Near-Net Zero Buildings in the North: Final Report | Project 11840.000

Arctic Canada Passive House Feasibility Study

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Executive Summary

Context

This study assesses the feasibility of achieving Passive House and near-net zero levels of energy performance for residential buildings (Steps 4 & 5 of the BC Energy Step Code) within Canada's challenging northern climate including all communities and regions within the Yukon, Northwest Territories and Nunavut (climate zones 7a to 8).

Tools for Compliance

Standards such as Passive House and codes such as the BC Energy Step Code (Step Code) follow enclosure-first principles yet use different energy modelling tools for compliance. As the Step Code and future policies base performance levels on existing programs such as Passive House, HOT2000, and hourly modelling programs, there is a need to better understand how the different modelling tools compare. This study compares the results from two modelling tools typically used for code compliance, HOT2000 and EnergyPlus™, versus the Passive House Planning Package (PHPP).

The tools used for code compliance have a set of standard assumptions for variable inputs such as schedules, set points, occupancy, etc. which are different for the standard assumptions used in Passive House compliance using PHPP. EnergyPlus, HOT2000, and PHPP also have different approaches of modelling various enclosure and mechanical systems and heat loss. These differences make aligning the two tools challenging. While it is possible to bring the results in PHPP closer to EnergyPlus or HOT2000 through aligning the variable inputs, considerable differences still exist and the methods to align them are non-trivial. Some of these differences are routed in core differences of the calculation algorithms for the two different tools.

Reaching High Performance Targets

This study demonstrates viable solutions to reach the energy targets in Steps 4 and 5 of the Step Code in the north as well as how Passive House certification using the Passive House Institute (PHI) program may be achieved in northern Canada. To do this, five northern archetypes were developed: articulated single family dwelling (SFD), simple form SFD, articulated multi-unit residential building (MURB), simple form MURB, and a 5-Plex. These archetypes were modelled in four northern locations: Fort St. John (climate zone 7a, 5,750 HDD), Whitehorse (climate zone 7b, 6,580 HDD), Yellowknife (climate zone 8, 8,170 HDD), and Resolute (climate zone 8, 12,360 HDD).

In anticipation of these near-net zero targets being very difficult to achieve in Canada's Far North, a set of highest performing practical energy conservation measures (ECMs) was established based on design experience and feedback from northern housing corporations. During the compliance modelling phase of work, these maximum measures were not exceeded so as to not go beyond what is currently feasible or practical with existing and available technologies and building practices. ECMs beyond these current practical northern limits are discussed in the report including thick walls with effective R-values of greater than R_{eff}-80 (IP), better than triple glazed windows with U-values better than <U-0.11 (IP), new cold climate mechanical ventilation systems, alternate space-heating and domestic hot-water equipment and systems.

The original Step Code targets (as of December 2017) were adapted by the BC government in response to how difficult the upper steps were to achieve in northern BC (the new targets were enacted in December 2018). Both sets of Step Code targets were modelled on the five northern archetypes in this study. The relaxation of the targets for climate zones 7a, 7b, and 8 in the new Step Code made Step 5 targets for Part 9 archetypes achievable using the highest performing practical ECMs. There were no adjustments to the Part 3 residential targets (of which Step 4 is the highest step), and thus the Step 4 targets were more challenging to achieve in the northern climate zones. The table below summarizes the energy modelling results and compliance with the high performance standards.

SUMMARY OF COMPLIANCE WITH HIGH PERFORMANCE TARGETS USING HIGHEST PERFORMANCE PRACTICAL ECMS FOR THE NORTH

		25% < CODE	STEP CODE (2017)		STEP CODE (2018)		PASSIVE HOUSE (PHI)
			STEP 4	STEP 5	STEP 4	STEP 5	
Fort St. John CZ 7a	SFD – articulated	Yes	Yes	Yes	Yes	Yes	No
	SFD – simple form	Yes	Yes	Yes	Yes	Yes	No
	MURB – articulated	Yes	Yes	N/A*	Yes	N/A*	Yes
	MURB – simple form	Yes	Yes	N/A*	Yes	N/A*	Yes
	5-Plex	Yes	Yes	Yes	Yes	Yes	No
Whitehorse CZ 7b	SFD – articulated	Yes	Yes	Yes	Yes	Yes	No
	SFD – simple form	Yes	Yes	Yes	Yes	Yes	No
	MURB – articulated	Yes	Yes	N/A*	Yes	N/A*	No
	MURB – simple form	Yes	Yes	N/A*	Yes	N/A*	Yes
	5-Plex	Yes	Yes	Yes	Yes	Yes	No
Yellowknife CZ 8	SFD – articulated	Yes	Yes	No	Yes	Yes	No
	SFD – simple form	Yes	Yes	Yes	Yes	Yes	No
	MURB – articulated	Yes	No	N/A*	No	N/A*	No
	MURB – simple form	Yes	Yes	N/A*	Yes	N/A*	No
	5-Plex	Yes	Yes	Yes	Yes	Yes	No
Resolute CZ 8	SFD – articulated	Yes	Yes	No	Yes	Yes	No
	SFD – simple form	Yes	Yes	No	Yes	Yes	No
	MURB – articulated	Yes	No	N/A*	No	N/A*	No
	MURB – simple form	Yes	No	N/A*	No	N/A*	No
	5-Plex	Yes	Yes	No	Yes	Yes	No

*The highest compliance target for Part 3 buildings within the BC Energy Step Code is Step 4

In Fort St. John and in Whitehorse, the Part 9 Step Code targets could be achieved by implementing innovative new dual core heat recovery ventilators (HRVs) without the need for preheat, very low air leakage rates (i.e. near Passive House level), triple glazed windows (U-0.17), and electric baseboard heating. In the two climate zone 8 locations, the ECMs required to meet the Step Code targets increased and often required quad glazed windows, and airtightness beyond Passive House levels (down to 0.15 ACH50 in some cases).

PHI Passive House targets were more challenging to meet than Step Code in all locations. Only the MURB archetypes were able to meet Passive House targets, and only in Fort St. John and Whitehorse (simple form, only). This illustrates the need to consider overall building design to meet high performance targets in the north—multiplexes with a simple rectangular form have lower energy use than smaller, individual residences. The differences in simple versus articulated SFDs and MURBs also demonstrate the importance of form factor in designing to reduce heating demand.

Overcoming Northern Barriers

Form factor is a critical energy efficient design consideration. More compact larger housing types (i.e. MURBs) are more efficient than SFDs for the same floor area. Achieving near-net zero or Passive House levels of thermal performance may only be feasible in compact larger multi-family housing types. Low window to wall ratios are also favourable, though for every building there will be an optimal window to wall ratio based on the selected window and wall, house orientation, and available solar radiation. Energy modelling can be used to assess the most optimal design.

There is a need for further development of high efficiency cold climate mechanical systems to help meet stringent absolute energy performance targets. Although using high efficiency electrical systems is ideal for reducing site energy consumption (upon which code-compliance metrics are based), not all northern communities have access to a clean electrical grid with sufficient capacity. This is a barrier that may need to be overcome if absolute targets are set, or targets could be relaxed in regions with limited electrical grid capacity. If fossil fuel systems are used, then the site energy consumption used for code compliance would be higher due to lower equipment efficiency.

Based on the sensitivity analysis of higher ECMs, technology development should be focused on better (lower U-value) windows with improved frames and better than quad performance glazing, 95% HRVs without the need for preheat. Testing cold climate heat pump heating and hot water systems as well as materials such as self-adhered membrane and tapes for field applied air barrier systems in cold north should also be considered, and training for achieving good airtightness and performing airtightness testing.

Costing

There is a notable difference in incremental capital cost (ICC) between simple form and articulated SFDs and MURBs, indicating that form factor is important for reaching high performance targets most cost-effectively. Improved enclosure measures allow downsizing the heating system, which can result in a mechanical equipment cost savings and balances out the ICC of the enclosure measures.

25% < code minimum cost is more consistent across climate zones compared to the absolute targets of the Step Code, illustrating the regional challenges in meeting absolute targets. In some scenarios (typically in Fort St. John and Whitehorse), achieving Step 4 has a lesser ICC than the 25% better than code target, partly because of the economic impact of improved enclosure measures decreasing mechanical equipment sizing.

Passive House targets could only be met for the MURB archetypes, not the SFDs or the 5-Plex. Even the MURBs could only meet the Passive House targets in Fort St. John and in Whitehorse (only the simplified form MURB in Whitehorse). Where Passive House targets were met for the MURB, the relative cost increase was between 11-15% of baseline construction costs. It is 4% less costly to meet Passive House for the simple form MURB versus the articulated form MURB in Fort St. John.

The incremental costs to meet Step 5 targets (for Part 9 buildings) range significantly depending on the archetype form factor and location. Step 5 could be met at a 9% cost increase over baseline construction costs for the simple form SFD in Fort St. John, Whitehorse, and Resolute. On the other hand, the articulated SFD met the Step 5 targets at a 23% cost premium. In contrast, the MURB experienced lower incremental cost to meet the Step 4 targets (highest step for Part 3 buildings), 1% to 7%, though the targets could not be met in all Far North locations (i.e. not in Resolute).

In general, it is more cost effective to achieve absolute energy performance targets for the MURB archetype than for the SFD or 5-Plex. Larger internal heat gains, smaller surface area to volume ratio, and a higher performance baseline result in lower incremental costs to achieve Step Code and Passive House performance targets for the MURB.

The high incremental costs to reach Step 5 and the inability to meet Passive House for SFDs in the Far North reflect that it may be unreasonable to continue using these single-family archetypes if high performance energy targets are used in the north. There are real challenges with meeting heating demand targets and a lack of cold-climate technology to cost-effectively meet Step 5 or Passive House with single family buildings in the north. A shift to other archetypes such as simple form MURBs and the development and testing of more cold-climate systems may be necessary if near-net zero energy targets are used in Canada's Far North.

Contents

Appendices

1 Introduction

Worldwide, buildings account for approximately one third of energy-related greenhouse gas emissions.[1] As countries around the world strive to reduce climate impacts, a building enclosure (aka envelope) first approach to energy efficiency in buildings has emerged as an effective option to decrease emissions from the built environment. This, coupled with right-sized energy efficient mechanical and ventilation systems, result in very low, near-net zero space conditioning energy performance and significant reductions in greenhouse gas (GHG) emissions from buildings. There are many uncertainties with the feasibility of reaching these ultra-high performance levels in challenging climates such as the Far North of Canada.

1.1 Project Overview

This study assesses the feasibility of achieving Passive House and near-net zero levels of energy performance as defined by Step 4 and 5 of the BC Energy Step Code, for residential buildings within Canada's challenging northern climate including the Far North (climate zones 7a to 8 in Figure 1.1, below).

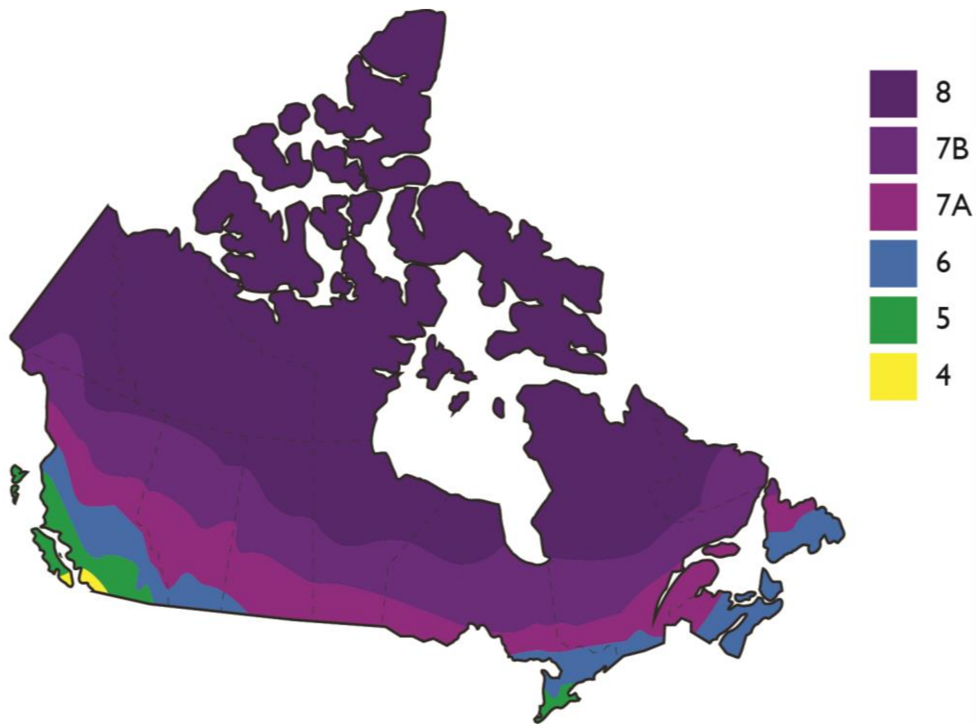


Figure 1.1 National Building and Energy Code climate map for Canada.

The findings in this study will facilitate the implementation of new near-net zero energy policies including a potential future National Energy Step Code and increasingly stringent greenhouse gas emission reduction targets in jurisdictions across Canada. This study also compares modelling tools including HOT2000 and EnergyPlus™ models versus the Passive House Planning Package (PHPP) as tools for code compliance. A 25% better than current code target is also assessed as a stepping stone to near-net zero targets. This work

[1] Frappé-Sénéclauze, T., Heerema, D., and Tam Wu, K. (2016): Accelerating Market Transformation for High-Performance Building Enclosures; Pembina Institute report .

addresses objectives for both NRCan and NRC code development and is aligned with the goals of the Pan-Canadian Framework on Clean Growth and Climate Change.

1.2 Modelling Tool Compatibility

Standards such as Passive House and codes such as the BC Energy Step Code follow enclosure-first principles yet use different energy modelling tools for compliance. As the Energy Step Code and future policies base performance levels on existing programs such as Passive House, HOT2000, and hourly modelling programs, there is a need to better understand how the different modelling tools compare. This is a challenging task because, in addition to various modelling tools, each policy and standard typically references its own set of standard modelling assumptions and protocols.

Different modelling programs inherently do not align perfectly as they are fundamentally different programs—EnergyPlus™, for example, is an hourly energy simulation program, while PHPP and WUFI (Wärme Und Feuchte Instationär – which translated means heat and moisture transiency) Passive use monthly/annual degree day calculations—yet, some adjustments can be implemented to make the results more comparable. Previous efforts to compare programs/standards have led to inconclusive results due to the significant differences between the modelling approaches.[2,3]

The work in this study will be valuable to jurisdictions that have adopted or are considering adopting one or more energy efficient building codes/standards such as Passive House or a performance-based Energy Step Code that leads to near-net zero levels of annual energy consumption. The results will help authorities set requirements and assess compliance with an understanding of how different modelling tools and protocols compare. This work will also assist building owners, designers, consultants, and project teams to understand how different standards and certification programs compare in terms of building energy performance, and to select the appropriate approach for their project. The analysis herein will especially inform setting performance targets in northern locations.

1.3 Passive House Institute (PHI)

The Passive House Institute (PHI) is driving innovation in high performance building enclosures.[4] An aspect of this innovation was the implementation of the first Passive House standard. This standard includes requirements for energy efficient buildings such as the following metrics, all with specific definitions and calculation procedures set by the PHI (further described in Section 2.3.1):

→ Heating Demand[5] ($kWh/m^2_{TFA}/yr$) or Heating Load[6] (W/m^2_{TFA})

→ Maximum Primary Energy[7] (PE) or Primary Energy Renewable[8] (PER) ($kWh/m^2_{TFA}/yr$)

[2] Multifamily New Construction Program (PON 3716): NYSERDA, <https://portal.nyserda.ny.gov/CORE_Solicitation_Detail_Page?SolicitationId=a0rt000000AGlIJAAT>.
[3] Ely, T. (2017): Comparison Study of Passive Houses using ERS, Prepared by City Green Solutions for Natural Resources Canada.
[4] Frappé-Sénéclauze, T., Heerema, D., and Tam Wu, K. (2016): Accelerating Market Transformation for High-Performance Building Enclosures; Pembina Institute report
[5] Heating demand is the annual heating demand for space conditioning within the Passive House enclosure.
[6] Heating Load is the maximum heating energy required by the building for space heating and conditioning of ventilation air calculated for a cold, clear day and a moderate overcast day.
[7] Primary Energy is the annual energy use of the building measured at the energy generation site.
[8] Primary Energy Renewable is the total annual energy use on site, includes multipliers on energy use based on the energy source and potential for simultaneous renewable production. Evaluates the building in an assumed future where all sources of energy are from 100% renewable sources.

- → Minimum airtightness requirements
- → Requirements for thermal comfort and hygiene

Furthermore, in this document, the terms “Passive House standard” and “Passive House” shall refer to those aspects as defined by the PHI. When another program which incorporates the concept of Passive House is described, the name of the determining body will be included.

The Passive House standard was developed in Germany and has been widely adopted, globally, as a method for achieving extremely low energy consumption in single-family dwellings (SFDs), multi-family residential buildings, and commercial buildings. The Passive House standard has been widely adopted in climate zones similar to the inland temperate climate of Germany yet has proven to be more difficult to achieve in significantly colder climates. For example, in Europe the majority of certified buildings are in regions between 40° and 60° latitude, with only a handful in Scandinavia above 60° latitude.

In North America, there are currently no Passive House Institute certified buildings farther north than climate zone 6.[9] Some northern buildings have been designed to achieve Passive House although did not achieve PHI certification due to higher than expected heating loads.

This study identifies the challenges of reaching Passive House certification in Northern Canada, including the Far North, and propose solutions to enable this standard to be used for new construction in colder climate zones including 7a, 7b, and 8 (see climate zone map, Figure 1.1).

1.4 BC Energy Step Code, Steps 4 & 5

The British Columbia government recently passed the BC Energy Step Code, which is a new voluntary energy compliance path within the BC Building Code (BCBC). It establishes progressive performance targets, or “Steps”, that support market transformation from the current energy efficiency requirements in the BCBC to net zero energy ready buildings by 2032.

This first edition of the code enacted in December 2017 includes requirements for each Step using the following metrics, all with specific definitions and calculation procedures set by subsections 9.36.6. and 10.2.3. of the BCBC (further described in Section 2.3.1):

- → Thermal Energy Demand Intensity[10] (TEDI, kWh/m²/yr) or Peak Thermal Load (PTL, W/m²)
- → Mechanical/Total Energy Use Intensity (MEUI[11] for Part 9/TEUI[12] for Part 3, kWh/m²/yr) or % better than EnerGuide reference house (%<ERS) for Part 9
- → Minimum airtightness requirements

[9] Certified Buildings Map: Passive House Institute, <https://database.passivehouse.com/buildings/map/>, [accessed August 2018].
[10] TEDI is the annual heating energy demand per square meter of gross floor area for space conditioning and conditioning of ventilation air.
[11] MEUI is the annual energy use on site per square meter of gross floor area including space heating equipment, space cooling equipment, fans, service water heating equipment, pumps and auxiliary HVAC equipment. It does not include appliances and lighting.
[12] TEUI is the annual energy use on site per square meter of gross floor area including space heating equipment, space cooling equipment, fans, interior and exterior lighting devices, service water heating equipment, pumps, auxiliary HVAC equipment, appliances, receptacle loads, elevators and escalators.

In December 2018, the Step Code was updated and the PTL metric was removed as it was found to be redundant with TEDI and the definition of the % better than reference house was redefined to allow for more than just the EnerGuide reference house. There were also changes to the targets, which are described later in this report.

The highest Step (Step 5 for Part 9 buildings, Step 4 for Part 3 residential buildings) of this code reflects performance levels near the Passive House standard. These upper steps are intended to achieve near-net zero ready levels of energy efficiency. In theory, net zero ready targets suggest that net zero may be possible with the addition of renewable energy sources such as onsite PV should the building owner desire to do so. Codes Canada is also developing a similar Energy Step Code with targets approaching net zero ready levels of construction. [13]

BC Housing commissioned a study to assess the cost implications of compliance with the Step Code: the 2017 Metrics Research report (herein referred to as the "Metrics Study").[14] The study found that Steps 4 and 5 could not be feasibly achieved for all archetypes in the colder climate zones (7a, 7b, 8), especially in the case of small houses. That study needed to significantly adjust the geometry of some archetypes to minimize surface area to volume ratios and corners. Window areas were also reduced, and the highest efficiency equipment options were implemented. This shows that it may not be feasible to reach such high levels of performance with articulated buildings and familiar technologies and that changes to geometry and fundamental design principles may be required.

Although the Metrics Study demonstrated that it is very difficult to comply with the Upper Steps above climate zone 6, the 2017 study did not focus on solutions since there are only ~4,000 residents in those areas in BC. The Metrics Study was updated in 2018 to reflect the changes to the metrics and targets as of December 2018. The updated Part 9 targets could be met as far north as Uranium City, SK (as a proxy for climate zone 8 in BC), though were not modelled any further north in Canada and the Part 3 targets could not all be met in all climate zones in BC.[15] This study will address the issue of meeting the Upper Steps for both Part 9 and Part 3 residential building types across Canada in climate zones 7a, 7b, and 8. This study aims to demonstrate viable solutions to reach the energy targets in Steps 4 and 5 as well as achieving Passive House certification in Northern Canada (an alternate approach to near-net zero performance), specifically including the Territories and remote Far North regions.

1.5 Challenges in the Far North

The Energy Step Code and the Passive House standard are very effective methods for achieving high levels of energy efficiency in the built environment, although the question of their feasibility in extreme climates in the Far North remains. There is a need to understand the barriers to implementation in Northern Canada where there are significant opportunities to minimize heating demand. In remote northern communities, this also

[13] Net Zero Ready is generally defined as buildings that have been designed to minimize their energy consumption to the point where the total amount of energy used by the building on an annual basis could be provided through on-site generation if this was added. Near-Net Zero refers to reducing energy consumption as much as possible/practical.

[14] BC Housing, Morrison Hershfield, E3 Eco Group, and Integral Group (2017): Energy Step Code Building Beyond the Standard, 2017 Metrics Research Summary Report, <http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/construction-industry/building-codes-and-standards/reports/bc_energy_step_code_metrics_research_report_summary.pdf>.

[15] BC Housing, Morrison Hershfield, E3 Eco Group, and Integral Group (2018): Energy Step Code Building Beyond the Standard, 2018 Metrics Research Full Report Update, <http://energystepcode.ca/app/uploads/sites/257/2018/09/2018-Metrics_Research_Report_Update_2018-09-18.pdf>.

means less reliance on fuel shipments and locally generated power, and the ability to construct new dwellings without overloading the existing local energy distribution capacity.

The challenges are both technical and non-technical. For example, there may be a need to develop new technologies such as higher performance windows and doors, higher R-value thin insulation, insulating window blinds, mechanical equipment with better frost control, or possible use of novel heat reclamation with the building stored water/grey-water/sewage etc. Non-technical challenges include the lack of trained labour force in some area, limitations on local construction equipment, materials transportation challenges, site access and weather windows including barge, sealift, and ice road availability (Figure 3.1), less solar availability during the coldest months of the year, availability of fuel and local utility capacities limiting the use of electrical energy for heat instead of heating oil, and other unique geographic constraints that can impact cost, design choices, and project decision making.

This study elucidates the specific enclosure and mechanical system requirements, the feasibility based on technology and capacity, and the associated costs to achieve ultra-high performance buildings in Northern Canada, including the Far North.

1.6 Research Questions

This study explores the feasibility of achieving Passive House performance and Steps 4 and 5 of the BC Energy Step Code for a range of residential building types in Northern Canada. The major research questions are:

- → What are the major challenges in achieving such high performance buildings in Northern Canada, including the Far North, and how can we overcome them?
  - → Are there available resources (labour capacity, renewables, etc.) to reach targets? Do sufficient technologies exist?
- → What are some effective strategies to achieve near-net zero targets, including changes to fundamental design methods (optimal form-factor, enclosure, mechanical)?
  - → What kind of future technologies need to be developed to achieve the energy targets in colder climates? Do the targets need to be adjusted?
- → How do the different modelling tools for achieving these targets compare and do their assumptions restrict their applicability to Northern Canada?
  - → Can results from PHPP, HOT2000, and EnergyPlus™ be used as comparable compliance paths?
- → What is the incremental cost of such high performance buildings in Northern Canada, including the remote locations?
  - → How do the costs compare between articulated versus simple geometry buildings and between remote versus more urban locations?

The following section describes the methodology that was used to answer these questions.

2 Methodology

To assess the feasibility of meeting high performance building codes and standards, in Northern Canada, the scope of work includes 5 Tasks. The results of these tasks are summarized in this report, and details of their methodology are provided in this Section.

1) **Literature review** to gather information on high performance buildings in the northern Arctic as well as the southern Antarctic global regions as well as to gather information on region-specific practices that may impact modelling assumptions.
2) **Modelling tool comparison** of different tools for energy code compliance (PHPP, HOT2000, and EnergyPlus™), highlighting the key differences that may affect a direct comparison of results from different programs. Strategies for aligning the modelling protocols are discussed.
3) **Compliance modelling** to understand what is needed to achieve Passive House targets and Steps 4 and 5 of the BC Energy Step Code (near-net zero performance) in Northern Canada. A 25% better than current energy code target is also assessed.
4) **Analysis of barriers** and challenges with reaching these targets in Northern Canada and the Far North. This will include an assessment of constructability and availability of materials (e.g. renewables and technology) in remote northern locations, as well as potential solutions to overcome key barriers.
5) **Costing analysis** for the materials and labour needed in constructible scenarios as defined in Task 3: Compliance modelling. This will include a cost comparison of buildings with simple geometry versus articulated buildings in reaching high performance targets.

2.1 Literature Review Methodology

A literature review was conducted to inform the analysis and to ensure that the proposed solutions to high performance design are applicable to the North. This task assessed examples of successful low energy housing in northern locations, focussing on buildings that had completed construction and had verified performance data to use as proof of concept for the technology implementation. Studies from all cold climate locations were included in the literature review.

In addition to review of published documents, discussions with northern housing stakeholders were conducted to ensure relevance of the housing characteristics and energy efficiency measures to Canada's North and to capture variations in local housing practices. Stakeholder consultation occurred via teleconferencing and in person at the Northern Housing Forum in Yellowknife, NWT.[16] The literature review summarizes northern-specific construction considerations, examples of strategies that have been used for high performance buildings in northern climates, and examples of how high performance energy targets have been adapted for northern climates by other jurisdictions or programs.

The literature review was used to provide insight into the following key areas to guide the study:

[16] Northern Housing Forum. Polar Knowledge Canada. Explorer Hotel, Yellowknife, NWT, Canada. May 1 – 3, 2018.

- → Identify characteristics of current northern housing construction including what is working and what could be improved.
- → Present examples of successful low energy or net zero energy housing in cold climates and assess which strategies were used to achieve targets.
- → Determine the design characteristics required for successful northern housing.
- → Characterize low energy performance targets adapted for use in northern locations.
- → Identify the key technologies used to achieve low energy targets and potential future technologies in development.

The literature review and stakeholder engagement were also leveraged to inform the selection of northern archetypes to use in the analysis of this study.

2.1.1 Archetype Development

Archetypes were developed for this feasibility study through consultation with project stakeholders as well as our previous work developing northern archetypes and projects with northern housing corporations. The literature review and consultation with project stakeholders informed the selection of three main archetypes:

- → Single family dwelling (SFD)
- → Multi-unit residential building (MURB)
- → 5-Plex row house

Within the SFD and MURB archetypes, two versions of building geometry were assessed (simple form factor and articulated design) for a total of five archetypes. These two different geometry scenarios will enable the comparison of costs and feasibility for reaching high performance targets for different design styles. The two scenarios have identical floor areas and mechanical systems for a direct comparison. With the different geometries, the five archetypes are:

1. Single family dwelling (SFD), simple form factor (Figure 2.1)
2. Single family dwelling (SFD), articulated design (Figure 2.2)
3. Multi-unit residential building (MURB), simple form factor (Figure 2.3)
4. Multi-unit residential building (MURB), articulated design (Figure 2.4)
5. 5-Plex row house (Figure 2.5)

For the SFD and 5-plex archetypes, three different ground conditions were used in the modelling work based on typical construction in the northern locations. Slab on grade was used in Fort St. John and Whitehorse, bedrock was used in Yellowknife, and elevated above grade was used in Resolute. Regional differences for connections to utilities and common fuel types are discussed in Section 6, though electric systems were used in the SFD and MURB modelling work for simplicity and comparability (i.e. energy use within fuel oil heated buildings can be estimated based on equipment and system efficiencies as compared to electrical heating at 100%).

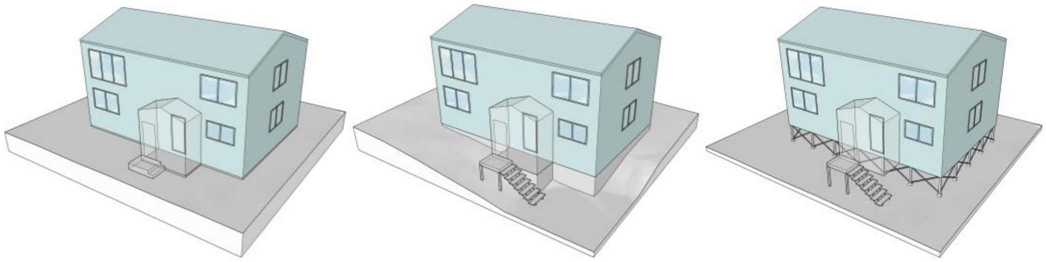


Figure 2.1 Single family dwelling (SFD), simple form factor. Three different ground conditions were used in different locations: slab on grade (left), on bedrock (centre), and elevated above permafrost (right).

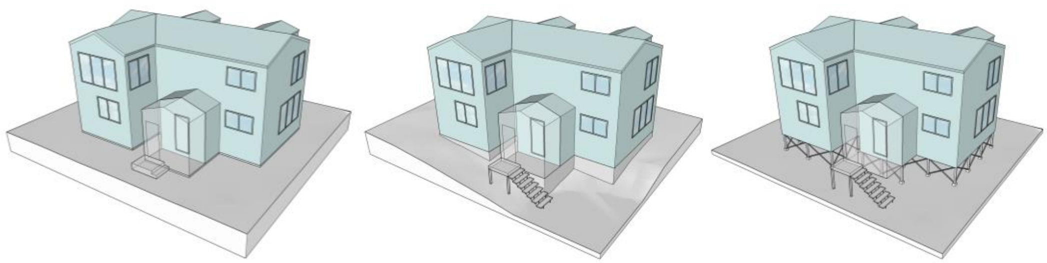


Figure 2.2 Single family dwelling (SFD), articulated form factor. Three different grounds conditions were used in different locations: slab on grade (left), bedrock (centre), and elevated above permafrost (right).

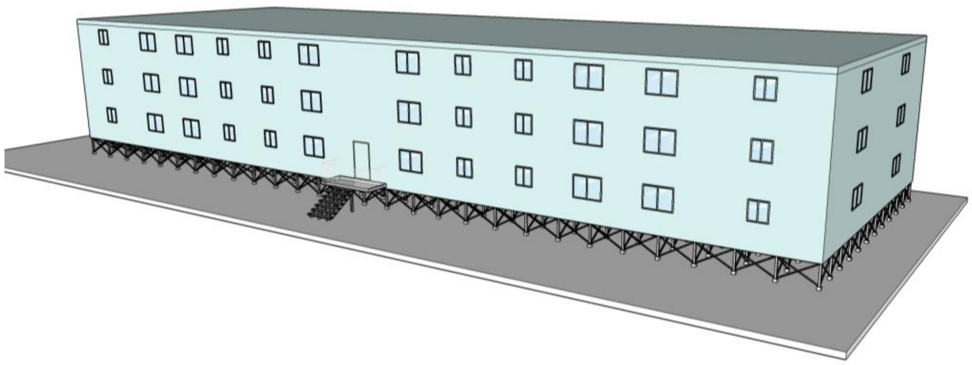


Figure 2.3 Multi-unit residential building (MURB), simple form factor.

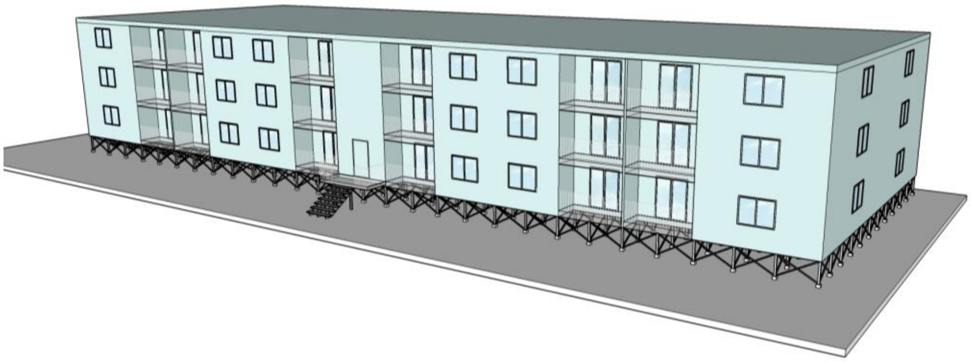


Figure 2.4 Multi-unit residential building (MURB), articulated form factor.

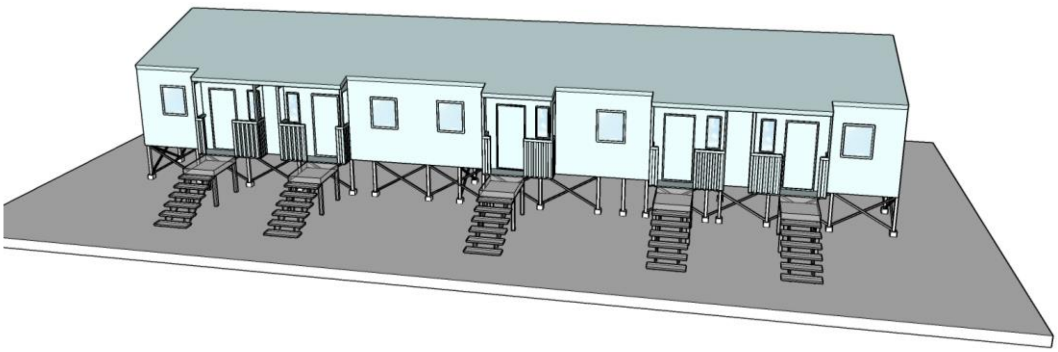


Figure 2.5 5-Plex row house elevated above permafrost. Different ground conditions were used in different locations. Front elevation image from Nunavut Housing Corporation's Public Housing 5Plex 2018-2019 drawings.

The key characteristics of the five archetypes are summarized in the table below. Note that the building characteristics shown here represent the baseline buildings (per NBC 9.36 or NECB); enclosure and mechanical systems are adjusted to meet high performance targets in the modelling tasks. There are slight variations in archetype floor characteristics depending on the permafrost conditions and typical building methods of the locations.

TABLE 2.1 SUMMARY OF ARCHETYPE CHARACTERISTICS				
ARCHETYPE	DESIGN/SHAPE	FEATURES	MECHANICAL*	NOTES
Single-family dwelling – *Articulated design*	- 15% window-to-wall ratio - Articulated, typical of newer neighbourhoods in Whitehorse/ Yellowknife	- Floor area: ~1,800 ft² - 2x6 wood framing - 3 bedrooms - Unheated storage room & entrance	- Heating: electric baseboards - DHW: electric - Ventilation: HRV with preheat - Other loads: standard EnerGuide base loads	Ground conditions to be adjusted for northern locations with permafrost (exposed floor) and bedrock (slab-on-grade).
Single-family dwelling – *Simplified form factor*	- 10% window-to-wall ratio - Rectangular, no articulation			
Multifamily dwelling – *Articulated design*	- 17% overall window-to-wall ratio - Articulated, with balconies, typical of Whitehorse/ Yellowknife	- Floor area: ~32,000 ft² - Suite size: ~900 ft² - 3-storeys - 2x6 wood framing	- Heating: electric baseboards - DHW: electric, in-suite - Ventilation: low efficiency in-suite heat recovery with electric pre- and post heat, air handling unit supplying corridor with tempered air ventilation - Other loads: NECB 2011 base loads	Electric systems are based on previous studies with NRCan & CHMC[17]. Energy consumption can be estimated for oil-based systems using effective equipment efficiencies.
Multifamily dwelling – *Simplified form factor*	- 9% window-to-wall ratio - Rectangular, no articulation, no balconies, typical of MURBs above treeline			
5-plex, row house	- 10% window-to-wall ratio - Rectangular, no articulation, no balconies	- Floor area: ~6,000 ft² - Suite size: ~1,000 ft² - 1-storey - 2x6 wood framing - Heated crawlspace	- Heating: oil-fired hydronic in CZ8; electric baseboards elsewhere - DHW: oil-fired indirect in CZ8; electric elsewhere - Ventilation: in-suite HRVs with hydronic preheat - Other loads: standard EnerGuide base loads	Ground conditions to be adjusted for northern locations with permafrost (exposed floor) and bedrock (slab-on-grade). Based on the 2018 Nunavut row houses design provided by Nunavut Housing Corporation.

*Mechanical efficiencies to be determined by code-minimum requirements.

[17] RDH Building Science Inc.: Energy Efficient Housing Guidelines for Whitehorse, YT: Energy Optimized House, <http://www.energy.gov.yk.ca/pdf/Energy-Efficient-Northern-Housing-Guide-Energy-Optimized.pdf>.

The SFD and MURB archetypes are used in the Modelling Tool Comparison work, whereas all 5 archetypes including the 5-Plex are used in the Compliance Modelling work.

2.2 Modelling Tool Comparison Methodology

This section describes the methodology used to compare the different modelling tools that may be used for compliance with future building code. Table 2.2 summarizes the models for Part 9 and Part 3 buildings for this comparative analysis. Two different modelling tools were used to model both a code-minimum archetype and a high performance archetype within each building type (Part 9 and Part 3). Following an analysis of key differences, the tools were aligned as closely as possible with user inputs that could be altered.

The modelling tools used in this analysis are as follows:

→ HOT2000 version 11.5: The tool used for Part 9 code-compliance modelling through the performance path with standardized EnerGuide inputs and protocols.

→ OpenStudio version 2.3.0, an EnergyPlus™ interface: A tool that is commonly used for Part 3 code-compliance using NECB-specified inputs and protocols.

→ Passive House Planning Package (PHPP) version 9.6a: The tool used for Passive House Institute (PHI) compliance along with its specified standard inputs and protocols. PHPP may be used for both Part 9 and Part 3 building types.

HOT2000 and PHPP were used to model both the high performance and code-minimum SFD archetypes. The HOT2000 and PHPP models were initially modelled using EnerGuide and PHI protocols, respectively. Then the PHPP model was aligned to the HOT2000 model using the standardized EnerGuide inputs and protocols.

OpenStudio (EnergyPlus™) and PHPP were used to model both the high performance and code-minimum MURB archetypes. The EnergyPlus™ and PHPP models were initially modelled using NECB and PHI protocols, respectively. Then the PHPP model was aligned to the EnergyPlus™ model using the standardized NECB inputs and protocols.

TABLE 2.2 SUMMARY OF MODELS FOR ASSESSMENT TOOL COMPARISON			
BUILDING TYPE	ARCHETYPE	ORIGINAL TOOLS; MODELLING INPUTS	ALIGNED TOOLS; MODELLING INPUTS
Part 9 – Single-family dwelling (SFD)	Articulated (Code-minimum)	HOT2000; EnerGuide	HOT2000; EnerGuide
		PHPP; PHI	PHPP; *EnerGuide**
	Simple form (High performance)	HOT2000 EnerGuide	HOT2000 EnerGuide
		PHPP PHI	PHPP *EnerGuide**
Part 3 – Multi-unit residential building (MURB)	Articulated (Code-minimum)	EnergyPlus™ NECB 2011	EnergyPlus™ NECB 2011
		PHPP PHI	PHPP *NECB 2011**
	Simple form (High performance)	EnergyPlus™ NECB 2011	EnergyPlus™ NECB 2011
		PHPP PHI	PHPP *NECB 2011**

*User-defined inputs have been modified to either EnerGuide or NECB where possible. The core algorithms have not been altered.

