Exploring the Performance Requirements of a Net Zero Energy Ready Code

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Abstract

The Pan-Canadian Framework on Clean Growth and Climate Change's goal for a net zero energy ready (NZER) model code by 2030 resulted in the proposal of a Tiered Code requirement to be included in the 2020 edition of the National Energy Code of Canada for Buildings (NECB). The proposal calls for Tiers 1 to 4, where Tier-1 is the NECB performance level, and Tiers-2 to 4 require a 25%, 50%, and 60% energy saving relative to Tier-1, respectively. This paper summarizes the simulation studies performed to validate that the tiers are technically achievable, and what the cost implications are. The building simulation tool OpenStudio was used to conduct annual energy simulations. The resulting building design solutions are used to: highlight the importance of different building aspects related to meeting the Tiers; present a set of costs associated with achieving the Tiers; and a comparison of the level of performance required by Tier-4 and other NZE/low energy and carbon standards.

Introduction

In 2016, the Canadian Commission for Building and Fire Codes (CCBFC) published a position paper on the long term development for energy codes (CCBFC, 2016). This document outlines the CCBFC's policy positions on energy code development and introduces the concept of a Tiered-code approach to permit a flexible framework for adopting jurisdictions while also defining an 'ultimate performance target'. This is a significant change from current codes where only minimum acceptable performance is defined. For new buildings, the 'ultimate performance target' is defined as 'net-zero energy ready'. In addition to new buildings, CCBFC also recognized the importance of existing building performance in reducing national energy demand. These objectives require technical guidance for improvements during alterations and renovations.

In parallel, the Pan-Canadian Framework on Clean Growth and Climate Change, the Federal, Provincial and Territorial governments' collective plan to address climate change (Environment and Climate Change Canada, 2016), are broadly in-line with the CCBFC position paper, the specific goals for the built environment are:

1. Making new buildings more energy efficient;
2. Retrofitting existing buildings, as well as fuel switching;
3. Improving energy efficiency for appliances and equipment;
4. Supporting building codes and energy efficiency in Indigenous communities.

An important difference between the two driving documents is that the Pan Canadian Framework is concerned with carbon emissions reductions whereas the energy codes are focused on reducing excessive energy use in buildings. The NECB and the National Building Code (NBC) together form the 'energy code'. Essentially, the provisions in NBC (Division B Section 9:36) are intended for housing and small buildings that do not require professional technical design (see Division A 1.3.3.3) (National Research Council of Canada, 2015). The CCBFC's Standing Committee on Energy Efficiency (SC-EE) manages code change proposals for the NECB and NBC Section 9:36. These proposals undergoing extensive review, including public review, and then final approval by the CCBFC.

This paper highlights some of the process and achievements of establishing code/technical requirements based on policy directions, with a specific focus on the simulation activities.

Preliminary work

An exploratory study on Part 3 buildings by Girgis-McEwen and Ullah (2018) evaluated different energy conservation measures (ECMs) applied to a Highrise Apt, Large Office, and a Big Box store in order to gauge the potential energy reductions obtainable. Similar work has been conducted for Codes Canada on previous occasions, for instance: Cornick S, Laouadi A and Macdonald I. (2015) and Arborus. (2017). A common theme in these studies has been:

1) Use of a limited number of archetype models
2) Pre-defined energy conservation measures

Net zero energy ready

CCBFC's position paper indicated that a Tiered performance code with the top tier reflecting 'net zero energy ready' performance is needed. A definition was provided:

A ***net-zero energy building*** *is defined as a high performance building that combines superior standards in* *energy efficiency with renewable energy production to offset all of the building's annual energy consumption. A* ***net-zero energy ready building*** *is defined as a high performance building that is built to the same level of energy efficiency as a net-zero energy building but does not include renewable energy production.*

Note that only accounting for annual energy without additional considerations, fails to identify peak load issues and the misalignment between renewable generation and energy demand (Clarke, Hensen, Johnstone and Macdonald, 1999). Wide-scale deployment of renewables without concern of temporal effects has resulted in the 'duck' curve (Lazar, 2016), forcing utilities to dramatically rebalance their operation as PV power declines in the evening while residential loads are increasing.

The definition of '*high* performance building' and '*superior* standards in energy efficiency' is open to interpretation. To inform on the selection of a performance target, two studies undertaken examined the following:

1. How close are current code minimum buildings to NZER performance levels?
2. What performance level are current NZE buildings achieving?

