

Setting Building Performance Standards with Limited Local Data

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ABSTRACT

An increasing number of jurisdictions have adopted building performance standards for large existing buildings, all based on years of reported benchmarking data. But what if a jurisdiction has not collected that data yet? Are such ambitious policies still possible? In some places—like Canada—cities may only have authority to collect performance data in support of an existing environmental performance requirement. Moreover, with limited time to dramatically reduce global emissions, even jurisdictions that could collect benchmarking data first are finding that they have little time to wait, and stakeholders often seek a clearer, earlier understanding of compliance pathways and costs.

This paper details a new, innovative approach to this problem. We have used statistical analysis and energy modeling to derive distributions of energy performance, as well as energy and carbon savings, across 5 building types, 48 archetypes, and 10 decarbonization packages. The analysis also includes lifecycle cost modeling and citywide emissions modeling that shows cost impacts and allows the selection of appropriate standard trajectories that incrementally drive deeper savings across increasing numbers of buildings. The paper details the methodology, key findings, limitations, and lessons learned. Finally, we will review ongoing implementation of Canada's first building performance standards policy, the introduction of secondary performance metrics, and the broader applicability of the work.

Introduction

The Building Performance Standard Wave

Building Performance Standards (BPS) are emerging as a best-practice policy for dealing with greenhouse gas emissions from existing buildings. If commercial buildings continue to be retrofitted at current national rates, it will take over 60 years to reach all buildings, and per-building savings would also be insufficiently modest—this has created growing consensus that meeting the challenge of climate change requires more direct regulation of existing buildings. (Nadel and Hinge 2020). In the U.S., the cities of Washington, D.C., New York City, Boston, Denver, and St. Louis have all adopted BPS policies, along with Montgomery County, Maryland. Under the National BPS Coalition, 28 other jurisdictions in the U.S. have committed to doing so by 2024 (IMT 2022). Most of these jurisdictions have had laws in place for several years requiring building owners to annually benchmark and report building energy use—in some cases, the cities have already collected over a decade of robust benchmarking data. However, more jurisdictions are recognizing there is no time to waste when it comes to fighting climate change and they are moving directly to BPS policies (indeed, 9 of the 34 members of the National BPC Coalition do not yet have benchmarking requirements in place).

In Canada, the situation with regard to benchmarking and BPS policies is legally more

complex. Most Canadian cities do not have the authority to adopt laws regulating energy use without the approval of the provincial government--in U.S. parlance, one might say that most Canadian cities do not have “home rule.” (Taylor and Dobson 2020). The City of Vancouver Charter provides the city with exceptional authority, including its own zoning and building codes, and is able to implement a BPS under its authority to set standards on heating equipment in buildings. However, even that is limited; benchmarking and reporting are allowed primarily as a tracking and compliance mechanism for an environmental regulation like BPS, rather than as a separate and prior requirement. Thus, the City needed to establish specific building performance standards *before* requiring the submission of any benchmarking data. This created a challenge to the common approach for setting BPS limits, which usually relies on said local data.

This paper explores how Vancouver has addressed this challenge, while also showing an alternate pathway to creating performance standards that could be used by a jurisdiction that wants to move directly to a BPS, along with a replicable approach for understanding compliance pathways and calculating the costs and benefits of a BPS.

Local Context

In November 2020, the Vancouver City Council approved the Climate Emergency Action Plan (CEAP) and the Zero Emission Building Retrofit (ZEB-R) Strategy, which put Vancouver on track to reduce its carbon pollution by 50% by 2030 enroute to 100% reduction by 2050 (City of Vancouver 2020). Leading up to 2020, the city had already reduced its emissions by 15% since its 2007 baseline, but the trajectory of the curve needed to bend significantly downward to meet the 50% target. With hydroelectric power providing over 95% of the electricity used in British Columbia, the electric grid has a very low emissions intensity—11 tCO₂e/MWh on average today, and expected to reach near-zero by 2030. Many Vancouver buildings are also served by one the city’s three district energy system (DES) utilities. Thanks to differing portfolios of natural gas, wastewater heat recovery, and electric resistance, DES system GHG intensities ranging from 60 to 252 tCO₂e/GWh (Gorter 2021). There is also a regulated market for “Renewable Natural Gas” (RNG), though supply has historically been highly constrained.

In consultations with city staff, building owners and managers expressed a strong preference for a performance-based approach to regulation, given the complexity and diversity of building heating systems. Commercial building owners also told the city that they wanted clarity on future requirements, so that they could make wise capital replacement decisions in their buildings. Based on this input, and modeled after the approach taken by New York City and Washington, D.C., the city council approved the ZEB-R strategy, which directs staff to develop a BPS of carbon pollution limits for the largest commercial and multi-family buildings in Vancouver. Integral Group, Elementa Engineering, WSP, and the Institute for Market Transformation were hired as consultants to characterize the building stock, develop potential targets, design and cost a variety of potential compliance pathways, and estimate the resulting impact on citywide emissions. In May 2022, the city council adopted Canada’s first BPS, based on the technical findings discussed in this paper.

Technical Analysis Approach

The analysis was divided into six stages:

1. *Building Stock Characterization and Clustering*: Multi-parameter clustering of the existing building stock was developed to capture variations in performance. Energy use data was estimated using existing studies and reference cities. Estimated energy use

across the building clusters was then mapped to understand the distributions of energy use and emissions.

2. *Energy Efficiency Measure (EEM) Packages*: For each building archetype, baseline equipment and envelope assumptions were developed, up to four levels of improvement. These were then grouped into 10 packages.
3. *Energy Modeling*: Energy models for each cluster were iteratively calibrated using robust building audit data, and the impact of all 10 measure packages were modeled for each archetype.
4. *Cost Modeling*: Energy models were calibrated and matched with cost models across all upgrade packages to generate first cost and lifetime-cost estimates and GHG emissions.
5. *Citywide Modeling*: Models were aggregated into a bottom-up model of citywide building energy use and emissions that looked at the impact of various implementation pathways to create cost-effective bounding scenarios, and estimated jobs impacts.
6. *Standard setting*: The citywide modeling, energy modeling, and cost results were used to set the proposed energy and emissions standards that were developed for each building type.