To align the modelling tools for Part 9 and for Part 3 code compliance, a list of inputs for the two assessment tools were created to determine key differences in assumptions and standardized inputs (Appendix A and Appendix C). These inputs were grouped into seven categories: base loads, building enclosure, temperature setpoints, ventilation system, natural air infiltration, heating and cooling system, and domestic hot water system. Although key differences were noted and aligned where possible, the modelling programs have fundamental differences that cannot be altered by the user. As such, a brief discussion of strategies for allowing the use of different programs for code compliance is provided in Section 4.

2.3 Compliance Modelling Methodology

This section describes the general methodology and the targets used for compliance modelling for Part 9 and Part 3 building types. For this part of the study two Part 9 archetypes were modelled, a 5-plex row house and a single-family dwelling plus the Part 3 MURB archetype. The 5-plex archetype was based on 2018 public housing provided by the Nunavut Housing Corporation. The single-family home and MURB archetypes were further split into two sub-archetypes, articulated and simple form. This was done to investigate the impact of building form factor in achieving specific performance targets.

Four locations were modelled, reflecting a range of northern conditions (Figure 2.6).

Figure 2.6 Four locations used in the compliance modelling analysis of the five northern archetypes: Fort St. John, climate zone 7a, 5750 HDD; Whitehorse, climate zone 7b, 6580 HDD; Yellowknife, climate zone 8, 8170 HDD; Resolute, climate zone 8, 12360 HDD.

2.3.1 Performance Metrics

The upper steps of the BC Energy Step Code and Passive House compliance were used as targets for achieving near-net zero performance. The BC Energy Step Code, and Passive House performance metrics are defined in Table 2.3, and Table 2.4, respectively.

TABLE 2.3 BC ENERGY STEP CODE PERFORMANCE METRICS		
Metric	**Unit**	**Definition**
Part 9 buildings		
PTL, Peak Thermal Load	W/m^2_{GFA}	Maximum heating energy required by the building for space conditioning and for conditioning of ventilation air, estimated by using an energy model, at a 2.5% January design temperature.
MEUI, Mechanical Total Energy Use Intensity	$kWh/m^2_{GFA}/yr$	Annual mechanical energy use on site, including heating, cooling, ventilation, service water heating, pumps, and auxiliary HVAC equipment. MEUI omits lighting and household appliances.
TEDI, Thermal Energy Demand Intensity	$kWh/m^2_{GFA}/yr$	Annual heating energy demand for space conditioning and conditioning of ventilation air.
%<ERS, % better than EnergyGuide reference house	%	Metric that results when, using HOT2000 software, version 11 or newer and Natural Resources Canada's EnerGuide Rating System, version 15 of newer, the energy consumption of the proposed building, not including the EnerGuide assumed electric base loads is compared

TABLE 2.3 BC ENERGY STEP CODE PERFORMANCE METRICS		
		against the corresponding automatically-generated reference house, not including the EnerGuide assumed electric base loads.
Part 3 buildings		
TEDI, Thermal Energy Demand Intensity	kWh/m^2_{GFA} /yr	Annual heating energy demand for space conditioning and conditioning of ventilation air.
TEUI, Total Energy Use Intensity	kWh/m^2_{GFA} /yr	Annual energy use on site, including heating, cooling, ventilation, service water heating, pumps, auxiliary HVAC equipment, lighting and plug load energy.

In December 2018, the Step Code was updated and the PTL metric was removed as it was found to be redundant with TEDI and the definition of the % better than reference house was redefined to allow for more than just the EnerGuide reference house.

The TEUI and MEUI requirements ensure that the building equipment and systems use energy efficiently. TEDI reflects the building's modelled heating demand, and is primarily influenced by building enclosure, thermal bridging, airtightness and the ventilation system. A lower TEDI value is achieved by designing the enclosure to be highly insulated, free of thermal bridges, and airtight. Using a heat recovery ventilator will minimize the energy used to condition the outdoor air.

TABLE 2.4 PASSIVE HOUSE PERFORMANCE METRICS*

Metric	Unit	Definition
Heating Demand	kWh/m^2_{TFA} /yr	Annual heating demand for space conditioning within the Passive House enclosure.
Heating Load	W/m^2_{TFA}	Maximum heating energy required by the building for space conditioning and for conditioning of ventilation air calculated for a cold, clear day and a moderate overcast day.
Primary Energy (PE)	kWh/m^2_{TFA} /yr	Annual energy use of the building measured at the energy generation site.
Primary Energy Renewable (PER)	kWh/m^2_{TFA} /yr	Total annual energy used on site, includes multipliers on energy use based on the energy source and potential for simultaneous renewable production. Evaluates the building in an assumed future where all sources of energy are from 100% renewable sources.
Frequency of overheating	%	Frequency of indoor temperature above the comfort limit, defined as 25 C

* The Passive House Standard also includes cooling load, and cooling demand. However, these metrics are not relevant in this study since the archetypes do not include cooling, the metrics are therefore not defined here.

The BC Energy Step Code and Passive House Standard also define minimum airtightness requirements, summarized in Table 2.7.

It should be noted that the BC Energy Step Code performance metrics are based on site energy use, meaning that they incorporate the site efficiencies, including the use of heat pumps or re-use of waste heat. The Passive House performance metrics on the other hand, include additional factors that accounts for the source of energy generation, including distribution and storage losses. This is imbedded in PHPP as a PER factor, which is location specific and provided by PHI.

Another difference between the BC Energy Step Code and Passive House metrics is the reference area that the metrics use. The BC Energy Step Code use the conditioned floor area, here referred to as Gross Floor Area (GFA). Passive House metrics are area normalized based on the treated floor area (TFA), which is a measure of the useful floor area with areas weighted depending on the use of the room.

The five archetypes were modelled to comply with the BC Energy Step 4 and 5, and Passive House, the targets are summarized in Table 2.5 and Table 2.6 for Part 9 and Part 3 buildings.

Table 2.5 summarizes the high performance code compliance targets for Part 9 and Part 3 buildings. For the Part 9 archetypes, HOT2000 was used to model six compliance targets: code-minimum per NBC 2015, 25% more energy efficient than code, and Step 4 and Step 5 of the BC Energy Step code. In December 2018, the Step Code targets for Part 9 were updated, Table 2.5 includes the revised Step 4 and Step 5 targets (2018), as well as the original (2017). For Part 3 archetypes, EnergyPlus™ was used to model three compliance targets: code-minimum per NECB 2011, 25% better than code, and Step 4 of the BC Energy Step Code (the highest step for Part 3 residential buildings).

TABLE 2.5 HIGH PERFORMANCE CODE COMPLIANCE TARGETS FOR PART 9 AND PART 3 BUILDINGS

Building type & modelling tool	Compliance target	TEDI (kWh/m^2_{GFA}/yr)	PTL (W/m^2_{GFA})	TEUI (kWh/m^2_{GFA}/yr)	MEUI (kWh/m^2_{GFA}/yr)	% < than ERS
Part 9 – SFD / 5-Plex HOT2000	Code minimum	-	-	-	-	-
	25% better than code	-	-	-25%	-	-
	Step 4 (2017)	50 or PTL	45 or TEDI	-	55	40
	Step 5 (2017)	15 or PTL	10 or TEDI	-	25	-
	Step 4 (2018)	CZ 7a: 55 CZ 7b: 65 CZ 8: 80	-	-	CZ 7a: 70 CZ 7b: 85 CZ 8: 100	40
	Step 5 (2018)	CZ 7a: 35 CZ 7b: 50 CZ 8: 60	-	-	CZ 7a: 55 CZ 7b: 65 CZ 8: 75	-
Part 3 – MURB EnergyPlus™	Code minimum	-	-	-	-	-
	25% better than code	-	-	-25%	-	-
	Step 4	15	-	100	-	-

Table 2.6 summarizes the Passive House compliance targets for Part 9 and Part 3. It should be noted that Passive House compliance targets are the same regardless of

building type. For Passive House compliance, PHPP was used to model to a heating demand target of 15 kWh/(m^2_{TFA} yr) or a heating load of 10 W/m², and a Primary Energy Renewable (PER) target of 60 kWh/(m^2_{TFA}/yr) or Primary Energy (PE) of 120 kWh/(m^2_{TFA}/yr).

TABLE 2.6 PASSIVE HOUSE TARGETS FOR PART 9 AND PART 3 BUILDINGS

Building type	**Modelling tool**	**Compliance target**	**Heating Demand (kWh/m²TFA /yr) Or Heating load (W/m²TFA)**	**Primary Energy Renewable (kWh/m²TFA/ yr) Or Primary Energy (kWh/m²TFA/ yr)**	**Frequency of overheating (%)**
Part 9 – SFD & 5-Plex	PHPP	Passive House Classic	15 or 10	60 or 120	< 10%
Part 3 – MURB	PHPP	Passive House Classic	15 or 10	60 or 120	< 10%

The BC Energy Step Code also defines minimum airtightness requirements for Step 2 to 5, for Part 9 buildings. There are no minimum airtightness requirements for the Part 3 building compliance targets, however, airtightness testing is required. Table 2.7 summarizes the BC Energy Step Code (Step 4 and 5), and Passive House minimum airtightness requirements.

TABLE 2.7 MINIMUM AIRTIGHTNESS REQUIREMENT

Target	**Minimum airtightness requirement**
BC Energy Step Code (Part 9 buildings)	
Step 4 (2017 & 2018)	1.5 ACH50
Step 5 (2017 & 2018)	1.0 ACH50
Passive House Standard	
Passive House Classic	0.6 ACH50

In anticipation of the near-net zero targets being very difficult to achieve in Canada's northern climate, a set of highest performance practical energy conservation measures (ECMs) were established based on design experience and feedback from northern housing corporations (Northwest Territories Housing Corporation, Nunavut Housing Corporation, and Yukon Housing Corporation). During the compliance modelling phase of work, these maximum measures were not exceeded so as to not go beyond what is currently feasible or practical with existing and available technologies and building practices. Many factors were considered when trying to determine the highest performing practical ECMs, these included:

- Constructability of building assemblies with practical levels of insulation and assembly thicknesses.
- Existing technology of high performance building components such as windows.

- → Availability of high performance building materials and components in the North.
- → Impact of measure on whole building energy performance.

The highest performance of building components used as measures to reach near-net zero energy targets in the North is listed in Table 2.8, below. These measures were exceeded in Section 6 to better understand which areas of construction should be improved for increasing performance beyond what is currently feasible.

TABLE 2.8 HIGHEST PERFORMING PRACTICAL BUILDING COMPONENTS USED AS MEASURES TO REACH TARGETS

COMPONENT	PERFORMANCE	DESCRIPTION/EXAMPLE
Building Enclosure		
Above ground wall	R_{eff}-80 ft²-hr-°F/Btu (RSI-14.1 m²-K/W)	This maximum recommended effective R-value is based on practical considerations for construction. It can be constructed in many different ways and would most simply be 2x6 split insulated wall with approximately 14" of exterior insulation attached with long screws or could alternately be a deep double stud wall system. This is the upper recommended limit for wall R-value as more exterior insulation would be practically difficult to build and deep framed walls become very thick and more challenging to effectively insulate with fibrous fill in these large of cavities.
Roof	R_{eff}-100 ft²-hr-°F/Btu (RSI-17.6 m²-K/W)	This maximum recommended effective R-value is based on the practical depth for insulation within an attic assembly and typical roof slope for northern house (above or below the tree line) to effectively manage snow and wind.
Exposed Floor	R_{eff}-80 ft²-hr-°F/Btu (RSI-14.1 m²-K/W)	This maximum recommended effective R-value is based on practical maximum depths of floor joists/trusses filled with batt or blown fibrous insulation or use of exterior rigid insulation similar to the wall system.
Slab on Grade	R_{eff}-40 ft²-hr-°F/Btu (RSI-7.0 m²-K/W)	This maximum recommended effective R-value is based on total heat loss through a ground bearing assembly and practical thickness of foam insulation.
Door	R-8 ft²-hr-°F/Btu (RSI-1.41 m²-K/W)	This is a practical performance limit based on available insulated door products currently on the market.
Window	U-0.12 Btu/ ft²-hr-°F (USI-0.69 W/ m²-K)	This is a practical performance limit based on available high performance frames with krypton filled quad-glazing IGUs and triple low-e coatings currently on the market.

TABLE 2.8 HIGHEST PERFORMING PRACTICAL BUILDING COMPONENTS USED AS MEASURES TO REACH TARGETS		
Window SHGC[18]	0.40	Relatively high balanced SHGC typically used in Passive House designs to maximize passive solar heat gains. Higher SHGC products are available with fewer low-e coatings though at expense of a higher IGU U-value.
Airtightness	SFD: 0.30 ACH50 MURB & 5-Plex: 0.15 ACH50	0.15 ACH50 is 4x tighter than the Passive House requirement and has been achieved on several new construction projects using an exterior sealed sheathing air barrier strategy for walls/roof. 0.30 ACH50 was used for the SFD since the larger surface area to volume ratio makes it a more challenging archetype.
Ventilation		
HRV efficiency	81%	This efficiency is the highest tested efficiency for a cold climate HRV that does not require preheat or defrost cycles based on a dual core system[19]. Note that higher efficiency (e.g. 95%) units require significant amount of pre-heat energy or defrost control and thus were not used for this northern modelling.
Ventilation rate corridor - MURB	10 cfm/suite	The lowest recommended ventilation rate for corridors using a balanced ventilation approach, based on industry expertise.
Mechanical System		
Space Heating System	Cold climate air source heat pump, annual COP 1.5-2.1[20].	COP depends on location due to differences in outdoor air temperature. Systems revert to electric resistance (COP 1.0) at a threshold low temperature.
Domestic Hot Water System	CO_2 heat pump, annual COP 2.5-3.0	COP depends on location due to differences in outdoor air temperature
Drain Water Heat Recovery (DWHR)	65%[21]	This is the maximum allowable DWHR efficiency in the HOT2000 modelling program, reflecting high performance units.

In scenarios where the highest performing practical ECMs were not required to meet the energy targets, the ECMs were selected using a design-team approach, optimizing the building performance while minimizing cost and complexity. In some scenarios, the highest performing practical ECMs were not enough to reach the energy targets, which is discussed in more detail in Section 5, and solutions for which are discussed in Section 6.

In January 2019 NRCan released HOT2000 version 11.6 fixing a problem with the energy saving calculations in relation to DWHR systems. Previous versions overestimated the

[18] G-value is typically used in Passive House modelling. SHGC refers to the overall heat gain coefficient for the glazing and window frame whereas g-value refers to the solar heat gain for the glazing only. A SHGC of 0.4 will roughly translate to a g-value of 0.5.
[19] Per testing by NRC (commercial unit), presented at Polar Forum April 30th, 2018.
[20] Kegal, M., Sager, J., Thomas, M., Giguere, D., and Sunye, R. (2017): Performance Testing of Cold Climate Air Source Heat Pumps; 12th IEA Heat Pump Conference.
[21] Average efficiency based on Passive House certified component database.

energy savings. Some energy modelling results used in this analysis are based on previous versions of HOT2000, though do not impact the overall conclusions of the analysis.

2.4 Incremental Capital Cost Analysis

Costing analysis was performed to estimate the capital cost of achieving the high performance targets modelled in the compliance modelling section. Costs were calculated as the incremental capital cost (ICC) of construction over a code-minimum baseline archetype for simple and articulated SFDs, MURBs, and simple 5-Plexes. For most ECMs, the ICC was the material cost of additional or higher performance materials or equipment over the code-minimum, plus any additional construction labour requirements to install.

The ICCs were analyzed as an area-normalized cost for each of the performance targets. Costs of achieving different performance targets were compared for buildings of simple versus articulated geometry in each climate zone. The change in cost across climate zones to achieve high performance targets was also compared. For Part 9 archetype buildings, the differences in ICC to meet the 2017 and 2018 BC Energy Step Code targets were compared. Finally, costs were analyzed as a percentage increase over the typical total cost of construction in each location modelled, referencing existing work done on construction costs in the Far North.

Where possible, ICCs were leveraged from past work carried out by RDH and BTY for CMHC. The costs from this past work represent material and labour costs specific to the northern locations studied in this report. For costs that were not assessed in this past work, location factors were used to adjust costs obtained from southern Canadian locations per common industry practice. The location factors inflate costs to account for higher labour costs, as well as transportation costs to deliver materials and equipment to northern locations. The factors are representative of each location in this study, however they cannot account for specific challenges such as seasonal transportation logistics.

3 Literature Review

A literature review was conducted to inform the analysis and to ensure that the proposed solutions to high performance design are applicable to the North, as described in Section 2.1. Resources that were consulted include published international studies and reports as well as stakeholder consultation with northern housing organizations via teleconferencing and in person at the Northern Housing Forum in Yellowknife, NWT.[22] The literature review summarizes northern-specific construction considerations, examples of strategies that have been used for high performance buildings in northern climates (section 3.2), and examples of how high performance energy targets have been adapted for northern climates by other jurisdictions or programs (section 3.3). A more detailed discussion of northern specific issues is discussed later in section 6.

3.1 Construction Considerations in Canada's North

Typical practice for providing housing to northern Canadian communities has been to adapt designs made specific to the South. This often neglects the specific cultural needs of northern communities. Research studies conducted by CMHC[23] have identified key characteristics of home design that can meet the needs of northern communities. General findings are that Inuit space use is focused more on social gatherings within a small number of rooms with greater interaction. Traditional food gathering, and preparation practices need to also be considered. Some southern designs can be modified to facilitate these preferred functions in the following ways:

→ Modify the design to eliminate long corridors and instead integrate open living rooms and kitchens.

→ Construct large open plan houses and include large, enclosed cold porch areas to facilitate local food gathering and preparation practices.

→ Favour single story instead of multi-storey construction for accessibility of elders. Homes above the frost line are typically already elevated above a crawlspace.

→ Install larger stainless-steel kitchen sinks for traditional food preparation.

→ Increase ventilation to account for more food prep and higher occupancy rates.

Design, construction, and operation of buildings in Canada's North faces numerous challenges associated with the relative geographic location and remoteness from the rest of the country. Challenges associated with the geographic or climatic characteristics include cold temperatures, high wind, snow and ice management, significant variations in solar patterns. Some examples of the unique challenges due to the remoteness of location are site access and conditions, transportation of goods, weather variables, availability of labour, construction equipment limitations, and scheduling challenges, among numerous others. All of these factors can influence the project decision making process and final cost to deliver housing. In addition to these generic challenges, each specific location has unique challenges resulting from geographic constraints, infrastructure development, and availability of personnel that can influence the suitability of construction.

[22] Northern Housing Forum. Polar Knowledge Canada. Explorer Hotel, Yellowknife, NWT, Canada. May 1 – 3, 2018.
[23] Dawson, P.C. (2004): An Examination of the Use of Domestic Space by Inuit Families Living in Arviat, Nunavut; Canada Mortgage and Housing Corporation, Socio-economic Series 04-031.

Transport logistics can be a significant challenge for construction in Northern communities. A map of the primary logistics routes in Canada is provided in Figure 3.1. The method of accessing communities in Canada's North varies significantly by location. The transportation requirements can add significantly to the construction costs and add additional considerations for timing and scheduling to account for appropriate weather windows. Many locations in Canada's North are not accessible by standard road systems typical in the South. Unique logistics features include:

→ Ice Roads – roads constructed seasonally over frozen land and water to allow transport of commercial goods into communities. Ice roads are typically available from late December to Early April.

→ Barges – barging is used to transport goods along Northern river systems and from large sea lift vessels to land.

→ Sea Lifting – the use of large shipping vessels to transport construction goods from Southern ports, such as Churchill, MB or St. Catherine's, QC, to Northern communities. Sea lifting is possible after the ice thaw, typically from early July to early October.

→ Flying – both materials and personnel can be transported by plane throughout the North. Some communities have dedicated airports and services with varying frequency throughout the year. In some instances, aircraft infrastructure will need to be constructed in communities specifically to facilitate materials transport by aircraft.

Figure 3.1 Logistics map of Canada, depicting the typical transport routes.[24]

There are also many considerations for mechanical systems in northern locations due to the cold temperatures. For example, frost protection of HRVs is a major concern when designing ventilation systems to bring in outdoor air. Since the outdoor air can reach temperatures as low as -60 degrees Celsius, HRVs tend to freeze up and need to either run in recirculation mode or run a preheat coil. Recirculation may not provide adequate ventilation to living spaces while preheat is energy intensive. Recent research in dual core HRVs for cold climates is advancing technology that can withstand very low temperatures without freezing up though costs are still quite high for these technologies and units themselves are large creating challenges for integration into smaller single family homes.

Considerations for fuel choice in the design of HVAC systems are also important in the North as many remote communities are reliant on intermittent fuel shipments. It is best practice to reduce the reliance on fuel shipments through energy efficiency, yet fuel switching to electricity is often not possible in very remote communities as they are off electrical grids and solar generation is not reliable in the winter. HVAC design should also consider the remoteness of the location as it is often difficult to source replacement parts for unique and complex systems. Complex systems are also more challenging to maintain in regions without access to trained HVAC contractors.

[24] RDH Building Science Inc. (2016): Illustrated Guide for Northern Housing Retrofit prepared for Natural Resources Canada and the Canada Mortgage and Housing Corporation.

In addition to transportation challenges, construction considerations in the North need to also consider the harsh climate conditions. For example, common construction materials used in the South may not be applicable in the North due to wide temperature swings including very cold temperatures and exposure to persistent ice and snow or freeze-thaw conditions. Common design strategies to achieve high performance buildings may also not be as applicable to the North, for example passive solar heat gains are not reliable during the coldest and darkest months of the year in higher latitudes. Potential solutions to these barriers for constructing high performance buildings in the North are explored in Section 6.

3.2 High Performance Buildings in the North

The extreme cold temperatures and challenging operating environment associated with northern locations has led to an interest in constructing low energy building pilot projects. These pilots allow for testing of novel design strategies and technologies believed to allow for reduced energy consumption within cold climates. In the cold climate of the Far North, low energy consumption is generally achieved by focussing on decreasing the heating demand. Examples of high performance buildings in the north have the commonality of using high R-value walls, low U-value windows, and airtightness measures.

Examples of these buildings constructed in the North include:

→ A low-energy Duplex constructed in Sisimut, Greenland[25] designed with a focus on improved enclosure performance which achieved a measured EUI of 140 kWh/m^2/yr.

→ A series of super-insulated residential buildings were constructed in Yukon and reported on by CMHC. These buildings relied on the use of improved enclosure performance to reduce energy consumption. The case studies consisted of single family, duplexes, or triplexes with measured energy consumption between 73 kWh/m^2/yr to 208 kWh/m^2/yr[26].

→ The Northern Sustainable Housing (NSH) projects funded in part by CMHC constructed in Canada's North with the goal of demonstrating affordable, energy-efficient housing in Northern locations. The buildings focused on improved enclosure performance and efficient mechanical systems. Modelled annual energy consumption was reported to range from 160 kWh/m^2/yr up to 530 kWh/m^2/yr.

→ A single family home was constructed by a local couple in Dillingham, Alaska, with help from friends not professional builders. The focus was on high performance enclosure to reduce heating demand, and high efficiency electric mechanical systems. It achieved a world record for airtightness by using a double-frame technique. Passive House principles were implemented, though the project was not certified. Modelled annual consumption was 68 kWh/m^2/yr.[27]

These example pilot projects as well as others that have already been reported on extensively, may be used to inform successful design strategies. The typical energy

[25] Rode, C., Vladyková, P., and Kotol, M. (2010): Air Tightness and Energy Performance of an Arctic Low-Energy House; DTU Library Technical Information Center of Denmark.
[26] Canada Mortgage and Housing Corporation (2017): Super-Insulated Housing in Yukon; Canada Mortgage and Housing Corporation.
[27] Marsik, T. (2012): Net Zero Energy Ready Home in Dillingham, Alaska; UAF Bristol Bay Campus, Alaska Building Science News.

efficiency features used in the construction of these attempts at low energy buildings in northern locations consist of:

- → Improved insulation of the building enclosure, including high R-value walls, roof, and foundation.
- → High performance windows with low-conductivity frames and triple to quadruple glazing to achieve low U-values.
- → Attention to achieving stringent airtightness targets.
- → Heat recovery ventilators (HRVs) with high heat recovery effectiveness and considerations for frost protection/preheat.
- → Improved heating system efficiency with high efficiency pellet heaters, electric baseboards, or cold climate air-source heat pumps.
- → Photovoltaic panels to supply renewable energy when possible.

These strategies have informed the methodology for achieving high performance energy targets in this study. Each building system was optimized to the highest performing practical ECM that is feasible with currently available technology and building practices. A discussion of potential opportunities for future product development and new building practices is provided Section 6.

3.3 Adapting Northern Targets

Due to the harsh climate typical of northern latitudes, there are examples of other jurisdictions and programs adapting their compliance targets to make them more achievable for northern locations. This section summarizes some examples of energy efficiency target adaptation for different climates.

3.3.1 PHIUS Targets

The single metric criteria used by the Passive House Institute means that mild climates may easily achieve certification, while certification may not be possible in extreme cold climates. Recognizing this challenge, the Passive House Institute US (PHIUS) has argued that certification criteria should be climate-specific.

PHIUS developed climate-specific space-conditioning certification targets starting with the PHIUS+ 2015 standard. Targets were developed based on research done by PHIUS and the Building Science Corporation[28] with support from the US DOE Building America program. The research used cost-optimization to develop formulas that generate custom performance criteria for heating and cooling load and demand that are specific to a particular location. The PHIUS+ 2015 standard was then based on these climate-specific criteria, and a new set of criteria could be generated for any new location where a certified building was being planned.

The PHIUS+ 2018 standard includes a new set of criteria that adjusts for climate, form ratio (a ratio of building enclosure area to usable interior conditioned area), occupant density (a ratio of usable interior conditioned floor area to number of modeled occupants), and cost of energy sources (per Province or State). It should also be noted that the PHIUS standard includes limits on whole building source energy intensity not

[28] Wright, G., Klingenberg, K., and Pettit, B. (2015): Climate-Specific Passive Building Standards; Building Science Corporation.

shown here. Building source energy targets are constant for all locations and are based on occupancy for residential archetypes whereas PHI targets are based on building area. The intent of this adaptation is to adjust the building enclosure performance within defined limitations yet maintain per-occupant whole-building performance.

Table 3.1 compares several PHI and PHIUS certification criteria requirements for a variety of climate zones. The targets may be more or less stringent than the PHI targets. The targets vary significantly between the PHIUS programs, particularly with the introduction of the 2018 standard that adjusts targets based on ratios for building form, occupant density, as well as Provincial- or State-wide energy costs. In the table shown, the target allowances for SFDs are greater than MURBs in all studied cases due to the form and occupancy ratios, not typology. Note that the space conditioning targets in Yellowknife and Whitehorse are notably affected by the Provincial/Territorial-specific costs of energy in relation to locations in Ontario and British Columbia. Yellowknife, especially, has very high electricity cost compared to these provinces, which makes the PHIUS 2018 heating targets more stringent because higher electricity prices justifies more investment in heat-saving upgrades.

TABLE 3.1 COMPARISON OF PHI AND PHIUS CERTIFICATION CRITERIA.

	Criteria	PHI	PHIUS+ 2015	PHIUS+ 2018* MURB	PHIUS+ 2018* SFD
Toronto, ON (Zone 6A)	Heating Demand, kWh/m^2	15	20.2	15.5	34.4
	Cooling Demand, kWh/m^2	15	5.7	6.0	23.7
	Heating Load, W/m^2	10	14.5	12.6	24.3
	Cooling Load, W/m^2	10	11.4	6.0	13.6
Fort St. John, BC (Zone 7A)	Heating Demand, kWh/m^2	15	31.0	22.7	48.9
	Cooling Demand, kWh/m^2	15	3.2	2.2	17.0
	Heating Load, W/m^2	10	19.6	19.2	35.3
	Cooling Load, W/m^2	10	9.5	3.5	8.5
Whitehorse, YK (Zone 7B)	Heating Demand, kWh/m^2	15	35	24.6	54.6
	Cooling Demand, kWh/m^2	15	3.2	4.1	15.8
	Heating Load, W/m^2	10	20.8	20.2	37.9
	Cooling Load, W/m^2	10	8.8	3.2	8.2
Yellowknife, NT (Zone 8)	Heating Demand, kWh/m^2	15	38.5	16.7	48.9
	Cooling Demand, kWh/m^2	15	3.2	6.6	18.3

TABLE 3.1 COMPARISON OF PHI AND PHIUS CERTIFICATION CRITERIA.					
	Heating Load, W/m^2	10	18.9	16.4	35.0
	Cooling Load, W/m^2	10	9.1	3.5	8.8

*Requirements within a climate zone and energy-cost region vary by building form and occupant density; values shown are based on the simple form-factor MURB and SFD modelled in this study: MURB 32,000 sf with occupancy of 29 m^2/people (3 people per suite), SFD 1,800 sf with total occupancy of 4 people.

3.3.2 Updates to the BC Energy Step Code

The BC Energy Step Code was enacted in December 2017. The first release of this new energy code for BC included whole building equipment and systems metrics (%<ERS or MEUI, and TEUI) as well as thermal energy demand intensity (TEDI) and peak thermal load (PTL) metrics. The tiered approach of the Step Code has different targets for the metrics from Steps 1 through 5. The first release of the Step Code had the same TEDI target for all climate zones in BC in Step 5, 15 kWh/m^2/yr. The inspiration of the Step 5 TEDI target came from the Passive House Heating Demand target, which is also 15 kWh/m^2/yr, albeit calculated differently. Comparative modelling has shown that TEDI and Passive House Heating Demand do not align, and that the Passive House target is typically more stringent (see Section 5 for compliance modelling to meet these targets).

After subsequent modelling studies, it was agreed that the 15 kWh/m^2/yr TEDI target was unreasonable for the northern climates in BC. Among other updates to the BC Energy Step Code, the TEDI targets for each of the seven climate zones in BC (4, 5, 6, 7a, 7b, and 8) were adjusted to provide a more realistic roadmap to Net Zero Energy Ready buildings, which is the goal of the Step Code. The relaxation of TEDI targets in upper climate zones provides builders throughout BC with a more feasible path to reach Step 5 using currently available technologies and design practices. These adjusted targets may be more feasible for northern Canada as well, though have not yet been extensively tested for suitability in regions outside BC.

Table 3.2 illustrates the changes to the TEDI targets from the original 2017 version of the Step Code compared to the updated 2018 version of the Step Code. Red denotes when the targets became more stringent (Steps 2-4 in lower climate zones) and green denotes when the targets were relaxed (Steps 2-4 in higher climate zones, and Step 5 for all locations except climate zone 4, which stayed at the original 15 kWh/m^2/yr limit).

TABLE 3.2 CHANGES TO THE TEDI METRIC IN THE BC ENERGY STEP CODE

Steps	**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7a**	**Zone 7b**	**Zone 8**
Step 1	N/A	N/A	N/A	N/A	N/A	N/A
2017 Step 2	45	60	70			
2018 Step 2	35	45	60	80	100	120
2017 Step 3	40	50	60			
2018 Step 3	30	40	50	70	90	105
2017 Step 4	25	40	50			
2018 Step 4	20	30	40	55	65	80
2017 Step 5	15					
2018 Step 5	15	20	25	35	50	60

As the Step Code does not consider energy supply, it remains unclear how the relaxation in TEDI targets for upper climate zones will affect northern buildings ability to reach Net Zero using onsite renewables, which may be more challenging in northern communities for two reasons:

1) Target relaxations for upper climate zones bring northern buildings further from the 0 kWh/m²/yr target of Net Zero, and

2) The availability of renewable energy to reach Net Zero may be more limited in northern locations.

This is currently not in the scope of the Step Code since they have defined Net Zero Ready as 'energy consumption as low as reasonably possible' and does not consider renewable energy supply.

3.3.3 Northern Europe Building Codes

Some northern European jurisdictions have made adaptations to building energy performance targets based on climate. Examples from Sweden, Greenland, and Norway are provided below.

Swedish National Building Code (3,500 – 7,000 HDD). Boverkets byggregler (BBR), version BSF 2011:6 (including addendums up until BSF 2018:4), regulates a buildings energy performance by setting maximum energy consumption targets for the buildings primary energy (EP_{pet}). The EP_{pet} metric is measured in kWh/m^2/yr. EP_{pet} is comprised of the building's energy use where the energy used for heating ($E_{uppv,i}$) has been adjusted with a geographical adjustment factor (F_{geo}), and multiplied with a primary energy factor (PE_i) based on the source of the energy (energy provider (district energy, electricity, etc.), and divided by the area of heated space (A_{temp}). The equation below is used in the Swedish building code to calculate a building's primary energy target based on geographic and energy source factors.

$$EP_{net} = \frac{\sum_{i=1}^{6}\left(\frac{E_{uppv,i}}{F_{geo}} + E_{kyl,i} + E_{tvv,i} + E_{f,i}\right) \times PE_i}{A_{temp}}$$

Figure 3.2 Equation used in the Swedish building code to calculate a building's primary energy target based on geographic and energy source factors.

The Swedish maximum targets for EP_{pet} are listed in Table 3.3. Previously, Sweden's energy targets were dependent on climate zones, where Sweden was divided into four climate zones. This approach was recently replaced by dividing Sweden into 21 counties, each county is assigned a geographic adjustment factor, F_{geo}. The geographical adjustment factor, also called climate index, ranges from 0.8 to 1.9. This climate index is used to, based on observed data and projections, describe the climate for the specific location, including seasonal variations as well as future climate scenarios. The heating degree days for Sweden vary between 3,500 and 7,000, where the most northern town can be compared to Whitehorse (Climate Zone 7b).

TABLE 3.3 THE SWEDISH ENERGY TARGETS FOR SINGLE FAMILY DWELLING AND MULTI-UNIT RESIDENTIAL BUILDINGS		
Residential Building Types	Energy Performance (EP_{pet},) kWh/m²/yr	Peak electric load, kW
Single Family Dwelling where the conditioned area (A_{temp}) is 50 m² or larger	90	$4.5+1.7\cdot(F_{geo}-1)$*
Single Family Dwelling where the conditioned area (A_{temp}) is less than 50 m²	No requirement	No Requirement
Multi-unit residential buildings	85*	$4.5+1.7\cdot(F_{geo}-1)$*

*Adjustments may be done based on hygiene and/or building size.

The peak electric load is defined as the peak electric load used for space heating, domestic hot water and ventilation, and varies with the geographical adjustment factor (F_{geo}).

There is also a Swedish standard based on Passive House adapted for the Swedish climate conditions; Forum for Energieffectiva Byggnader (FEBY) – which translates to Forum for Energy-efficient Buildings. The latest requirements are defined in FEBY18. The standard has three levels (FEBY Gold/ Silver/Bronze) and are designed to integrate with the BBR regulations and definitions mentioned above.

In the Swedish adaptation of the Passive House standard, a building's peak heat loss, VFT_{DVUT} ($W/(m^2\cdot A_{temp})$) for buildings larger than 600 m² is adjusted by the 'DVUT' by location. DVUT is the 'dimensioned outdoor winter temperature' based on the years 1981 – 2010. The following is the maximum peak heat loss for the three levels:

1) Gold; 14 W/m²
2) Silver; 19 W/m²
3) Bronze; 22 W/m²

For buildings smaller than 600m² an additional ($600 - A_{temp}$)/110 W/m² is permitted. There is also a relaxation for colder climates:

→ +1 W/m² for locations where DVUT is below -17 degrees Celsius

→ +2 W/m² for locations where DVUT is below -22.1 degrees Celsius

Greenland Building Code. Greenland has energy performance targets in its building code, with relaxations for colder climate zones. The Greenland Building Code (Bygningsreglement, 2006) splits energy performance by geographic location with Zone 1 being south of polar circle and Zone 2 north of the polar circle[29]

→ Zone 1: 420 + 280/e [MJ/m²] per year, where e is the number of storeys.

→ Zone 2: 510 + 325/e [MJ/m²] per year, where e is the number of storeys.

[29] Vladykova, P. and Rode, C.: Integrated Design and Passive Houses for Arctic Climates, < https://www.researchgate.net/publication/237742656>.

Norwegian Building Standard (4,500 – 7,500 HDD). In 2010 a new building standard, NS 3700, was implemented in Norway. The NS 3700 defines a maximum value admitted for the annual net space heating needs and is based on the Passive House standard though with targets adapted for varying climates. The annual net space heating need (Q_{max}) is dependent on both the local annual mean outdoor temperature ($Ø_{ym}$) and the local space heating peak design outdoor temperature, which is defined as the lowest 3-days mean temperature during a 30-year measurement period[30]. The indoor set point is fixed at 21 degrees Celsius for the calculation of Q_{max}:

$$Q_{corr} = \max\left(\left(250 - A_{fl}\right), 0\right) / 100,$$

$$\begin{aligned} Q_{max} = {} & 15.0 + 5.4 \times Q_{corr} + (2.1 + 0.59 \times Q_{corr}) \\ & \times \max((6.3 - \theta_{ym}), 0). \end{aligned}$$

Figure 3.3 Equation used in the Norwegian building standard to calculate a building's annual space heating target based on local temperature averages. A_{fl} is floor area.

The above mentioned jurisdictions have acknowledged the need to adjust the building energy performance targets based on climate. Adaptations to energy targets within Canada is further discussed in Section 7.3.2.

3.4 Key Findings from Literature Review

→ Challenges associated with the geographic or climatic characteristics include cold temperatures, high wind, snow and ice management, significant variations in solar patterns. For these reasons, common strategies for high performance buildings in southern Canadian latitudes are not adequate for the north.

→ Transport logistics can be a significant challenge for construction in Northern communities. The transportation requirements can add significantly to the construction costs and add additional considerations for timing and scheduling to account for appropriate weather windows.

→ A review of case studies found that in the cold climate of the Far North, low energy consumption is generally achieved by focussing on decreasing the heating demand. Examples of high performance buildings in the north focus on using high R-value walls, low U-value windows, and airtightness measures.

→ Heat recovery ventilators (HRVs) with high heat recovery effectiveness and considerations for frost protection/preheat were also common in northern case studies, as well as improved heating system efficiency with high efficiency pellet heaters, electric baseboards, or cold climate air-source heat pumps.

→ Other jurisdictions (e.g. Swedish National Building Code, Greenland Building Code, Norwegian Building Standard) have acknowledged the difficulty in reaching near-net zero energy targets in extreme northern climates and have modified energy targets to reflect differences in locations and heating needs (e.g. PHIUS, BC Energy Step Code, jurisdictions in Scandinavia).

→ There should be a balance between allowing for enough flexibility in targets depending on the heating demand variations of locations and minimizing the

[30] Georges, L., Berner, M., and Mathisen, H.M. (2014): Air heating of passive house in cold climates: Investigation using detailed dynamic simulations; Building and Environment, V. 74, p. 1-12.

complexity of how targets are calculated. These literature review scenarios offer a range of examples of strategies, each finding this balance for their jurisdiction.

4 Modelling Tool Comparison

In anticipation of a National Step Code and other future high performance regulations, it is important to understand the tools that may be used to comply with these codes and standards. If more than one modelling tool or protocol is accepted for compliance how do the different modelling methodologies compare? Should the different tools be aligned to ensure comparable compliance with the same targets? What are some considerations that need to be addressed when more than one tool may be used for compliance?

This section outlines key differences between different whole-building model types, a comparison and alignment of HOT2000 and PHPP for SFD archetypes, and a comparison and alignment of EnergyPlus and PHPP for MURB archetypes for one northern location. Key considerations for modelling buildings in the Far North and recommendations for using multiple tools for code compliance are also provided.