A simulation study by Beausoleil-Morrison, Meister and Brown (2018) addressed the first question by examining the performance of existing buildings with renewable systems. Their results indicate some single family homes can nearly achieve NZER status, but requires the maximum number of PV panels possible for the building, which is financially impractical. This indicates ECMs for the building are needed in order to achieve NZER.

The second question was addressed by reviewing existing performance data. This data is sensitive to building type and limited guidance is available.

Tier Development

Defining minimum performance as the current energy code and the highest level as NZER, the SC-EE proposed an additional two Tiers between these performance levels (i.e. four Tiers in total):

- Tier-1 is the enforced edition of the NECB,
- Tier-2 requires a 25% energy reduction from Tier-1,
- Tier-3 requires a 50% energy reduction from Tier-1,
- Tier-4 requires a 60% energy reduction from Tier-1.

Note these Tiers are performance based (except Tier-1), i.e. there is not a prescriptive solution to achieving the targets. Design teams will be free to select the parameters that work for each building individually (within the constraints of the codes).

The SC-EE required support on two fronts:

1) Are these Tiers technically achievable for a range of archetypes?
2) What magnitude of incremental costs should be expected for each tier?

Methodology

For the analysis, OpenStudio was used to model a reference set (baseline) of NECB 2017 compliant archetype buildings, and a proposed set of Tier-compliant archetypes. The base models were generated using Natural Resources Canada's Building Technology Assessment Platform (BTAP) (CanmetEnergy, 2019) which establishes a baseline annual energy consumption for the archetypes. These models are based on the US Department of Energy's archetypes (CanmetEnergy, 2019). Afterwards, ECMs were applied to these archetypes to achieve Tiered-code compliant buildings. At the time of writing, NECB 2017 is the most recent version of the NECB and was used as the reference (baseline) to establish energy targets (once published NECB 2020 will become the reference).

An engineering approach was employed to determine suitable ECMs for each Tier. This 'expert based' approach was applied in favour to an optimization approach as many of the ECMs required to fully automate this process were undefined and the problem is multi-objective, but the simulations only consider a single objective (for instance daylighting is not calculated but considered in the codes development process).

The engineering approach employed the 'Hill-Climbing method' – essentially the largest demands on energy consumption in the archetypes were addressed first. Beginning with the NECB 2017 archetypes, high energy demand components (e.g. lighting, infiltration losses, and fan energy) were identified and corresponding ECMs were applied to the archetypes via an iterative approach to achieve the energy savings required by each Tier.

The selection of ECMs were based on the advice from the SC-EE's working groups, ASHRAE's Advanced Energy Design Guides: Achieving Zero Energy (ASHRAE, AIA, IES, USGBC, & US-DOE, 2018, 2019), and the CaGBC's zero carbon report (Canada Green Building Council, 2019).

Once solutions were developed for each Tier, cost estimates were generated to account for the envelope, lighting, and HVAC changes associated with achieving the energy performance levels. The cost components include overhead, material, labour, equipment, and profit. These estimates exclude elements such as structural components and electrical wiring (assumed to be constant between the reference and proposed buildings).

Simulations

The study considered the following six archetypes:

- Secondary School (2 storeys, 19,592 m^2),
- Medium (3 storeys, 4,982 m^2) and Large (12 storeys, 46,320 m^2) Offices,
- Warehouse (1 storey, 4,835 m^2),
- Retail Strip Mall (1 storey, 2,090 m^2),
- and Highrise Apt (10 storeys, 7,836 m^2).

Annual simulations of each archetype were conducted for five locations: Victoria BC, Windsor ON, Montreal QC, Edmonton AB, and Yellowknife YK, representing climate zones (CZ) 4 to 8. Both the reference (NECB 2017) and proposed (Tier-compliant set of archetypes) were simulated and the differences costed, totalling 120 simulations.

Following public review an additional set of 30 Tier-4 simulations were conducted.

Pre-Public Review Tier-4 Sample Design Solution Set

Through annual simulations using OpenStudio, it was demonstrated that every archetype-location can achieve Tier-4 (and by extension the lower Tiers). Each solution is unique. Table 1 presents a description of the reference NECB 2017 archetype and the Tier-4 equivalent for the Secondary School, Warehouse, Highrise Apt, and Retail Strip Mall; Table 2 presents the same for the Medium and Large Offices.

Table 1: Tier-4 Description of the Secondary School, Warehouse, Highrise Apt, and Retail Strip Mall in CZ 4-8.