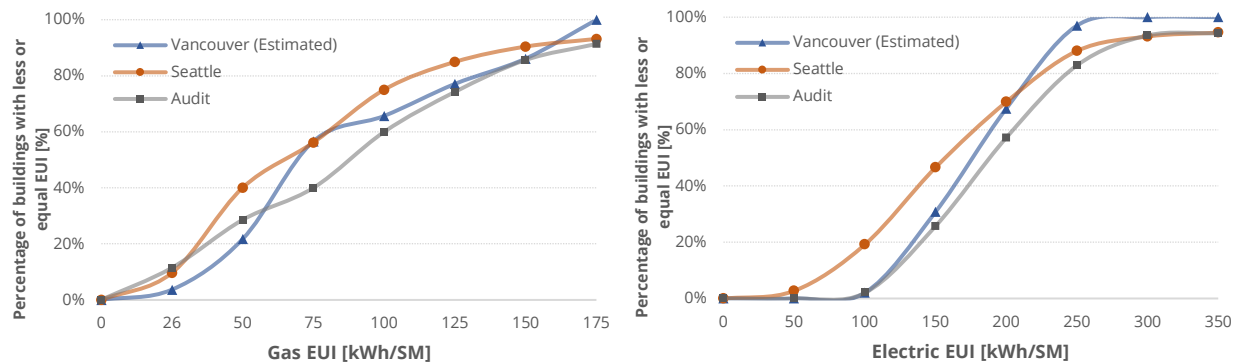
Building Stock Characterization:

An original approach was adopted in order to characterize the existing building stock and identify representative building archetypes that can serve as the basis for energy-efficiency measure recommendations and policy development. Given there is no preexisting local energy benchmarking dataset to draw on, we estimated energy use data using a mix of audit data, benchmarking data from an appropriate reference city, and prior studies conducted for the City of Vancouver. Floor area by building type was sourced from data maintained by the province and the City.

Studies conducted by Morrison Hershfield and RDH provided hourly models calibrated to 2016 data and to envelope sensitivity analyses for office, retail, and multifamily archetypes. These studies effectively allowed for assignment of approximate electrical and gas Energy Use Intensities (EUIs) for “new construction” buildings within each archetype of interest (McClung and Schoenfeld 2020; RDH 2018). Using equipment efficiencies and envelope sensitivities, EUIs by building type were estimated based on year of construction. Electricity and gas EUIs were estimated for each building using “new construction” EUIs and linear regression equations for quantifying dependence on vintage (Ek and Love 2020). For multifamily buildings, additional data on EUI distributions and typical building system configurations was derived from studies of the condominium housing stock, which comprises over 80% of multifamily floor area in the city (RDH 2017).

The EUI estimates generated were validated against several sources. Over the past decade, Integral, WSP, and our partners have performed energy audits on buildings with a combined floor area exceeding 25% of the total covered building floor area. Due to confidentiality agreements, the data had to be anonymized, and could not be directly matched to buildings. Rather, our audit data provided a robust set for confirming the modeled EUI distributions. In addition, the data was compared to the City of Seattle’s energy benchmarking data. Seattle forms a good sanity check due to the completeness of dataset (99% compliance), similarity in climate, and similarity in building stocks of Seattle and Vancouver (City of Seattle 2021). As shown in Figure 1, the building EUI distributions are reasonably well-aligned.

Figure 1: Comparison of Gas (left) and Electricity (right) EUIs generated with reference data sets



The covered building dataset was then partitioned into representative sub-archetypes using k-means clustering conducted based on electricity and gas EUIs scaled to the same magnitude, building type, and size. While EUI does largely control for size, the higher ratio of envelope surface to floor area can result in higher EUIs for smaller buildings—and in addition, larger buildings were more likely to be connected to district energy systems. Building age was found to be one of the key features distinguishing clusters. In general, “older” buildings were built before 1980, and “newer” buildings were built after. The final clusters and their mean size and performance are shown in Table 1. Because Vancouver will regulate office and retail buildings first, more fine-grained clustering was applied to those building types.

Table 1: Building Clusters with Mean Gross Floor Area (GFA) and Energy Use Intensity (EUI)

Building Type	Cluster	Year Built Mean	GFA Mean (ft ²)	GFA Mean (m ²)	Gas EUI (kWh /m ²)	Electric EUI (kWh /m ²)	Site EUI (kBtu /ft ²)	GHGI Mean (kgCO ₂ e /m ²)
Office	Older High-Rise Office	1960	377,813	35,100	72	165	75.1	18.2
	Newer High-Rise Office	1993	351,980	32,700	49	147	62.1	11.3
	Older Medium Office	1955	130,243	12,100	148	228	119.2	30.0
	Newer Medium Office	1993	141,007	13,100	100	202	95.7	20.8
	Small Office	1981	38,675	3,593	143	234	119.5	28.2
Retail	Large Retail	1997	440,244	40,900	40	145	58.6	12.3
	Older Medium Retail	1937	193,750	18,000	100	182	89.4	20.7
	Newer Medium Retail	2002	139,931	13,000	54	139	61.2	11.7
	Small Retail	1992	39,310	3,652	123	148	85.9	23.8
Hotel	Small Hotel or Motel	1961	56,058	5,208	206	146	111.6	42.2
	Large Hotel	1985	495,730	46,055	173	158	104.9	32.4
Warehouse	Non-Refrigerated Warehouse	1990	56,736	5,271	74	102	55.8	17.7
Multi-unit Residential Building (MURB)	Older Mid-Rise MURB	1968	38,803	3,605	140	73	67.5	26
	Newer Mid-Rise MURB	1997	46,844	4,352	123	76	63.1	23
	High-Rise MURB	1992	157,175	14,602	119	68	59.3	22.4
	Garden Apt. Complex	1987	59,137	5,494	121	77	62.8	24.3