4.1 Previous Studies

Differences between energy performance results using different modelling tools and protocols has been recognized in recent years. There have been studies to assess key differences, although not comprehensively and also not with a northern focus. Below are summaries of previous studies that considered different modelling tools. Our study builds on this previous work by exploring how the tools/protocols may be aligned as well as considering applicability to the North.

4.1.1 NYSERDA Report

In 2016, The New York State Energy Research and Development Authority (NYSERDA) commissioned a study to evaluate the equivalency and translational capacity of PHIUS, PHI, and ASHRAE 90.1 Appendix G energy standards.[31] The goal was to allow a variety of rating systems to qualify building projects for incentives under the NYSERDA Multifamily New Construction Program (MF NCP). The report found significant differences between the modelling protocols for the three programs, which resulted in a discrepancy of nearly two-fold when comparing the baseline building using ASHRAE 90.1 (modelled in eQuest) versus Passive House (using the protocols of the PHI and modeled in PHPP). The baseline used the prescriptive requirements of ASHRAE Standard 90.1 2010 and 90.1 2010 Appendix G Baseline Design. Nevertheless, the study still moved forward with an energy analysis and comparison of the three programs and stated an approximate 30% energy improvement by certifying through PHI or PHIUS compared to the baseline.

The 30% improvement reported in the NYSERDA study is significantly lower than the expected 50-60% improvement of Passive House buildings compared to typical new construction that meets most North American building codes.[32] This raises questions of the validity of comparing energy efficiency standards that use different modelling tools and protocols. The NYSERDA study also only considered energy conservation measures "*commonly seen on projects certified through each program*" as opposed to a whole building approach that would be needed to compare the energy consumption across multiple programs and standards. For example, their study modelled design features

[31] Karpman, M. and Beaulieu, S. (2017): ASHRAE 90.1 Appendix G / PHIUS+ / Passivhaus Comparison Evaluation for Multifamily Buildings; Prepared for New York State Energy Research and Development Authority, NYSERDA Report 17-19.
[32] PNNL Reference Code Minimum for MURBs in British Columbia is 135 kWh/m². Passive House energy demand limit is 60 kWh/m², which may be <56% reduction depending on fuel mix.

typical of passive design such as U-0.14 windows, but did not take into account every characteristic of the building that makes it a Passive House such as optimizing shading and thermal bridging, which is modelled in detail using the certification protocols of PHI and PHIUS (using the PHPP and WUFI Passive modelling tools respectively) but not as rigorously applied in modelling protocols such as ASHRAE 90.1 Appendix G.

4.1.2 City Green Solutions Report

In December and January 2016/2017, City Green Solutions performed a comparison and analysis to better understand key differences and modelling results for houses modelled using HOT2000 (Versions 10.51 and 11.3), the Passive House Planning Package (PHPP), and WUFI Passive.[33] City Green Solutions used certified Passive House projects or projects undergoing certification located on Southern Vancouver Island and the Lower Mainland for the comparison of PHPP and HOT2000 v10.51 and v11.3. The project was funded by NRCan.

The report found that there are many differences between HOT2000, PHPP, and WUFI Passive. Some of the differences between the software packages appear to have a more significant impact than others. The key differences were summarized to include, but are not limited to, the following examples:

→ The heated floor areas are being calculated differently in HOT2000, PHPP, and WUFI Passive causing the energy intensity metrics to be based on different areas and volumes.

→ Interior temperature settings and climate files are different.

→ There is a strong emphasis on comfort in Passive House and as a result PHPP provides metrics that allow the modeller to evaluate overall comfort. For example, the surface temperature of windows and frequency of overheating.

→ There are different ways of calculating the total energy consumption. For example, while HOT2000 only calculates the energy consumed on-site, PHPP and WUFI Passive calculate the total annual source energy use of the building including all distribution and storage losses.

→ HOT2000 operates with mainly static standard operating conditions (e.g. 2 adults and 1 child home 50% of time, hot water 169 – 197 L/day, 25.6 GJ/year baseloads), whereas in PHPP and WUFI Passive the operating conditions are based on the size of the building and user input.

→ HOT2000 uses a fixed internal heat gain whereas PHPP calculates the internal heat gain based on the treated floor area of the building.

→ The plug loads in HOT2000 are fixed loads that get added to the building whereas in PHPP they are calculated depending on the number of occupants, type of lighting, and connections to hot water for the dishwasher etc.

This past report compared ninety-five software and energy modelling inputs for Part 9 buildings in southern climates. The study herein builds off this previous work by considering both code-minimum and high performance versions of both Part 9 and Part 3 archetypes, and in a northern location. This study assesses how the model results deviate

[33] Ely, T. (2017): Comparison Study of Passive Houses using ERS, Prepared by City Green Solutions for Natural Resources Canada.

differently at opposite ends of performance range. A key value in this current work is to overcome these differences and suggest how the tools and protocols may be aligned for more similar predicted energy results.

4.2 Key Differences

Modelling performed for various programs, including Passive House (PHPP), Part 9 (HOT2000), and Part 3 (hourly modelling) projects, differ in two primary ways. First, different software programs use different algorithms to estimate heating/cooling loads and energy use, which leads to differences in the overall results even when identical inputs are used. Second, different programs reference different modelling protocols with standard inputs and assumptions. Each of these differences needs to be considered when comparing results across various modelling tools and programs. These key differences are discussed further in the following sections.

4.2.1 Differences in Algorithms

A key difference between PHPP, HOT2000, and hourly modelling software programs are the algorithms used to estimate heating/cooling loads and building energy use. ASHRAE Fundamentals 2017 (Chapter 19) summarizes various building energy estimation and modelling methods that can be used to estimate annual heating and cooling loads and energy use. Each method varies in accuracy and computational intensity.

The three tools discussed in this report use three distinctly different energy estimation methods.

- → **PHPP**: The PHPP tool uses a monthly Degree Day calculation to estimate heating and cooling loads. The heating/cooling load is calculated based on enclosure and ventilation losses/gains and internal gains, which is then multiplied by monthly heating or cooling degree day values for the location to estimate heating/cooling needs. Various factors are applied to account for thermal mass, solar and internal heat gains, etc.
- → **HOT2000**: The program HOT2000 uses a bin method calculation to estimate heating and cooling loads. This method is a variation of the degree day method where monthly climate data arranged in temperature “bins” are used where each bin contains the number of hours of occurrence within a certain temperature range. This allows for a more detailed calculation than the degree day method, but still does not include hourly calculations.
- → **Hourly Tools**: There are many different hourly energy modelling tools (e.g. EnergyPlus, DOE2, IESVE, etc.) that use a variety of algorithms. These programs calculate heating/cooling loads and energy use at every hour of the year (8760 hours), or sometimes at sub-hourly time steps. These tools allow for greater precision and detail than degree day and bin method calculations as they account for coincident loads at every hour. For example, where PHPP and HOT2000 use internal gains averaged over a month or temperature bin, hourly tools use a schedule to account for more realistic internal gains at each hour of the day. Hourly tools also better account for the impacts of climate, thermal mass, and complex HVAC systems.

Another key difference in the algorithms of these programs is the number of thermal zones that they model. A thermal zone is a space or group of spaces with similar heating/cooling loads. For example, in a multifamily residential building, suites along the South elevation will experience different loads than suites along the North elevation, and so should be separated as distinct zones in a model. PHPP and HOT2000 are single-zone models, while hourly programs allow the building to be modelled with multiple zones.

Overall, the difference in algorithms between the modelling tools leads to different results, though it is not possible to state generally how results would vary from one building to another. While larger and more complex buildings typically benefit from more detailed models (e.g. hourly models), tools like HOT2000 and PHPP are sufficient (and in some ways better) for simple buildings like single family homes since they are often faster to model and do not necessarily require a registered professional's oversight.

4.2.2 Differences in Modelling Protocols

In addition to software differences, various modelling tools and codes/standards have different modelling protocols or "rules" under which models are developed. These differences can have a significant impact on the results and should be noted when modelled results from various programs/standards are compared.

Table 4.1 summarizes many of the differences between the three types of modelling tool protocols discussed in this report. Though the list is not comprehensive, it provides a sense of the large number of differences that can contribute to discrepancies in model results.

TABLE 4.1 SUMMARY OF KEY DIFFERENCES BETWEEN MODELLING PROTOCOLS FOR RESIDENTIAL BUILDINGS			
	PHPP	HOT2000	Hourly Tools
General			
Areas	Treated Floor Area (TFA); interior measurements, excludes partition walls and applies reduction factors for certain spaces (e.g. stairs)	Conditioned Gross Floor Area (GFA), measured using interior dimensions	Conditioned Gross Floor Area (GFA), measured using interior dimensions
Climate	Typical weather year based on historical data (period unknown) developed using PHI internal process.	Typical weather year based on historical data (30 years) from Environment Canada compiled by NRCan based on CWEC files.	Typical weather year based on hourly data compiled following Canadian Weather for Energy Calculations (CWEC) protocol. Most recent update uses 30-year period ending 2014.
Lighting, Appliance/Plug Loads, and Internal Gains			
Occupancy	Standard occupancy calculated based on an equation that considers number of dwelling units and floor area.	Single family: 2 adults, 1 child, 50% at home Multifamily: 2 adults, 50% at home	Varies depending on modelling standard. City of Vancouver guideline is 2 people for first bedroom + 1 per additional bedroom.
Schedules / Hours	Annual operating hours are defined for each end use.	Loads defined as kWh/day so operating hours are not used.	Hourly schedules consider typical residential profiles for occupancy, lighting, appliance/plug loads for weekdays and weekends.
Lighting & Plug Loads	Estimates are entered for each end use (e.g. each appliance, plus general values for lighting and entertainment). Standard values are typically used for certification. Lighting and plug loads tend to be lower in PHPP than in HOT2000 and hourly models.	Standard kWh/day per dwelling unit values are used.	Standard W/m^2 values are typically used together with hourly schedules. Specific annual consumption (e.g. EnergyStar rating) of larger appliances may also be used.
Exterior Loads	Most loads outside the thermal envelope are excluded (e.g. lighting, parkade fans).	Exterior loads like lighting and miscellaneous outdoor use are included.	Exterior loads like lighting and parkade lighting/fans are included (though normalized to the gross floor area).

TABLE 4.1 SUMMARY OF KEY DIFFERENCES BETWEEN MODELLING PROTOCOLS FOR RESIDENTIAL BUILDINGS			
Elevator Energy	Estimated using PHI elevator energy calculator, mainly relying on typical assumptions for motor energy and usage.	Not included	Typically entered as an additional load; some guidelines provide a standard kW per elevator used in combination with a typical residential schedule.
Internal Gains	Standard value used irrespective of loads modelled. Value depends on building type (e.g. dwelling versus student/seniors housing).	Based on the standard values for occupancy, lighting, and plug loads modelled.	Based on occupancy, lighting, and plug loads as modelled.
Temperature Set Point / Set Back	Heating: 20 C Cooling: 25 C	Heating: 21 C, night set back to 18 C for 8 hours Cooling: 25 C with no set back	Heating: NECB 2011 is 22 C, night set back to 18 C for 6 hours Cooling: 24 C with no set back
Domestic Hot Water			
Flow Rate	25 L/person/day	Single family: 169 - 197 L/day Multifamily: 110 - 129 L/day (depending on location and year house was built)	NECB 2011: 500 W/person[34]
Schedules	None	None	Hourly schedule based on typical residential use.
Pipe Insulation & Losses	Model includes for losses through pipe length.	3% of hot water load plus 120 W/tank	Pipe insulation and losses can be modelled but not typically accounted for.
Plumbing Vent Stack Losses	Modelled as a thermal bridge unless Air Admittance Valves are used.	Not modelled	Not modelled
Building Enclosure			
Infiltration	Tested value used in final model (ACH50) based on Vn50 calculated using treated floor area.	Tested value used in final model (ACH50) based on gross floor area.	Depends on standard; often typical values (not tested) are used. Option to choose between various infiltration

[34] NECB 2011 prescribe peak service hot water rate as W/person

TABLE 4.1 SUMMARY OF KEY DIFFERENCES BETWEEN MODELLING PROTOCOLS FOR RESIDENTIAL BUILDINGS			
			models and input methods (e.g. ACH vs enclosure leakage vs flow rate).
Enclosure area takeoffs	External surface area (including wall thickness)	Internal surface area (excluding wall thickness)	Internal surface area (excluding wall thickness)
Thermal Bridging Accounting	Comprehensive thermal modelling required.	Limited thermal bridging included in assembly definition.	Extent of thermal bridging depends on standard; typically, not considered in as much detail as PHPP.
Window Accounting	size-specific vs standard, installation, modelling standards. The components of the window are broken down and the performance of each part is entered.	Size and window type can be specified; however, window installation is not accounted for. Window frame components are not broken down into as much detail as PHPP.	Size and window type can be specified; however, window installation is not accounted for. Window frame components are not broken down into as much detail as PHPP.
Shading	Interior shades can be included. Exterior overhangs modelled as designed. Horizon shading is modelled.	Occupant controlled interior shades not considered. Exterior overhangs modelled as designed. Horizon shading not considered.	Occupant controlled interior shades not considered. Exterior shading and overhangs modelled as designed. Horizon shading typically not considered.
HVAC Systems			
Part Load Performance	Not modelled	Modelled using default load factors	Modelled using typical or product specific curves
Fan Efficiency & Pressure	Fan energy (Wh/m²) entered	Typically, auto-calculated; option to select energy efficient motor	Typically modelled based on pressure drop and efficiency
HRV Duct Lengths & Insulation	Duct losses between unit and outside are modelled	Duct losses between unit and outside are accounted for but values are left at default values.	Not modelled
HVAC Systems	Modelling tools have many differences when more complex mechanical systems are used (e.g. VRF, VAV). Detailed discussion is beyond the scope of this study.		

4.3 Modelling Considerations for the North

In addition to directly comparing the PHPP modelling tool to the tools currently used for code compliance, each tool was also assessed for applicability to the North. In general, several model protocols for the three tools were found to not be reasonable assumptions for the North. Some examples include:

→ **Occupancy**: Occupancy rates are generally much higher in northern housing (especially Nunavut) than what is assumed as standard operating conditions in modelling protocols. For example, a home that is assumed to have 2.5 adults may have up to 18 people residing in it full time.[35] This is partly due to the lack of adequate housing in remote regions and the traditional way of living with multiple families all in one shared abode.

→ **Lighting**: Higher latitudes have larger seasonal variation in lighting requirements as days in the summer are longer and nights in the winter are longer. Modelling protocol schedules for lighting do not reflect these seasonal variations, which may impact heating demand as well as lighting load profiles.

→ **Plug loads**: Traditional food preparation in remote rural regions may be much more frequent and prolonged compared to southern assumptions. Traditional food preparation involves a large amount of boiling and cooking for larger groups of people than in southern assumptions. Other base load assumptions that are missed in standard protocols are heat tracing of exterior pipes/equipment, car block heaters, and in-building sewer systems.

→ **Ventilation**: Higher occupancy rates and more frequent boiling and cooking may increase the ventilation requirements in northern housing. This is currently not captured with the standard ventilation protocols. It is common in the North to use pre-heater strategies in HRVs to avoid problems due to frost built-up. This can add significantly to the energy consumption. Unfortunately, the current version of HOT2000 does not model pre-heater accurately.

It is worth noting these differences as they may affect the overall performance of the buildings after construction, post-occupancy. For example, higher occupancy rates may decrease the heating demand through higher passive internal heat gains and also increase ventilation energy consumption through higher outdoor air rates. Although there are many modelling protocol assumptions that are not applicable to the North, it may still be necessary to have standard operating conditions/model inputs for consistent building-to-building comparison across the country.

If more accurate model results are desired for northern regions—reflecting the as-built and occupied performance—it may be recommended that a set of Northern Modelling Guidelines be created to standardize the modelling protocols for the North. These may be similar in nature to the City of Vancouver Modelling Guidelines,[36] which standardized model inputs for Part 3 buildings in Vancouver and throughout BC as they are referenced in the BC Energy Step Code.

[35] Northern Housing Forum. Polar Knowledge Canada. Explorer Hotel, Yellowknife, NWT, Canada. May 1 – 3, 2018.
[36] City of Vancouver: Energy Modelling Guidelines, Land Use and Development Policies and Guidelines, <https://guidelines.vancouver.ca/E006.pdf>.

4.4 Part 9 Modelling Tool Comparison

The single-family dwelling (SFD) archetypes were used to compare Part 9 modelling tools and their standard protocols. Two versions of this archetype were used: an articulated building with code-minimum performance components and a simple form building with high performance components (typical of Passive House design). Both PHPP and HOT2000 were used to model the two SFDs in climate zone 7b Whitehorse.

The comparison of results using the standard operating conditions and protocols for each modelling tool are presented in section 4.4.1 and an alignment of the two tools is presented in section 4.4.2.

4.4.1 Comparison of HOT2000 vs PHPP

This section outlines a comparison of the modelled results from using HOT2000 and PHPP to model Step Code and Passive House metrics on the same two SFD archetypes. The various building components such as opaque and transparent assemblies, ventilation system, and space heating and domestic hot water heating systems were identical in both modelling programs as the focus of this comparison was to determine the differences in the modelling tools. Three key metrics from each high performance compliance method have corresponding, similar metrics as shown in Table 4.2.

TABLE 4.2 KEY METRICS FOR COMPARISON

METRIC TYPE	PASSIVE HOUSE	STEP CODE
Total Energy Consumption	Primary Energy Renewable (PER) *(though TEUI is used for comparison with Step Code)*	Total Energy Use Intensity (TEUI)*
Annual Heating Energy	Heating Demand	Thermal Energy Demand Intensity (TEDI)
Peak Heating	Heating Load	Peak Thermal Load (PTL)

*TEUI is a Step Code metric for Part 3 buildings and is the closest to the Passive House PER metric in terms of representing whole building energy use; thus, TEUI was used for this comparison work. For Part 9 Step Code compliance, MEUI is used instead of TEUI.

Figure 4.1 compares TEUI, heating demand, and heating load modelled in PHPP to the TEUI, TEDI, and PTL metrics modelled in HOT2000 for a code-minimum SFD archetype. The TEUI and heating metrics are higher when modelled in PHPP. As noted in Figure 4.1, the metrics calculated in PHPP (for Passive House) versus HOT2000 (for Step Code) use different definitions of floor area – these are aligned in section 4.5.2.

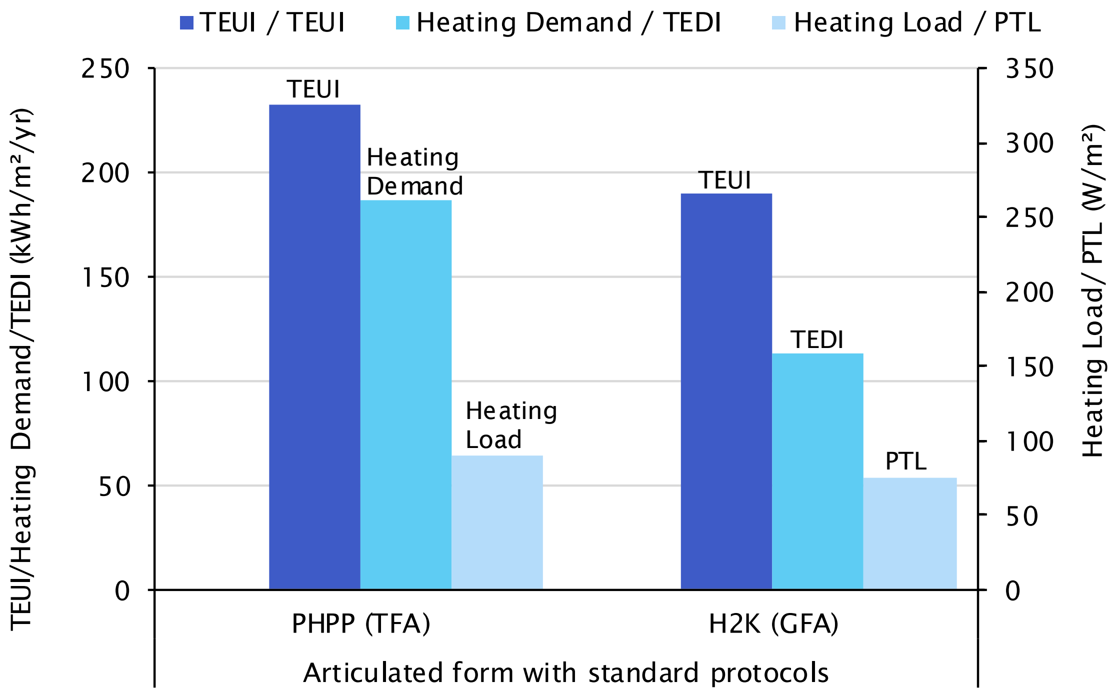


Figure 4.1 Comparison of metrics calculated using PHPP and HOT2000 for a Part 9 code-minimum building using standard protocols. The reference areas used to calculate the metrics is shown in parenthesis for the two different protocols (TFA vs GFA).

A similar trend was observed with a high performance SFD archetype. Figure 4.2 compares the Passive House metrics in PHPP to the Energy Step Code metrics in HOT2000 for a high performance SFD using standardized modelling protocols for each tool. Similar to the code-minimum model, key discrepancies were noted for the modelled TEUI and heating demand/TEDI energy results. As with the code-minimum SFD, the metrics calculated for the high performance SFD in PHPP (for Passive House) versus HOT2000 (for Step Code) use different definitions of floor area – these are aligned in section 4.5.2.

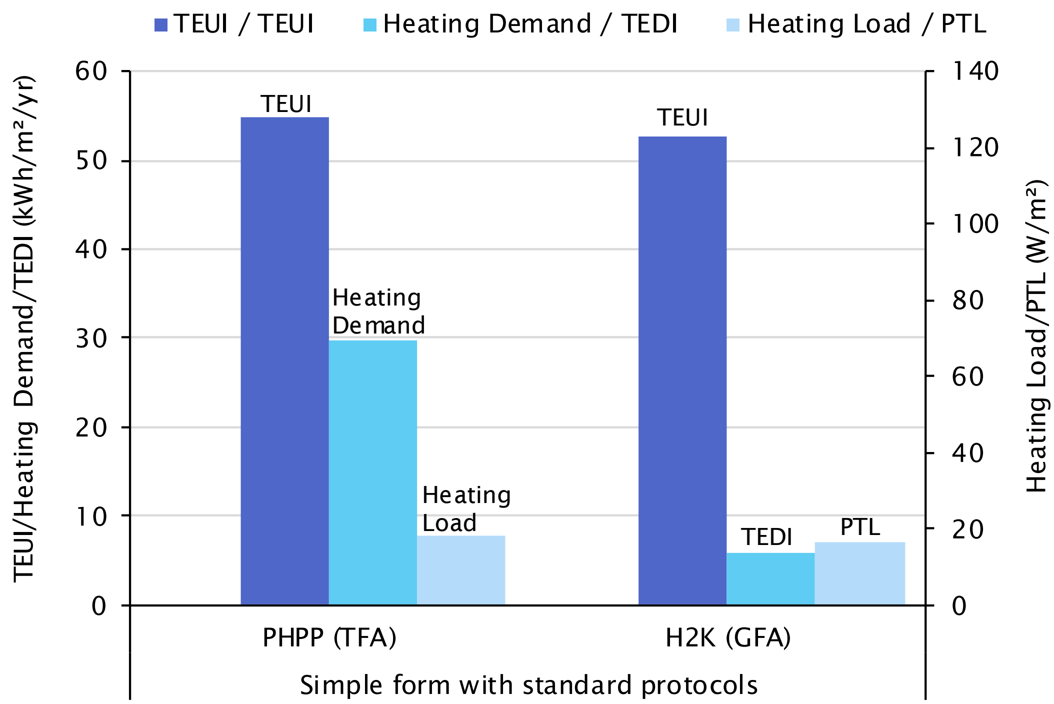


Figure 4.2 Comparison of metrics calculated using PHPP and HOT2000 for a Part 9 high performance building using standard protocols. The reference areas used to calculate the metrics is shown in parenthesis for the two different protocols (TFA vs GFA).

The differences in these metrics result from several different factors. These include differences in the core algorithm as mentioned in section 4.2.1, differences in modelling protocols, and assumptions prescribed through the different compliance paths (Step Code and Passive House). The most notable difference is in the reference area that these metrics use. HOT2000 uses gross floor area (m_{GFA}), which is a measure of floor area within the enclosure, including partition walls. PHPP uses treated floor area (m_{TFA}), which is a measure of the useful floor area with areas weighted depending on the use of the rooms. For example, stair heads and landings have a 60% reduction factor while flights of stairs are not counted. These reduction factors are based on the guidelines laid out in the German living space ordinance [WoflV] for residential buildings, and German norm DIN 277 for non-residential buildings. As a result, treated floor areas typically range between 80–85% of conditioned floor area. A smaller reference area yields higher TEUI and heating demand, which is consistent with the findings presented in Figure 4.1 and Figure 4.2 For this study, an 85% reduction factor was assumed and a comparison of net energy consumption without floor area dependence is provided later in Figure 4.4.

To further understand the differences between the modelling tools and protocols, a breakdown of the heat losses and gains was created for the high performance PHPP and HOT2000 models. The losses and gains are plotted in Figure 4.3 in kWh/yr with the difference being the demand required for space heating. Heat losses are broken down into opaque, transparent assemblies, thermal bridging, ventilation, and non-useful heat gains. The non-useful heat gain is defined in PHPP as a method of accounting for the surplus of heat that is not or partially useable. Heat gains are broken down into solar and internal heat gains.

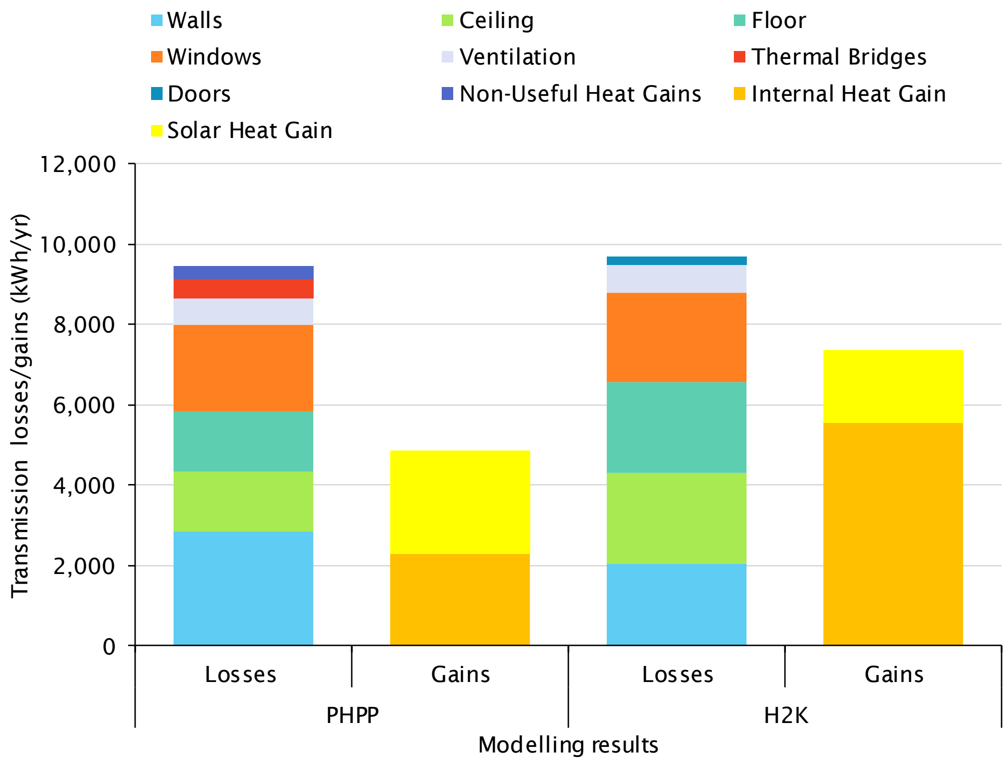


Figure 4.3 Transmission losses and gains comparison between PHPP and HOT2000 for high performance building with standard protocol.

There are minor differences in transmission losses of the floors, walls, and ceilings. This could be attributed to the use of external enclosure area in PHPP and the difference in the underlying model algorithms. The standard Passive House modelling protocol requires the use of external surface area whereas the modelling protocol in HOT2000 uses internal surface area. Therefore, the thicker the wall assembly, the bigger the differences as a higher surface area will lead to a higher estimated heat loss. For the high performance SFD, this difference is around 20%.

Also, PHPP accounts for thermal bridges directly where the length of each thermal bridge and the linear transmittance can be calculated using 2D/3D modelling software such as THERM or Heat3 for linear and point transmittances respectively. In contrast, HOT2000 accounts for thermal bridges by adjusting the framing factor depending on inputs (e.g. number of corner studs, number of bottom and top plates etc.), but it does not allow the user to model the specific heat loss of the actual detail. However, geometric thermal bridges are not accounted for. The thermal bridge losses in HOT2000 are incorporated into the effective insulation values and therefore into the transmission losses of the floor, walls and ceilings, but they are not listed explicitly.

One major difference between the two protocols are the internal heat gain assumptions. The default assumption in PHPP for average annual internal heat gain is significantly lower than HOT2000, which may be another cause of the deviations between heating demand and TEDI. These differences can be attributed to cultural difference in how buildings are used but also more efficient appliances and lighting used in Europe.

Figure 4.4 compares the breakdown of the total site energy usage estimations modelled using PHPP and HOT2000. The breakdown consists of four main categories: space heating, domestic hot water, ventilation, and lighting and appliances. While the total energy use is similar, there are significant differences between lighting and appliances and space heating estimates. The built-in assumptions and usage patterns for plug loads and lighting in PHPP are much lower than HOT2000.

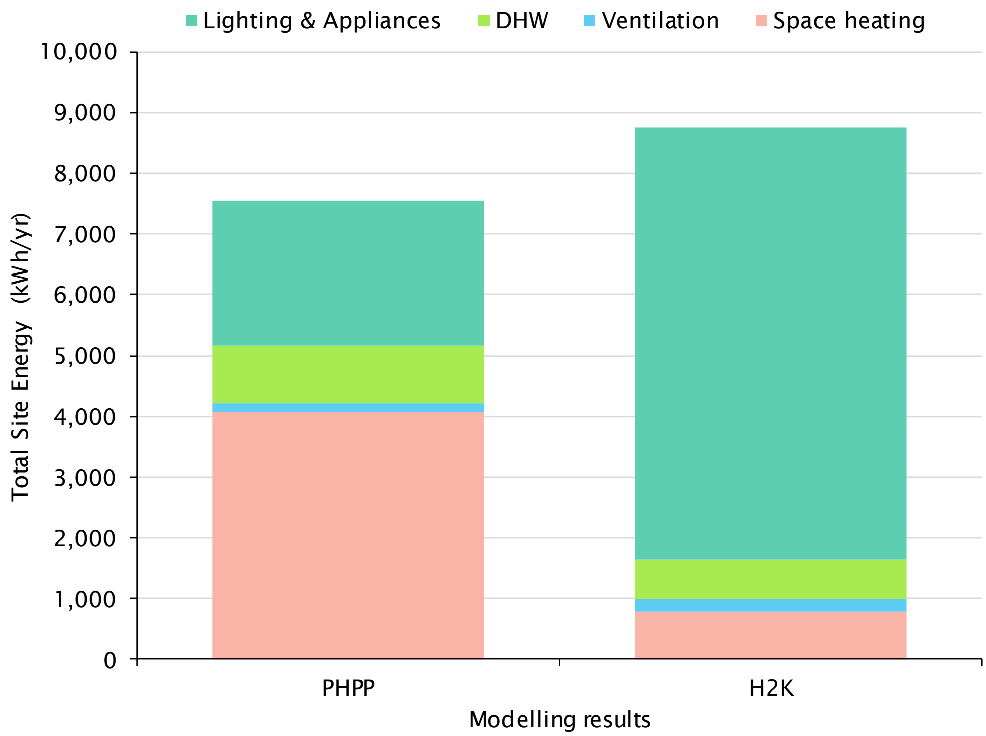


Figure 4.4 Comparison of annual site energy calculated using PHPP and HOT2000 for the high performance SFD building with standard protocols.

The weather files in the protocol for HOT2000 and PHPP were also compared. Figure 4.5 compares the global radiation and Figure 4.6 compares the average monthly exterior dry bulb temperature between HOT2000 and PHPP weather files for Whitehorse. The global radiation in PHPP tends to be lower in the winter months and higher in the summer months when compared to HOT2000. However, these differences are relatively minor. The monthly exterior dry bulb temperature is higher in the winter months and lower in the summer months when compared to HOT2000.

The monthly exterior dry bulb temperature and global solar radiation both affect the modelled space heating. The expected result of a lower monthly exterior dry bulb temperature is higher space heating, due to larger temperature differences and therefore heat losses. The higher transmission losses in the HOT2000 model is shown in Figure 4.3.

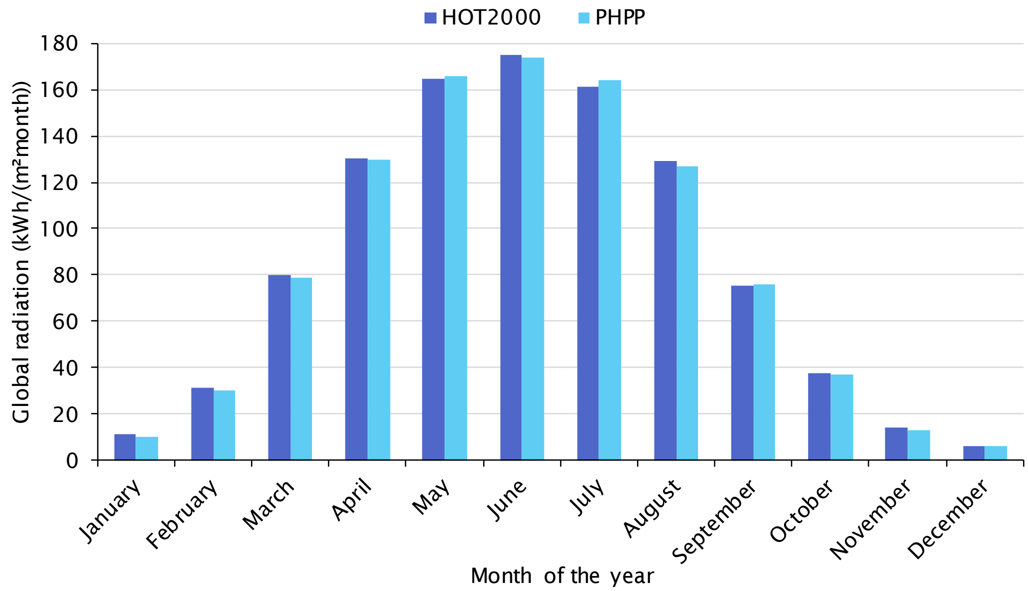


Figure 4.5 Global radiation comparison between PHPP and HOT2000 weather files in Whitehorse. There are no major differences between the two types of modelling software.

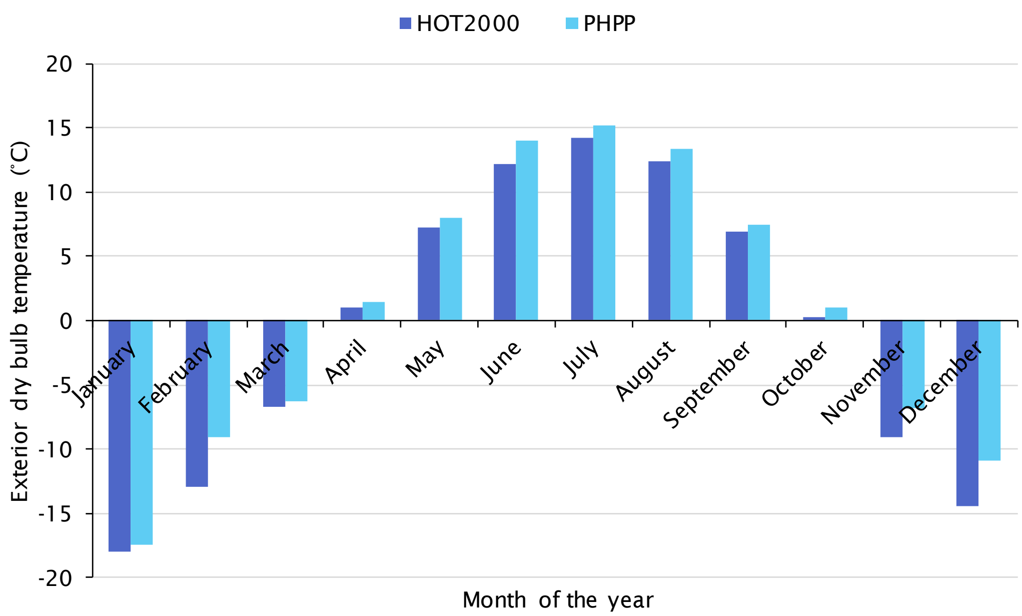


Figure 4.6 Monthly average exterior dry bulb temperature comparison for PHPP and HOT2000 weather files in Whitehorse.

4.4.2 Alignment of Part 9 Tools

In the second part of the modelling tool comparison work, the user-defined inputs in the two tools were aligned to assess the differences in results. The modelling protocols and assumptions in PHPP were modified to match the HOT2000 model to align the key metrics as presented in the previous section.

Table 4.3 summarizes the list of user-defined inputs used for the model in HOT2000, PHPP, and PHPP adjusted to align with HOT2000 (EnerGuide protocol). A detailed summary of all inputs for each model is attached in Appendix A. Major adjustments to the PHPP model include updates from treated floor area to gross floor area and external to internal enclosure surface area. The plug loads and lighting loads were also adjusted in PHPP to match HOT2000 as the assumptions in HOT2000 are generally higher than in PHPP. HOT2000 also assumes more than double the domestic hot water usage than in PHPP, so this was adjusted in PHPP.

As shown in Figure 4.3, the internal heat gains were significantly different with the assumption in HOT2000 (EnerGuide) being approximately three times in PHPP, so this was adjusted in PHPP. The PHPP standard assumptions are based on a very energy efficient building with highly efficient appliances and a European approach to plug loads, which tends to be more energy conservative than North American assumptions in EnerGuide. When more efficient appliances and lower plug loads are assumed, the internal heat gains are reduced.

The ventilation schedule and air flow rates were adjusted as well. In HOT2000, the ventilation schedule assumes the heat recovery ventilator runs for 6.8 hours per day on normal flow rate, 1.2 hours per day at 2.5 times the normal flow and off during the rest of the time. In contrast, Passive House buildings requires continuous ventilation at all times, with 23 hours per day at normal flow rate and 1 hour per day at a boost flow rate.

TABLE 4.3 SUMMARY OF USER-DEFINED MODEL INPUTS THAT WERE ADJUSTED TO ALIGN PHPP WITH HOT2000.

Input	**PHPP with standard protocol**	**PHPP with aligned protocol**	**HOT2000**
Reference floor area	Treated floor area	Gross floor area	Gross floor area
Enclosure area	External area	Internal area	Internal area
Electrical appliances (kWh/day)	5.1	6.3	6.3
Lighting (kWh/day)	0.25	2.6	2.6
Other electric (kWh/day)	5.3	9.7	9.7
Average exterior use (kWh/day)	None	0.9	0.9
Hot water load (L/day)	72.5	175.6	175.6
Hot water temperature (˚C)	60	55	55
Occupancy	2.9 occupants	1.5 occupants	2 adults, 1 child 50% at home
Internal heat gain (W/m²)	2.5	7.8	7.8
Setpoint temperature (˚C)	20	21	21
Schedule	23 h/d @ normal 1 h/d @ boost	6.8 h/d @ normal 1.2 h/d @ 2.5x normal	6.8 h/d @ normal 1.2 h/d @ 2.5x normal
Supply air (L/s)	56 (boost) 29 (normal)	32	32
Exhaust air (L/s)	56 (boost) 29 (normal)	32	32

TABLE 4.3 SUMMARY OF USER-DEFINED MODEL INPUTS THAT WERE ADJUSTED TO ALIGN PHPP WITH HOT2000.			
Other fans	None (condensation dryer)	Direct vent dryer @ 38L/s for 56 mins/day	Direct vent dryer @ 38 L/s for 56mins/day

Figure 4.7 shows the PHPP and HOT2000 results for the code-minimum SFD using both the standard and aligned protocols. After the adjustments to the user-defined inputs, the core metrics in PHPP show a closer alignment to HOT2000 results, however minor differences still exist. These differences could lie in fundamental differences in the algorithms that cannot be aligned through user-defined inputs (see Section 4.2.2) which will be examined in detail later.