Component	NECB 2017	Tier-4
Wall R-value [W/(m^{2}K)]	0.183 – 0.315	0.100 – 0.158
Roof R-value [W/(m^{2}K)]	0.121 – 0.189	0.100 – 0.142
Window U-value [W/(m^2·K)]	1.4 – 2.1	0.7 – 1.2
Window-Wall Ratio	0.2 – 0.4	0.08 – 0.26
Air Leakage [L/(s·m^2)]	1.45	0.2 – 0.8
Shading	N/A	Horizontal (30% window length)
Air Handling Unit	MAU, RTU	Through Wall DOAS+ERV, VAV
Heating/Cooling	Baseboard, Boiler, DX Cooling	Baseboard (only in some), Condensing Boiler, DX Cooling
Service Hot Water	Electric/Gas Water Tank	Air Source Heat Pump (ASHPWH)
Lighting	NECB Table 4.2.1.6	70%-85%
Electrical Equipment	NECB Table A-8.4.3.2.(1) and (2)	70%-85% reduction

Complete results and data for the archetypes are available (Vuong, Barssoum, Macdonald and Wills, 2019). The ranges for Tier-4 map to the climate zones in an expected manner (e.g. CZ 8 solutions have more insulation, smaller windows and less infiltration compared to CZ 4 and 5 locations).

Energy Performance Discussion

For all Tiers increasing the opaque insulation yielded less energy savings than reducing fenestration thermal transmittance. Increasing opaque insulation results in diminishing rates of return on energy reduction; although heating energy decreased, cooling energy (fan, water pump) increased. It should be noted that thermal bridging in the envelope remains a concern (while easy to simulate, construction is challenging) and improving air-tightness was identified as the most cost effective route to achieving higher performance.

The direct energy savings from reduced lighting more than compensates for increased space heating. As a result, for Tier-4, more efficient lighting technology that can deliver a reduction in the range of 70% to 85% compared to current code are needed. This will be a challenge for the lighting industry; indications from the SC-EE members are that 50% to 60% are achievable with current technology.

HVAC ECMs (e.g. substituting constant volume (CAV) with variable volume (VAV) systems, using dedicated outdoor air system (DOAS) etc.), significantly decrease energy consumption in the archetypes. This is ascribed to the inefficient nature of CAV rooftop units and make-up air units prescribed in the NECB 2017 reference buildings, compared to VAV systems.

Table 2: Tier-4 Description of the Medium and Large Offices in CZ 4 to CZ 8.

Component	NECB 2017	Tier-4
Wall R-value [W/(m^{2}K)]	0.183 – 0.315	0.074 – 0.218
Roof R-value [W/(m^{2}K)]	0.121 – 0.189	0.076 – 0.162
Window U-value [W/(m^2·K)]	1.4 – 2.1	0.7 – 1.1
Window-Wall Ratio	0.2 – 0.4	0.05 – 0.15
Air Leakage [L/(s·m^2)]	1.45	0.2 – 0.8
Shading	N/A	Horizontal (30% window length)
Air Handler	MAU, RTU	DOAS+ERV, VRF Indoor Terminal
Heating/Cooling	Baseboard, Boiler, Chiller	VRF, Baseboards, Condensing Boiler, Chiller
Service Hot Water	Electric/Gas Water Tank	ASHPWH
Lighting	NECB Table 4.2.1.6	70%-85% reduction
Electrical Equipment	NECB Table A-8.4.3.2.(1) and (2)	70%-85% reduction

Capital cost Estimates

Cost estimates were sub-contracted to a professional cost estimator. Table 3 presents the costs for Tier-2 and Tier-3 in Edmonton only; the ECMs applied are similar to Tier-4 (less efficient) and are available to the reader (Vuong, Barssoum, Macdonald and Wills, 2019). Table 4 lists location cost factors for the Tiers (used in conjunction with Table 3, to estimate costs for other locations). Lastly, Table 5 presents the cost estimates for Tier-4 for all locations. The incremental per area costs are shown in these tables; positive values denote additional cost over, and negative values represent cost savings from, the NECB 2017 reference. The third-party consultant provided estimates that reflect the envelope, lighting, and HVAC costs; the estimates encompass labour, equipment, material, overhead, and profit.

The results show the sample solution sets for the School, Warehouse, Retail Strip Mall, and Highrise Apt result in an incremental capital cost investment to reach the Tiers; compared to the Medium and Large Offices which show a reduction to reach the higher Tiers. Note that these represent a single costing data point and other solutions are possible.