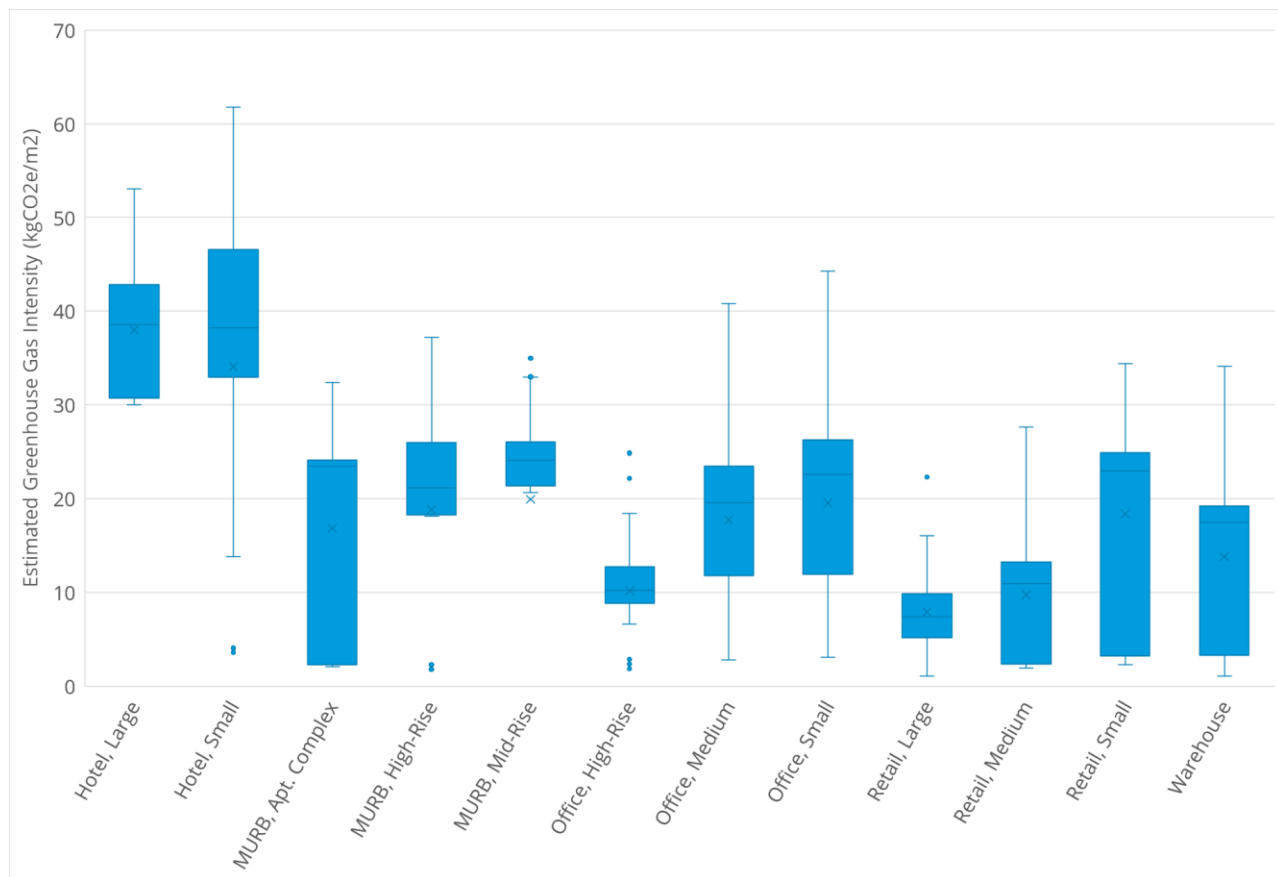
For each building type and cluster, two to four common heating systems were identified and studied as baseline scenarios, with different baseline heating scenarios having different retrofit pathways. Due to the mild climate, cooling is not common in Vancouver-area multifamily housing, though it is in commercial buildings. Central gas-fired domestic hot water (DHW) or service hot water (SHW) boilers were assumed for all building types, with the exception of apartment complexes, where both gas-fired and electric-resistance in-unit DHW boiler variants were modeled. As shown in Table 2, combining the clusters and heating variants results in 48 unique *archetypes*—e.g., Older High-Rise Office with District Heat, Large Retail with Rooftop Units, or Newer Mid-Rise Multi-unit Residential Building (MURB) with electric baseboards and fireplaces.

Table 2: Building Archetypes Analyzed

Building Type	Cluster	Heating System Plant Variants					Cooling System
		Central Boiler	Rooftop Units	District Heat	Electric Resistance	Other	
Office	Older High-Rise Office	✓		✓			Central
	High-Rise Office	✓		✓			Central
	Older Medium Office	✓	✓	✓	✓		Central
	Newer Medium Office	✓	✓	✓	✓		Central
	Small Office	✓	✓		✓		Central
Retail	Large Retail	✓	✓	✓			Central
	Older Medium Retail	✓	✓				Central
	Newer Medium Retail	✓	✓				Central
	Small Retail		✓		✓		Central
Hotel	Small Hotel / Motel	✓	✓		✓		PTAC
	Large Hotel	✓		✓			Central
Warehouse	Non-Refrigerated Warehouse	✓	✓		✓		None
Multi-unit Residential Building (MURB)	Older Mid-Rise MURB	✓		✓	✓		None
	Newer Mid-Rise MURB	✓		✓	✓	Gas Fireplace + Electric Baseboard	None
	High-Rise MURB	✓		✓	✓	Gas Fireplace + Electric Baseboard	None
	Garden Apartment Complex				✓	Furnace	None

Using tax data on heating equipment and system maps for each of the district energy utilities, all buildings were mapped to a heating system variant, and from this, a full range of Greenhouse Gas Intensities (GHGIs) was calculated, which are visualized in Figure 2. These distributions were important to the citywide modeling and the target setting discussed below, as well as to engagement with stakeholders.

Figure 2: Greenhouse Gas Intensity (GHGI) distributions by building type



Energy Efficiency and Carbon Reduction Packages

For each archetype, we developed a set of assumptions about baseline conditions and various energy efficiency measures (EEMs) that were most commonly implemented in the region. The methodological approach is based on prior work with the City of Toronto (Integral 2021). These assumptions were developed based on audit data of over 50 facilities collected by the consultant team and also consultant experience in the local region. For each major energy-related building system, up to four levels of upgrades were defined. These were then grouped into 10 retrofit packages to represent different levels of investment and intervention in the building. Table 3 below presents the 10 retrofit package descriptions.

Since the goal of the BPS is to drive electrification and deep GHG savings, only the “minimum equipment intervention” and “like for similar” packages include new gas-fired equipment; these packages provide reference comparisons to the other packages. In addition, since Vancouver’s BPS will not regulate electric use, and the GHGI of the electric grid is low, lighting, plug loads, and solar photovoltaic measures were excluded from the study. Including lighting measures, in particular, would likely improve the cost-effectiveness of many upgrade packages (though there is some additional justification for not including lighting, as in many buildings those upgrades have been completed, or will soon be required).