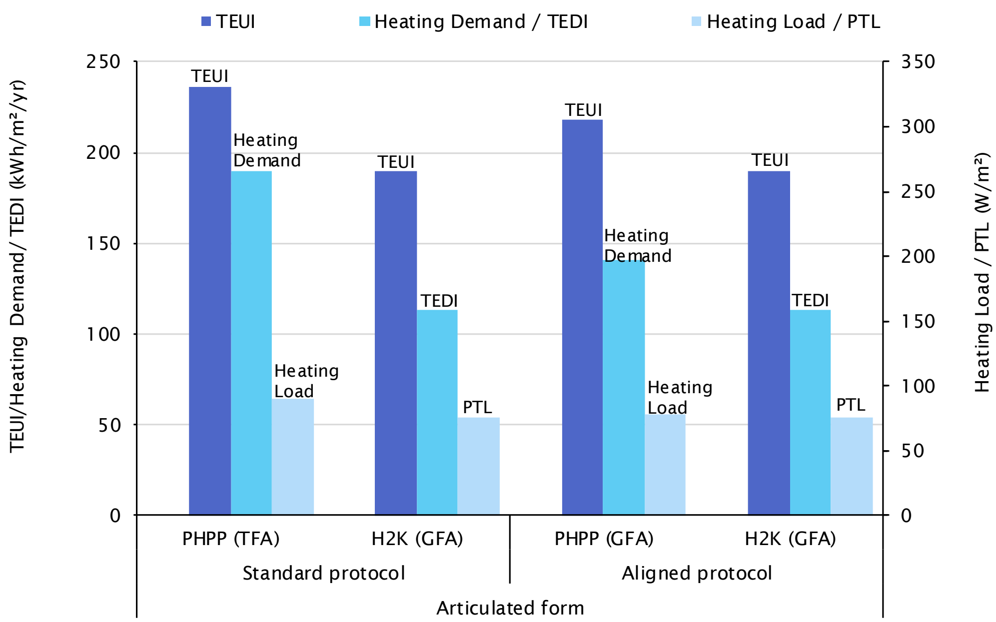


Figure 4.7 Comparison of PHPP and HOT2000 results for the code-minimum SFD using standard and aligned protocols. The reference areas used for each software is shown in parenthesis.

Figure 4.8 compares the results of PHPP to HOT2000 for the high performance SFD using both the standard and aligned protocol. The heating demand and TEDI metrics calculated in PHPP and in HOT2000 show closer alignment after the modification to the variable inputs. The discrepancy between TEUI has increased, which is discussed further when the breakdown of the site energy is examined (Figure 4.11).

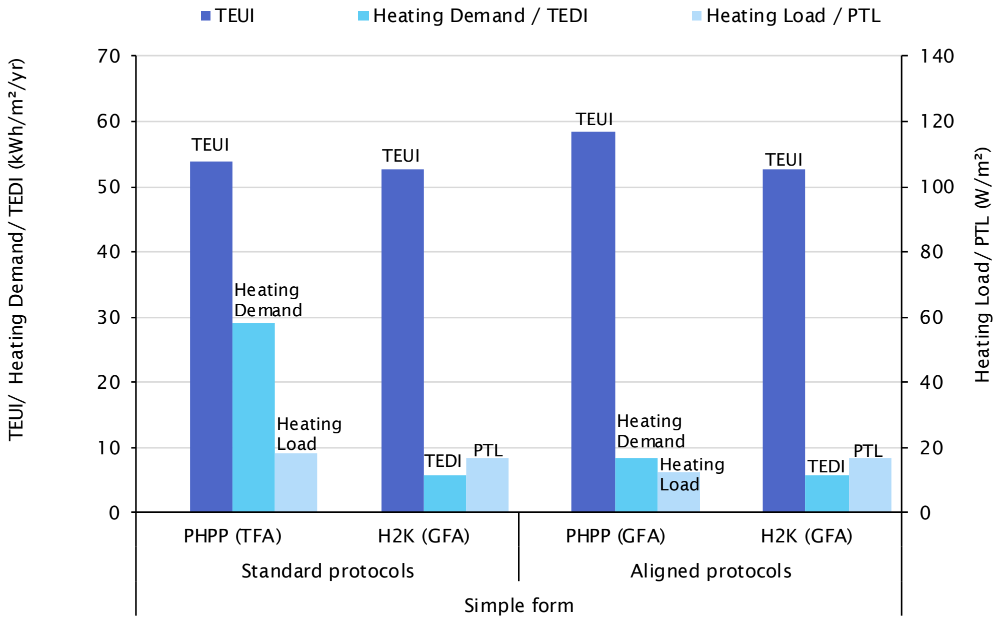


Figure 4.8 Comparison of PHPP and HOT2000 results for the high performance SFD using standard and aligned protocols. The reference areas used for each software is shown in parenthesis.

Figure 4.9 compares the heat losses and gains between PHPP and HOT2000 for the high performance SFD building with the standard and aligned protocols. There were minor changes to heat losses in opaque assemblies due to internal surface areas used in the aligned protocol.

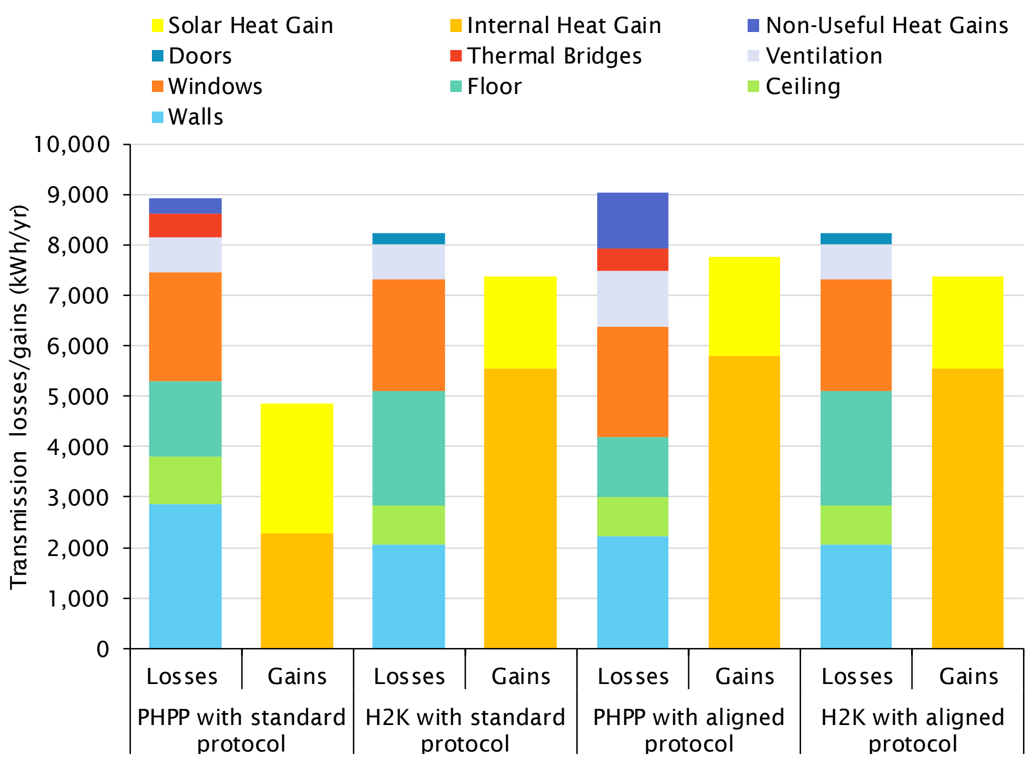


Figure 4.9 Heat losses and gains in PHPP and HOT2000 before and after alignment for the high performance building. The HOT2000 model remained a constant as PHPP was aligned to HOT2000.

While the heat losses and gains are similar for the aligned models, there are still minor differences in the breakdown of losses and gains, which may be attributed to the different algorithms in the respective tools.

An additional comparison of the energy end use breakdown was carried out for the code-minimum and high performance archetype to further understand the discrepancies in modelled results. As HOT2000 does not calculate PER, it is more useful to compare the site energy breakdown of TEUI by end use in kWh/yr. This analysis allows for the direct comparison of the end uses and negate the differences in reference area. This is shown in Figure 4.10 for the code minimum SFD, and Figure 4.11 for the high performance SFD. The end use is broken down into space heating, ventilation, domestic hot water, and lighting and appliances.

Figure 4.10 shows closer alignment of end uses for the code-minimum SFD archetype modelled in PHPP and in HOT2000. Though there is still a discrepancy in the space heating energy.

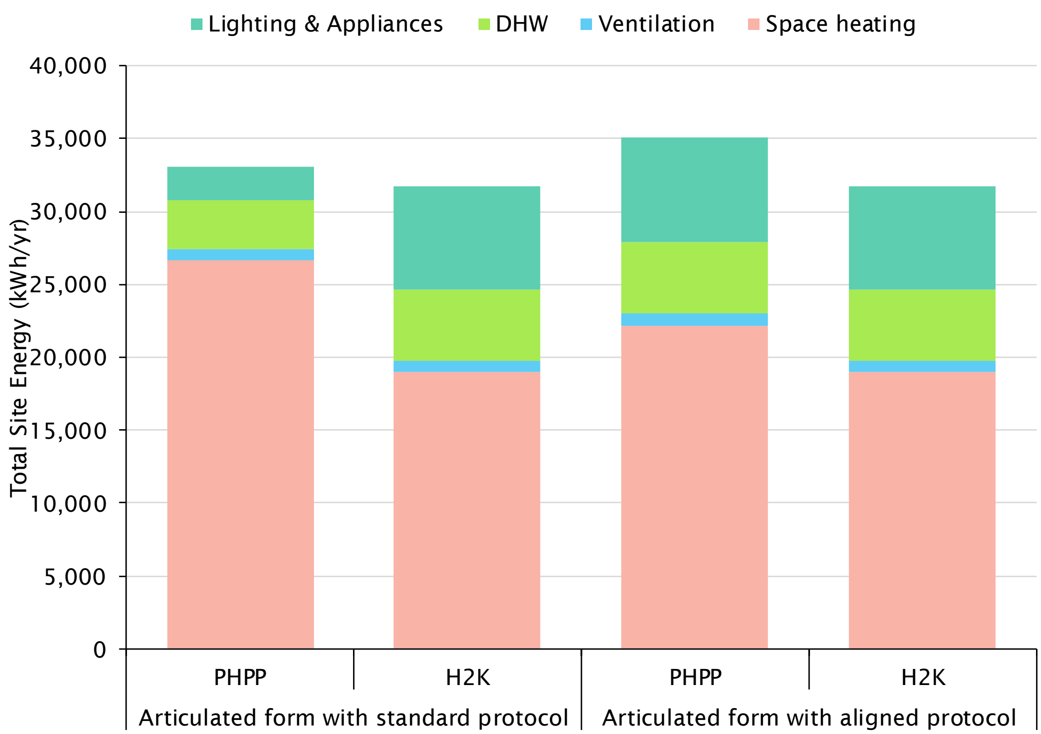


Figure 4.10 Comparison of annual site energy use for the code minimum SFD with both standard and aligned protocol. The breakdown of space heating, domestic hot water and lighting and appliances all show a closer alignment using the aligned protocol.

In Figure 4.11, space heating and lighting and appliances were able to be aligned while considerable differences were still present in domestic hot water consumption results after the alignment. The higher domestic hot water PHPP estimate is primary due to the way PHPP accounts for losses, accounting for domestic hot water heat losses from distribution and circulation losses of the pipe network. In contrast, HOT2000 does not allow users to directly account for heat losses from the domestic hot water system. HOT2000 assumes a constant domestic hot water baseload based on the default usage assumptions. In addition to this, a heat pump was modelled for the high performance scenario. PHPP and HOT2000 each have different methods of accounting for heat pumps.

In PHPP, the coefficient of performance at different outdoor air temperatures is entered to describe the performance curve of the specific heat pump, so PHPP uses the appropriate coefficient of performance to calculate the site energy used. In contrast, HOT2000 does not allow the user to enter in the performance curve. Instead, a coefficient of performance for the heat pump is modelled at a specific temperature and HOT2000 calculates a performance curve based on this. This calculated curve is then used to estimate the energy consumption of the heat pump. It may partly be due to these differences that the discrepancy in site energy is larger after alignment, as observed previously. In addition, for the high performance scenario, drain water heat recovery was modelled. This introduces further discrepancies as the drain water heat recovery system is accounted differently between the modelling software. In PHPP, the drain water heat recovery system is only applied to the shower usage whereas in HOT2000, it is applied to the entire domestic hot water load. This is an important distinction as the domestic hot water load includes kitchen faucets, dishwashers, and bathroom faucet usages.

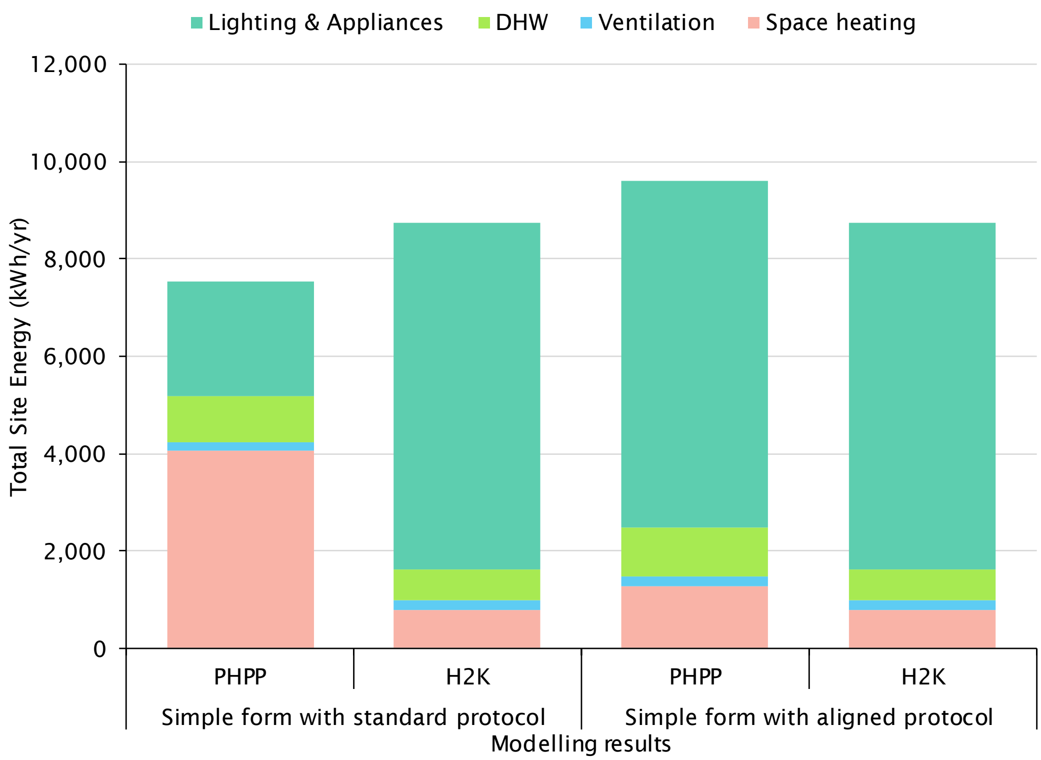


Figure 4.11 Comparison of annual site energy use for the high performance SFD with both standard and aligned protocol.

The lack of complete alignment of the two tools creates complications for using two different modelling tools for compliance with building codes or energy efficiency programs. Further considerations for using different tools for compliance are discussed in section 4.6.

4.4.3 Key findings from Part 9 modelling tool comparison

This section summarizes the key findings from the modelling tool comparison of the articulated and simple form single family dwelling archetype using HOT2000 and PHPP.

- → HOT2000 and PHPP have different approaches of accounting for some of the enclosure and mechanical systems. These differences make aligning the two tools challenging.
- → HOT2000 has some built in assumptions that makes modelling simpler, however, because of this, it does not allow users to optimize the building for some of those aspects. For example, HOT2000 makes various assumptions regarding thermal bridges while in PHPP, each unique junction is modelled.
- → While it is possible to bring the results in PHPP closer to HOT2000, considerable differences still exist and the methods to align them are non-trivial. Some of these differences depend on the type of mechanical system because of how these systems are accounted for in the two different tools. For example, a closer alignment was observed with the building using electric baseboards than the building using air source heat pumps.

4.5 Part 3 Modelling Tool Comparison

The multi-unit residential building (MURB) archetypes were used to compare Part 3 modelling tools and their standard protocols. Two versions of this archetype were used: an articulated building with code-minimum performance and a simple form building with high performance characteristics (typical of Passive House design). Both PHPP and EnergyPlus were used to model the two MURBs in Whitehorse, with protocols based on Passive House and NECB, respectively.

The comparison of results using the standard operating conditions and protocols for each modelling tool are presented in section 4.5.1 and an alignment of the two tools is presented in section 4.5.2.

4.5.1 Comparison of EnergyPlus vs PHPP

This section outlines a comparison of the modelled results from using EnergyPlus and PHPP to model Step Code and Passive House metrics for the same two MURB archetypes. The various building components such as opaque and transparent assemblies, ventilation system, and space heating and domestic hot water heating systems were identical in both modelling programs as the focus of this comparison was to determine the differences in the modelling tools. Two key metrics from each high performance compliance method (Passive House and Step Code) have corresponding metrics to each other as shown in Table 4.4.

TABLE 4.4 KEY METRICS FOR COMPARISON		
METRIC TYPE	PASSIVE HOUSE	STEP CODE
Total Energy Consumption	Primary Energy Renewable (PER) *(though TEUI is used for comparison with Step Code)*	Total Energy Use Intensity (TEUI)
Annual Heating Energy	Heating Demand	Thermal Energy Demand Intensity (TEDI)

Figure 4.12 compares TEUI and heating demand modelled in PHPP to the TEUI and TEDI modelled in EnergyPlus for the code-minimum MURB archetype in Whitehorse. The results show that there are significant differences in TEUI calculated using the two different

modelling tools/protocols. In contrast, the annual heating energy metrics, heating demand and TEDI, are much closer for the two methods.

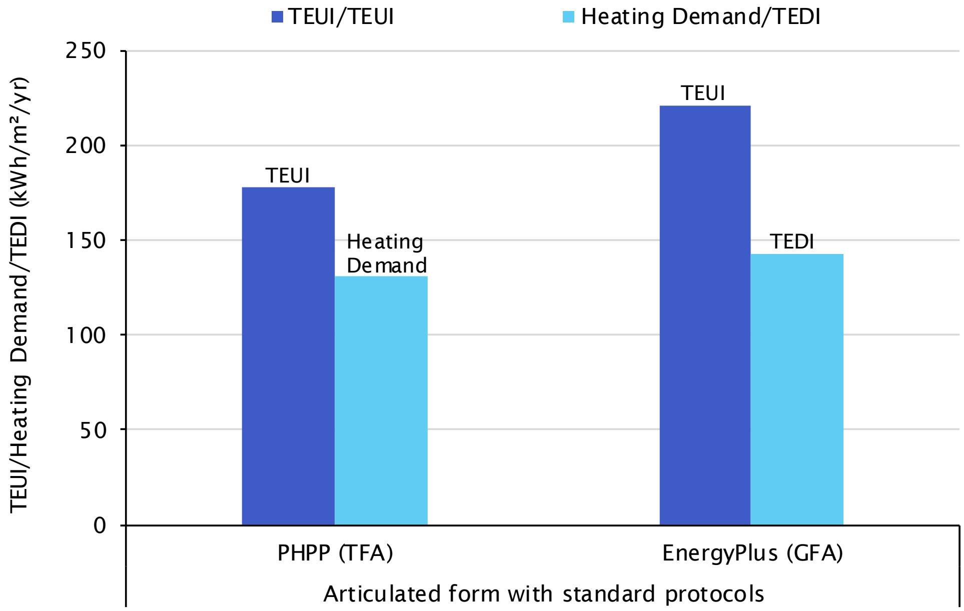


Figure 4.12 Comparison of PHPP and EnergyPlus for the articulated MURB using standard protocols. The reference areas used to calculate the metrics is shown in parenthesis for the two different protocols.

The same comparison was carried out for a high performance MURB archetype in Whitehorse. Figure 4.13 compares the Passive House metrics in PHPP to the Energy Step Code metrics in EnergyPlus for the high performance MURB using the standardized modelling protocol for each tool. In contrast to the code-minimum archetype, both TEUI and heating metrics show significant discrepancies for the high performance MURB.

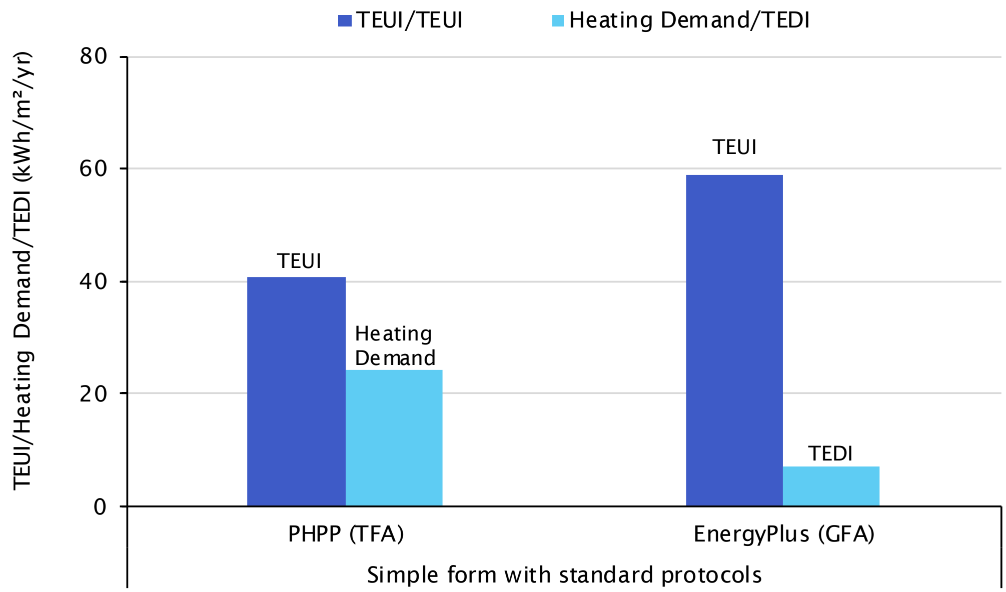


Figure 4.13 Comparison of PHPP and EnergyPlus for the high performance MURB using standard protocols. The reference areas used to calculate the metrics is shown in parenthesis for the two different protocols.

The differences in these metrics could result from several different factors. These include differences in the core algorithm as mentioned in section 4.2.1, differences in modelling protocol and assumptions prescribed through the different compliance paths (Step Code or Passive House). The most notable difference is in the reference area that these metrics use. EnergyPlus uses gross floor area (m_{GFA}), which is a measure of floor area within the enclosure, including partition walls. PHPP uses treated floor area (m_{TFA}), which is a measure of the useful floor area with areas weighted depending on the use of the rooms. For example, corridors in multi-unit common areas, and stair heads and landings have a 60% reduction factor while flights of stairs are not counted. As a result, treated floor areas typically range between 80 – 85% of conditioned floor area for multi-unit residential buildings. For this study, the treated floor area is 85% of the condition floor area for multi-unit residential buildings.

To further understand the differences between the modelling tools and protocols, a breakdown of the heat losses and gains was created for the high performance PHPP and EnergyPlus model. The losses and gains are plotted in Figure 4.14 in kWh/yr. Heat losses are broken down into opaque, transparent assemblies, thermal bridging, ventilation, and non-useful heat gains. The non-useful heat gain is defined in PHPP as a method of accounting for the surplus of heat that is not or partially useable. Heat gains are broken down into solar and internal heat gains. The difference between the heat losses and gains is the demand required for space heating.

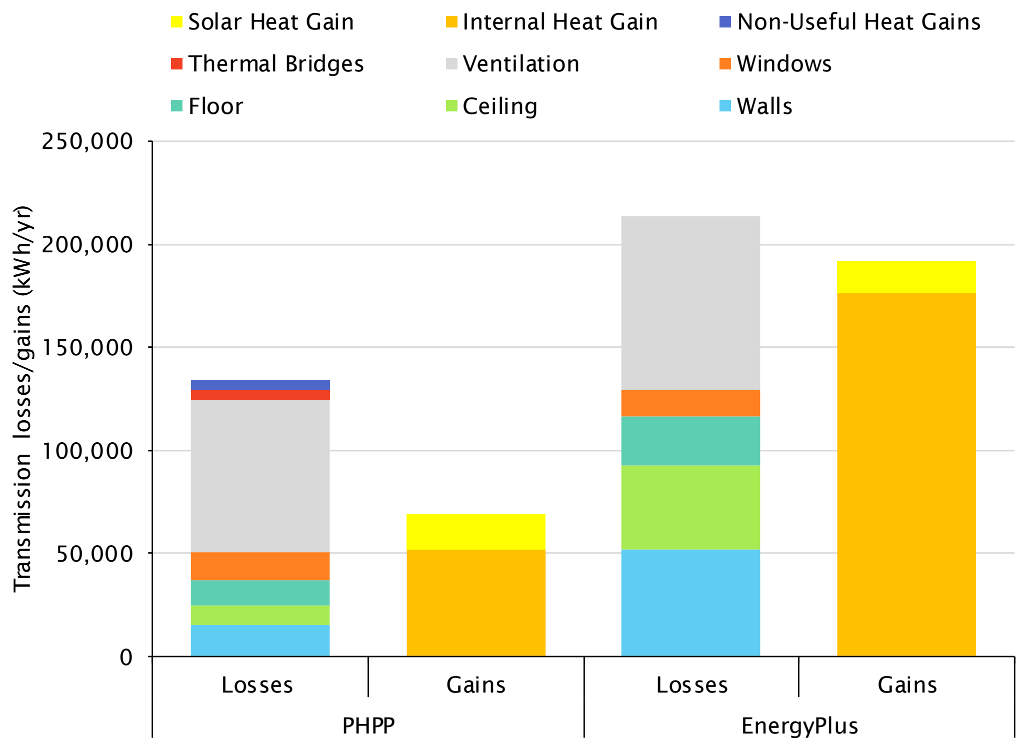


Figure 4.14 Transmission losses and gains comparison between PHPP and EnergyPlus for the high performance MURB with standard protocols.

There are significant differences in the transmission losses of the floors, walls, and ceilings in the two modelling tools. This could be attributed to the use of external enclosure area in PHPP and the difference in the calculation algorithm. For the high performance MURB, the difference between internal and exterior surface area was 10%. Also, PHPP accounts for thermal bridging directly where the length of each thermal bridge and linear transmittance can be entered. In contrast, EnergyPlus does not directly account for thermal bridging. Instead, users input their own calculated effective R-value for each assembly type, though NECB allows for the exclusion of some thermal bridges.

Another major difference between the two protocols is the internal heat gain assumption. The default assumptions in PHPP for average annual internal heat gain is significantly lower than EnergyPlus which base the internal heat gains on modelled plug loads, lighting, and occupancy. The internal heat gain in PHPP is 2.6 W/m² while the assumption in EnergyPlus is 6.8 W/m² implemented with a schedule. This is another cause of the deviations between heating demand and TEDI.

Figure 4.15 compares the breakdown of the total site energy use simulation modelled using PHPP and EnergyPlus. The breakdown consists of four main categories; lighting and appliances, domestic hot water (DHW), ventilation, and space heating. While the ventilation is similar for the two tools and protocols, there are differences between lighting and appliances, domestic hot water, and space heating estimates. The standard assumptions and usage patterns for lighting and appliances and domestic hot water in PHPP are much lower than EnergyPlus. The deviation in space heating is partly due to the difference in internal heat gain assumptions and the difference in how transmission losses are calculated, as previously mentioned.

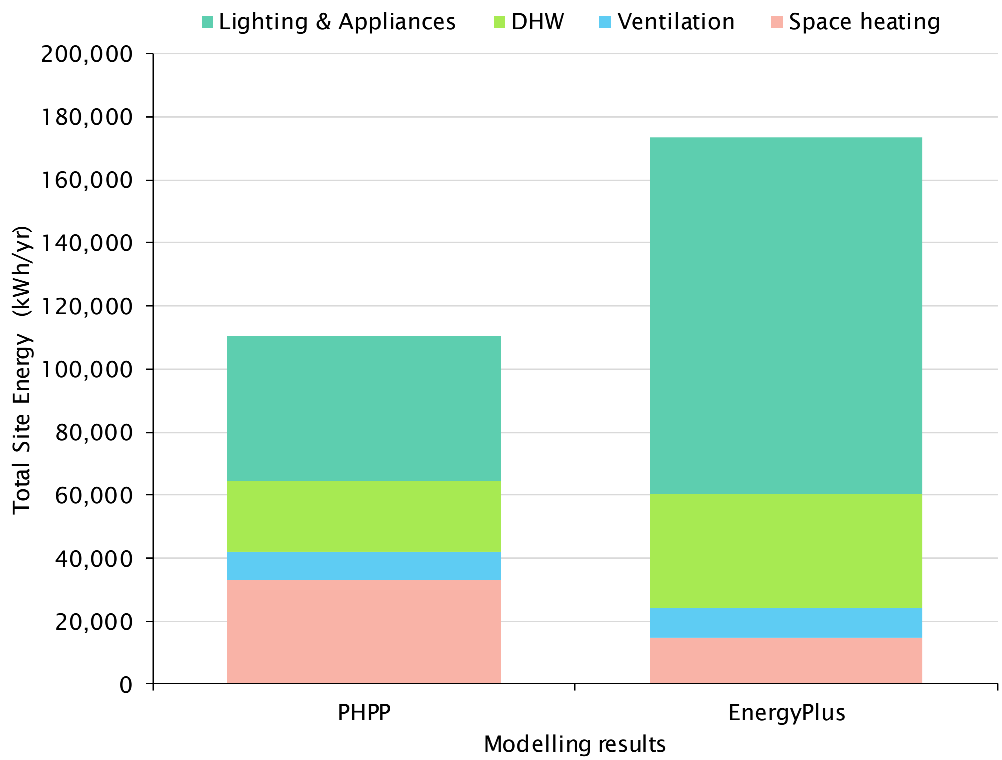


Figure 4.15 Comparison of annual site energy calculated using PHPP and EnergyPlus for the high performance MURB with standard protocol.

The weather files in the protocols for PHPP and EnergyPlus were also compared. Figure 4.16 compares the global radiation and Figure 4.17 compares the average monthly exterior dry bulb temperature between PHPP and EnergyPlus weather files (CWEC 2016) for Whitehorse. The monthly exterior dry bulb temperature used in PHPP is noticeably higher than the monthly exterior dry bulb temperature in EnergyPlus. The monthly global radiation is slightly lower in PHPP for certain months.

The monthly exterior dry bulb temperature and global solar radiation both affect the modelled space heating. The expected result of a higher monthly exterior dry bulb temperature is lower space heating, due to smaller temperature differences and therefore lower heat losses. Figure 4.14 shows that the transmission losses of the floors, walls and ceilings in PHPP are lower compared to the transmission losses calculated in EnergyPlus, which may be partly a result of the exterior dry bulb temperature deviation. The deviation in global radiation is expected to mainly be seen in the modelled solar heat gains; Figure 4.14 shows that the difference in solar heat gains between the two types of software is relatively small.

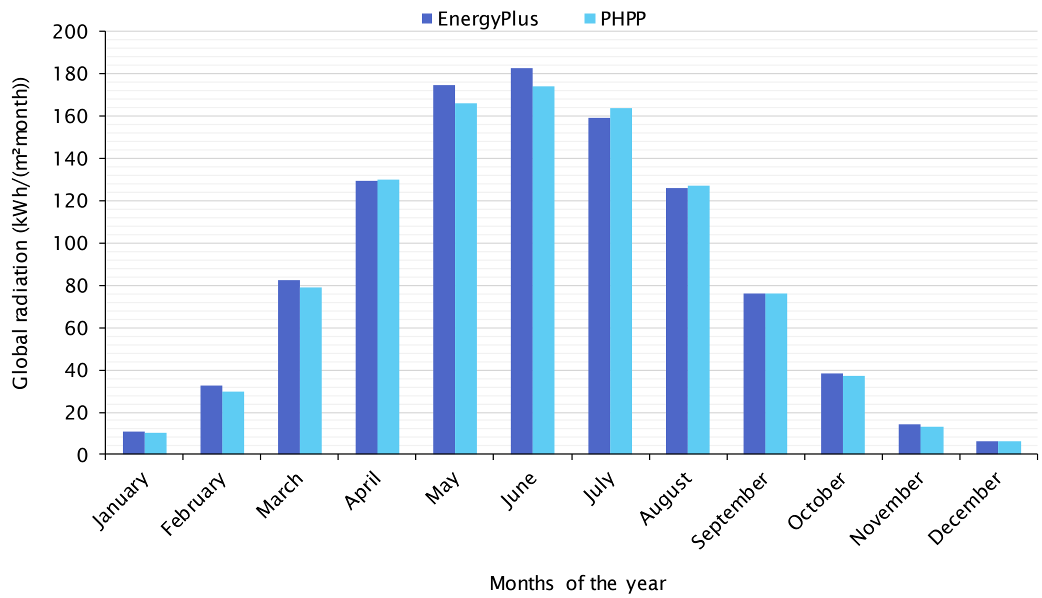


Figure 4.16 Global radiation comparison between EnergyPlus and PHPP weather files for Whitehorse.

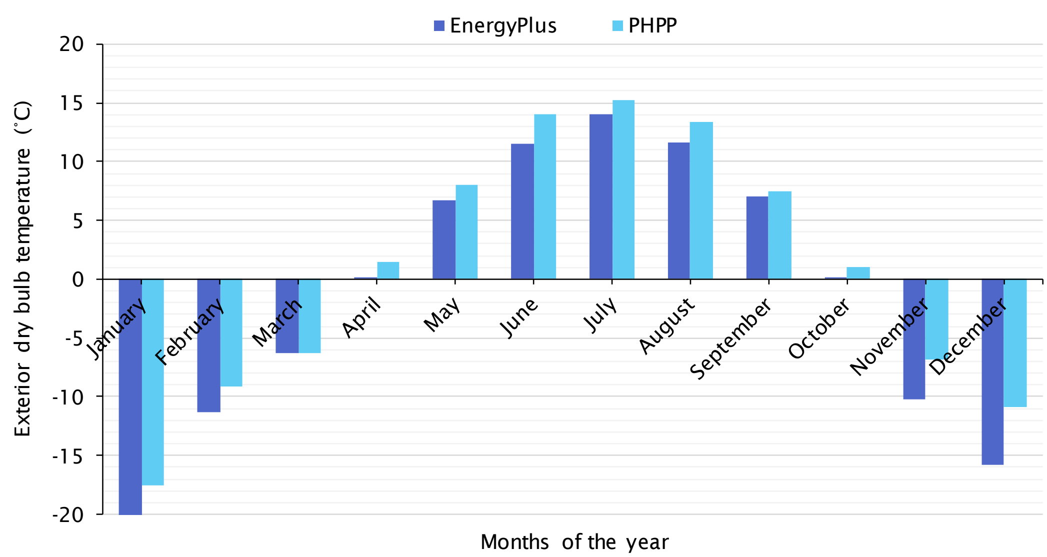


Figure 4.17 Monthly average exterior dry bulb temperature comparison between EnergyPlus and PHPP weather files for Whitehorse.

4.5.2 Alignment of Part 3 Tools

In the second part of the modelling tool comparison work, the user-defined inputs in the two tools were aligned to further assess the differences if two tools are used for code compliance targets. The modelling protocols and assumptions in PHPP were modified to match the EnergyPlus model (NECB protocol), to align the key metrics as presented in the previous section.

Table 4.5 summarizes the list of user-defined inputs adjusted in PHPP to align with NECB/EnergyPlus. A detailed summary of all inputs for each model is attached in Appendix C. Adjustments to the PHPP model include updates from treated floor area to gross floor area and weather file. The plug loads, lighting loads, and domestic hot water loads were also adjusted in PHPP to match NECB as the assumptions in PHPP are generally lower than in NECB.

As shown in Figure 4.14 , the internal heat gains were significantly different, with the assumptions in EnergyPlus being approximately three times higher than the standard assumptions in PHPP, so this was adjusted in PHPP. The PHPP standard assumptions are based on a very energy efficient building with highly efficient appliances and a European approach to plug loads, which tends to be more energy conservative than North American assumption in the NECB. When more efficient appliances and lower plug loads are assumed, the internal heat gains are reduced.

TABLE 4.5 SUMMARY OF USER-DEFINED MODEL INPUTS THAT WERE ADJUSTED TO ALIGN PHPP WITH ENERGYPLUS

Input	PHPP with standard protocol	PHPP with aligned protocol	EnergyPlus
Reference floor area	Treated floor area	Gross floor area	Gross floor area
Enclosure area	External area	Internal area	Internal area
Weather file	PHPP climate data	CWEC 2016	CWEC 2016
Base loads			
Electrical appliances (kWh/day)	107	167	167
Lighting (kWh/day)	8	138	138
Average exterior use (kWh/day)	None	7	7
Hot water load (L/person/day)	25	60	60
Hot water temperature (˚C)	55	60	60
Occupancy	2.2 ppl/suite annual average	2.04 ppl/suite annual average	3 ppl/suite 68% at home
Internal heat gain (W/m²)	2.6	6.8*	6.8**
Temperature			
Setpoint temperature	20	22	22

*Pro-rated to account for NECB schedule.
**Applied with a schedule.

Figure 4.18 shows the PHPP and EnergyPlus results for the code-minimum MURB using both the standard and aligned protocols. The alignment results in a greater difference between heating demand and TEDI. A comparison of the breakdown of site energy consumption is shown in Figure 4.21 for the code-minimum MURB.

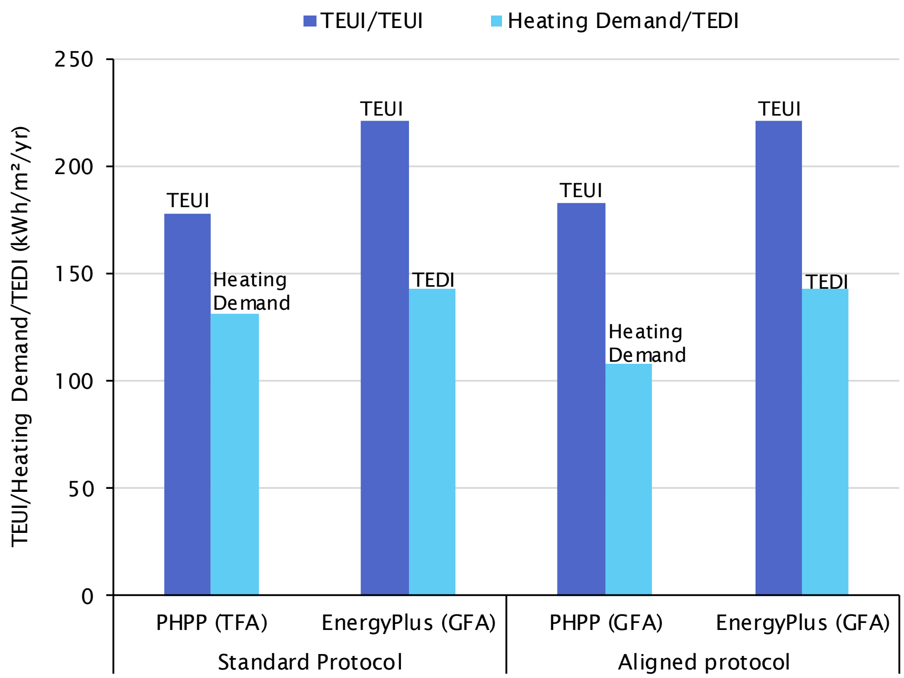


Figure 4.18 Comparison of PHPP and EnergyPlus results for the code-minimum MURB using standard and aligned protocols. The reference areas used for each software is shown in parenthesis.