Table 3: Tier-2 and Tier-3 Archetype Incremental per Area Cost (\$/m^2) in Edmonton.

Archetype	Tier-2	Tier-3
Secondary School	$83	$57
Medium Office	-$52	-$164
Large Office	-$25	-$94
Warehouse	$57	$48
Retail Strip Mall	$52	$16
Highrise Apt	$18	$34

Table 4: Location Cost Factors for Tier-2 and Tier-3

Location	Cost Factor
Victoria	1.05
Windsor	0.98
Montreal	0.97
Edmonton	1.00
Yellowknife	1.15

Table 5: Tier-4 Archetype Incremental per Area Cost ($/m2) for Various Locations (CZ 4 to CZ 8).

Archetype	Victoria BC (CZ 4)	Windsor ON (CZ 5)	Montreal QC (CZ 6)	Edmonton AB (CZ 7A)	Yellowknife YK (CZ 8)
Secondary School	$44	$59	$58	$58	$32
Medium Office	-$102	-$150	-$162	-$174	-$55
Large Office	-$97	-$91	-$29	-$52	-$65
Warehouse	$50	$111	$36	$53	$48
Retail Strip Mall	$78	$4	$60	$70	-$7
Highrise Apt	$57	$37	$11	$36	-$37

The cost reductions for the Offices is due to reduced glazing area and HVAC loads. A review of the detailed cost components show that reduced window-wall ratio (WWR) resulted in a significant direct decrease in the overall envelope cost, even though other aspects of the envelope were enhanced and became more expensive (e.g. higher opaque and window insulation levels). Indirectly, the reduced glazing area and more efficient HVAC systems (e.g. DOAS, VRF) decreased HVAC loads which require smaller capacity HVAC systems; thus, counteracting the higher cost of a VRF system. This is in line with the CaGBC's report on building zero carbon buildings (Canada Green Building Council, 2019).

Post-Public Review: Additional Tier-4 Solution Set

To incorporate elements from public-review comments (related to the Tiers and other proposed changes that had an indirect effect), an additional set of Tier-4 simulations were conducted (a set of Tier-4 simulations would allow the analysis to be extended to lower Tiers). A description of these solutions are presented in Table 6 and Table 7.

Table 6: Post-Public Review Tier-4 Description of the Secondary School, Warehouse, Highrise Apt, and Retail Strip Mall in CZ 4-8.

Component	NECB 2017	Tier-4
Wall R-value [W/(m^{2}K)]	0.183 – 0.315	0.103 – 0.227
Roof R-value [W/(m^{2}K)]	0.121 – 0.189	0.087 – 0.162
Window U-value [W/(m$^2\cdot$K)]	1.4 – 2.1	0.7 – 1.2
Window-Wall Ratio	0.2 – 0.4	0.08 – 0.18
Air Leakage [L/(s$\cdot$m^2)]	1.45	0.2 – 0.6
Shading	N/A	Horizontal – (50% window length
Air Handling Unit	MAU, RTU	Through Wall DOAS+ERV, VAV
Heating/Cooling	Baseboard, Boiler, DX Cooling	Baseboard (only in some), Condensing Boiler, more efficient DX Cooling
Service Hot Water	ASHPWH COP 3.0	ASHPWH COP 4.5
Lighting	NECB Table 4.2.1.6	65%-80%
Electrical Equipment	70%-85% reduction	70%-85% reduction

The notable differences in the additional set of solutions include limiting low WWRs, excluding energy savings from plug loads and heat pumps for service water heating, and reduced insulation levels for some cases.

Prior to public review, 4 out of 30 Tier-4 buildings had WWR < 0.1, compared to 2 out of 30 post-public review. Credit from plug loads are not considered in energy savings as it is largely occupant dependent and outside the scope of the code. Similarly, energy savings from using a heat pump water heater is evaluated relative to an ASHPWH, instead of electric/gas water heaters.

Table 7: Post-Public Review Tier-4 Description of the Medium and Large Offices in CZ 4 to CZ 8.

Component	NECB 2017	Tier-4
Wall R-value [W/(m^{2}K)]	0.183 – 0.315	0.076 – 0.189
Roof R-value [W/(m^{2}K)]	0.121 – 0.189	0.076 – 0.177
Window U-value [W/(m^2·K)]	1.4 – 2.1	0.6 – 1.5
Window-Wall Ratio	0.2 – 0.4	0.05 – 0.2
Air Leakage [L/(s·m^2)]	1.45	0.2 – 0.6
Shading	N/A	Horizontal – (50% window length)
Air Handler	MAU, RTU	DOAS+ERV, VRF Indoor Terminal
Heating/Cooling	Baseboard, Boiler, Chiller	VRF, Baseboards, Condensing Boiler, Chiller
Service Hot Water	ASHPWH COP 2.5	ASHPWH COP 4.5
Lighting	NECB Table 4.2.1.6	55%-85% reduction
Electrical Equipment	70%-85% reduction	70%-85% reduction

Tier-4: Net Zero Energy Ready Performance?