Table 3: High-level package descriptions

Tune-Up	Controls optimization, setpoint adjustments, commissioning – these measures were also included in other nine packages.
Minimum equipment intervention	Planned building-level like-for-similar heating, ventilation, and air conditioning (HVAC) upgrades only. (This package, which focuses on improving the efficiency of gas-fired equipment, was included to provide a comparison point in the cost modelling.)
Like for Similar (LFS)	Planned building-level envelope and HVAC equipment upgrades only (this package provides a comparison point for alternate envelope retrofit approaches). We call this package “like for similar” and not “like-for-like” because market forces and code requirements often make a true like-for-like replacement unlikely.
Minimum fuel switching	Minimum first cost fuel switching option, either in building or at District Energy System (DES) plant.
Partial Fuel Switch	Partial fuel switching using heat pumps, while keeping natural gas as an auxiliary or backup source. No envelope measures. (In archetypes with rooftop units or furnaces as the primary heating source, this package represents a full fuel switch.)
LFS + partial fuel switch	Planned upgrades to envelope + partial fuel switch of HVAC systems, while retaining natural gas as an auxiliary or backup source.
LFS + full fuel switch	Planned upgrades to envelope + full fuel switching of HVAC systems to all-electric heat pump options.
Fuel Switch Ready	Envelope improvements and upgrades to be ready for future enhanced fuel switch, with no HVAC improvements other than retrocommissioning and controls upgrades. (This particular package is designed as an interim step for a building owner who has recently replaced expensive HVAC systems.)
Deep Retrofit	A holistic package of envelope measures, HVAC system changes, etc., including complete electrification, supported by extensive upgrades to controls and sensors.
Max Potential	Best-in-class envelope measures, system changes, and complete electrification, supported by more extensive upgrades to controls and sensors. High-cost options such as ground-source heat pumps (geo-exchange) are included here.

The baseline and measure level assumptions are provided for one of the archetypes in Table 4 as an example. This table shows scenarios for older buildings; newer buildings generally have better wall and roof insulation and more glazing, and so the packages for newer buildings include fewer envelope measures. The four HVAC variations represent three different sub-archetypes with different baseline heating systems (as shown in Table 2). In general, these baseline heating systems shape the HVAC upgrade pathways, with centralized heat recovery chillers replacing boilers, heat pump rooftop units (RTUs) replacing gas-fired RTUs, ductless mini-split heat pumps replacing electric baseboards, etc. The district energy pathway was tailored to the district steam system used in downtown Vancouver, where the system operator is seeking regulatory approval to meet 20% to 40% of its load with electric boilers. (Gorter 2021).

Table 5 then shows how these measures combine into packages. For multifamily housing, cooling was not included in the baselines, but was included in all Level 2 and above HVAC plant upgrades, to reflect the increased need for cooling in the Northwest due to a warming climate.

Table 4: Carbon reduction measure matrix for the “older office” archetypes and its heating variants. Not all building elements have all four levels of retrofits; the way packages are put together is shown in the following table.

	Baseline (Level 0)	Level 1	Level 2	Level 3	Level 4
Walls (W)	Concrete or Veneer-Clad Wall with No insulation (R-1.5)	Interior existing walls retrofit with 2" of spray foam (R-5)	Over-clad wall with 4" new exterior insulation (R-15)	Interior Retrofit + Re-Clad	
Roof (R)	3" Insulation in Roof (R-10)	Re-roofed with 5" of insulation (R-20)	Re-roofed with 7" of insulation and reduced thermal bridging (R-30)		
Window (G)	Single glazed aluminum frames (U-1.1, SHGC-0.5)	Standard double-glazed, air-filled aluminum frames (U-0.45, SHGC-0.35)	Improved double-glazed, argon-filled aluminum frames (U-0.35, SHGC-0.3)	Triple-glazed, argon-filled aluminum frames (U-0.30, SHGC-0.3)	
Air Seal (AS)	Poor Air Sealing	Improved air sealing	Further improved air sealing	Air sealing to current code requirements	
HVAC Distribution (SYS)	Existing - VAV	Optimize Fan/pump system optimization with high efficiency component upgrades and speed drives	Add Energy Recovery Ventilator (ERV) plus CO ₂ control to existing VAV system	Energy Recovery Ventilator (ERV), Dedicated Outdoor Air System (DOAS), 4-pipe Fan Coils	
HVAC Plant A (F.A)	Central boiler and chiller, no fuel switching	New condensing gas-fired boiler and chiller upgrade	Max allowable (per electric service) electric resistance boiler - DHW/space heating	Water to water heat pump / heat recovery chiller - 50% GHG reduction	Water-to-water + Air Source Heat pumps + Electric boiler backup
HVAC Plant B (F.B)	District Steam Gas-Fired Boiler; Building Chiller	District Steam Gas + Electric Boilers for 15% of demand; Building Chiller	District Steam Gas + Electric Boilers for 40% of demand; Building Chiller	Building Water to water heat pump / heat recovery chiller	Low-Temp Hot Water water-water heat pump
HVAC Plant C (F.C)	Typical DX RTU w/ 80% eff. furnace, constant speed fan W/ RTU damper control	Best in Class RTU w/ 85% efficiency, VAV and enhanced control	New heat pump RTUs w/ gas backup @ 0°C	New heat pump RTUs w/ electric backup @ 0°C + ERV	
HVAC Plant D (F.D)	Electric Baseboards (no cooling)	Heat Pump PTAC	Heat Pump VRF		
DHW /SHW	Central gas-fired water heater (80% efficient)	Higher efficiency Gas Condensing Boiler	Electric boiler DHW heater	Heat Pump hot water heater	
Controls (C)	No improvement	Controls retrocommissioning with new CO ₂ and motion sensors	Controls retrocommissioning + fault detection and diagnostic software		

Table 5: EEM Package Assignment for the Older Office Archetypes. The coding in the cells refers to the rows and columns in the above table, e.g., G0 = baseline (level 0) window glazing, W1 = level 1 retrofit for walls, F3.B = level 3 retrofit for HVAC Plant Variant B, etc. Coloring is for readability only, with darker shades for higher levels.