Figure 4.19 compares the results of PHPP to EnergyPlus for the high performance MURB using both the standard and aligned protocols. After the adjustments to the user-defined inputs, the heating demand in PHPP shows a closer alignment to TEDI in EnergyPlus. The TEUI is closer after the alignment. A comparison of the breakdown of site energy consumption simulated by both models have been done and is shown in Figure 4.22 for the simple form, high performance MURB.

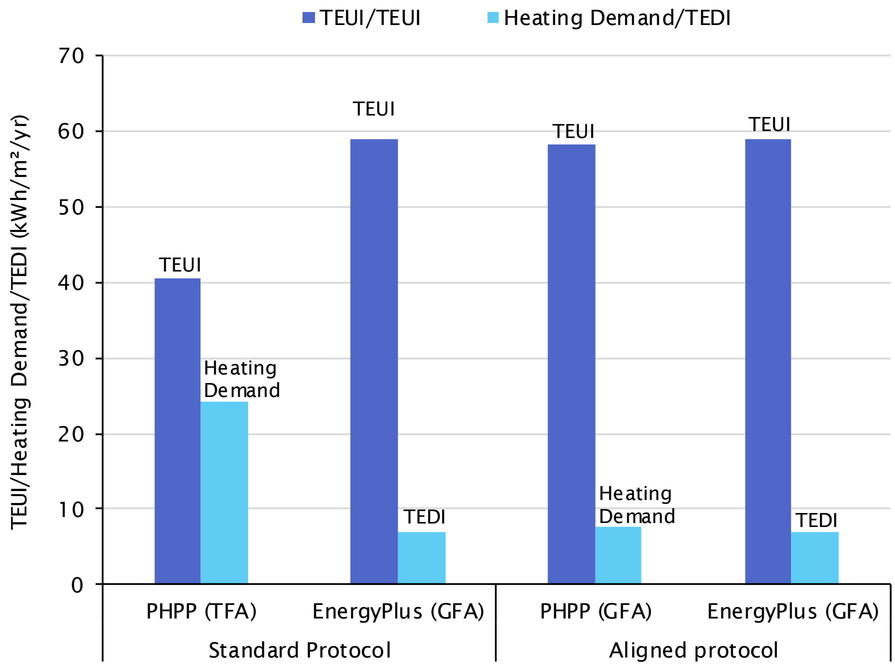


Figure 4.19 Comparison of PHPP and EnergyPlus results for the high performance MURB using standard and aligned protocols. The reference areas used for each software is shown in parenthesis.

Figure 4.20 compares the heat losses and gains between PHPP and EnergyPlus for the high performance MURB archetype with the standard and aligned protocol. There were minor changes to heat losses in opaque assemblies due to internal surface areas used in the aligned protocol; this trend was also found for the SFD.

After the alignment, the solar heat gains in PHPP only increased slightly. The alignment of the protocols included an increased solar heat gain coefficient of the glazing in PHPP, the expected result of this alignment is an increase in solar heat gains. However, the alignment of the weather file results in a lower global solar radiation for certain months. The overall change to the solar heat gains calculated in PHPP after the alignment is therefore small, only 2%, higher compared to the results using the standard PHPP protocol.

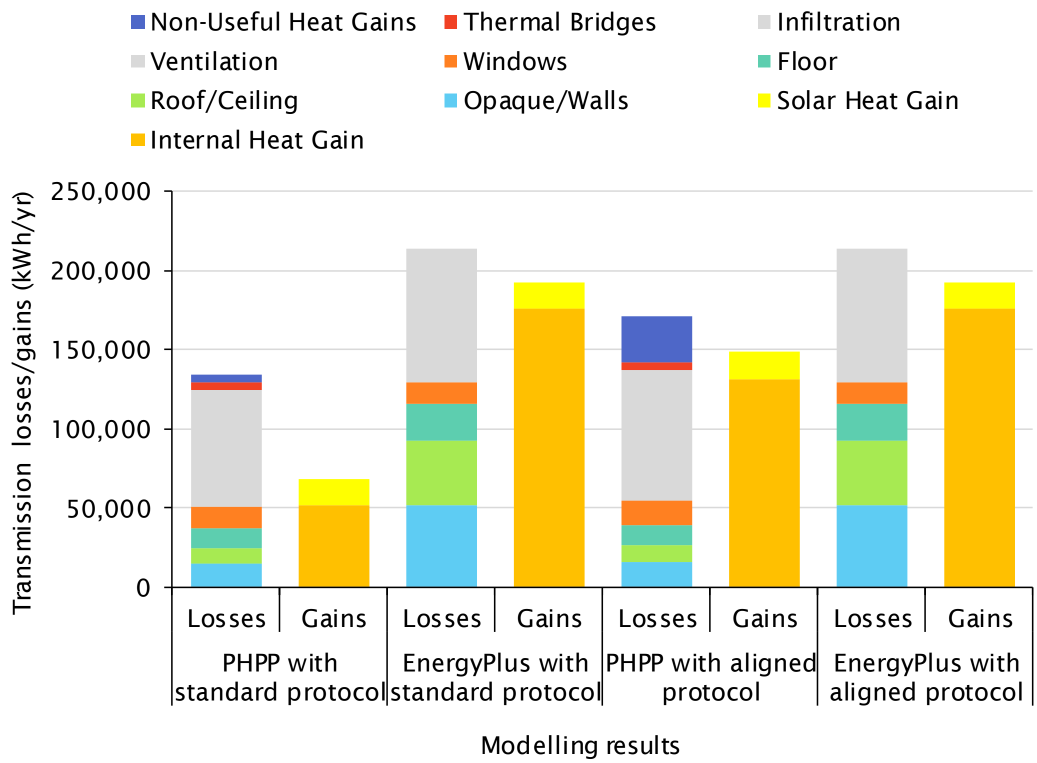


Figure 4.20 Heat losses and gains in PHPP and EnergyPlus before and after alignment for the high performance MURB. The EnergyPlus model remained constant and PHPP was aligned to EnergyPlus using NECB protocols.

An additional comparison of the energy end use and breakdown was carried out for the code minimum and high performance archetypes to further understand the modelled results. The comparison of site energy break down is shown in Figure 4.21 for the code minimum MURB archetype and Figure 4.22 for the high performance MURB archetype. The end use is broken down into space heating, ventilation, domestic hot water, and lighting and appliances.

Figure 4.21 shows closer alignment for the code minimum MURB modelled in both tools, in part due to the increase in domestic hot water, and lighting and appliances loads in PHPP using the NECB standard inputs.

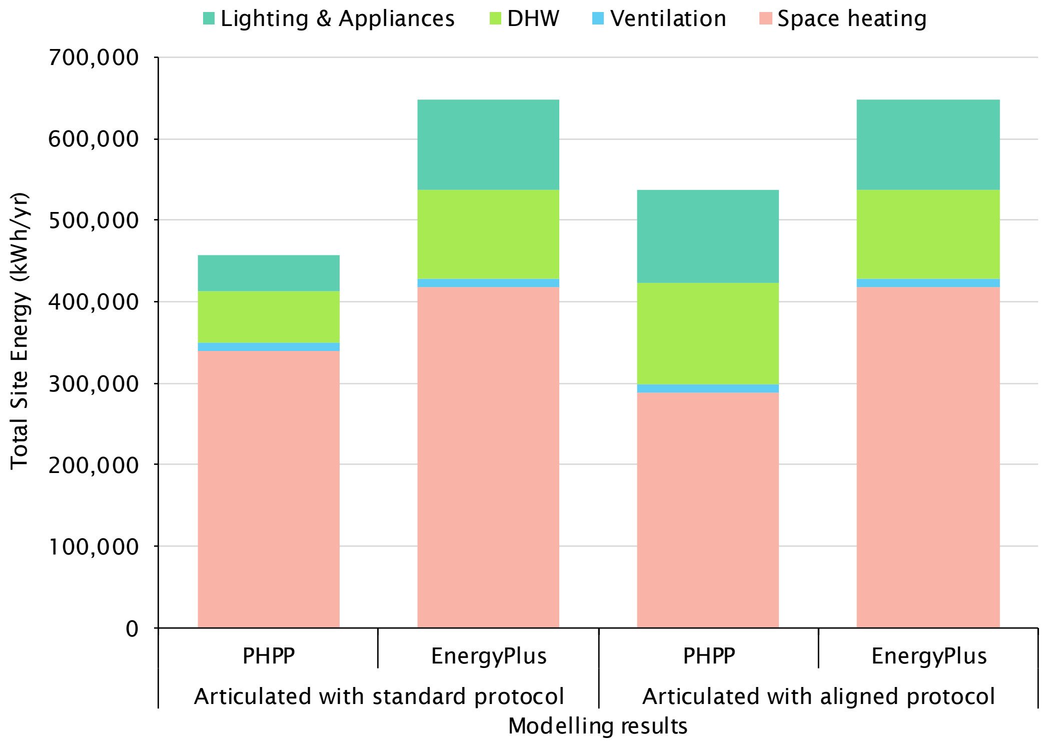


Figure 4.21 Comparison of annual site energy use for the code minimum MURB with both standard and aligned protocol.

Figure 4.22 illustrates a comparison of total annual site energy consumption broken down by the four key end-use categories for the high performance MURB archetype. The plug loads, lighting, and ventilation were able to be aligned closely while considerable differences were still present in domestic hot water. The higher domestic hot water PHPP estimate is in part due to the way PHPP accounts for losses. PHPP accounts for domestic hot water heat losses from distribution and circulation losses of the pipe network. In contrast, EnergyPlus models do not typically include distribution heat losses from the domestic hot water system.

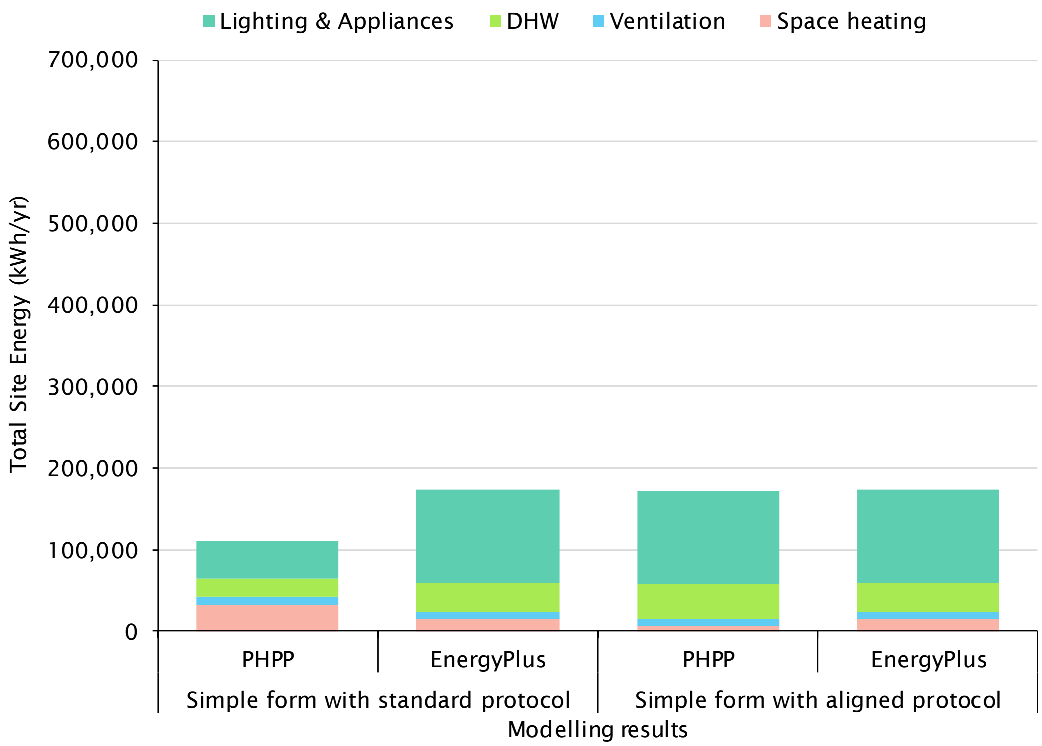


Figure 4.22 Comparison of annual site energy for the high performance MURB with both standard and aligned protocol.

For both the code-minimum and high performance MURBs the space heating estimate in PHPP is lower than the estimate in EnergyPlus, even after alignment. As the inputs in PHPP have been adjusted to match EnergyPlus (following NECB protocols), the remaining discrepancy likely predominantly lies in the algorithms.

The lack of complete alignment of the two tools creates complications for using two different modelling tools for compliance with building codes or energy efficiency programs. Considerations for using different modelling tools for code compliance is discussed in Section 4.6.

4.5.3 Key findings from MURB modelling tool comparison

This section summarizes the key findings from the modelling tool comparison of the code-minimum and high performance MURB archetypes using EnergyPlus and PHPP.

→ EnergyPlus and PHPP have different approaches of modelling various enclosure and mechanical systems. These differences make aligning the two tools challenging.

→ While it is possible to bring the results in PHPP closer to EnergyPlus, considerable differences still exist and the methods to align them are non-trivial. Some of these differences are routed in core differences of the calculation algorithms for the two different tools.

4.6 Using Different Compliance Tools

Using various modelling tools for %-better-than targets does allow for an apples-to-apples comparison if the same tool is used for both a reference and a proposed building model (i.e. as in Part 8 of NECB). Though a shift to using energy performance targets (e.g. EUI, TEDI) creates the need for a clear set of standard modelling protocols and guidelines to eliminate discrepancies between different tools, protocols, and different modeller approaches. In general, it is not advisable to allow using different types of compliance tools to meet the same energy target for code-compliance. This study, as well as others[37], has shown that different modelling tools produce varying results even with aligned user inputs due to different calculation algorithms.

One method to compensate for the varied results from different tools may be to use a % factor difference when setting targets to account for the discrepancy between results that can't be aligned, though this is not recommended. This method would be complex due to variations between building types, sizes, climates, etc. and would need much more in-depth modelling to determine appropriate factors across all sectors in Canada, especially the North. Passive House heating demand and Step Code TEDI use different assumptions in their calculation (most notably, different floor areas) and Passive House compliance has additional comfort requirements that need to be met, which change the overall effective building performance resulting from the use of the different tools and protocols.

For example, a much simpler approach may be to base the code on the most common path (e.g. HOT2000) and allow an optional compliance path for the most stringent target based on certification with that standard (e.g. Passive House compliance using PHPP). In contrast, projects that use PHPP yet do not achieve Passive House certification would not meet code. The certification process is in place to prevent gaming or misuse of the modelling tool. As part of the quality assurance, a Design Stage Review letter could be required as part of the building permit application.

[37] Ely, T. (2017): Comparison Study of Passive Houses using ERS, Prepared by City Green Solutions for Natural Resources Canada.

5 Compliance Modelling

The five archetypes listed in Section 2.1.1 were analyzed to assess the feasibility of reaching high performance, near-net zero ready energy targets in Northern Canada. The Upper Steps of the BC Energy Step Code were used as example targets, as well as Passive House compliance. This section presents the results of this energy analysis, answering the questions: What energy conservation measures are needed to reach near-net zero ready targets in the North? Can these targets be reached with existing technology and design practices?

5.1 Baselines, Targets, & Compliance Summary

An overview of the baseline energy performance of the five archetypes is provided below. The high performance targets used in this compliance modelling work are also discussed, as well as a summary of which of these targets could be met by the five archetypes in the four northern locations.

5.1.1 Baseline Energy Consumption

The baseline energy performance of the two SFD archetypes, the two MURB archetypes, and the 5-Plex is provided below.

SFD Baselines

The SFD archetypes are 2-storey wood-frame buildings, approximately 1,800 ft² (167 m²) in size. Two-storeys were used as this is common in northwest Canada and because north-eastern housing corporations are transitioning away from the single-storey over crawlspace archetype.[38] Electric systems were modelled for space heating and DHW for simplicity and as this reflects new construction in northwest Canada. The results can be extrapolated to other systems (e.g. fuel oil furnace, pellet stove) using differences in equipment efficiency.

Two different SFD geometries are compared: a simple rectangular form with no balconies and low window-to-wall ratio, and an articulated design with articulation[39] with slightly higher window-to-wall ratio (as seen in Figure 5.1 and Figure 5.2). Table 5.1 lists the specific ground condition modelled at each location.

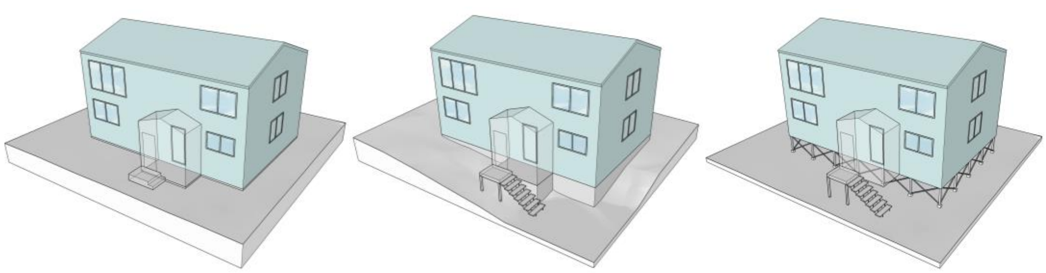


Figure 5.1 Single family dwelling (SFD), simple form factor. Three different ground conditions were used in different locations: slab on grade (left), on bedrock (centre), and elevated above permafrost (right).

[38] Based on discussions with Nunavut Housing Corporation, 2018.
[39] Articulation refers to bump outs and recesses of the envelope, which increases the number of thermal bridges, corner details to consider during air barrier implementation and also increases the surface area through which heat may be lost to the outdoors.

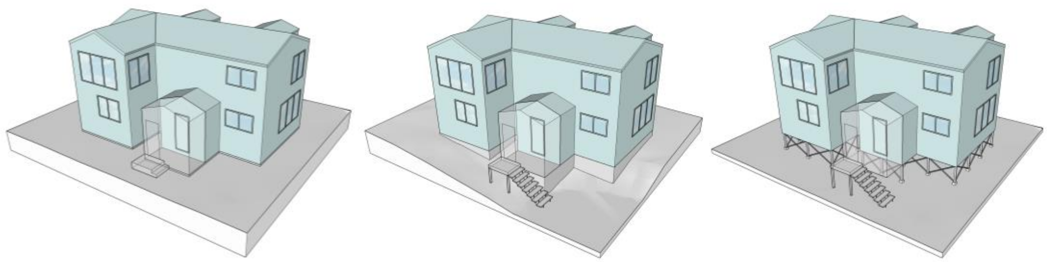


Figure 5.2 Single family dwelling (SFD), articulated form factor. Three different ground conditions were used in different locations: slab on grade (left), bedrock (centre), and elevated above permafrost (right).

TABLE 5.1 GROUND CONDITIONS USED AT EACH LOCATION.		
Location	**Ground condition**	
	Articulated	**Simple Form**
Climate zone 7a – Fort St. John	Slab on grade	Slab on grade
Climate zone 7b – Whitehorse	Bedrock[40]	Bedrock
Climate zone 8 (urban) – Yellowknife	Elevated above permafrost	Elevated above permafrost
Climate zone 8 (remote) - Resolute	Elevated above permafrost	Elevated above permafrost

The energy analysis of the two geometries are compared in this section to show the difference in feasibility of reaching targets with different architectural designs.

The articulated and simple form buildings were modelled with NBC 2015 9.36 code minimum requirements for the baseline models. Using HOT2000, the baseline energy consumption was calculated for the SFD archetypes as well as their end-use breakdown (Figure 5.3). The dominant end-use for these northern locations is heating energy as the heating demand in the colder climates is significantly higher than in the south, where DHW and lighting and appliances play a larger role.

[40] The bedrock condition is modelled like a slab on grade in HOT2000 and PHPP.

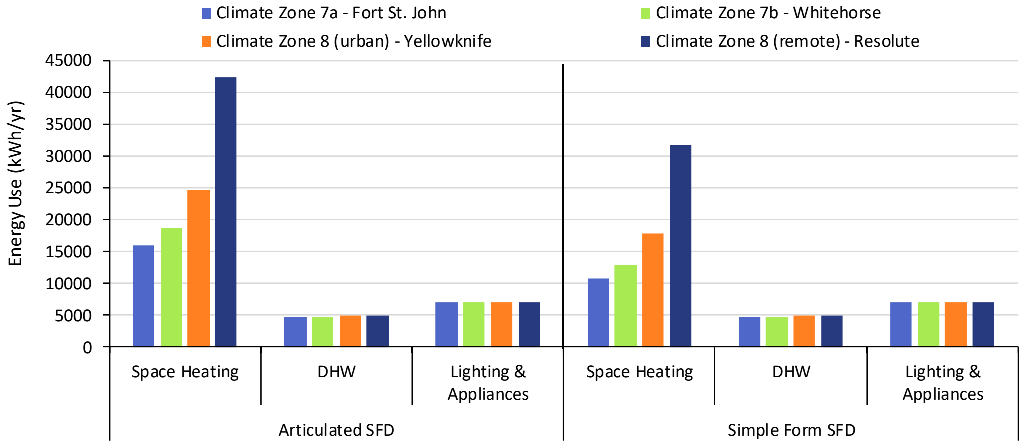


Figure 5.3 Baseline energy end-use breakdown for the articulated and simple form SFD archetypes in the four locations, using NBC 2015 code-minimum requirements.

The thermal energy demand intensity is shown in Figure 5.4 for the baseline archetypes in four northern locations. The dashed yellow line represents the Step 5 (2017) TEDI target of 15 kWh/m²/yr. The dashed orange lines represent the Step 5 (2018) TEDI targets which are adjusted for each climate zone. The Step 5 (2018) TEDI target is 35, 50, and 60 kWh/m²/yr for climate zone 7a, 7b and 8, respectively. As expected, the location that is farthest north (Resolute, 12,360 HDD) has the highest heating energy demand compared to the four locations. The articulated version of the SFD archetype also has higher heating energy demand than the simple form SFD for all four locations.

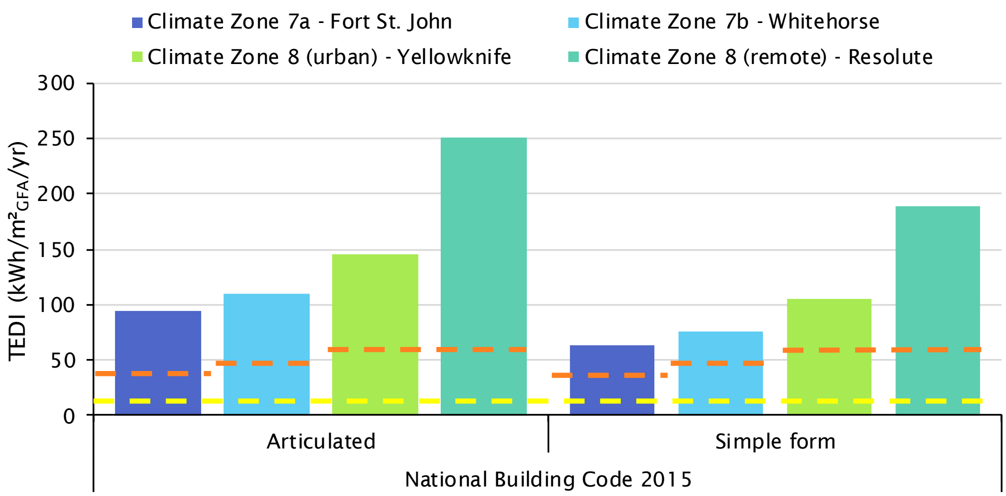


Figure 5.4 The results of TEDI for articulated and simple form SFD archetypes for all climate zones using NBC 2015 code minimum requirements. The dashed yellow line represents the Step 5 (2017) TEDI requirement of 15 and the dashed orange lines represents the Step 5 (2018) TEDI requirement, which varies for each climate zone.

These baseline model results show that HDD of the building location as well as building form factor have a measurable impact on heating energy. The impact of HDD on heating energy is further illustrated in Figure 5.5 for both the articulated and simple form SFD. The correlation of TEDI with HDD is linear for both SFD archetypes, indicating that the colder the location the harder it will be to meet one non-climate specific TEDI target for all northern locations.

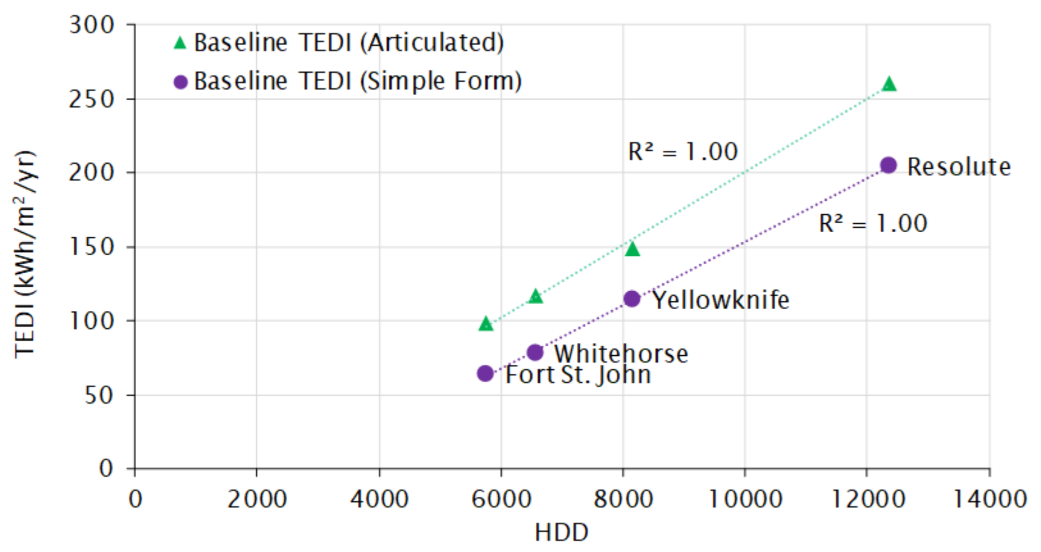


Figure 5.5 Correlation of TEDI with HDD for the four northern locations. The articulated SFD is shown in green triangles; the simple form SFD is shown in purple circles.

Comparison of NBC 2010 to NBC 2015

The 2010 version of the NBC was compared to the newer 2015 version to assess the impact of updates pertaining to energy efficiency. After reviewing the two versions of NBC, no changes were found in section 9.36 that would affect the energy analysis (i.e. sub-section 9.36.5). As such, there were no differences to model and no upgrade measures to cost in the later phase of this study.

MURB Baselines

The MURB archetypes are 3-storey wood-frame buildings with 29 suites, approximately 32,000 ft^2 (2,900 m^2) in size. There are several possible ventilation strategies for the MURB archetypes. For the baseline, code-minimum buildings, low-efficiency (50%) HRVs provide ventilation in suites, while the corridor air is provided with a separate air handling unit. To reach higher ventilation system efficiency, this ventilation strategy is changed to a zoned approach with heat recovery for grouped suite zones as well as the corridor zone. This enables the use of larger, dual-core commercial HRVs that do not require pre-heat even in extreme cold climates.[41]

Electric systems were modelled for space heating and for DHW for simplicity and as this reflects new construction in north-west Canada. The results can be roughly extrapolated to other systems (e.g. fuel oil furnace, pellet stove) using differences in equipment efficiency.

Two different MURB geometries are compared: a simple rectangular form with no balconies and low window-to-wall ratio, and an articulated design with balconies and a slightly higher window-to-wall ratio (as seen in Figure 5.6 and Figure 5.7).

[41] Per testing by NRC, presented at Polar Forum April 30th, 2018.

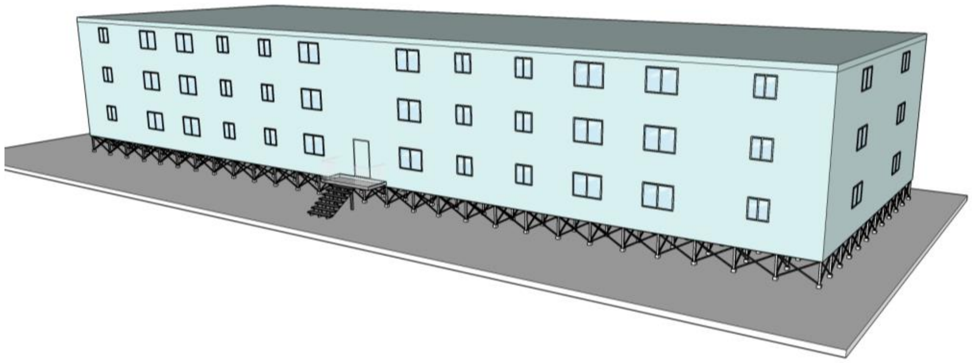


Figure 5.6 Multi-unit residential building (MURB), simple form factor.

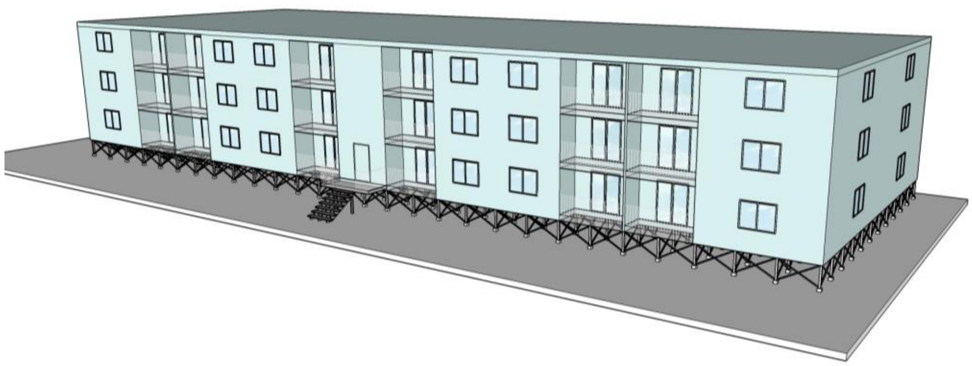


Figure 5.7 Multi-unit residential building (MURB), articulated form factor.

The energy analysis of the two geometries are compared to show the difference in feasibility of reaching targets with different architectural designs. The energy analysis of the MURB archetypes includes a comparison of NECB 2011 and NECB 2015, a 25% better than code target, Step 4 of the BC Energy Step Code, and Passive House compliance.

The articulated and simple form MURBs were modelled with NECB 2011 code minimum requirements. The energy end use breakdown is provided in Figure 5.8 where the space heating demand is shown as the highest end use varies the most with location.

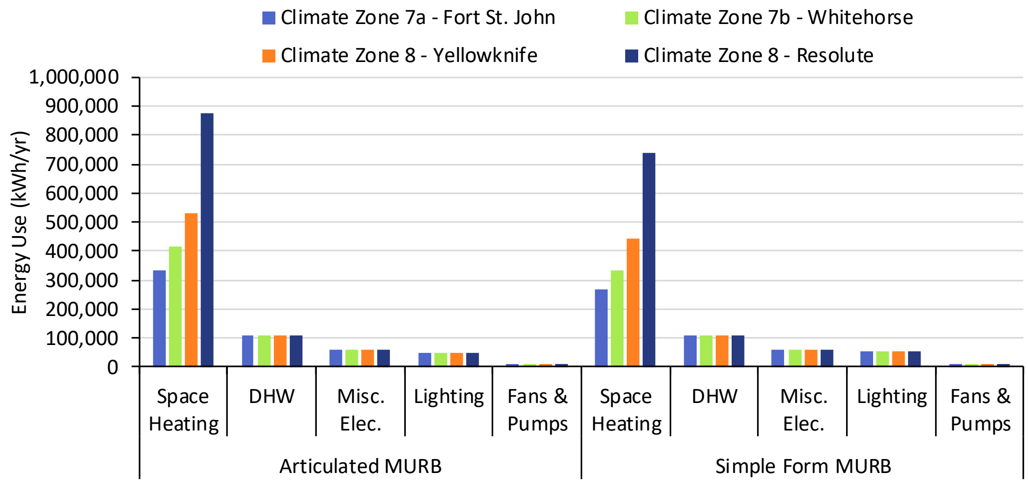


Figure 5.8 Baseline energy end-use breakdown for the articulated and simple form MURB archetypes in the four locations, using NECB 2011 code-minimum requirements.

Figure 5.9 presents the TEDI results for the baseline articulated and simple form MURB archetypes in the four locations. The dashed line represents the Step 4 TEDI target of 15 kWh/m$^2_{GFA}$/yr. Step 4 is the highest step of the BC Energy Step Code for Part 3 residential buildings and there is no Step 5 as there was in the previous SFD section.

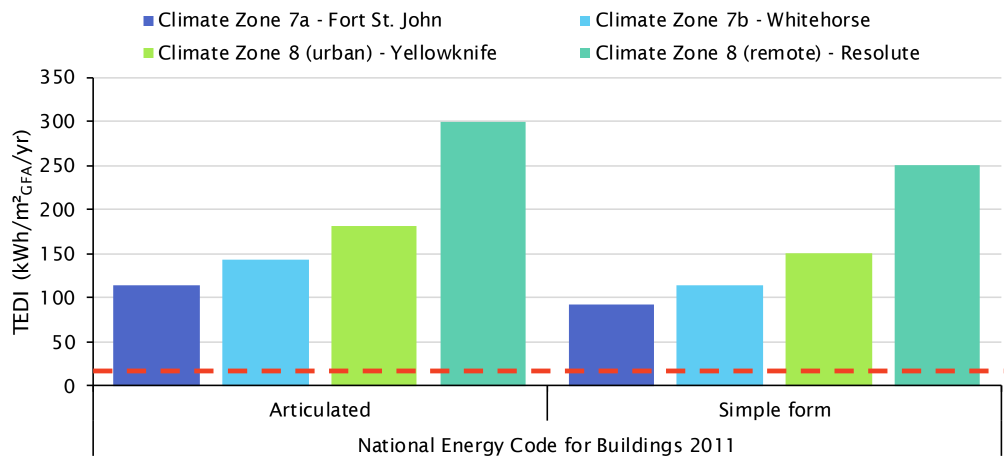


Figure 5.9 TEDI for the articulated and simple form building for the four northern locations using NECB 2011 code minimum requirements. The dashed line represents the Step 4 TEDI requirement of 15 kWh/m$^2_{GFA}$/yr.

There are two key observations from this analysis. First, simple form building in general has a lower TEDI than an articulated building. More importantly, a colder climate will exacerbate this difference due to increases in losses through the thermally weak portion of the enclosure such as windows and thermal bridging. For example, the difference between the articulated and simple form in Resolute is more than double that of the same buildings in Fort St. John.

The second observation is that the colder the climate, the harder it will be to meet the Step 4 target. The buildings in colder climate zones will require significantly more energy improvements to meet the Step 4 TEDI target.

Figure 5.10 shows the TEUI results for the baseline articulated and simple form MURB archetypes using NECB 2011 code-minimum requirements, with the Step 4 target of 100 $kWh/m^2_{GFA}/yr$ shown for reference.

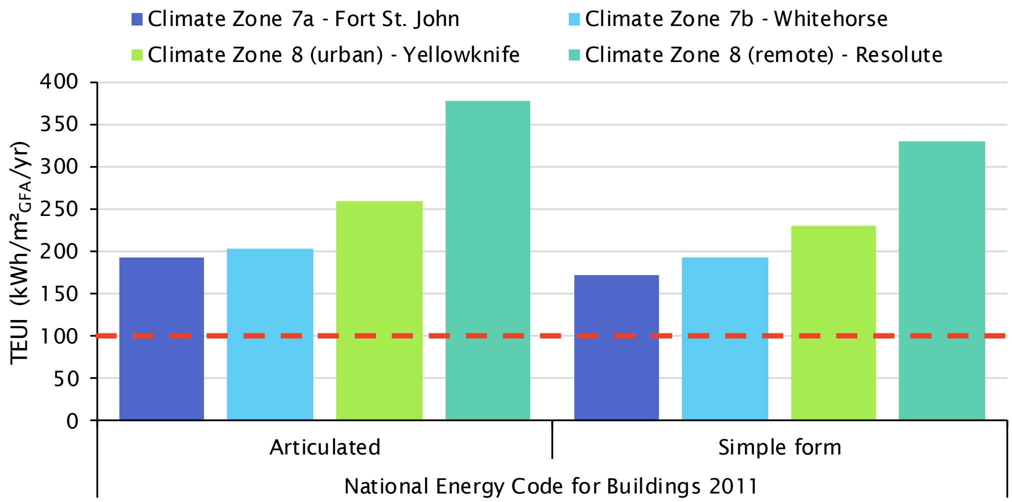


Figure 5.10 The results of TEUI for articulated and simple form for all climate zones using NECB 2011 code minimum requirements. The dashed line represents the Step 4 TEUI requirement of 100 $kWh/m^2_{GFA}/yr$.

The simple form building has a lower TEUI than the articulated building for each location, a trend that is more pronounced for the colder locations. This difference is primarily attributed to the difference in space heating demand.

It should also be noted that the gap between NECB 2011 baseline to Step 4 requirement of 100 $kWh/m^2_{GFA}/yr$ is significant for all northern locations.

Comparison of NECB 2011 to NECB 2015

There is no significant difference between NECB 2011 (Part 8) and NECB 2015 (Part 8). Relevant enclosure R-values, heating system, peak receptacle, service water heating load, operating schedules, HRV efficiency, heating setpoint and fan power are unchanged.

Changes have been made to the building type lighting power density (LPD) and occupant density for multi-unit residential buildings (from 6.5 W/m^2 to 5.5 W/m^2 and 60 m^2/occupant to 25 m^2/occupant, respectively). However, in this study the LPD and occupant density were modelled using the space-by-space method.

The space-type LPD for dwellings is unchanged. The space-type LPD for corridors/ transition area was given for two different widths in NECB 2011. In NECB 2015, the space-type lighting power density is given as one value, independent of the width of the space. Since the corridor is wider than 2.4 meters for the modelled archetypes, no change was made.

TABLE 5.2 LIGHTING POWER DENSITY USING THE SPACE-BY-SPACE METHOD		
Space type	NECB 2011	NECB 2015
Corridor/transition area (space type)	≤ 2.4 m – 8.4 W/m² > 2.4 m – 7.1 W/m²	7.1 W/m²

The space-type occupant density for the corridor is unchanged. The occupant density for the suites was not modelled according to NECB, which would have resulted in 1.5 people per suite. Instead, it was assumed that the occupant density was 3 people per suite.

5-Plex Baseline

In addition to the SFD and MURB archetypes, a row house archetype was included in the analysis to reflect new construction in Nunavut, and much of Northwest Territories. The 5-Plex row house archetype is based on the design drawings provided by the Nunavut Housing Corporation and includes mechanical systems that use fuel-oil in the climate zone 8 locations, which is typical of that region. Table 5.3 lists the specific ground condition modelled at each location.