As a result of establishing compliance using a reference/proposed design approach, a compliant design can have a range of total energy usage intensities (TEUIs). This can be seen by comparing the pre- and post-public review Tier-4 solutions' EUI in Table 8. Both proposed solutions show a 60% energy reduction from their respective reference buildings, but the post-public review EUIs are lower. This is attributed to a reduced electrical equipment energy consumption in the reference building in the post-public review study. The reference/proposed comparison alone makes it difficult to determine if a building is NZER (i.e. NZE if taken further by adding site generation).

Therefore, in order to establish a frame of reference, the EUIs of the Tiered solutions were compared to the target EUIs from relevant design guides/standards. Table 9 presents the EUI targets from the Toronto Green Standard (TGS). Table 10 presents the EUI targets from the ASHRAE Advanced Energy Design Guides: Achieving Zero Energy (AEDG: AZE). The TGS is a municipal standard detailing Tiered requirements for multi-unit residential (five units or more) and industrial, commercial and institutional (ICI) buildings; it contains voluntary top Tiers 3 and 4 which contain requirements (total energy, thermal energy demand, and greenhouse gas intensities) that are "high performance, near zero emissions" (City of Toronto, 2018). On the other hand, the AEDG: AZE include guidelines and technical strategies for designing NZE offices and schools. The guide refers to a "zero energy building" as one that exports equal or more energy than it receives annually, source energy wise. It notes that NZE may not be possible due to parameters beyond the building's design (e.g. utility, site constraints), in which case, the guidelines goals are used to achieve zero energy ready buildings (ASHRAE, AIA, IES, USGBC, and US-DOE, 2018, 2019).

Table 8: Tier-4 Archetype TEUI for each Location (kWh/m^2).

	Archetype	**Victoria BC (CZ 4)**	**Windsor ON (CZ 5)**	**Montreal QC (CZ 6)**	**Edmonton AB (CZ 7A)**	**Yellowknife YK (CZ 8)**
Pre-Public Review	Secondary School	46	61	56	70	75
	Medium Office	47	51	50	51	48
	Large Office	38	45	40	43	40
	Warehouse	28	31	38	43	49
	Retail Strip Mall	60	74	69	80	85
	Highrise Apt	53	66	66	76	86
Post-Public Review	Secondary School	39	53	51	60	68
	Medium Office	39	43	43	51	40
	Large Office	27	30	30	32	35
	Warehouse	28	31	38	43	49
	Retail Strip Mall	59	70	68	75	85
	Highrise Apt	44	57	58	68	85

Table 9: Toronto's Green Standard TEUI Targets (kWh/m^2) (City of Toronto, 2018).

Building Type	Total Energy Usage Intensity (kWh/m^2)	
	Tier 3	Tier 4
Multi-unit Building (≥4 storey)	100	75
Multi-unit Building (≤6 storey)	100	70
Office	100	65
Retail	90	70
Mixed Use	100	74

Table 10: ASHRAE Design Guide EUI Targets (kWh/m^2) (ASHRAE, AIA, IES, USGBC, & US-DOE, 2018, 2019).

Climate Zone	ASHRAE AEDG for Small to Medium Offices EUI Target	ASHRAE AEDG for K-12 School EUI Target
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

A comparison of the TEUI from Table 8 to Table 9 and 10, shows the Tier-4 solutions to meet or exceed the EUI requirements of the AEDG: AZE and TGS. While, the NECB does not regulate thermal demand or greenhouse gas intensities, it can be seen that the pre- and post-public review Medium and Large Offices (27 – 51 kWh/m^2) are more energy efficient than buildings required by the TGS that are intended to be high performing and near zero emissions (65 kWh/m^2 for Toronto, CZ-5). Comparing the Tier-4 archetype EUIs to the AEDG NZE target EUI show the Tier-4 Secondary School's EUIs (pre-public review: 46 – 75 kWh/m^2; post-public review 39 – 68 kWh/m^2) have a similar level of performance to the AEDG EUI (56 – 75 kWh/m^2); the Offices exceed the AEDG target EUIs. Notably, the Medium Office has a lower TEUI for all relevant climate zones (47-51 kWh/m^2) than the AEDG target (55-114 kWh/m^2). Although there isn't an EUI target that guarantees NZE or NZER, by having the majority of the sample solutions presented satisfying or exceeding the target EUIs set by TGS and the AEDG: AZE, it demonstrates that the proposed Tier-4 requirement describes a level of performance that aligns with the energy performance of a near zero emission (in CZ 5) and NZER building.