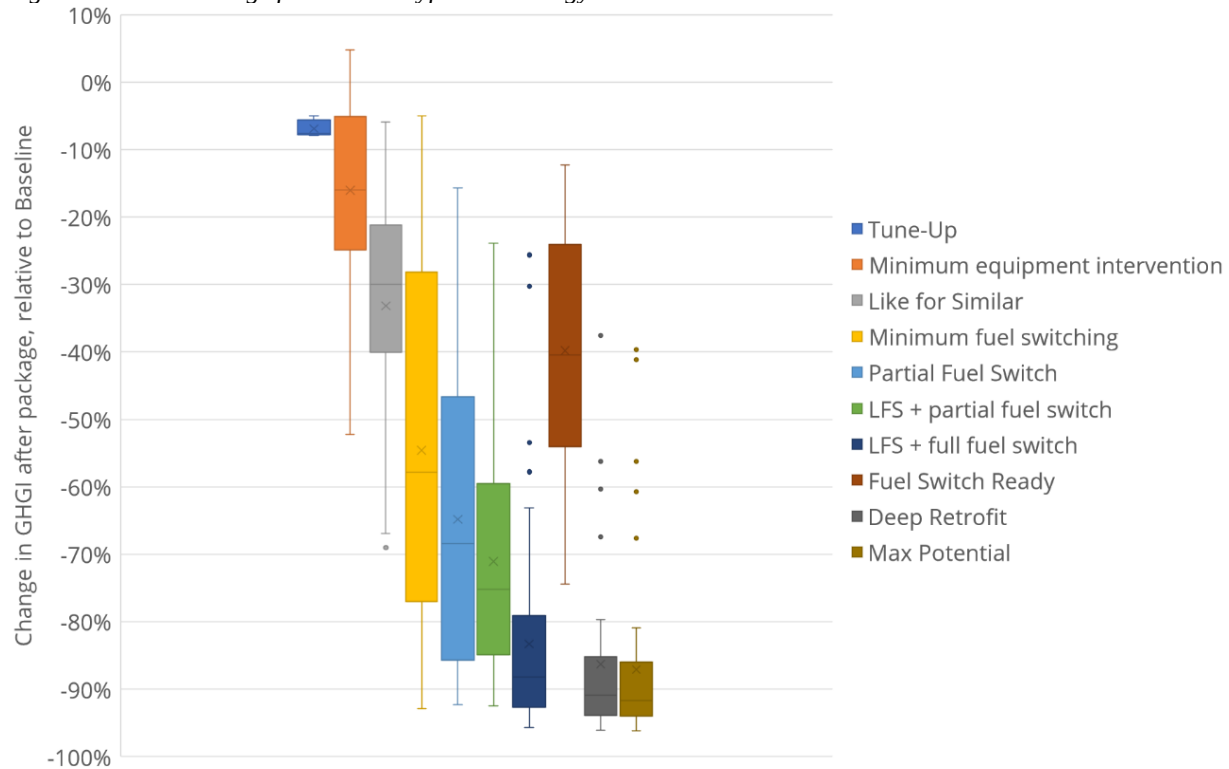
	Tune-Up	Minimum equipment intervention	Like for Similar	Minimum fuel switching	Partial Fuel Switch	LFS + partial fuel switch	LFS + full fuel switch	Fuel Switch Ready	Deep Retrofit	Max Potential
Walls (W)	W0	W0	W1	W0	W0	W1	W1	W2	W2	W3
Roof (R)	R0	R0	R1	R0	R0	R1	R1	R2	R2	R2
Window (G)	G0	G0	G1	G0	G0	G1	G1	G2	G2	G3
Air Seal (AS)	AS0	AS0	AS1	AS0	AS0	AS1	AS1	AS2	AS2	AS3
HVAC Dist. (SYS)	SYS0	SYS1	SYS1	SYS1	SYS1	SYS1	SYS2	SYS0	SYS2	SYS3
HVAC Plant A (F.A)	F0.A	F1.A	F1.A	F2.A	F3.A	F3.A	F4.A	F0.A	F4.A	F4.A
HVAC Plant B (F.B)	F0.B	F0.B	F0.B	F1.B	F2.B	F2.B	F3.B	F0.B	F3.B	F4.B
HVAC Plant C (F.C)	F0.C	F1.C	F1.C	F2.C	F3.C	F2.C	F3.C	F0.C	F3.C	F3.C
HVAC Plant D (F.D)	F0.D	F0.D	F0.D	F0.D	F1.D	F1.D	F2.D	F0.D	F2.D	F2.D
DHW	DHW0	DHW1	DHW1	DHW2	DHW3	DHW3	DHW3	DHW0	DHW3	DHW3
Controls (C)	C1	C1	C1	C1	C1	C1	C1	C2	C2	C2

Energy and Emissions Modeling

3D prototype energy models were constructed for each archetype in eQuest energy simulation software and calibrated based on local weather and the mean EUIs generated through the clustering. (While a wide distribution of EUIs and GHGIs had been estimated, mean EUIs were used to calibrate the energy models so that the results could be rolled back up to the citywide level.) The baseline envelope and mechanical design inputs were used in the calibration model. For building systems where the baseline package specifications did not include a specific assumption—including air sealing, lighting, and outdoor air ventilation—building age was used

to calculate the minimum allowable design performance under the building code at the time of construction. The measure packages were then evaluated in the energy modeling analysis to assess energy savings and greenhouse gas emissions reduction potentials of the packages. GHGI reductions for all the archetypes are shown in Figure 3.

Figure 3: GHGI Savings for all archetypes and energy sources



Key findings from the energy modeling include:

- *Minimum Intervention* (i.e., HVAC replacement with modern gas-fired equipment) produces minimal savings and may even increase emissions in some archetypes.
- *Minimum Fuel Switch* (i.e., electric boilers, or heat pump RTUs with gas backup) produces sufficient savings for the near-term targets at lower capital costs and may be a sufficient endpoint for higher-performing buildings, but will increase operating costs and may have grid impacts that were beyond the scope of this study.
- *Partial Fuel Switch* produces nearly the same GHG savings as *Like-for-Similar + fuel switch* in newer buildings and buildings with RTUs, without the need for envelope work
- *Fuel Switch Ready* retrofits in buildings that recently replaced HVAC equipment can reduce GHGs by 35-74%.
- *Like-For-Similar envelope replacement + full fuel switch* produces nearly as significant emissions savings (74%-93%) as *Deep Retrofit* or *Max Potential* packages (81%-94%).
- Deeper envelope improvements have limited added GHG savings relative to business-as-planned (BAP) envelope improvements, but more substantial EUI and Thermal Energy Demand Intensity (TEDI) reductions.
- Many packages yield similar levels of GHG savings for all archetypes/clusters, though there is wide divergence for *Minimum Fuel Switching*, *Partial Fuel Switch* and *Fuel Switch Ready* options.