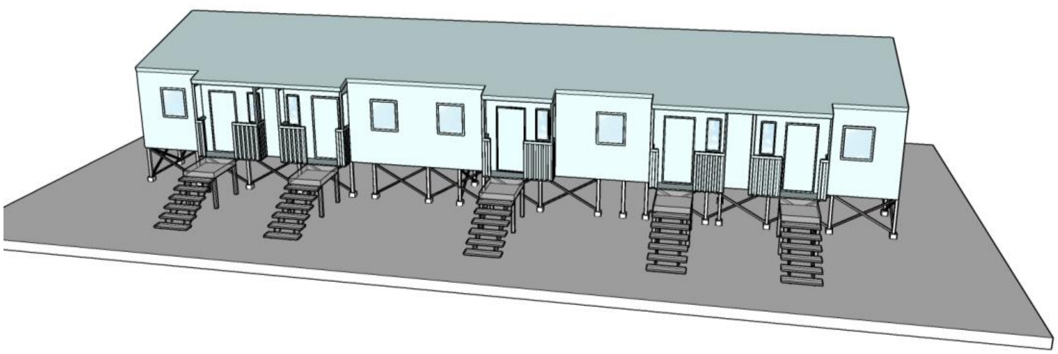


Figure 5.11 5-Plex row house. Front elevation image from Nunavut Housing Corporation's Public Housing 5Plex 2018-2019 drawings.

TABLE 5.3 GROUND CONDITIONS USED AT EACH LOCATION.	
Location	**Ground condition**
Climate zone 7a – Fort St. John	Slab on grade
Climate zone 7b – Whitehorse	Bedrock[42]
Climate zone 8 (urban) – Yellowknife	Elevated above permafrost
Climate zone 8 (remote) - Resolute	Elevated above permafrost

The 5-Plex was modelled with NBC 2015 9.36 code minimum requirements for the baseline models using HOT2000 (Figure 5.12). A large jump in space heating energy consumption is seen for the two climate zone 8 locations (Yellowknife and Resolute) since fuel oil systems are used in those locations, whereas electricity is used for the other two locations. A similar, yet less drastic, increase in energy consumption can be seen for the DHW energy use in the two climate zone 8 locations for the same reason.

[42] The bedrock condition is modelled like a slab on grade in HOT2000 and PHPP.

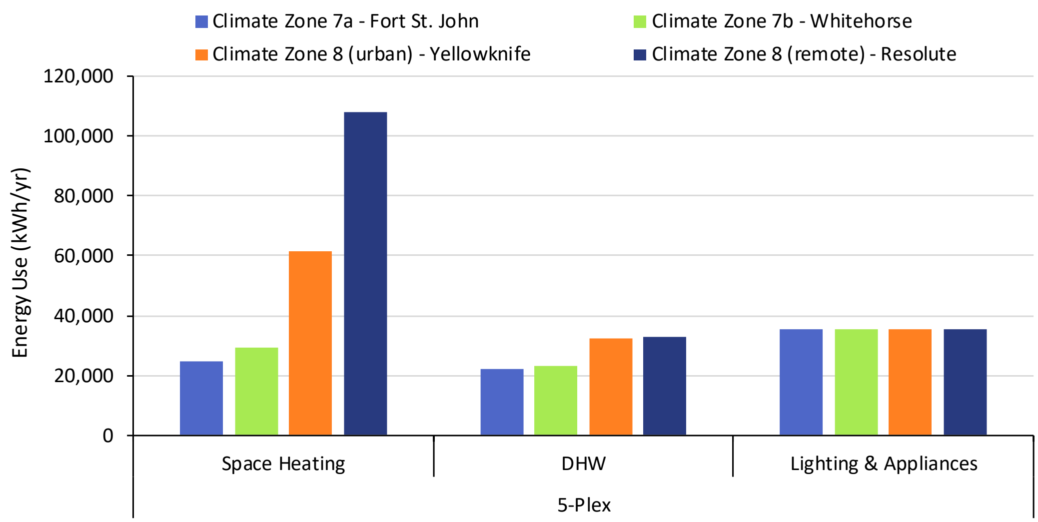


Figure 5.12 Baseline energy end-use breakdown for the 5-Plex archetype in the four locations, using NBC 2015 code-minimum requirements.

The thermal energy demand intensity is shown in Figure 5.13. The dashed yellow line represents the Step 5 (2017) TEDI target of 15 kWh/m²/yr. The dashed orange lines represent the Step 5 (2018) TEDI targets which are adjusted for each climate zone. The Step 5 (2018) TEDI target is 35, 50, and 60 kWh/m²/yr for climate Zone 7a, 7b and 8, respectively. As expected, the location that is farthest north (Resolute, 12,360 HDD) has the highest thermal energy demand compared to the four locations.

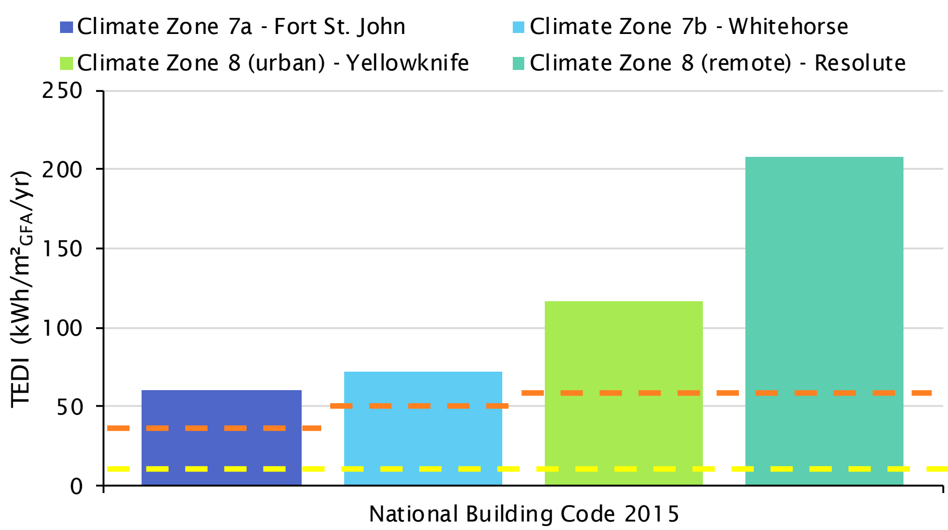


Figure 5.13 TEDI results for the 5-Plex in all four locations (Fort St. John, Whitehorse, Yellowknife and Resolute). The dashed yellow line represents the Step 5 (2017) TEDI requirement of 15 and the dashed orange lines represents the Step 5 (2018) TEDI requirement, which varies each climate zone.

These baseline model results illustrate that HDD value of the building location has a significant impact on heating energy, similar to the SFD and the MURB baseline results.

The 5-Plex for climate zone 8 was modelled with both electric resistance and fuel oil systems for the NBC 2015 9.36 code minimum scenario for comparison. The mechanical energy use intensity is shown in Figure 5.14. As expected, the fuel oil heating systems have the higher site energy use intensity compared to the electric resistance heating systems due to a lower efficiency. Absolute energy targets (e.g. Step 5 MEUI target) will be more challenging to meet with fuel oil systems, since the compliance targets are based on site energy and the fuel oil systems consume more energy than electric systems, due to lower equipment efficiencies. Though using electric systems may be difficult in many remote northern communities for lack of reliable grid connection, further discussed in Section 7.1.6.

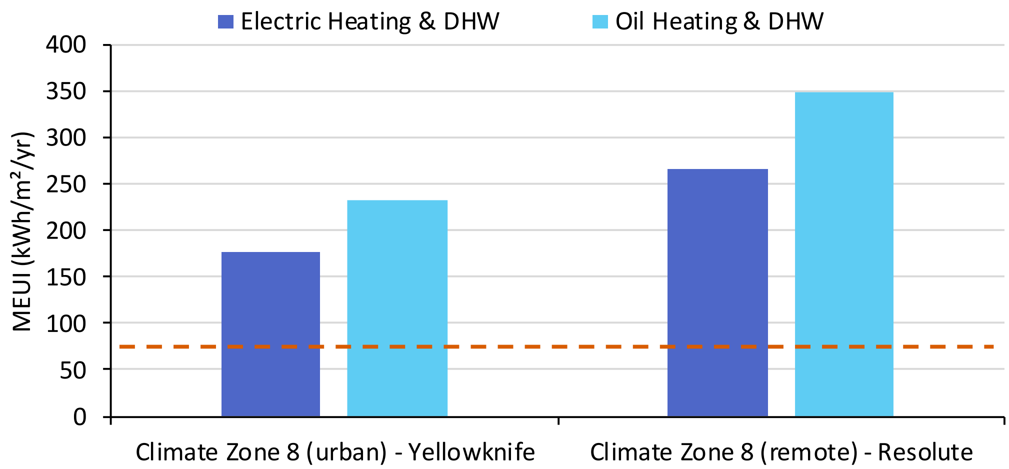


Figure 5.14 A comparison of MEUI for the 5-Plex in climate zone 8 locations (Yellowknife and Resolute) for eclectic resistance vs. fuel oil heating systems. The Step 5 (2018) MEUI target is shown with a dashed line for reference.

5.1.2 High Performance Targets

To better understand how high performance energy targets may be achieved in the north, examples targets were selected for analysis (Table 5.4).

The 25% better than code target achieves energy savings proportional to the baseline energy consumption. This type of relative target has benefits including that it does not penalize buildings that inherently consume high energy (e.g. restaurants or buildings in very cold regions). The downside to using a relative energy target (i.e. comparing to a reference model) is that it does not encourage building designers to improve poor features that are also present in the reference model such as a highly articulated form factor. There are also challenges with selecting an appropriate reference HVAC system for comparison.

Absolute performance targets such as used in the BC Energy Step Code and Passive House may be better at encouraging low energy design though there are challenges with achieving these targets for all building types and in all locations. The climate, usage, occupant density, and processes that occur within the building significantly impact the EUI. Similarly, typical construction and design practices of the marketplace for the building typology also have an impact.

An overview of the relative and absolute performance targets modelled in this study are provided in Table 5.4. The actual targets for each are provided in the Methodology section.

TABLE 5.4 PERFORMANCE TARGETS FOR COMPLIANCE MODELLING				
	25% < CODE	**BC STEP CODE (2017)**	**BC STEP CODE (2018)**	**PASSIVE HOUSE**
SFDs	25% < NBC 2015	Steps 4 & 5	Steps 4 & 5	Passive House Classic
MURBs	25% < NECB 2011	Step 4	Step 4	Passive House Classic
5-Plex	25% < NBC 2015	Steps 4 & 5	Steps 4 & 5	Passive House Classic

5.1.3 Summary of Compliance

To achieve the near-net zero ready performance targets set by Passive House and the BC Energy Step Code, first a set of maximum practically achievable energy conservation measures (ECMs) was established (see Section 2.3). A building with the entire suite of maximum ECMs represents the maximum achievable building performance for that archetype using existing technologies and common building practices. In some cases, this was not enough to reach the near-net zero ready targets for the very cold locations in this study. Alternative technologies and building designs for these cases are discussed in Section 6.

TABLE 5.5 SUMMARY OF COMPLIANCE WITH HIGH PERFORMANCE TARGETS USING HIGHEST PERFORMING PRACTICAL ECMS FOR THE NORTH							
		25% < CODE	STEP CODE* (2017)		STEP CODE* (2018)		PASSIVE HOUSE
			STEP 4	STEP 5	STEP 4	STEP 5	
Fort St. John CZ 7a	SFD – articulated	Yes	Yes	Yes	Yes	Yes	No
	SFD – simple form	Yes	Yes	Yes	Yes	Yes	No
	MURB – articulated	Yes	Yes	N/A	Yes	N/A	Yes
	MURB – simple form	Yes	Yes	N/A	Yes	N/A	Yes
	5-Plex	Yes	Yes	Yes	Yes	Yes	No
Whitehorse CZ 7b	SFD – articulated	Yes	Yes	Yes	Yes	Yes	No
	SFD – simple form	Yes	Yes	Yes	Yes	Yes	No
	MURB – articulated	Yes	Yes	N/A	Yes	N/A	No
	MURB – simple form	Yes	Yes	N/A	Yes	N/A	Yes
	5-Plex	Yes	Yes	Yes	Yes	Yes	No
Yellowknife CZ 8	SFD – articulated	Yes	Yes	No	Yes	Yes	No
	SFD – simple form	Yes	Yes	Yes	Yes	Yes	No
	MURB – articulated	Yes	No	N/A	No	N/A	No
	MURB – simple form	Yes	Yes	N/A	Yes	N/A	No
	5-Plex	Yes	Yes	Yes	Yes	Yes	No
Resolute CZ 8	SFD – articulated	Yes	Yes	No	Yes	Yes	No
	SFD – simple form	Yes	Yes	No	Yes	Yes	No
	MURB – articulated	Yes	No	N/A	No	N/A	No
	MURB – simple form	Yes	No	N/A	No	N/A	No
	5-Plex	Yes	Yes	No	Yes	Yes	No

*Step Code targets are different for Part 9 and Part 3 buildings. Part 9 buildings have targets ranging from Step 1 to Step 5, whereas Part 3 residential buildings have targets ranging from Step 1 to Step 4 (so there are no Step 5 targets for Part 3). The updates to the Step Code included adapting the Part 9 targets, though the Part 3 targets were unchanged (so the same Part 3 targets apply to the 2017 and 2018 Step Code iterations).

The details for how the performance targets were achieved (when they were achieved) for the five archetypes is outlined below for Fort St. John (5.2), Whitehorse (5.3), Yellowknife (5.4), and Resolute (5.5).

5.2 Climate Zone 7a – Fort St. John

The following section outlines how low-energy building targets may be achieved for the five archetypes in Fort St. John as an example for climate zone 7a. Energy modelling results are shown for the articulated and simple form SFDs (5.2.1), the articulated and simple form MURBs (5.2.2), and the 5-Plex (5.2.3).

5.2.1 SFDs in Fort St. John

This section presents how various high performance energy targets can be achieved for the SFD archetypes in Fort St. John using commonly available technologies and building practices.

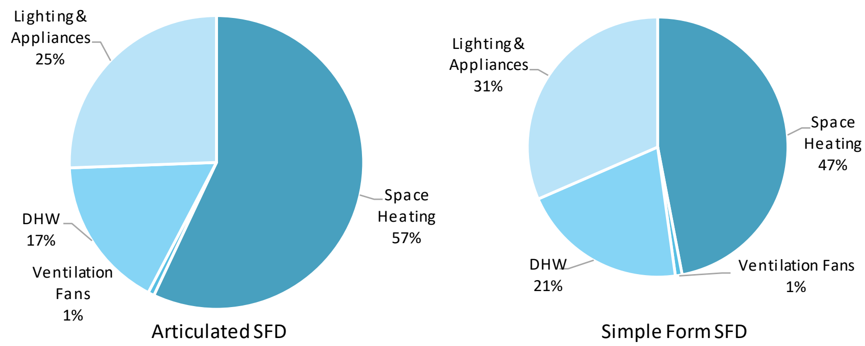


Figure 5.15 Baseline energy consumption break down for the baseline NBC 2015 SFDs in Fort St. John.

25% Better Than Code

The baseline SFD models were adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the NBC model. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption.

To meet the 25% energy target, several minor enclosure ECMs were implemented as well as an increase to the HRV efficiency. The 25% energy target could have been met with fewer ECMs if more of an airtightness improvement was made, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

- → Reduction in air leakage rate from 2.5 ACH50 to 1.5 ACH50
- → Increased insulation of opaque assemblies:
  - → Roof from R_{eff}-49 to R_{eff}-60
  - → Walls from R_{eff}-17 to R_{eff}-30 (articulated) or R_{eff}-22 (simple form)
  - → Slab from R_{eff}-16 to R_{eff}-22
- → Windows from double glazed U-0.28 to low-conductivity doubles U-0.25 (articulated) or triples U-0.20 (simple form)
- → Doors from R-3.6 to R-4
- → Increase HRV efficiency from 60/55% to 81%, dual core no preheat (articulated) or 70% (simple form)
- → Add drain water heat recovery at 42% effectiveness (simple form, only)

Figure 5.16 shows the total energy consumption of the baseline SFDs and of the 25% better than code SFDs in Fort St. John. The starting baseline energy use and the 25%

reduced energy consumption are higher for the articulated SFD archetype compared to the simple form SFD archetype.

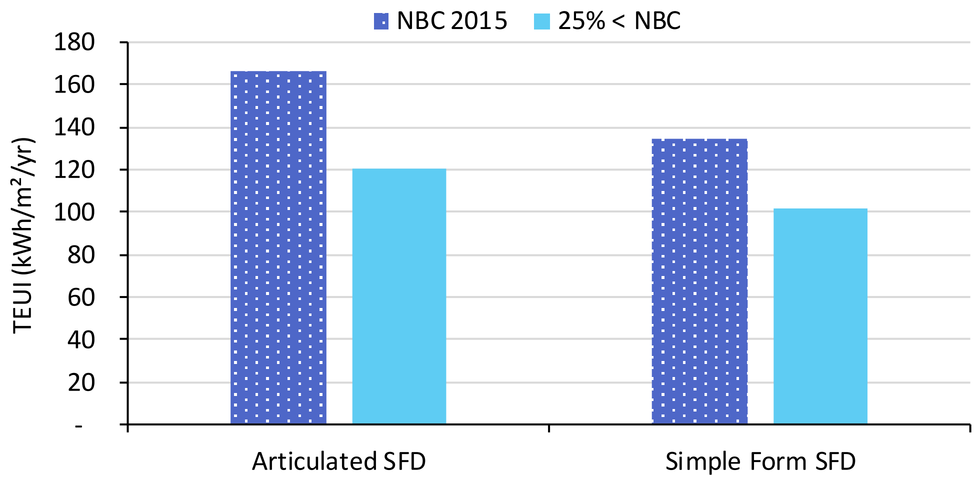


Figure 5.16 Total Energy Use Intensity of the NBC 2015 baseline SFD models and the 25% better than code SFD models in Fort St. John.

As shown here, the articulated SFD can reach the 25% target with similar ECMs as the simple form SFD (with a trade off between wall insulation and better windows) and is not encouraged to use further ECMs (or better design) to match the lower energy consumption of its simple form counterpart.

Step 4 of the BC Energy Step Code

The baseline SFD models were adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr). A percent better than reference house may also be used as an alternate compliance path for Step 4, though the results presented here focus on MEUI since this is the only mechanical energy compliance path for Step 5 (shown later). A detailed summary of all model inputs is attached in Appendix E.

The Step 4 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

ECMs Beyond Baseline (NBC 2015):

- Reduction in air leakage rate from 2.5 ACH50 to 1.0 ACH50 (articulated) or 1.5 ACH50 (simple form)
- Increased insulation of opaque assemblies:
  - Roof from R_{eff}-49 to R_{eff}-60 (articulated) or R_{eff}-50 (simple form)
  - Walls from R_{eff}-17 to R_{eff}-25 (articulated) or R_{eff}-20 (simple form)
  - Slab from R_{eff}-16 to R_{eff}-30 (articulated) or R_{eff}-20 (simple form)
- Windows from double glazed U-0.28 to low-conductivity doubles U-0.25
- Doors from R-3.6 to R-5 (articulated) or R-4 (simple form)

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat (articulated) or 65% (simple form)

→ Add drain water heat recovery at 65% effectiveness (articulated, only)

The following figures show the energy modelling results for reaching Step 4 (2018) targets. TEUI is shown for comparison with the total energy consumption of the baseline and the 25%<code target. Step Code metrics MEUI and TEDI are also shown, with the baseline, 25%<code, and original Step 4 (2017) included for comparison.

Figure 5.17 shows that the performance targets of the Step Code result in larger energy savings for the articulated archetype, which began with a high baseline energy consumption.

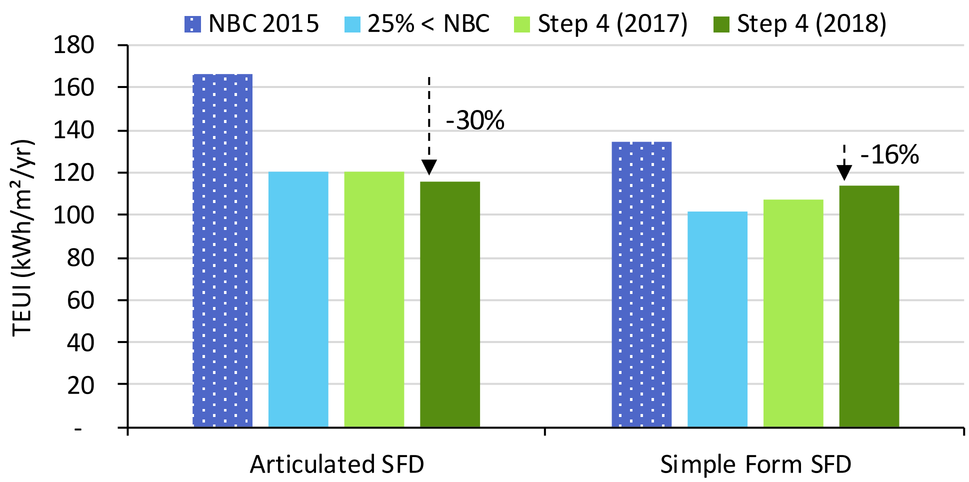


Figure 5.17 Total EUI for the articulated and simple form SFDs in Fort St. John, showing the reduction in energy consumption resulting from reaching Step 4 (new Step Code target, dark green). The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

Although the articulated SFD is over the Step 4 MEUI target, the model still complied using the alternate %<REF pathway. The percent better than reference house metric may be used as an alternate compliance path for Step 4, though the results presented here focus on MEUI since this is the only mechanical energy compliance path for Step 5 (shown later).

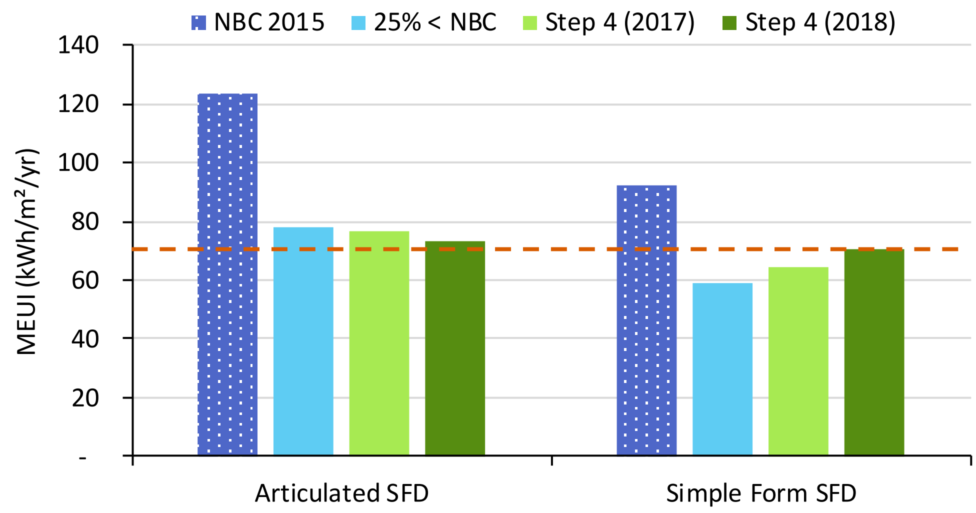


Figure 5.18 MEUI for the articulated and simple form SFDs in Fort St. John, showing the new Step Code Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

The TEDI for the simple form SFD is well below the Step 4 (2018) TEDI limit (Figure 5.19). This is because this archetype was MEUI-limited and the measures that were implemented to reduce MEUI for compliance let to lower TEDI than necessary.

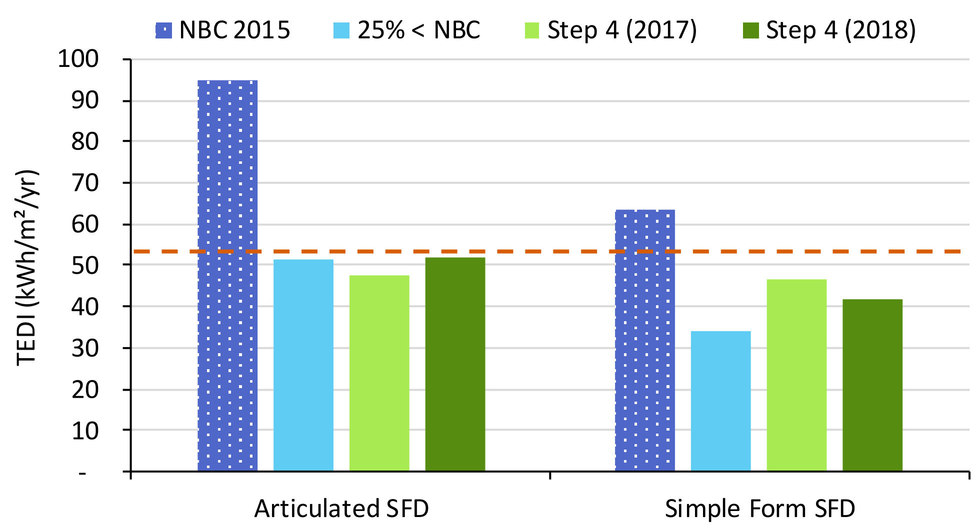


Figure 5.19 TEDI for the articulated and simple form SFDs in Fort St. John, showing the new Step Code Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

Step 5 of the BC Energy Step Code

The baseline SFD models were adjusted by implementing ECMs to meet the targets in Step 5 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr).

The Step 5 targets from the original Step Code (December 2017) and the updated Step Code (December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

To meet the Step 5 energy targets, several major enclosure ECMs and mechanical efficiency improvements were implemented. Many of the highest performing practical ECMs (Section 2.3) were necessary for the articulated SFD, while less stringent ECMs were necessary for the simple form SFD, demonstrating the benefit of starting with a simple form design. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 0.3 ACH50 (articulated) or 1.0 ACH50 (simple form)

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-49 to R_{eff}-60 (articulated) or R_{eff}-50 (simple form)

  → Walls from R_{eff}-17 to R_{eff}-30 (articulated) or R_{eff}-22 (simple form)

  → Slab from R_{eff}-16 to R_{eff}-35 (articulated) or R_{eff}-20 (simple form)

→ Windows from U-0.28 to triples U-0.18 (articulated) or low-conductivity doubles U-0.25 (simple form)

→ Doors from R-3.6 to R-6 (articulated) or R-5 (simple form)

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat (articulated) or 70% (simple form)

→ Add R-12 blanket to DHW tank (articulated, only)

→ Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 5 (2018) targets. TEUI is shown for comparison with the baseline and Step 4-compliant models, as well as original Step 5 (2017). Step Code metrics MEUI and TEDI are also shown, with the baseline, Step 4 models, and original Step 5 (2017) included for comparison.

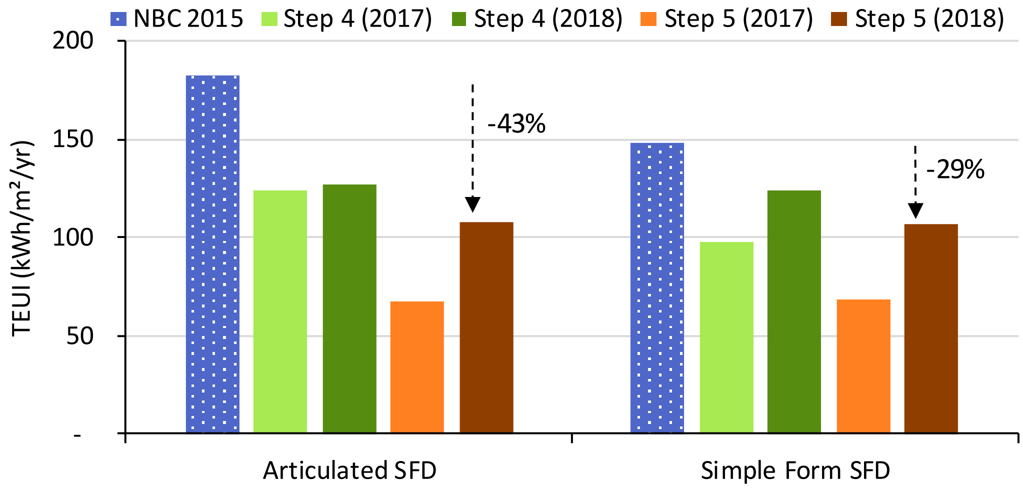


Figure 5.20 Total EUI for the articulated and simple form SFDs in Fort St. John, showing the reduction in energy consumption resulting from reaching Step 5 (new Step Code target, dark red). The Step 4-compliant and Step 5 (2017) models are shown for comparison (greens and light orange, respectively).

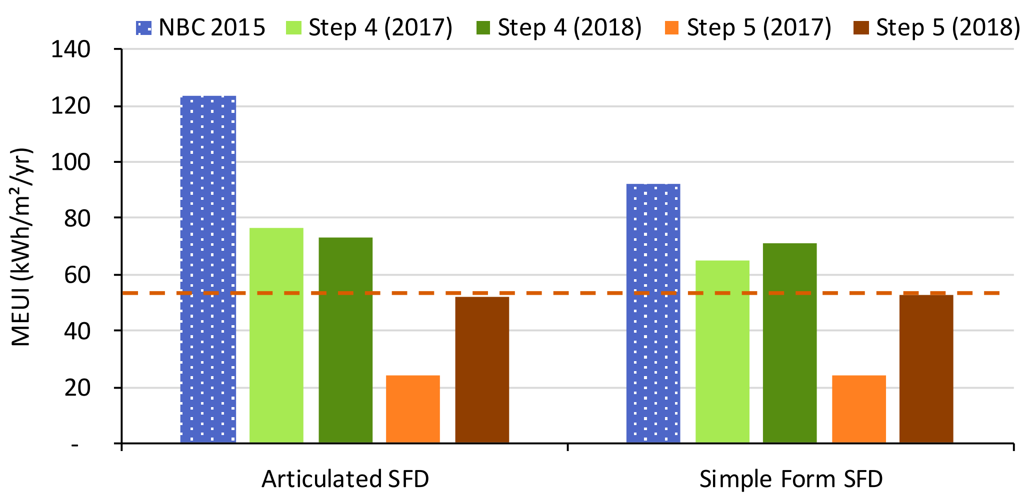


Figure 5.21 MEUI for the articulated and simple form SFDs in Fort St. John, showing the new Step Code Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

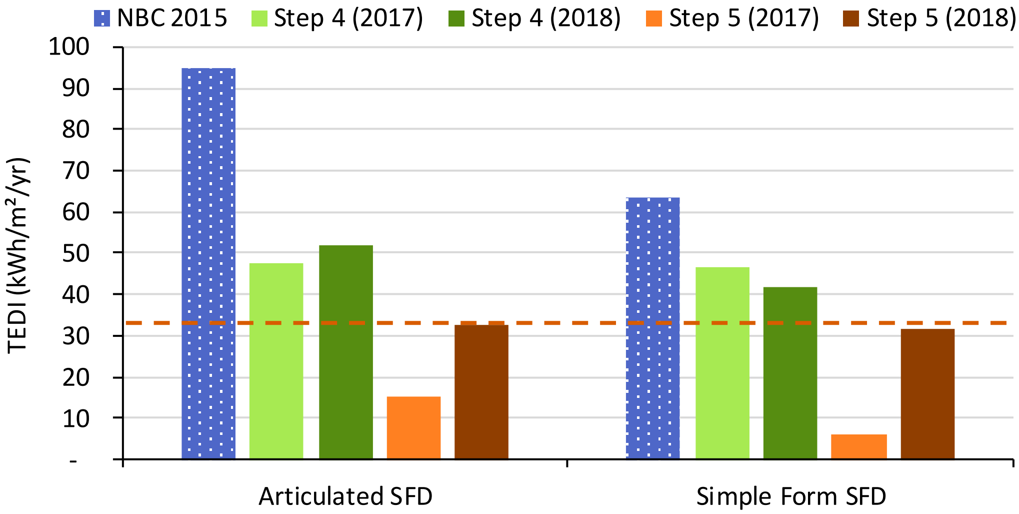


Figure 5.22 TEDI for the articulated and simple form SFDs in Fort St. John, showing the new Step Code Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Passive House

The baseline SFD models were adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for total building energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 did not meet the heating demand or heating load targets and thus, even though the PER target was met for the simple form SFD, neither SFD model met the Passive House standard. The PHPP-modelled results of using the highest performing practical ECMs are shown in Figure 5.23 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NBC 2015):

→ Did not meet Passive House

  → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.23.

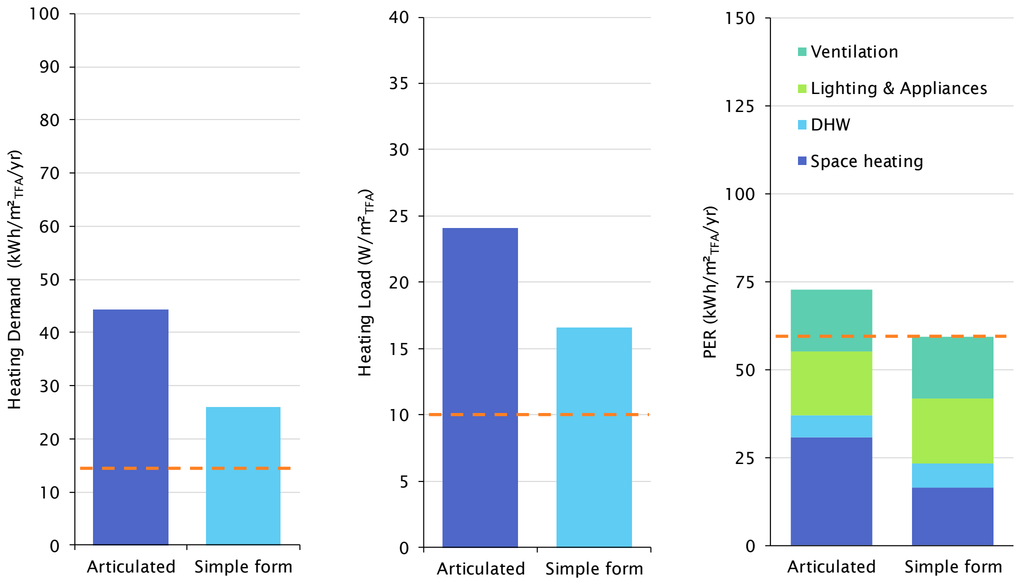


Figure 5.23 The heating demand (left), heating load (middle), and PER (right) of both articulated and simple form SFD models in Fort St. John. The Passive House targets are shown in orange dashed lines – only the PER target is met for the simple form SFD.

Even with the highest performance practical ECMs outlined in Section 2.3, the articulated and simple form SFD models did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices (e.g. higher R-value enclosures, different wall types not common to the North), and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

→ The 25% better than code target was met by implementing several minor enclosure ECMs as well as increased heat recovery. The 25% energy target could have been met with fewer ECMs if more of an airtightness improvement was made, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs.

→ The Step 4 targets resulted in similar energy improvements as the 25% better than code target for the SFDs in Fort St. John. Increased insulation and low-conductivity windows, coupled with higher HRV efficiency and airtightness, help reach the targets.

→ The Step 5 targets require the articulated SFD to use several of the highest performance practical ECMs outlined in Section 2.3, while the simple form SFD does not need such stringent measures to meet Step 5. This demonstrates the importance of starting with simple form designs to meet high performance targets.

→ Passive House targets were not achieved with the highest performance practical ECMs for the SFDs in Fort St. John. Although the PER target was met by the simple form SFD, neither archetype met the heating demand or heating load targets.

Section 6 provides alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets.

This additional analysis will assess the impact of ECMs beyond the highest performance practical ECMs outlined in Section 2.3.

5.2.2 MURB in Fort St. John

This section presents how various high performance energy targets can be achieved (and which cannot be achieved) for the MURB archetypes in Fort St. John using commonly available technologies and building practices.

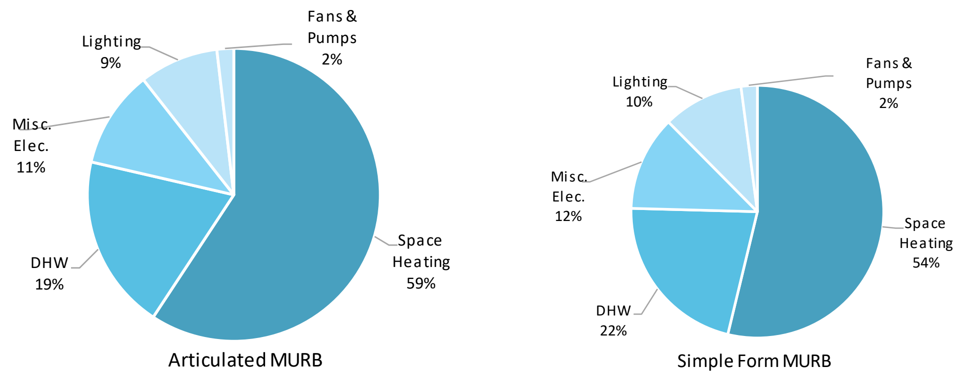


Figure 5.24 Baseline energy consumption break down for the baseline NECB 2011 MURBs in Fort St. John.

25% Better Than Code

The baseline MURB models were adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the reference NECB 2011 model per Part 8 of NECB. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption.

The ECMs that were implemented to meet the 25% energy target are listed below. To meet the 25% energy target, several minor enclosure ECMs were implemented as well as an increase to the HRV efficiency. The 25% energy target could have been met with only airtightness improvement (beyond 0.6 ACH50 Passive House levels), though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs. A detailed summary of all model inputs is attached in Appendix F.

ECMs Beyond Baseline (NECB 2011):

→ Reduction in air leakage rate from 0.25 L/s-m² at 5 Pa (2.2 ACH50) to 0.125 L/s-m² at 5 Pa (1.1 ACH50)

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-35 to R_{eff}-39 (simple form, only)

  → Walls from R_{eff}-27 to R_{eff}-32 (simple form, only)

  → Exposed floors from R_{eff}-35 to R_{eff}-41 (simple form, only)

→ Windows from double glazed (U-0.39) to triple glazed (U-0.17) (articulated and simple form)

→ Increase in-suite HRV efficiency from 50% to 70%

Figure 5.25 shows the total energy consumption of the baseline MURBs and of the 25% better than code MURBs in Fort St. John. Both the starting baseline energy use and the 25% reduced energy consumption are higher for the articulated MURB archetype compared to the simple form MURB archetype. As shown in Figure 5.25, the 25% better than code target achieves energy savings proportional to the baseline energy consumption. The articulated MURB can reach the 25% target with less aggressive ECMs than the simple form MURB and is not encouraged to use further ECMs (or better design) to match the lower energy consumption of its simple form counterpart.

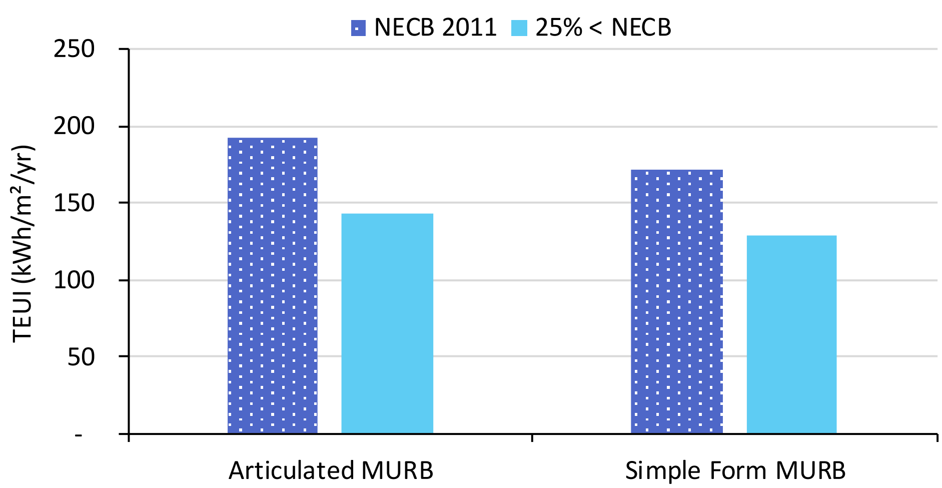


Figure 5.25 Total Energy Use Intensity of the NECB 2011 baseline MURB models and the 25% better than code MURB models in Fort St. John.