Discussion

This paper has presented possible solutions to the proposed performance Tiers in the 2020 NECB. The solutions were developed using an 'expert based' approach rather than a fully automated method. This approach was adopted due to the complexities of the modelling and restrictions in defining a multi-criteria optimization strategy.

The primary research question related to the feasibility of the Tier-4 definition – was it possible to create a design based off existing archetypes that achieved this performance? This was successfully demonstrated twice (once before public review and after public review with slightly different constraints).

The study did not examine a set of applicable factors that would influence building performance in real world application of the code or high performance building design. Notably, building form was not considered. In addition, thermal-zoning remained the same for each archetype throughout the study. These two aspects of building design are typically driven by factors other than overall energy use (e.g. function, site constraints). It is expected that professionals will develop solutions that are optimal for their projects based on these considerations and multiple client objectives. It is suggested that the resulting designs should use the information presented in this paper as a starting point and dial back specifications where possible (for instance reduce wall insulation values).

The ECMs used are embedded in the differences between the descriptions of the reference and Tier-4 buildings in Tables 1 and 2 and Tables 6 and 7. Generally, ECMs that address major energy use, as previously described (e.g. lighting, infiltration), are applied with different magnitudes based on location (e.g. more insulation in higher CZ, less insulation in lower CZ). Some ECMs were not included in the study and it is expected that others will be applicable to other designs. One of note was drain water heat recovery – this measure could be applicable in some cases where hot water use is high (e.g. sports centres) but not in others where hot water use is minimal (e.g. strip malls).

The secondary research question was related to costs. The initial solution set was costed by a professional cost estimator for the selected buildings and locations. The differences were marginal for most cases but showed considerable variation between locations.

Previous work has shown considerable variation in costs for given energy performances (and performance for a given cost). Using data supplied from British Columbia (BC), a range of energy savings obtainable against incremental cost for commercial buildings is shown in Figure 1. It shows that a 40% energy reduction is attainable for both <1% or +4% incremental cost. Furthermore, energy savings of +30% are possible with an overall cost reduction (<0% incremental cost). The figure also depicts the possibility of simultaneous energy savings and capital cost reduction. The variation in cost and performance is large but cost efficient energy upgrades are obtainable. A similar relationship is expected for the Tiered code.

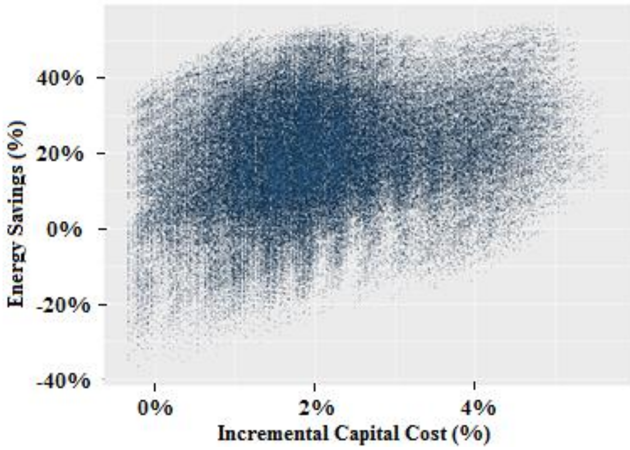

Figure 1: BC Commercial Building Level of Energy Savings for given Cost Increment

Future Work

The authors are interested in finding optimal solutions both in terms of energy performance but also cost-optimal solutions.

Conclusion

This paper summarizes the approach taken to developing evidence in support of the proposed energy performance Tiers of the NECB. Batch processing of archetype models was employed using OpenStudio. To develop the solution sets for each Tier an engineering approach was taken due to the complexity of the problem. The example solution sets were costed to provide an indication of incremental cost. The results showed that the energy performance levels are achievable and cost effective. Compared to existing guidelines and other standards, the proposed NECB 2020 Tier-4 generally aligns with the energy performance of a near zero emission and NZER building.

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