Lifecycle Cost Analysis

Cost Modeling Approach:

To understand the cost impacts of various packages, lifecycle cost analysis was conducted for a 25-year time period. The capital cost and life-cycle cost analysis for each package builds on the process used to develop the calibrated baseline models and measure matrices.

- Characteristics of clusters/archetypes used to set baseline features for modeling are also used to find exemplar facilities within the WSP capital planning/condition assessment database (and other datasets, where relevant). Class D capital cost estimates were calculated by A.W. Hooker and Associates using these reference projects (CCA 2012).
- Measures are described in more detail to suit how they would achieve the associated energy-related improvement for the selected facilities (matching the measures to building).
- These more detailed descriptions offer some feedback to the modeling process, but are mostly used by a third-party cost consultant to develop measure-level pricing.
- Measure-level pricing is adjusted for appropriate equipment downsizing benefit for each package, based on the approximate load reduction from the corresponding energy model.
- Electric infrastructure upgrades were excluded from the study due to the lack of specific data and the limited scope of the study. In general, packages that did not assume full fuel switching, such as the “minimum fuel switching” and “partial fuel switching,” are sized to avoid the need for an electrical service upgrade. Grid impacts of increased electric demand across the city were likewise outside the scope of the study.
- All costs are in 2022 Canadian Dollars (multiply by 0.8 for the US dollar equivalent).

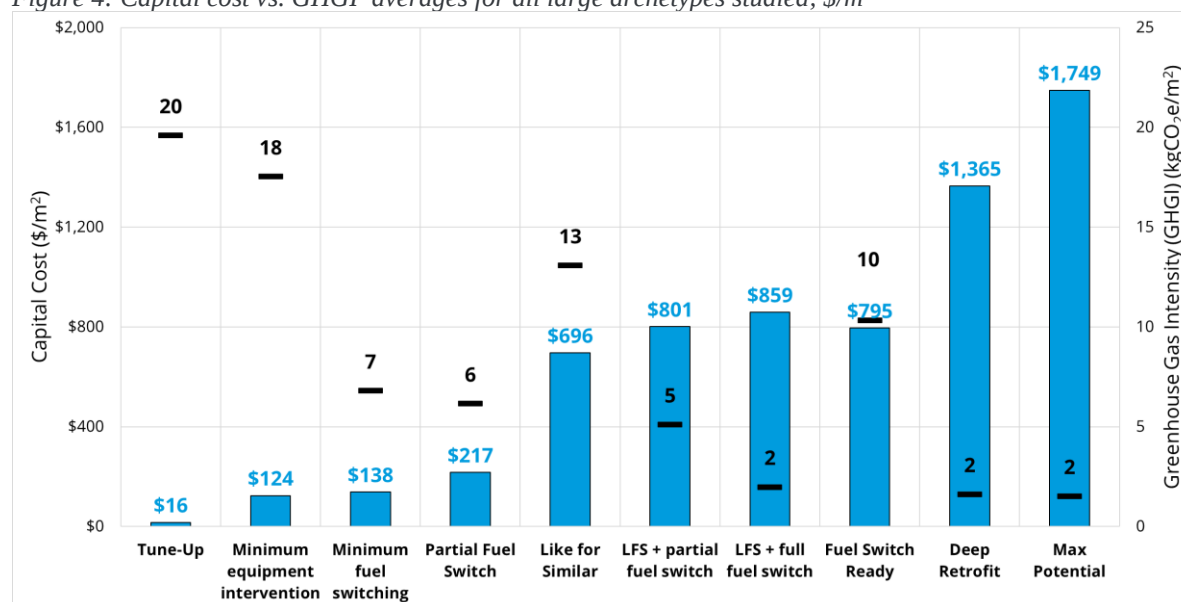
The energy savings by fuel from the models and adjusted package-specific capital costs are inputs to a life-cycle cost analysis (LCCA) for each package, including the baseline (“do nothing”) case which reflects only energy savings and no equipment change. The LCCA process includes accounting for capital (initial capital, replacement, and residual value of equipment at the end of the analysis time period); energy cost (escalating at agreed-to rates over time); and interest and discount rates specified by the city. Residual value of initial/renewed capital, linearly depreciated, as of the end of the 25-year period was included to capture the fact that some service components have longer lifespans than 25 years; incorporating residual value highlights the benefits of investing in building envelope measures. The Canadian federal carbon tax was broken out of energy costs as a separate line item, starting at \$50/tCO_{2e} in 2022, and escalated linearly to \$170/tCO_{2e} by 2030, and staying flat thereafter, per federal guidance (Canada 2021;). Because this carbon tax is economy-wide, it is included in owner costs.

Each package can then be compared to any of three relevant baselines, as described above: Baseline (i.e., energy-only change), Minimum Equipment (i.e., typical HVAC renewal) or Like-for-Similar (i.e., Minimum Equipment and enclosure renewal). These three base cases reflect three reference points for different policy-scale and facility-scale decision-making.

Cost Findings

As shown in Figure 4, packages range widely in price per m² with equipment-only changes in \$100-200/m² cost, like-for-similar changes in \$600-800/m², and deeper packages, which include renewal of facades and transformation of HVAC systems toward energy-efficient and low-carbon choices, range from \$900-1800/m², which puts them in a similar range as a new construction project.