Step 4 of the BC Energy Step Code

The baseline MURB models were adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for whole building energy consumption (Total Energy Use Intensity (TEUI), kWh/m²/yr). A detailed summary of all model inputs is attached in Appendix F.

The heating demand, TEDI, target is difficult to meet in cold climates since the original BC Energy Step Code targets for Part 3 buildings are intended for climate zone 4, only. As such, the ECMs that were implemented to meet Step 4 with this archetype are all heating demand reduction measures, which result in meeting the Step 4 TEDI target. The TEUI target was incidentally also met by implementing these ECMs. Because of the higher performance baseline for the simple form MURB, less stringent enclosure ECMs were required to meet Step 4 targets for the simple form archetype compared to the articulated archetype.

ECMs Beyond Baseline (NECB 2011):

→ Reduction in air leakage rate from 0.25 L/s-m² at 5 Pa (2.2 ACH50) to 0.020 L/s-m² at 5 Pa (0.15 ACH50)

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-35 to R_{eff}-53 (articulated) or R_{eff}-39 (simple form)

  → Walls from R_{eff}-27 to R_{eff}-41 (articulated) or R_{eff}-32 (simple form)

  → Exposed floors from R_{eff}-35 to R_{eff}-50 (articulated) or R_{eff}-41 (simple form)

→ Windows from double glazed (U-0.39) to quadruple glazed (U-0.12)

→ Ventilation strategy changed from in-suite HRVs with pre- and post-heat and MUA unit supplying corridors with tempered air, to centralized/zoned ventilation system with 81% heat recovery (by dual core units with no preheat required) for suites and corridors.

These ECMs work to reduce the heating demand of the MURB archetypes and successfully meet the Step 4 TEDI target of 15 kWh/m²/yr, shown in Figure 5.27, the TEDI target is shown for reference by the orange dashed line. The MURB archetypes also meet the Step 4 TEUI target of 100 kWh/m²/yr. As shown in Figure 5.26, the whole building energy consumption is reduced by 46% to 52% compared to the baseline NECB 2011.

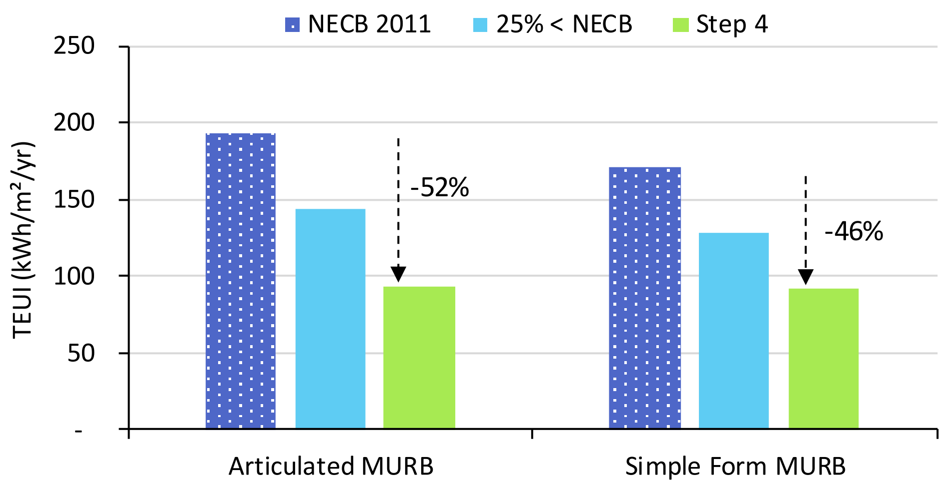


Figure 5.26 Total Energy Use Intensity of the NECB 2011 baseline, the 25% better than code, and the Step 4 BC Energy Step Code MURB models in Fort St. John. The Step 4 performance targets result in a 52% and a 46% reduction in energy consumption for the articulated and simple form MURB archetypes, respectively.

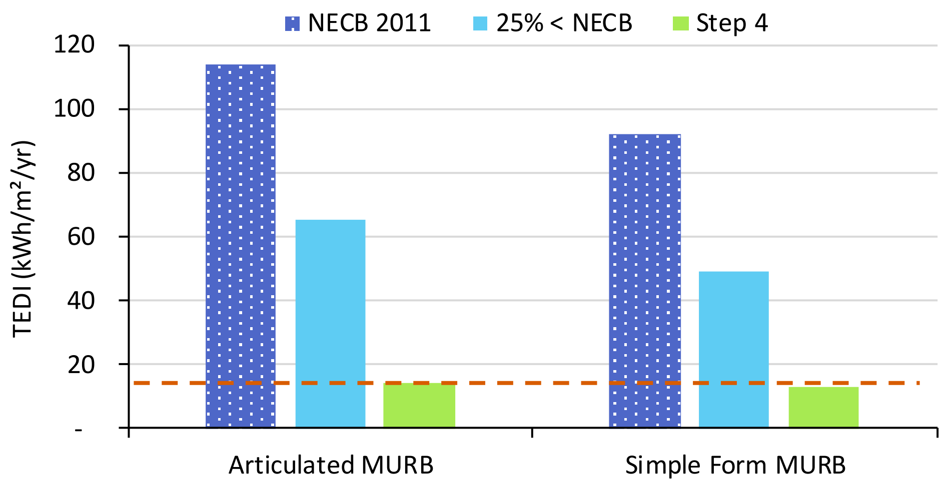


Figure 5.27 Thermal Energy Demand Intensity of the NECB 2011 baseline, the 25% better than code, and the Step 4 BC Energy Step Code MURB models in Fort St. John. Step 4 TEDI target of 15 kWh/m²/yr is shown for reference by the orange dashed line.

It is the heating reduction measures that drive the energy savings in the Step 4 BC Energy Step Code models. The combination of ECMs listed above are one example of how Step 4 targets may be achieved in Fort St. John, though the performance-based energy targets may be complied with by using alternate combinations of ECMs. In other, colder climates even the highest performance practical ECMs outlined in Section 2.3 may not meet the Step 4 TEDI targets.

Passive House

The baseline MURB models were adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for source energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 result in meeting the Passive House targets in Fort St. John. The results are shown in Figure 5.23 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NECB 2011):

→ Reduction in air leakage rate from 0.25 L/s-m² at 5 Pa (2.2 ACH50) to 0.020 L/s-m² at 5 Pa (0.15 ACH50)

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-35 to R_{eff}-100

  → Walls from R_{eff}-27 to R_{eff}-80

  → Exposed floors from R_{eff}-35 to R_{eff}-80

→ Windows from double glazed (U-0.39) to quadruple glazed (U-0.12)

→ Ventilation system changed from in-suite HRVs with pre- and post-heat and MUA unit supplying corridors with tempered air, to centralized/zoned ventilation system with 81% efficient dual core HRV for suites and corridors.

→ Reduced corridor outdoor air rate from 20 cfm/door to 10 cfm/door.

→ Space heating system changed from electric baseboards to cold climate air source heat pumps with a VRF distribution system.

→ Domestic hot water system changed from electric tank to CO_2 heat pumps.

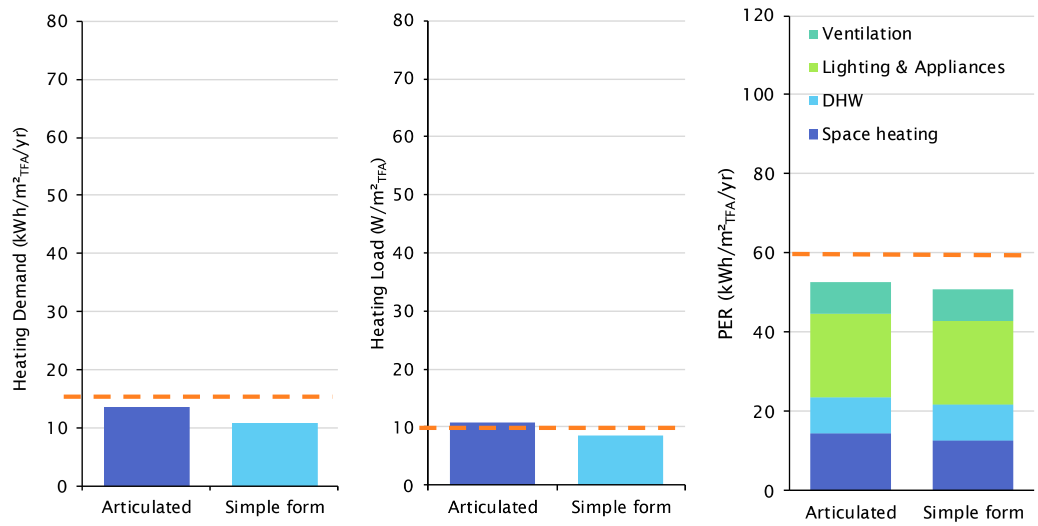


Figure 5.28 The heating demand (left), heating load (middle), and PER (right) of both articulated and simple form MURB models in Fort St. John with the ECMs in Section 2.3. The Passive House targets are shown in orange dashed lines – articulated and simple form MURB meet the Passive House targets.

It is the heating reduction measures that drive the energy savings in the Passive House models. The combination of ECMs listed above are one example of how Passive House targets may be achieved in Fort St. John. Though the performance-based energy targets may be complied with by using alternate combinations of ECMs.

Key Takeaways

→ The articulated MURB archetype has higher energy consumption than the simple form MURB archetype baseline. This makes it harder to reach fixed targets such as TEDI and TEUI.

→ The 25% target can be met for the MURBs in Fort St. John (CZ 7a) by measures including better airtightness, triple glazed windows, 70% heat recovery effectiveness, and increased insulation (simple form).

→ Step 4 BC Energy Step Code targets can be met for the MURBs in Fort St. John (CZ 7a) using heating demand reduction measures including increased insulation, better airtightness, quadruple-glazed windows, and ventilation with 81% heat recovery and no preheat. The potential challenges in attaining very low air leakage rates in the Far North will be discussed in Section 6.

→ The Passive House standard can be met for both MURBs in Fort St. John (CZ 7a) using heating demand reduction measures including increased insulation, better airtightness, quadruple-glazed windows, ventilation with 81% heat recovery and no preheat, cold climate air source heat pump for space heating, and CO_2 heat pump for domestic hot water heating.

- → The analysis presented here used high efficiency electric systems, which provides a best-case scenario assuming that buildings will be able to connect to an electric grid. This may be difficult to accomplish in many remote northern communities and so a comparison of electric versus fuel oil or propane systems in provided in Section 6. Non-electric systems may not meet PER due to fuel factors.

5.2.3 5-Plex in Fort St. John

This section presents how various high performance energy targets can be achieved for the 5-Plex archetype in Fort St. John using commonly available technologies and building practices. The baseline 5-Plex in Fort St. John was modelled with electric systems in contrast to the climate zone 8 locations where it is modelled with fuel oil systems.

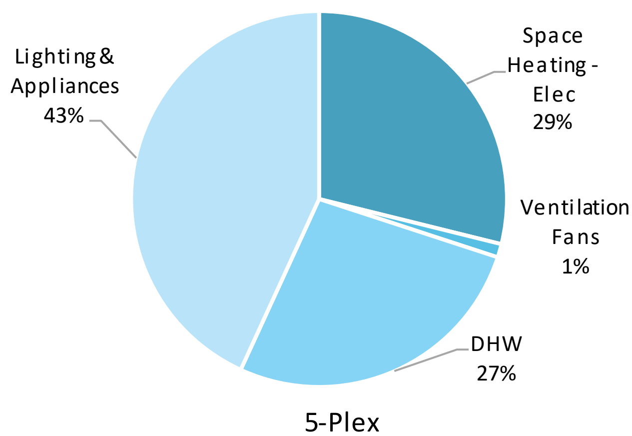


Figure 5.29 Baseline energy consumption break down for the baseline NBC 2015 5-Plex in Fort St. John.

25% Better Than Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the NBC model. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption.

To meet the 25% energy target, several minor enclosure ECMs were implemented as well as an increase to the HRV efficiency. The 25% energy target could have been met with fewer ECMs if more of an airtightness improvement was made, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

- → Reduction in air leakage rate from 2.5 ACH50 to 1.5 ACH50
- → Increased insulation of opaque assemblies:
    - → Roof from R_{eff}-28.5 to R_{eff}-40

- Walls from R_{eff}-17 to R_{eff}-35
- Slab from R_{eff}-16 to R_{eff}-25

→ Windows from double glazed U-0.28 to low-conductivity doubles U-0.25

→ Increase HRV efficiency from 60/55% to 81%, dual core no preheat

→ Add drain water heat recovery at 65% effectiveness

Figure 5.16 shows the total energy consumption of the baseline 5-Plex and of the 25% better than code 5-Plex in Fort St. John.

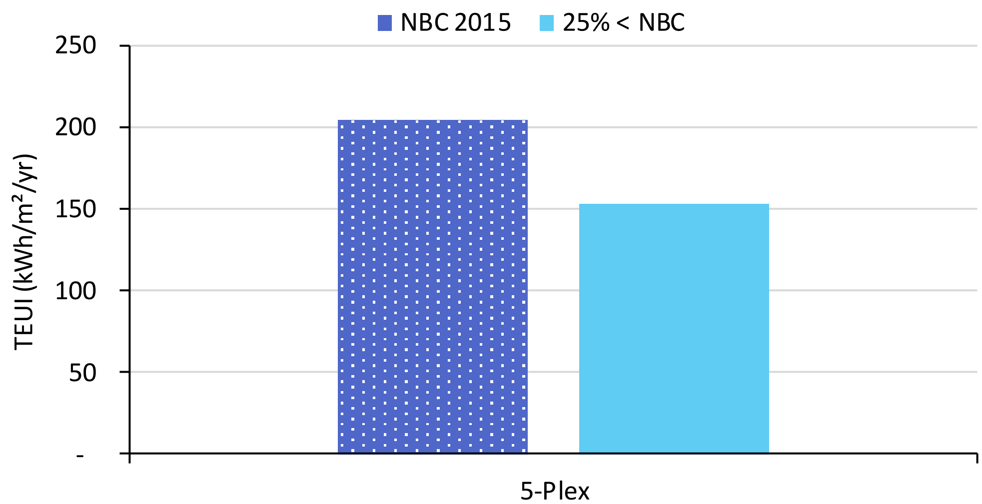


Figure 5.30 Total Energy Use Intensity of the NBC 2015 baseline 5-Plex model and the 25% better than code 5-Plex model in Fort St. John.

Step 4 of the BC Energy Step Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr). A detailed summary of all model inputs is attached in Appendix E.

The Step 4 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 1.5 ACH50

→ Increased insulation of opaque assemblies:

- Roof from R_{eff}-28.5 to R_{eff}-50
- Walls from R_{eff}-17 to R_{eff}-20
- Slab from R_{eff}-16 to R_{eff}-20

→ Windows from double glazed U-0.28 to low-conductivity doubles U-0.25

→ Increase HRV efficiency from 60/55% to 81%, dual core no preheat

→ Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 4 (2018) targets. TEUI is shown for comparison with the total energy consumption of the baseline and the 25%<code target. Step Code metrics MEUI and TEDI are also shown, with the baseline, 25%<code, and original Step 4 (2017) included for comparison.

Figure 5.32 shows that the performance targets of Step 4 result in 23% energy savings compared to the baseline, similar to the 25%<code target. Figure 5.32 shows the MEUI.

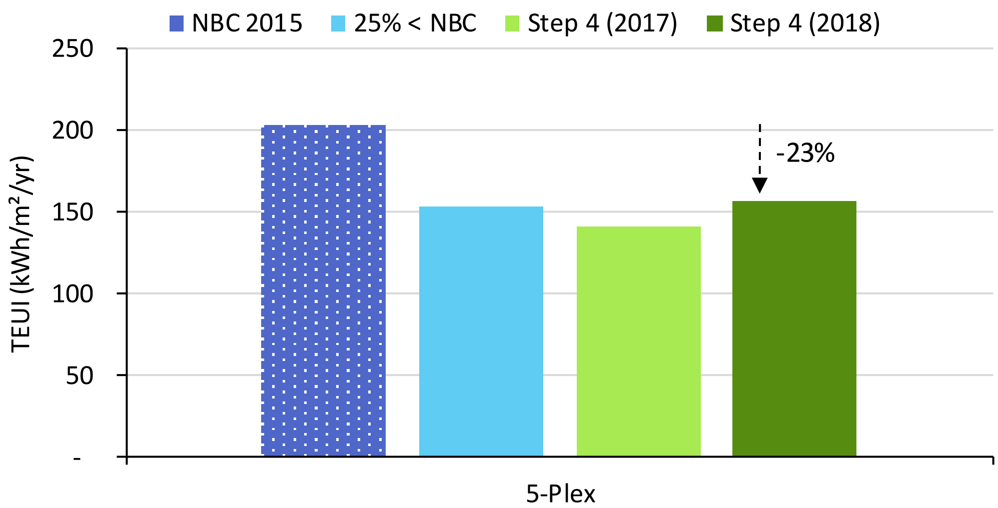


Figure 5.31 Total EUI for the 5-Plex in Fort St. John, showing the reduction in energy consumption resulting from reaching Step 4 (new Step Code target, dark green). The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

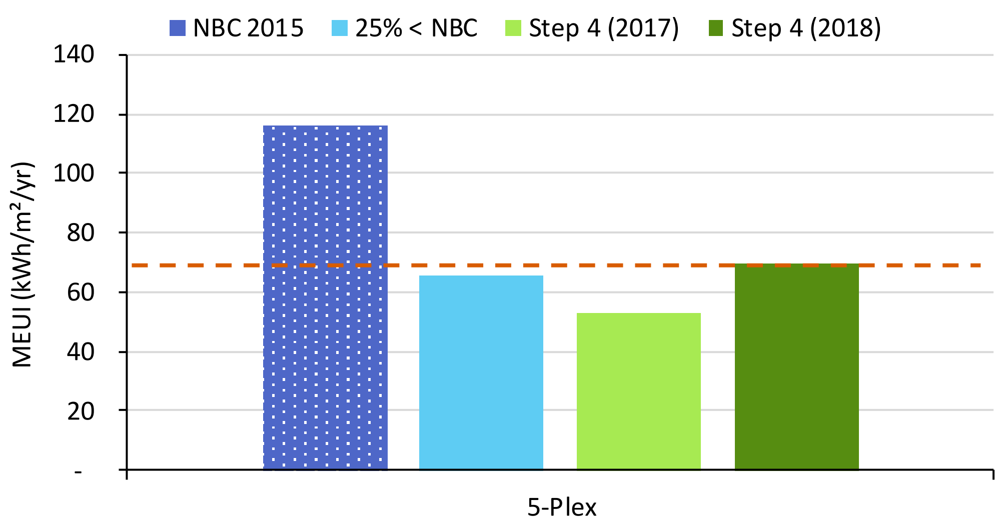


Figure 5.32 MEUI for the 5-Plex in Fort St. John, showing the new Step Code Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

The TEDI of the Step 4 model is well below the Step 4 TEDI target (Figure 5.33). This is due to the 5-Plex being limited by the MEUI metric. Since it was more difficult to meet the MEUI target, many enclosure measures were implemented to decrease the energy consumption. The enclosure measures (and HRV efficiency improvement) that were necessary to meet the MEUI metric led to a much lower TEDI than the Step 4 limit.

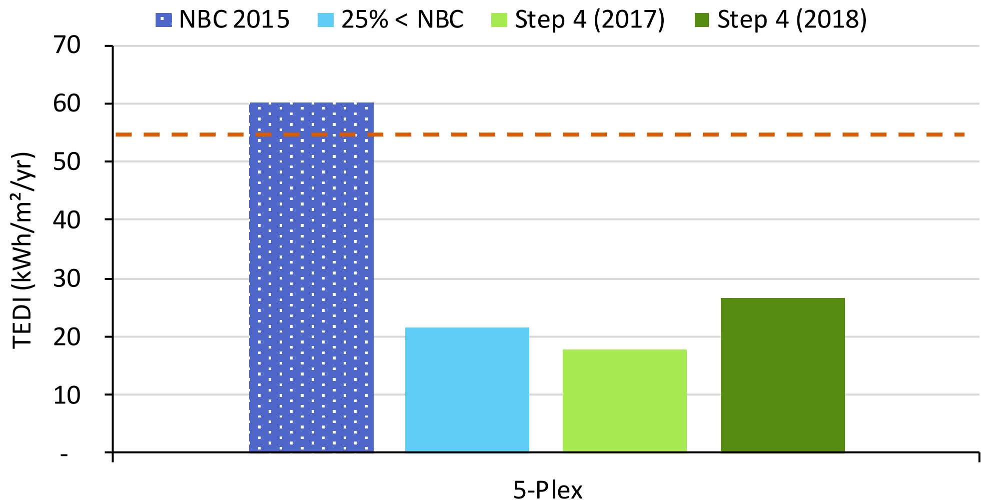


Figure 5.33 TEDI for the 5-Plex in Fort St. John, showing the new Step Code Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

Step 5 of the BC Energy Step Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets in Step 5 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr).

The Step 5 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

To meet the Step 5 energy targets, several major enclosure ECMs and mechanical efficiency improvements were implemented. Many of the highest performance practical ECMs in Section 2.3 were necessary for the 5-Plex. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 0.6 ACH50

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-28.5 to R_{eff}-60

  → Walls from R_{eff}-17 to R_{eff}-22

  → Slab from R_{eff}-16 to R_{eff}-20

→ Windows from double glazed U-0.28 to triples U-0.21

→ Increase HRV efficiency from 60/55% to 81%, dual core no preheat

→ Upgrade from electric baseboards to cold climate air-source heat pump for space heating

→ Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 5 (2018) targets. TEUI is shown for comparison with the baseline and Step 4-compliant models, as well as original Step 5 (2017). Step Code metrics MEUI and TEDI are also shown, with the baseline, Step 4 models, and original Step 5 (2017) included for comparison.

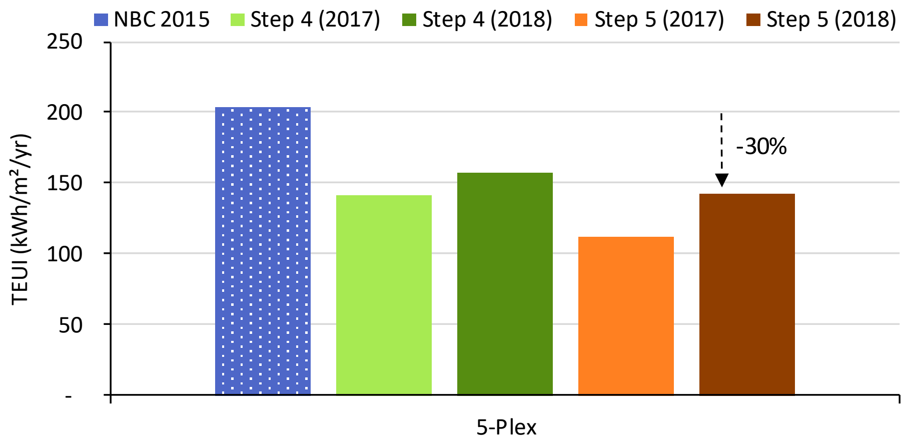


Figure 5.34 Total EUI for the 5-Plex in Fort St. John, showing the reduction in energy consumption resulting from reaching Step 5 (2018, dark red). The Step 4-compliant and Step 5 (2017) models are shown for comparison (greens and light orange, respectively).

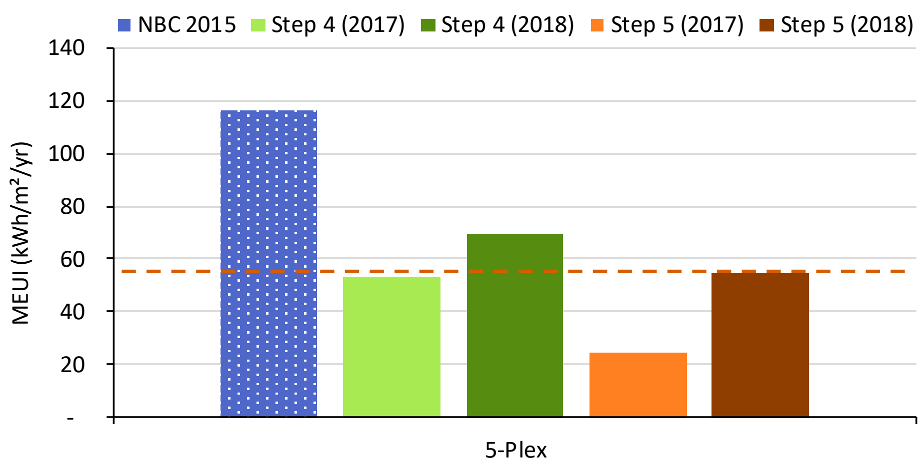


Figure 5.35 MEUI for the 5-Plex in Fort St. John, showing the new Step Code Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Similar to the Step 4 results, the TEDI of the Step 5 model is well below the Step 5 TEDI target (Figure 5.36). This is due to the 5-Plex being limited by the MEUI metric. Since it was more difficult to meet the MEUI target, many enclosure measures were implemented to decrease the energy consumption. The enclosure measures (and HRV efficiency improvement) that were necessary to meet the MEUI metric led to a much lower TEDI than the Step 5 limit.

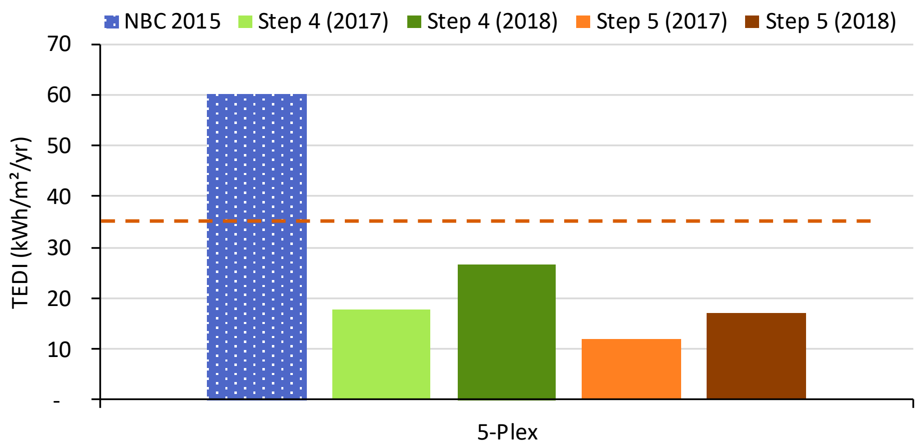


Figure 5.36 TEDI for the 5-Plex in Fort St. John, showing the new Step Code Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Passive House

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for total energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 did not enable the 5-Plex model to meet the Passive House standard. The results are shown in Figure 5.37 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NBC 2015):

→ Did not meet Passive House

  → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.37.

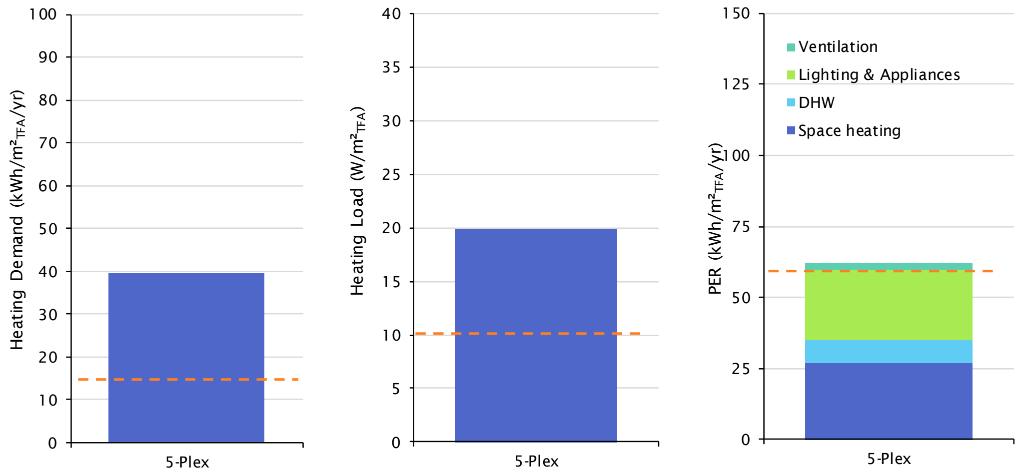


Figure 5.37 The heating demand (left), heating load (middle), and PER (right) of the 5-Plex model in Fort St. John. The Passive House targets are shown in orange dashed lines.

Even with the highest performance practical ECMs outlined in Section 2.3, the 5-Plex model did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices (e.g. different wall types not common to the North), and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

→ The 25% energy target could have been met with fewer ECMs if more of an airtightness improvement was made, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with minor enclosure improvements (slightly more insulation and better double glazed or triple glazed windows) as well as increased heat recovery for ventilation and DHW.

→ The Step 4 targets resulted in similar energy improvements as the 25% better than code target for the 5-Plex in Fort St. John. Increased insulation and low-conductivity windows, coupled with higher HRV efficiency and airtightness, help reach the targets.

→ The Step 5 targets require the 5-Plex to use more insulation than for Step 4 and upgrade to triple glazed windows, though the largest differences are the airtightness improvement from 1.5 ACH50 (for Step 4) to Passive House level 0.6 ACH50 and the CCASHP.

→ The 5-Plex was MEUI-limited in Step 5, meaning several additional heating demand reduction ECMs were implemented to meet the MEUI target and resulted in lower TEDI than necessary.

→ Passive House targets were not achieved with the highest performing practical ECMs for the 5-Plex in Fort St. John (per Section 2.3).

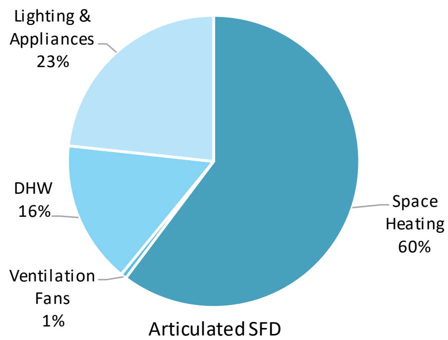
Section 6 will provide alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets. This additional analysis will assess the impact of ECMs beyond the highest performance practical ECMs outlined in Section 2.3.

5.3 Climate Zone 7b – Whitehorse

The following section outlines how low-energy building targets may be achieved for the five archetypes in Whitehorse as an example for climate zone 7b. Energy modelling results are shown for the articulated and simple form SFDs (5.3.1), the articulated and simple form MURBs (5.3.2), and the 5-Plex (5.3.3).

5.3.1 SFD in Whitehorse

This section presents how various high performance energy targets can be achieved for the SFD archetypes in Whitehorse using commonly available technologies and building practices.



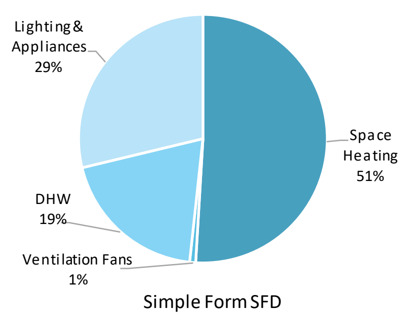


Figure 5.38 Baseline energy consumption break down for the baseline NBC 2015 SFDs in Whitehorse.

25% Better Than Code

The baseline SFD models were adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the NBC model. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption.

To meet the 25% energy target, several minor enclosure ECMs were implemented as well as an increase to the HRV efficiency. The 25% energy target could have been met with only airtightness improvement, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

- → Reduction in air leakage rate from 2.5 ACH50 to 1.5 ACH50
- → Increased insulation of opaque assemblies:
  - → Roof from R_{eff}-59 to R_{eff}-70 (articulated)
  - → Walls from R_{eff}-17.5 to R-$_{eff}$30 (articulated) or R_{eff}-22 (simple form)
  - → Slab from R_{eff}-16 to R_{eff}-25 (articulated) or R_{eff}-22 (simple form)
- → Windows from low-conductivity doubles U-0.25 to triples U-0.20 (simple form, only)

→ Doors from R-4 to R-5

→ Increase HRV efficiency from 60/55% to 81%, dual core no preheat (articulated) or 70% (simple form)

→ Add drain water heat recovery at 65% effectiveness (simple form, only)

Figure 5.39 shows the total energy consumption of the baseline SFDs and of the 25% better than code SFDs in Whitehorse. The baseline energy use and the 25% reduced energy consumption are each higher for the articulated SFD archetype compared to the simple form SFD archetype.

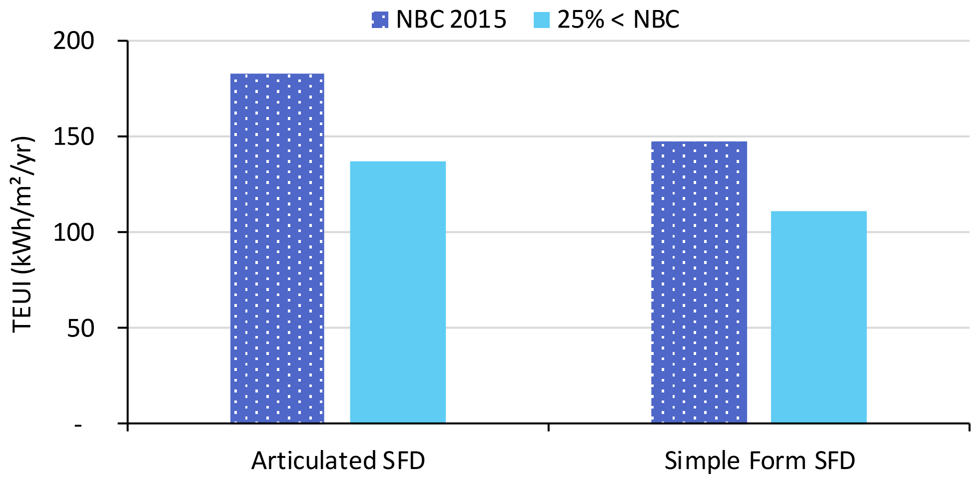


Figure 5.39 Total Energy Use Intensity of the NBC 2015 baseline SFD models and the 25% better than code SFD models in Whitehorse.

As shown here, the articulated SFD can reach the 25% target with similar ECMs as the simple form SFD (with a trade off between wall insulation and HRV to windows and drain water heat recovery) and is not encouraged to use further ECMs (or better design) to match the lower energy consumption of its simple form counterpart.

Step 4 of the BC Energy Step Code

The baseline SFD models were adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr). A percent better than reference house may also be used as an alternate compliance path for Step 4, though the results presented here focus on MEUI since this is the only mechanical energy compliance path for Step 5 (shown later). A detailed summary of all model inputs is attached in Appendix E.

The Step 4 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 1.0 ACH50 (articulated) or 1.5 ACH50 (simple form)

→ Increased insulation of opaque assemblies:

  → Walls from R_{eff}-17.5 to R_{eff}-30 (articulated) or R_{eff}-22 (simple form)

  → Slab from R_{eff}-16 to R_{eff}-30 (articulated) or R_{eff}-22 (simple form)

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat (articulated) or 65% (simple form)

→ Add drain water heat recovery at 65% effectiveness (articulated, only)

Less stringent ECMs were necessary for the simple form SFD to meet the Step 4 (2018) targets compared to the articulated SFD, demonstrating the benefit of starting with a simple form design. Both SFDs in Whitehorse require fewer ECMs to meet the Step 4 targets compared to in Fort St. John in part due to the relaxation of 2018 Step Code targets for climate zone 7b relative to 7a and also the higher base enclosure performance prescribed by code for the Whitehorse baselines.

The following figures show the energy modelling results for reaching Step 4 (2018) targets. TEUI is shown for comparison with the total energy consumption of the baseline and the 25%<code target. Step Code metrics MEUI and TEDI are also shown, with the baseline, 25%<code, and original Step 4 (2017) included for comparison.

Figure 5.40 shows that the performance targets of the Step Code result in larger energy savings for the articulated archetype, which began with a higher baseline energy consumption.

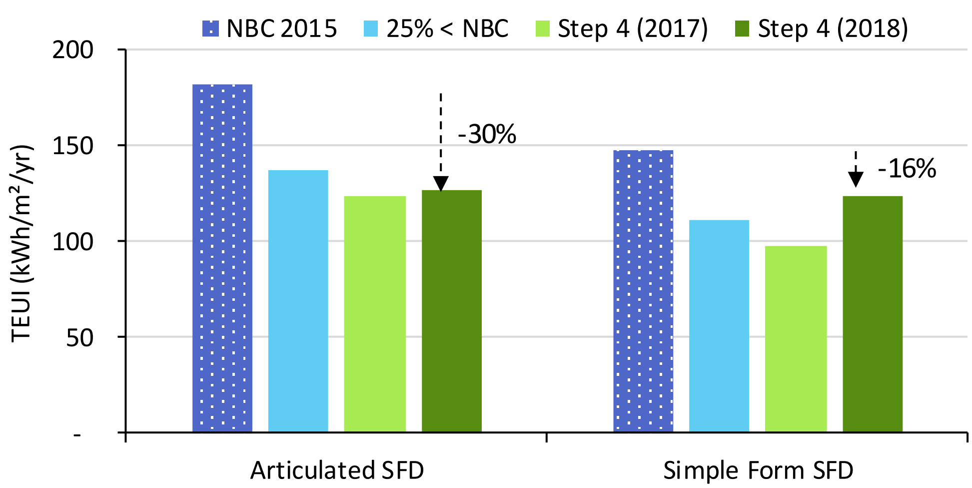


Figure 5.40 Total EUI for the articulated and simple form SFDs in Whitehorse, showing the reduction in energy consumption resulting from reaching Step 4 (2018, dark green). The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

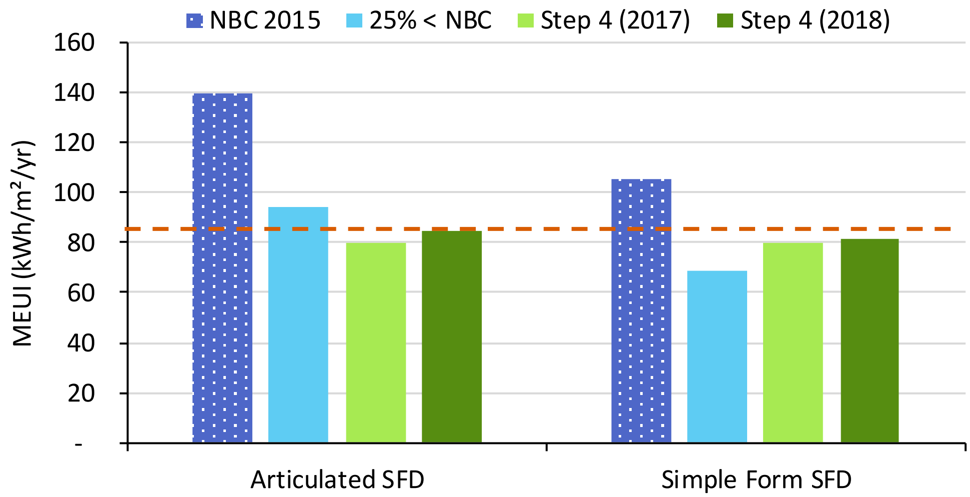


Figure 5.41 MEUI for the articulated and simple form SFDs in Whitehorse, showing the Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

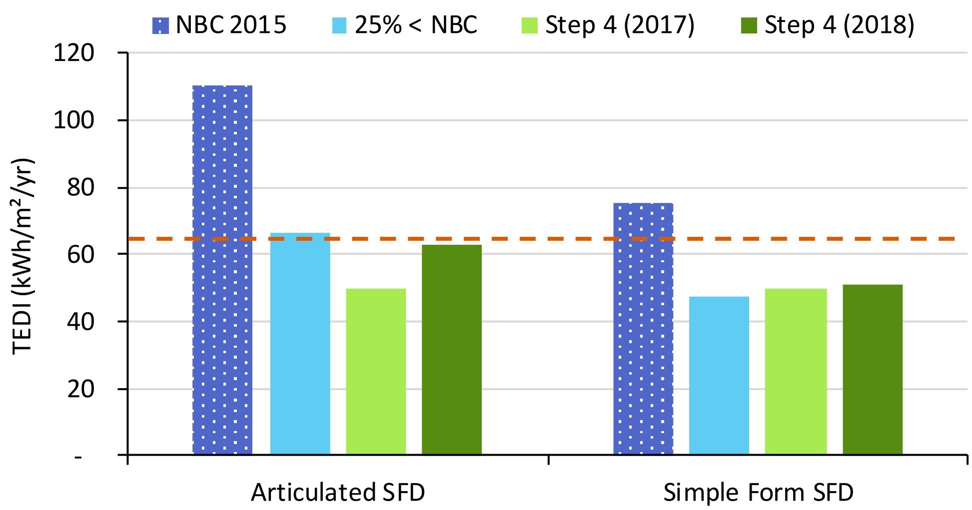


Figure 5.42 TEDI for the articulated and simple form SFDs in Whitehorse showing the Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

Step 5 of the BC Energy Step Code

The baseline SFD models were adjusted by implementing ECMs to meet the targets in Step 5 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr).

