Cooling</b>	Gas Boiler and Cooling Tower	Reduced capacity for Gas Boiler and Cooling Tower	VRF Heating and Cooling	VRF Heating and Cooling
<b>Ventilation</b>	Coupled with Air Handler	Coupled with Air Handler	DOAS conditioned with Boiler and Cooling Tower	DOAS conditioned with Boiler and Cooling Tower
<b>Additional Zone Equipment</b>	Hot water baseboards			
<b>Hot Water System</b>	Gas Water Heater (83% Efficiency)	Gas Water Heater (83% Efficiency)	Air source (outdoor) heat pump (COP 3) with electrical heating	Air source (outdoor) heat pump (COP 3) with electrical heating
<b>Component Efficiencies</b>	Gas Boiler (83%), Fan (55%), Pump (71% - 92%), ERV (50%)	Enhanced Boiler Efficiency (92%)	Enhanced Efficiencies for: Fan (72%), Pump (91%), Boiler (95%), ERV (80%)	Enhanced Efficiencies for: Fan (72%), Pump (91%), Boiler (95%), ERV (85%)

## Appendix B - Detailed Cost Breakdown for Edmonton

Table 22. NECB 2017 Total Costs (Envelope, Lighting, and HVAC)

Building	Victoria	Windsor	Montreal	Edmonton	Yellowknife
<b>Secondary School</b>	\$14,177,124	\$14,035,086	\$13,821,089	\$14,859,831	\$17,715,845
<b>Warehouse</b>	\$4,963,323	\$5,062,875	\$4,937,606	\$5,336,667	\$6,370,778
<b>Retail Strip mall</b>	\$2,418,514	\$2,452,663	\$2,357,827	\$2,591,816	\$3,070,557
<b>Highrise MURB</b>	\$4,733,780	\$4,675,484	\$4,566,744	\$5,086,342	\$5,978,852
<b>Medium Office</b>	\$4,186,029	\$4,389,488	\$4,262,476	\$4,627,995	\$4,767,915
<b>Large Office</b>	\$25,345,145	\$24,836,687	\$24,279,250	\$25,694,952	\$28,974,530

Table 23. Tier 2 Envelope and Lighting Costs and Cost Increments.

Edmonton Archetype	NECB 2017 Envelope Cost	Tier 2 Envelope and Additional Lighting Cost	Envelope and Lighting Cost Increment
<b>Secondary School</b>	\$13,095,231	\$13,838,235	\$743,004
<b>Warehouse</b>	\$4,953,657	\$5,184,082	\$230,425
<b>Retail Strip mall</b>	\$2,297,852	\$2,399,976	\$102,124
<b>Highrise MURB</b>	\$4,038,802	\$4,214,926	\$176,124
<b>Medium Office</b>	\$2,856,255	\$2,948,314	\$92,059
<b>Large Office</b>	\$14,708,532	\$15,683,525	\$974,993

Table 24. Tier 2 HVAC Costs and Cost Increments.

Edmonton Archetype	NECB 2017 HVAC Cost	Tier 2 HVAC Cost	Tier 2 Incremental HVAC Cost
<b>Secondary School</b>	\$1,764,600	\$2,638,400	\$873,800
<b>Warehouse</b>	\$383,010	\$428,200	\$45,190
<b>Retail Strip mall</b>	\$293,964	\$300,300	\$6,336
<b>Highrise MURB</b>	\$1,047,540	\$1,010,900	-\$36,640
<b>Medium Office</b>	\$1,771,740	\$1,420,000	-\$351,740
<b>Large Office</b>	\$10,986,420	\$8,847,100	-\$2,139,320

Table 25. Tier 3 Envelope Costs and Cost Increments.

Edmonton Archetype	NECB 2017 Envelope Cost	Tier 3 Envelope and Additional Lighting Cost	Envelope Cost Increment
<b>Secondary School</b>	\$13,095,231	\$13,615,224	\$519,993
<b>Warehouse</b>	\$4,953,657	\$5,055,859	\$102,202
<b>Retail Strip mall</b>	\$2,297,852	\$2,339,168	\$41,316
<b>Highrise MURB</b>	\$4,038,802	\$4,134,767	\$95,965
<b>Medium Office</b>	\$2,856,255	\$2,964,734	\$108,479
<b>Large Office</b>	\$14,708,532	\$16,086,537	\$1,378,005

Table 26. Tier 3 HVAC Costs and Cost Increments.

Edmonton Archetype	NECB 2017 HVAC Cost	Tier 3 HVAC Cost	Tier 3 Incremental HVAC Cost
<b>Secondary School</b>	\$1,764,600	\$2,362,640	\$598,040
<b>Warehouse</b>	\$383,010	\$513,590	\$130,580
<b>Retail Strip mall</b>	\$293,964	\$285,344	-\$8,620
<b>Highrise MURB</b>	\$1,047,540	\$1,215,380	\$167,840
<b>Medium Office</b>	\$1,771,740	\$844,000	-\$927,740
<b>Large Office</b>	\$10,986,420	\$5,232,000	-\$5,754,420

Table 27. Tier 4 Total Costs (Envelope, Lighting, and HVAC)

Building	Victoria	Windsor	Montreal	Edmonton	Yellowknife
<b>Secondary School</b>	\$15,032,051	\$15,183,541	\$14,958,004	\$15,992,271	\$18,333,719
<b>Warehouse</b>	\$5,202,910	\$5,601,000	\$5,111,995	\$5,591,549	\$6,604,185
<b>Retail Strip mall</b>	\$2,582,531	\$2,460,922	\$2,483,336	\$2,738,866	\$3,055,896
<b>Highrise MURB</b>	\$5,177,690	\$4,962,567	\$4,651,522	\$5,371,852	\$5,688,763
<b>Medium Office</b>	\$3,678,153	\$3,640,648	\$3,456,913	\$3,759,424	\$4,493,221
<b>Large Office</b>	\$20,862,318	\$20,643,477	\$22,950,790	\$23,274,777	\$25,943,318