Figure 4: Capital cost vs. GHGI averages for all large archetypes studied, \$/m²



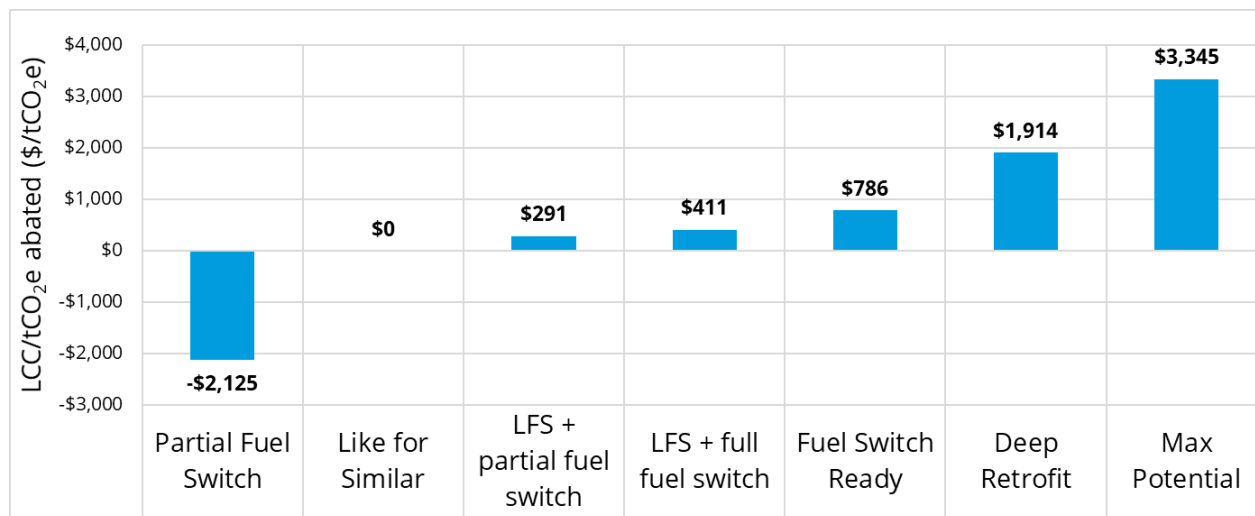
All facilities are likely to require at least one significant replacement of major HVAC equipment over the course of a 25-year study period. When compared to that case, alternate equipment choices such as heat recovery chillers and heat-pump rooftop units employed in the minimum and partial fuel-switch cases offer alternatives that are close to cost-neutral on a net present value basis, as shown in Table 6. The results are similar when comparing buildings that have to invest in enclosure upgrades as well compared to their fuel-switched alternatives.

Table 6: Incremental Lifecycle Cost, also known as Net Present Cost, vs. Minimum Equipment replacement for all large archetypes studied, in \$/m². Negative equals a positive Net Present Value (NPV).

	Tune-Up	Like for Similar	Minimum fuel switching	Partial Fuel Switch	LFS + partial fuel switch	LFS + full fuel switch	Fuel Switch Ready	Deep Retrofit	Max Potential
Total Lifecycle Cost (LCC)	-\$57	-\$9	-\$5	\$489	\$502	\$547	\$505	\$892	\$1,236
Capital LCC	-\$133	-\$4	\$30	\$580	\$630	\$703	\$613	\$1,227	\$1,714
Energy LCC	\$31	\$21	\$5	-\$37	-\$39	-\$35	-\$46	-\$69	-\$76
Carbon LCC	\$5	-\$28	-\$31	-\$13	-\$34	-\$42	-\$22	-\$43	-\$43
Residual LCC	\$40	\$1	-\$8	-\$40	-\$55	-\$79	-\$40	-\$222	-\$359

In the longer term, all facilities will require action towards decarbonization at the site level if the long-term goal is to decarbonize the entire stock. As shown in Figure 6, comparing all options that achieve significant emissions reduction (i.e. >50% average reduction or <8 kgCO₂e/m²/year) to their like-for-similar reference case shows that the cost of minor investment is paid for by incremental energy and carbon cost savings, but deeper investment in site-level reductions will require substantial additional resources.

Figure 6: Lifecycle Carbon Abatement Cost, relative to a like-for-similar replacement in Net Present Cost per tCO₂e; negative means cost savings



Citywide Modeling

With the results of the clustering and archetype-specific results above, we can transform the average baselines over time toward desired, policy-driven scenarios of citywide GHG reduction. Scenarios apply reductions according to a transformation/roll-out plan for each cluster based on discussions with the policy development team and in alignment with policy drivers for the specific sector (or even archetype). For BPS-like policies, it is assumed that facility operators will complete major facility activities (e.g., equipment change and/or enclosure renewal) at most twice before 2050, with the majority of facility operators making only one major change.

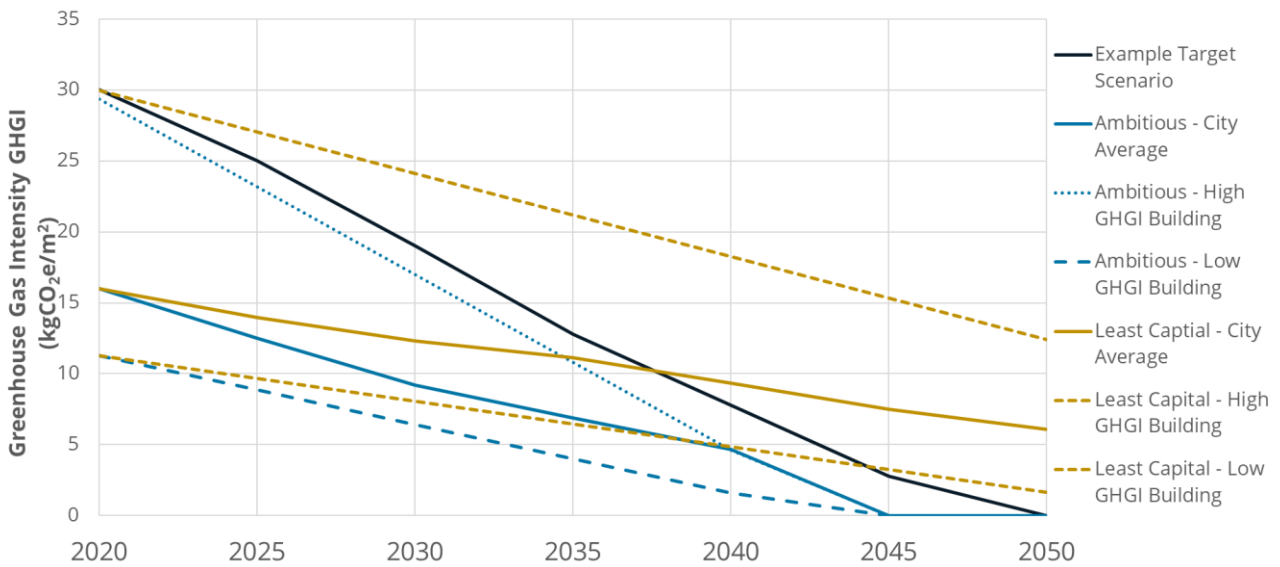
To date, two guiding scenarios have been studied. These two scenarios were used to help set the initial, interim, and final targets for each sub-sector and to confirm that the final facility-scale decarbonization action across all sectors was sufficient to achieve the City's long-term goals.

1. **Least Capital.** This pessimistic scenario assumes that all property owners will spend the least possible to achieve at least a 50% reduction in on-site emissions by 2050.
2. **Ambitious.** Likewise, this optimistic scenario assumes that all property owners will cost-effectively invest in an 80% reduction in on-site emissions by 2040 and also choose to achieve zero emissions through the purchase of renewable energy by 2045.

Figure 7 shows the city-wide modeling results, in five-year increments, of the Ambitious and Least Capital scenarios (solid-colored lines) as well as a range of archetype-specific pathways (dotted color lines). The black line shows a draft of the target for large commercial facilities intersecting the Least Capital scenario by 2037 while staying well-above the Ambitious scenario in the near term, but approaching it quickly by 2040. The selected target offers a reasonable middle road between the Ambitious and Least Capital paths.

The two bounding scenarios can also be transformed into key metrics for city-wide decarbonization action and related co-benefits. Both bounding scenarios achieve greater than 50% reduction by 2050, with remaining emissions attributed primarily to grid electricity and district energy. Cumulative emissions are reduced by 25% to 40%, with the Ambitious scenario offering a greater reduction due to a faster pace of change than other scenarios.

Figure 7: Ambitious and Least Capital pathways as compared to assumed GHGI targets



Financially, the bounding scenarios result in an incremental citywide investment for office and retail buildings over a business-as-planned scenario of \$1.5 to \$2.3 billion over 30 years. This cost reflects the range of investment needed to achieve office and retail building emissions of 5 kgCO₂e/m² (or less) by 2050. Direct jobs impacts were estimated assuming labor at 50% of the capital costs for envelope retrofits and 30% of the costs for other retrofit items, in line with assumptions used in similar studies (City of Toronto 2021). The investments driven by the policy are projected to create 200-350 FTE direct jobs per year in the construction industry, with many more indirect jobs in related or supportive sectors such as engineering, planning, and facility operations and management.

Target Setting and Policy Development

Based on the bounding scenarios created by the Least Capital and Ambitious scenarios, we were able to recommend a GHGI target pathway that optimized for both cost and GHG savings, while helping achieve the city's overall community-wide reduction goals. Setting a long-term zero emissions target is particularly critical for long-term capital planning by building owners. This is a key learning from other BPS case studies and was a key recommendation of the External Advisory Group. Setting interim targets is also important to provide a trajectory of improvement and prevent owners from kicking the can down the road.

Based on the clustering, costing, and citywide modeling, we recommended specific onsite and district GHGI targets for large office and retail buildings over 100,000 ft² for 2026. Targets were set at 25 kgCO₂e/m²/yr. for office and 14 kgCO₂e/m²/yr. for retail—aiming to cover the worst-performing 25% of large office and retail buildings initially, and start a trajectory between the Ambitious and Least Capital pathways. The city will also move to implement a benchmarking requirement, and may seek to revise targets as better data becomes available.

In addition, the Council has set a 2040 net zero emissions target for these buildings. RNG can be expected to be a critical pathway for some buildings to comply with near and long-term targets. However, RNG is a limited resource, and allowing buildings to meet the final GHGI targets through extensive RNG use could undercut the effectiveness of the program, and pull RNG away from higher value uses. Therefore, we worked with the City to develop a second BPS

enforcement metric: a *Heat Energy Use Intensity Limit*, a.k.a. a gas and district energy site EUI limit. The limit was set at 25 kWh/m²/yr., based on what the EEM packages showed could be cost-effectively achieved through a partial fuel switch or like-for-similar plus partial fuel switch.

We also recommend the city explore these best practice alternative compliance pathways:

1. A building-specific “trajectory approach,” where a building proposes to match the % reductions of the targets, but against their own baseline performance, providing an allowance for buildings with high GHGIs while preserving ambition (IMT 2021).
2. For buildings with no central HVAC systems, a prescriptive compliance option of replacing gas fired RTUs with heat pump RTUs with electric backup, as this upgrade is particularly cost-effective.
3. Finally, the City could also consider offering a custom “Retrofit Roadmap” approach wherein the building owner provides a Level 2 energy audit and detailed building performance improvement plan (which still must reach net zero carbon by 2040).

Further Discussion

Based on the above analysis, and extensive stakeholder engagement not discussed here, the City of Vancouver adopted the first BPS in Canada in May 2022. The City also adopted a regulatory roadmap that describes the phased introduction of prescriptive time-of-replacement equipment standards for secondary heating equipment, and the future expansion of carbon pollution limits to cover additional building types. The regional government, Metro Vancouver Regional District (MVRD), is also examining creating its own BPS system, to synergize with and expand the work done in Vancouver throughout the region.

While we have been able to estimate targets, savings, and costs without any benchmarking data, when a jurisdiction is able to collect sufficient verified benchmarking data prior to enforcing a BPS, that remains preferable. However, where such data is not available, the approach outlined in this paper can be used assuming a few key prerequisites:

1. First, it proved critical to reference and compare against a robust benchmarking dataset from another city in the same climate zone. Sufficient city benchmarking datasets now exist for many of the major climate zones in the U.S. and Canada. The following is a list of ASHRAE climate zones that contain jurisdictions with robust datasets, based on our experience working with these cities and their data: 2A (Orlando), 3A (Atlanta), 3B (San Diego), 3C (Los Angeles, San Francisco), 4A (New York City, Washington D.C.), 4C (Seattle), 5A (Toronto, Boston, Chicago), 5B (Denver), 6A (Minneapolis).
2. Having a robust set of audit data and reference buildings was also very useful. Access to reference building data for energy modeling assumptions and first costs was important.
3. As outliers are rarely fully captured in any modeling exercise, creating alternative compliance pathways for edge cases is especially important.

In addition to providing a model for creating an initial BPS in the absence of preexisting benchmarking data, the methodology laid out in this study is a replicable approach for any jurisdiction with a BPS that needs to understand retrofit pathways, potential citywide savings, and economic costs and benefits—even if targets have already been set.

Furthermore, having BPS limits for both GHGI and Site EUI (or heating energy use) is an exciting development—one we believe can help ensure that GHG-based BPS policies do not undermine energy efficiency, create equity burdens, or misdirect scarce renewable resources.

The research team is currently continuing to analyze the other building types. Through changing weather files, the team is also examining the potential impacts of a province-wide BPS.

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