The Step 5 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

To meet the Step 5 energy targets, several major enclosure ECMs and mechanical efficiency improvements were implemented. Many of the highest performance practical ECMs (per Section 2.3) were necessary for the articulated SFD, while less stringent ECMs were necessary for the simple form SFD, demonstrating the benefit of starting with a simple form design. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 0.3 ACH50 (articulated) or 1.0 ACH50 (simple form)

→ Increased insulation of opaque assemblies:

  → Walls from R_{eff}-17.5 to R_{eff}-30 (articulated) or R_{eff}-25 (simple form)

  → Slab from R_{eff}-16 to R_{eff}-35 (articulated) or R_{eff}-30 (simple form)

→ Windows from low-conductivity doubles U-0.25 to triples U-0.17

→ Doors from R-4 to R-6

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat (articulated) or 70% (simple form)

→ Add R-12 blanket to DHW tank (articulated, only)

→ Add drain water heat recovery at 65% effectiveness (articulated, only)

The following figures show the energy modelling results for reaching Step 5 (2018) targets. TEUI is shown for comparison with the baseline and Step 4-compliant models, as well as original Step 5 (2017). Step Code metrics MEUI and TEDI are also shown, with the baseline, Step 4 models, and original Step 5 (2017) included for comparison.

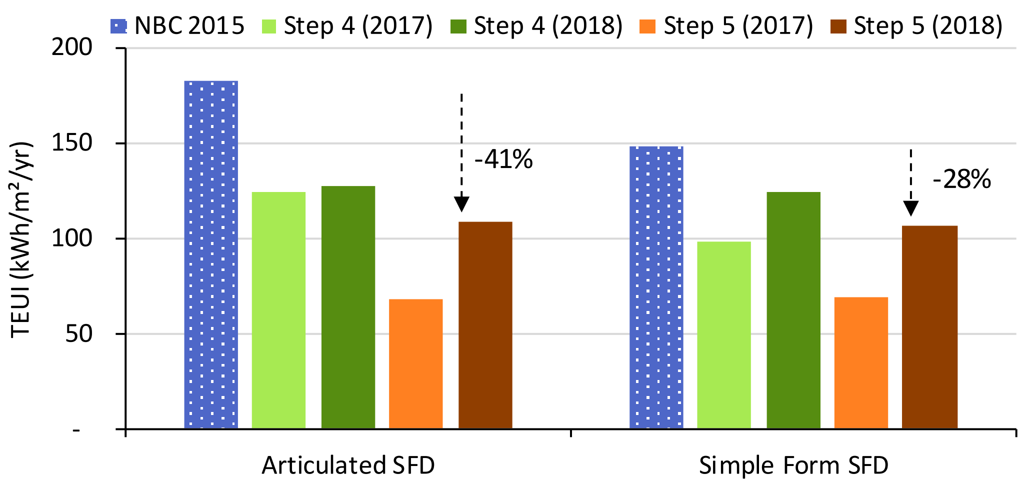


Figure 5.43 Total EUI for the articulated and simple form SFDs in Whitehorse, showing the reduction in energy consumption resulting from reaching Step 5 (2018, dark red). The Step 4-compliant and Step 5 (2017) models are shown for comparison (greens and light orange, respectively).

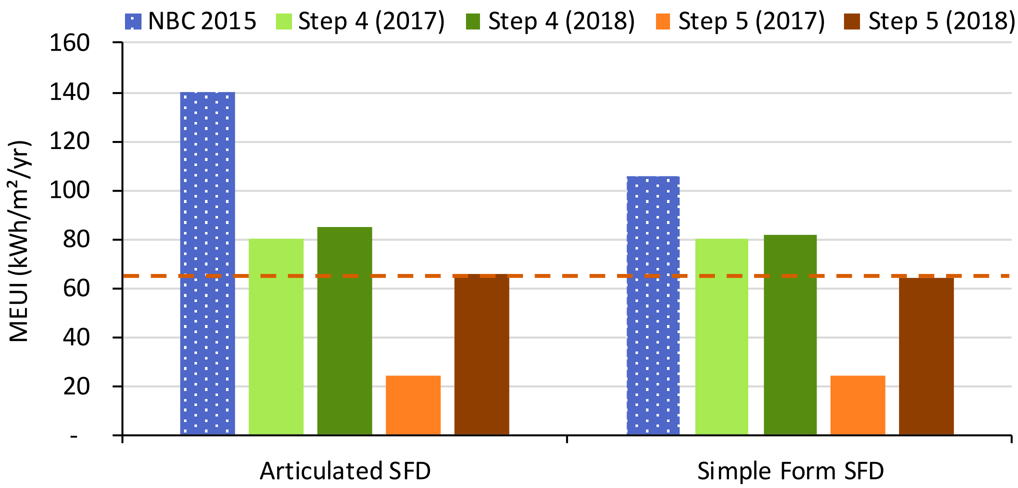


Figure 5.44 MEUI for the articulated and simple form SFDs in Whitehorse, showing the new Step Code Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Similar to the Step 4 results, the TEDI of the Step 5 models is below the Step 5 (2018) TEDI target (Figure 5.45). This is due to the SFD being limited by the MEUI metric, and the measures that were implemented to reduce MEUI for compliance led to lower TEDI than necessary.

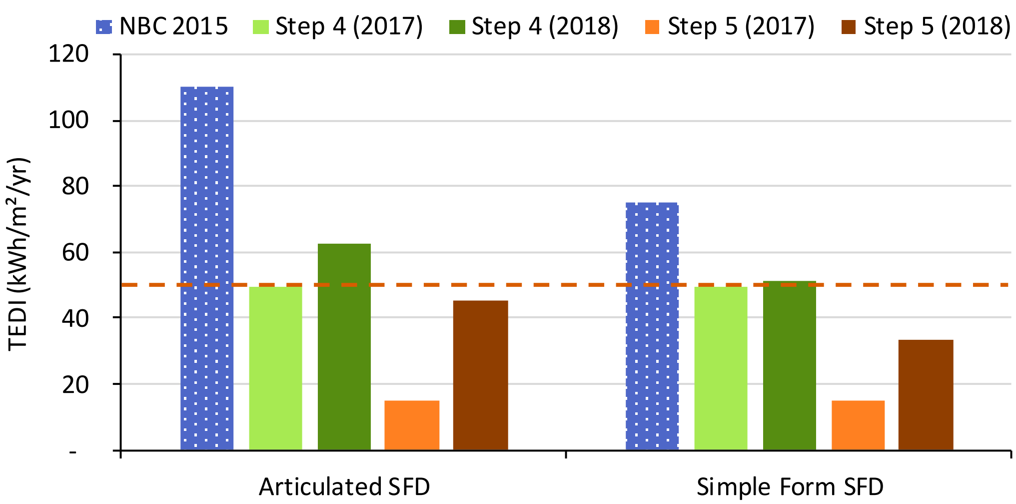


Figure 5.45 TEDI for the articulated and simple form SFDs in Whitehorse, showing the new Step Code Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Passive House

The baseline SFD models were adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for total building energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 did not meet the PER, heating demand, or heating load targets and thus neither SFD model met the Passive House standard. The results are shown in Figure 5.46 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NBC 2015):

- → Did not meet Passive House
  - → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.46

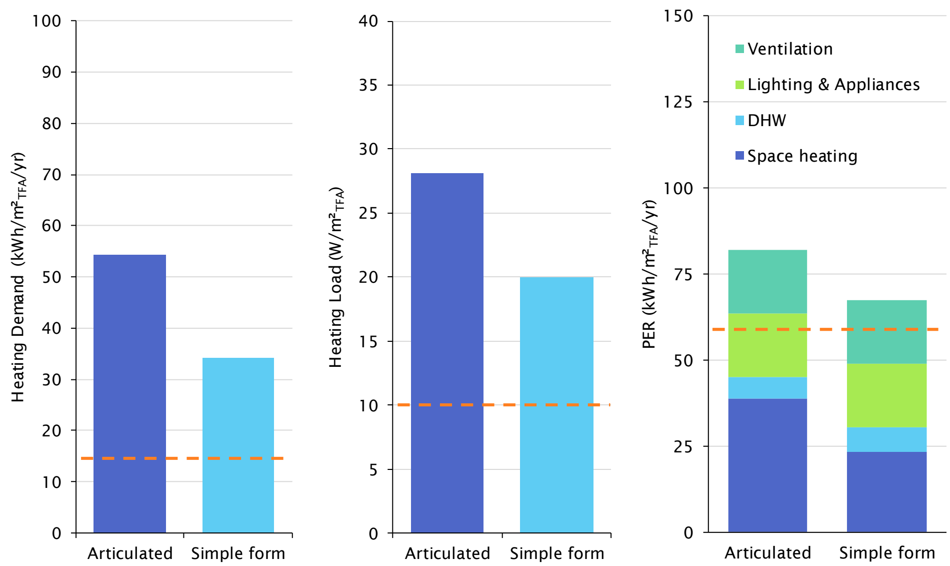


Figure 5.46 The heating demand (left), heating load (middle), and PER (right) of both articulated and simple form SFD models in Whitehorse. The Passive House targets are shown in orange dashed lines.

Even with the highest performance practical ECMs outlined in Section 2.3, the articulated and simple form SFD models did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices (e.g. higher R-value enclosures, different wall types not common to the North), and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

- → The 25% better than code target was met by implementing several minor enclosure ECMs as well as increased heat recovery. The 25% energy target could have been met with only airtightness improvement, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs.
- → The Step 4 targets resulted in similar energy improvements as the 25% better than code target for the SFDs in Whitehorse (16% to 30% energy savings). More stringent ECMs were required for the articulated SFD to reach Step 4, which resulted in higher

energy savings compared to the simple form SFD due to differences in baseline energy consumption. Increased insulation and low-conductivity windows, coupled with higher HRV efficiency and airtightness, were implemented to reach the targets.

→ The Step 5 targets require the articulated SFD to use several of the highest performing practical ECMs outlined in Section 2.3, while the simple form SFD does not need such stringent measures to meet Step 5. This demonstrates the importance of starting with simple form designs to meet high performance targets.

→ ECMs to reach Step 5 of the 2018 Step Code in Whitehorse are similar for these archetypes in Fort St. John, indicating that the updates to the Step Code targets in 2018 resulted in the intended 'leveling' of effort to reach targets in different climates.

→ Passive House targets were not achieved with the highest performance practical ECMs for the SFDs in Whitehorse.

Section 6 will provide alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets. This additional analysis will assess the impact of ECMs beyond the highest performance practical ECMs outlined in Section 2.3.

5.3.2 MURB in Whitehorse

This section presents how various high performance energy targets can be achieved (and which cannot be achieved) for the MURB archetypes in Whitehorse using commonly available technologies and building practices.

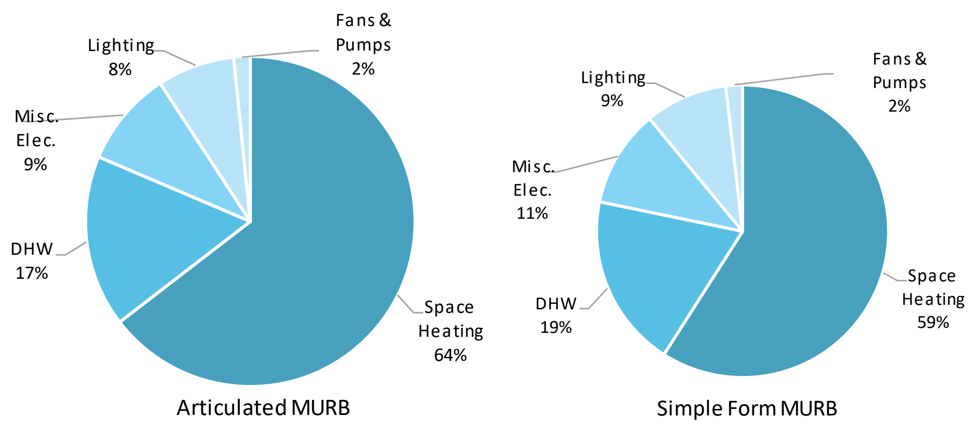


Figure 5.47 Baseline energy consumption break down for the baseline NECB 2011 MURBs in Whitehorse.

25% Better Than Code

The baseline MURB models were adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the reference NECB 2011 model per Part 8 of NECB. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption. The ECMs that were implemented to meet the 25% energy target are listed below. A detailed summary of all model inputs is attached in Appendix F.

ECMs Beyond Baseline (NECB 2011):

→ Reduction in air leakage rate from 0.25 L/s-m² at 5 Pa (2.2 ACH50) to 0.125 L/s-m² at 5 Pa (1.1 ACH50)

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-35 to R_{eff}-39 (simple form, only)

  → Walls from R_{eff}-31 to R_{eff}-32 (simple form, only)

  → Exposed floors from R_{eff}-35 to R_{eff}-40 (simple form, only)

→ Windows from double glazed (U-0.39) to triple glazed (U-0.17)

Increase in-suite HRV efficiency from 50% to 70%

Figure 5.48 shows the total energy consumption of the baseline MURBs and of the 25% better than code MURBs in Whitehorse. Both the starting baseline energy use and the 25% reduced energy consumption are higher for the articulated MURB archetype compared to the simple form MURB archetype.

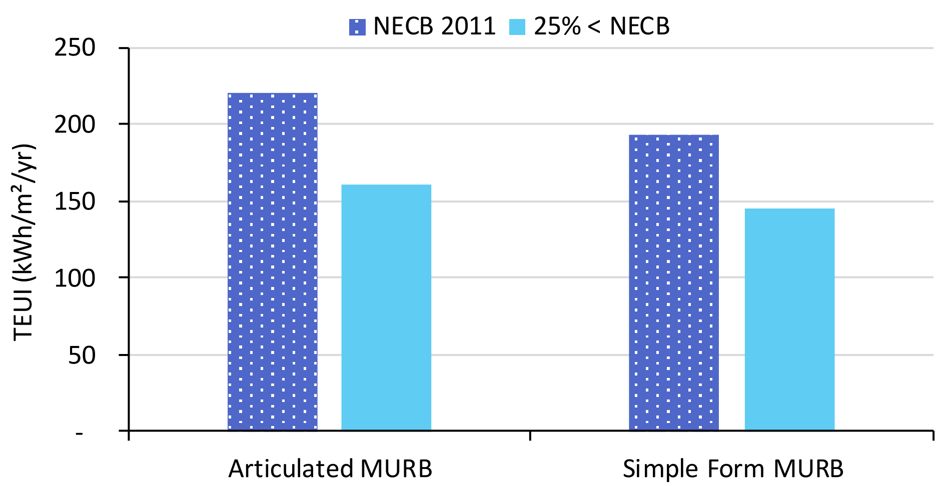


Figure 5.48 Total Energy Use Intensity of the NECB 2011 baseline MURB models and the 25% better than code MURB models in Whitehorse.

As shown in Figure 5.48, the 25% better than code target achieves energy savings proportional to the baseline energy consumption. The articulated MURB can reach the 25% target with less aggressive ECMs than the simple form MURB and is not encouraged to use further ECMs (or better design) to match the lower energy consumption of its simple form counterpart.

Step 4 of the BC Energy Step Code

The baseline MURB models were adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for whole building energy consumption (Total Energy Use Intensity (TEUI), kWh/m²/yr).

The heating demand, TEDI, target is difficult to meet in cold climates since the original BC Energy Step Code targets for Part 3 buildings are intended for climate zone 4, only. As such, the ECMs that were implemented to meet Step 4 with this archetype are all heating demand reduction measures, which result in meeting the Step 4 TEDI target. The TEUI target was incidentally also met by implementing these ECMs. Because of the lower energy consumption of the simple form MURB baseline, less stringent enclosure ECMs were required to meet Step 4 targets for the simple form archetype compared to the articulated archetype. A detailed summary of all model inputs is attached in Appendix F.

ECMs Beyond Baseline (NECB 2011):

→ Reduction in air leakage rate from 0.25 L/s-m² at 5 Pa (2.2 ACH50) to 0.020 L/s-m² at 5 Pa (0.15 ACH50)

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-40 to R_{eff}-76 (articulated) or R_{eff}-48 (simple form)

  → Walls from R_{eff}-31 to R_{eff}-61 (articulated) or R_{eff}-40 (simple form)

  → Exposed floors from R_{eff}-40 to R_{eff}-70 (articulated) or R_{eff}-41 (simple form)

→ Windows from double glazed (U-0.39) to quadruple glazed (U-0.12)

→ Ventilation strategy changed from in-suite HRVs with pre- and post-heat and MUA unit supplying corridors with tempered air, to centralized/zoned ventilation system with 81% heat recovery (by dual core units with no preheat required) for suites and corridors.

→ Reduced make-up air flow rate to corridor from 20 cfm/door to 10 cfm/door (articulated)

These ECMs work to reduce the heating demand of the MURB archetypes and successfully meet the Step 4 TEDI target of 15 kWh/m²/yr, shown in Figure 5.50 (the TEDI target is shown for reference by the orange dashed line). The MURB archetypes also meet the Step 4 TEUI target of 100 kWh/m²/yr, shown in Figure 5.49. The whole building energy consumption is reduced by 52% to 58% compared to the baseline NECB 2011.

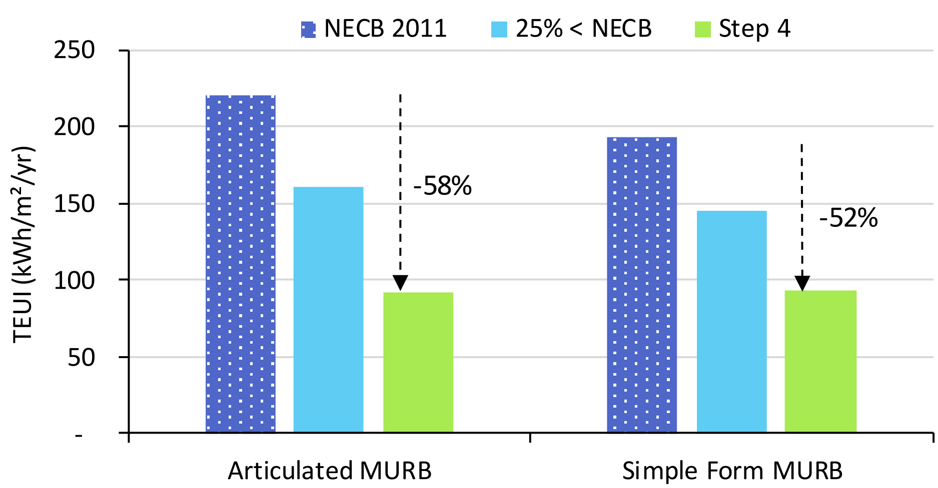


Figure 5.49 Total Energy Use Intensity of the NECB 2011 baseline, the 25% better than code, and the Step 4 BC Energy Step Code MURB model in Whitehorse. The Step 4 performance targets result in a 58% and a 52% reduction in energy consumption for the articulated and simple form MURB archetypes, respectively.

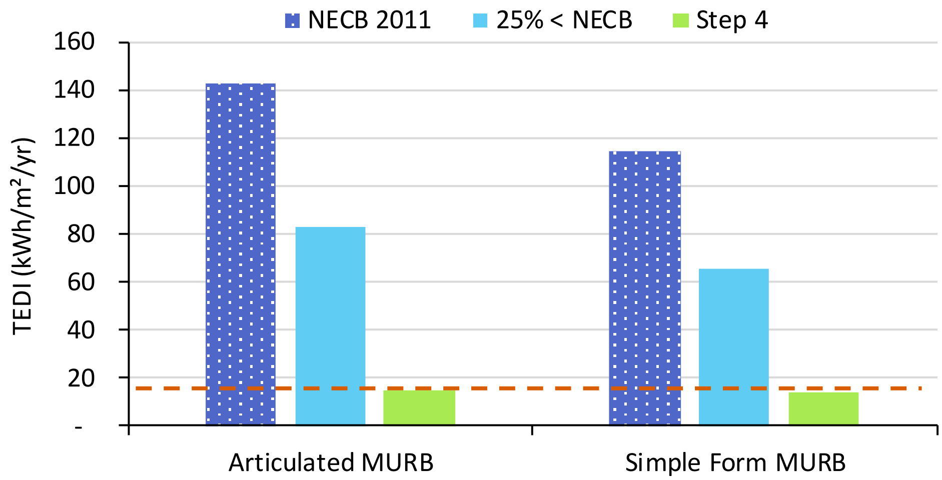


Figure 5.50 Thermal Energy Demand Intensity of the NECB 2011 baseline, the 25% better than code, and the Step 4 BC Energy Step Code MURB models in Whitehorse. Step 4 TEDI target of 15 kWh/m²/yr is shown for reference by the orange dashed line.

It is the heating reduction measures that drive the energy savings in the Step 4 BC Energy Step Code models. The combination of ECMs listed above are one example of how Step 4 targets may be achieved in Whitehorse, though the performance-based energy targets may be complied with by using alternate combinations of ECMs. In other, colder climates even the highest performance practical ECMs outlined in Section 2.3 may not meet the Step 4 TEDI targets.

Passive House

The baseline MURB models were adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for source energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The simple form MURB archetype meets the Passive House targets in Whitehorse, with the highest performing practical ECMs outlined in Section 2.3. However, the Passive House targets were not met for the articulated MURB archetype. The results are shown in Figure 5.51 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NECB 2011):

Articulated MURB:

- → Did not meet Passive House
    - → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.23.

Simple form MURB:

- → Reduction in air leakage rate from 0.25 L/s-m² at 5 Pa (2.2 ACH50) to 0.020 L/s-m² at 5 Pa (0.15 ACH50)
- → Increased insulation of opaque assemblies:

- → Roof from R_{eff}-40 to R_{eff}-100
- → Walls from R_{eff}-31 to R_{eff}-80
- → Exposed floors from R_{eff}-40 to R_{eff}-80

→ Windows from double glazed (U-0.39) to quadruple glazed (U-0.12)

→ Ventilation system changed from in-suite HRVs with pre- and post-heat and MUA unit supplying corridors with tempered air, to centralized/zoned ventilation system with 81% efficient dual core HRV for suites and corridors.

→ Reduced outdoor air rate to corridors from 20 cfm/door to 10 cfm/door.

→ Space heating system changed from electric baseboards to cold climate air source heat pumps with a VRF distribution system.

→ Domestic hot water system changed from electric tank to CO_2 heat pumps.

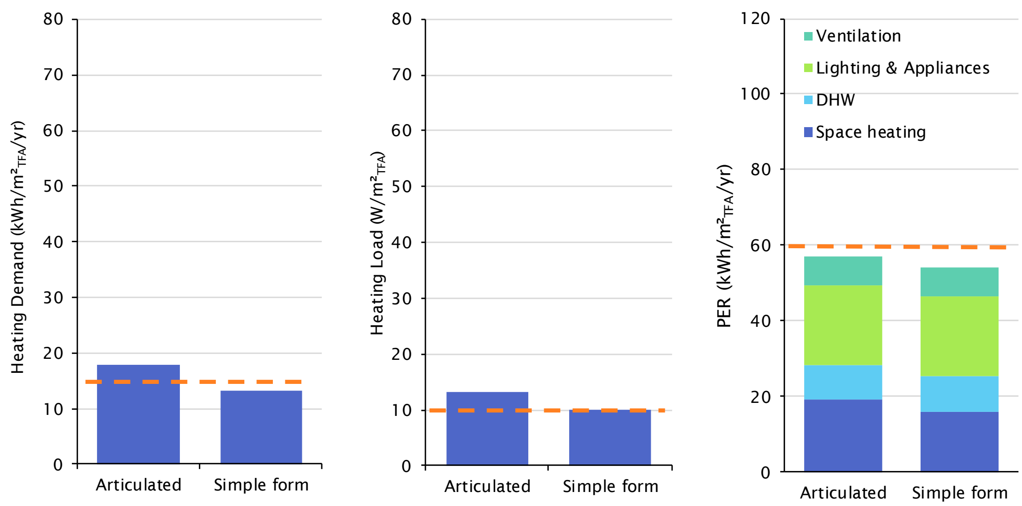


Figure 5.51 The heating demand (left), heating load (middle), and PER (right) of both articulated and simple form MURB models in Whitehorse with the ECMs in Section 2.3. The Passive House targets are shown in orange dashed lines—only the simple form MURB meets the Passive House targets

Even with the highest performing practical ECMs outlined in Section 2.3, the articulated MURB model did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices (e.g. higher R-value enclosures, different wall types not common to the North), and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

→ The 25% target can be met for the MURBs in Whitehorse by measures including better airtightness, triple glazed windows, 70% heat recovery effectiveness, and increased insulation, though more of these measures are required for the simple form MURB compared to the articulated MURB – disincentivizing the better design.

- The articulated MURB archetype has higher baseline energy consumption than the simple form MURB archetype, which makes it harder to reach fixed targets such as TEDI and TEUI in the Step Code.
- Step 4 BC Energy Step Code targets can be met for the MURBs in Whitehorse using heating demand reduction measures including increased insulation, better airtightness, quadruple-glazed windows, and a zoned ventilation system with 81% heat recovery with no preheat.
- The Passive House standard can be met for the simple form MURB in Whitehorse. using several of the highest performing practical ECMs outlined in Section 2.3, including increased insulation, better than Passive House airtightness, quadruple-glazed windows, zoned ventilation system with 81% heat recovery and no preheat, cold climate air source heat pump VRF system for space heating, and CO_2 heat pump for domestic hot water heating.
- The Passive House standard cannot be met by the articulated MURB in Whitehorse (CZ 7b). The limiting targets are the heating demand and heating load targets, while the PER target could be met using the highest performance practical ECMs outlined in Section 2.3.
- The analysis presented here used high efficiency electric systems, which provides a best-case scenario assuming that buildings will be able to connect to a clean electric grid. This may be difficult to accomplish in many remote northern communities. Non-electric systems may not meet PER due to fuel factors.

Section 6 will provide alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets. This additional analysis will assess the impact of ECMs beyond the highest performing practical ECMs outlined in Section 2.3.

5.3.3 5-Plex in Whitehorse

This section presents how various high performance energy targets can be achieved for the 5-Plex archetype in Whitehorse using commonly available technologies and building practices.

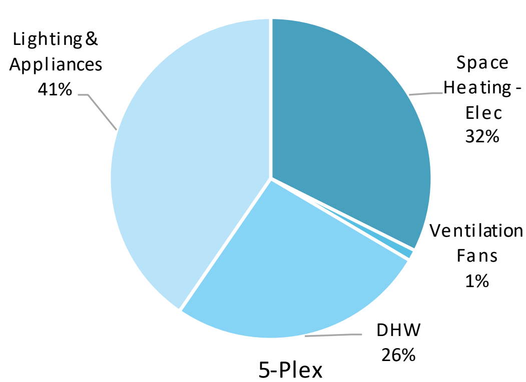


Figure 5.52 Baseline energy consumption break down for the baseline NBC 2015 5-Plex in Whitehorse.

25% Better Than Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the NBC model. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption.

To meet the 25% energy target, several enclosure ECMs were implemented as well as an increase to the HRV efficiency and drain water heat recovery. The 25% energy target could have been met with fewer ECMs if more of an airtightness improvement was implemented, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 1.5 ACH50

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-28.5 to R_{eff}-40

  → Walls from R_{eff}-17.5 to R_{eff}-35

  → Slab from R_{eff}-16 to R_{eff}-25

→ Doors from R-4 to R-6

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat

→ Add drain water heat recovery at 65% effectiveness

Figure 5.53 shows the total energy consumption of the baseline and the 25% better than code 5-Plex in Whitehorse.

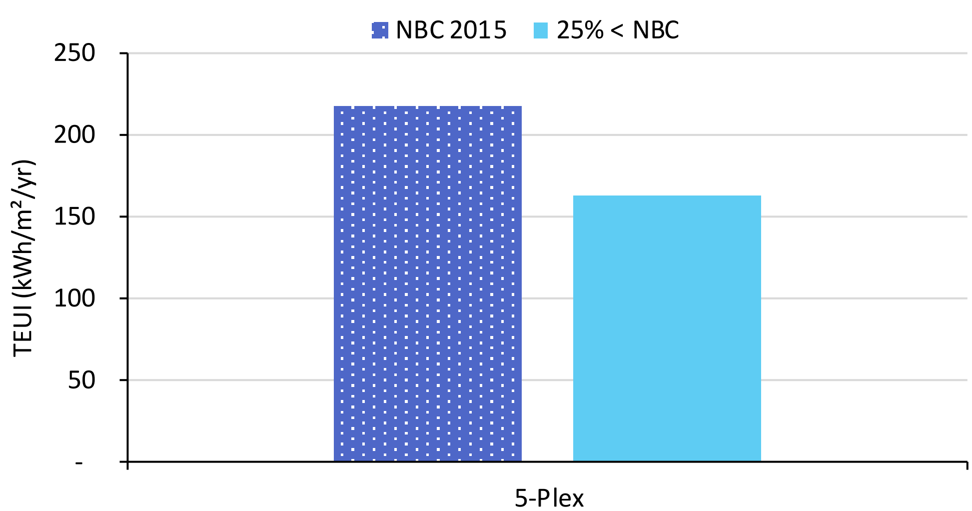


Figure 5.53 Total Energy Use Intensity of the NBC 2015 baseline 5-Plex model and the 25% better than code 5-Plex model in Whitehorse.

Step 4 of the BC Energy Step Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand

(Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr). A detailed summary of all model inputs is attached in Appendix E.

The Step 4 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

ECMs Beyond Baseline (NBC 2015):

- → Reduction in air leakage rate from 2.5 ACH50 to 1.5 ACH50
- → Increased insulation of opaque assemblies:
  - → Roof from R_{eff}-28.5 to R_{eff}-50
  - → Walls from R_{eff}-17.5 to R_{eff}-20
  - → Slab from R_{eff}-16 to R_{eff}-20
- → Increase HRV efficiency from 60/55% to 81%, dual core no preheat
- → Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 4 (2018) targets. TEUI is shown for comparison with the total energy consumption of the baseline and the 25%<code target. Step Code metrics MEUI and TEDI are also shown, with the baseline, 25%<code, and original Step 4 (2017) included for comparison.

Figure 5.54 shows that the performance targets of Step 4 result in 22% energy savings compared to the baseline, similar to the 25%<code target.

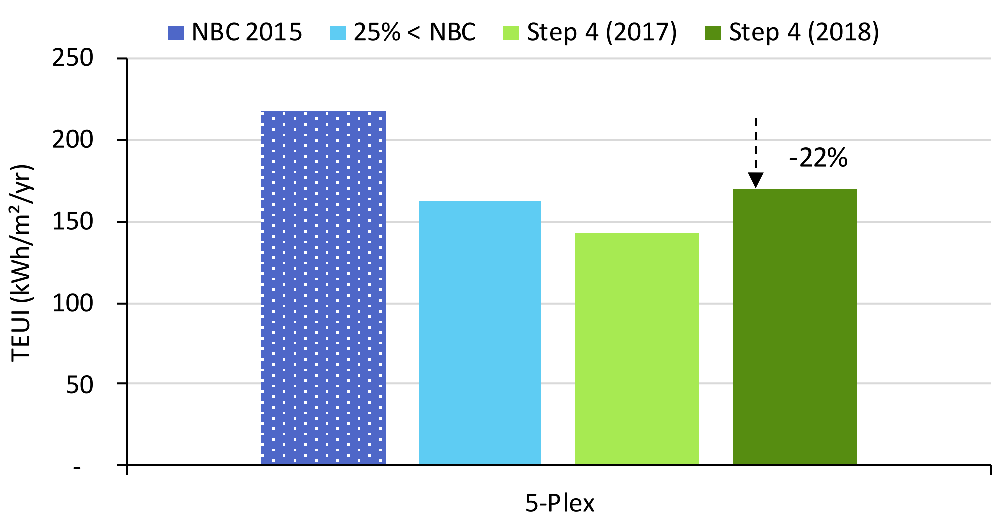


Figure 5.54 Total EUI for the 5-Plex in Whitehorse, showing the reduction in energy consumption resulting from reaching Step 4 (2018, dark green). The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

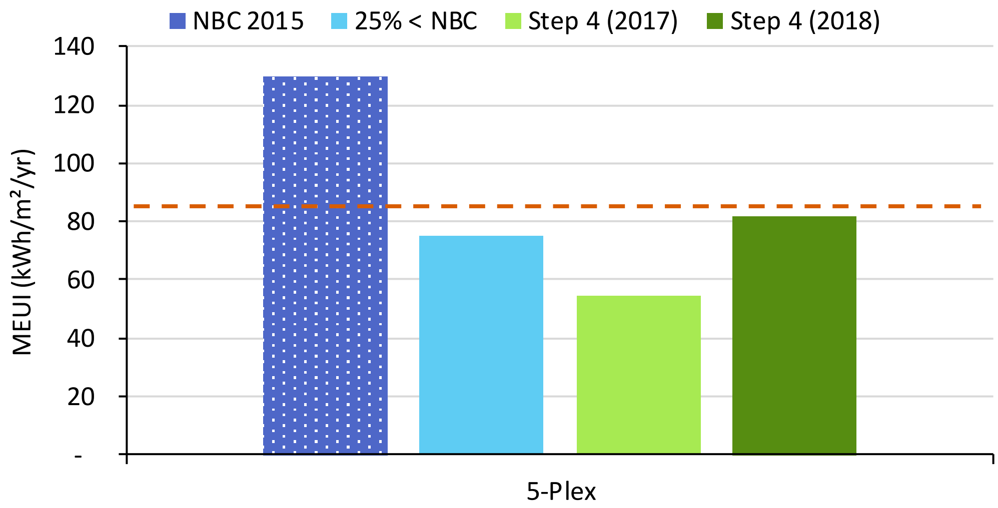


Figure 5.55 MEUI for the articulated and simple form SFDs in Whitehorse, showing the Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

The TEDI of the Step 4 model is well below the Step 4 TEDI target (Figure 5.56). This is due to the 5-Plex being limited by the MEUI metric. Since it was more difficult to meet the MEUI target, many enclosure measures were implemented to decrease the energy consumption. The enclosure measures (and HRV efficiency improvement) that were necessary to meet the MEUI metric led to a much lower TEDI than the Step 4 limit.

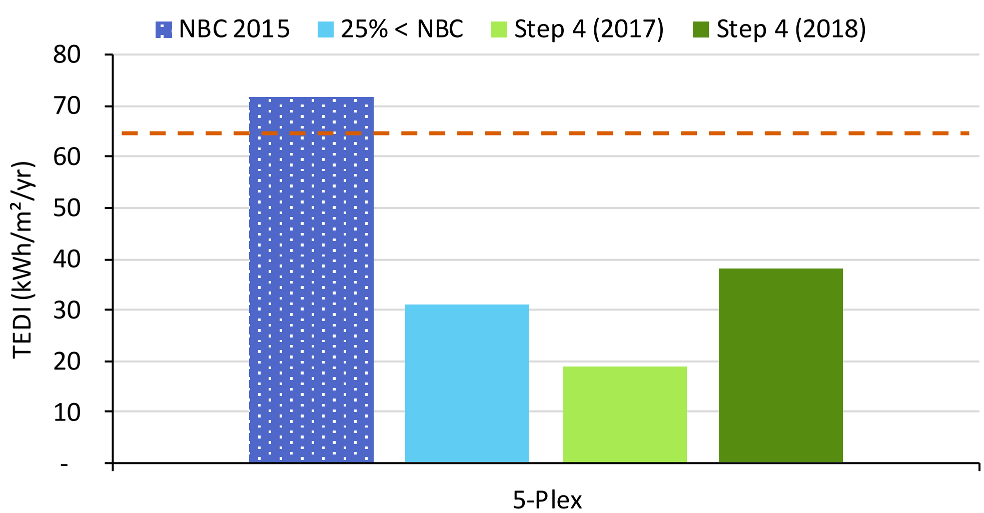


Figure 5.56 TEDI for the 5-Plex in Whitehorse, showing the Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

Step 5 of the BC Energy Step Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets in Step 5 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr).

The Step 5 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

To meet the Step 5 energy targets, several major enclosure ECMs and mechanical efficiency improvements were implemented. Many of the highest performance practical ECMs Section 2.3 were necessary for the 5-Plex. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

- → Reduction in air leakage rate from 2.5 ACH50 to 1.0 ACH50
- → Increased insulation of opaque assemblies:
  - → Roof from R_{eff}-28.5 to R_{eff}-60
  - → Walls from R_{eff}-17 to R_{eff}-25
  - → Slab from R_{eff}-16 to R_{eff}-20
- → Windows from low-conductivity doubles U-0.25 to triples U-0.17
- → Doors from R-4 to R-5
- → Increase HRV efficiency from 60/55% to 81%, dual core no preheat
- → Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 5 (2018) targets. TEUI is shown for comparison with the baseline and Step 4-compliant models, as well as original Step 5 (2017). Step Code metrics MEUI and TEDI are also shown, with the baseline, Step 4 models, and original Step 5 (2017) included for comparison.

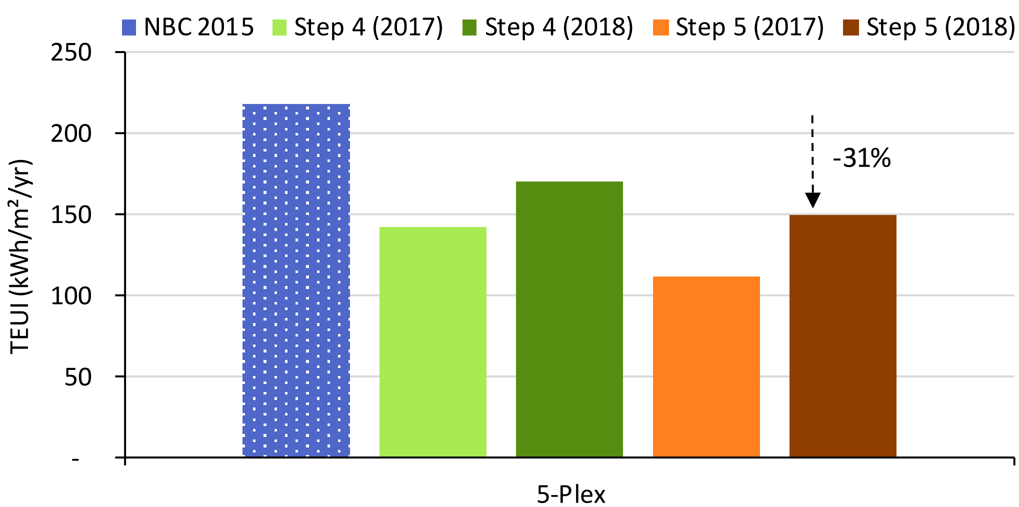


Figure 5.57 Total EUI for the 5-Plex in Whitehorse, showing the reduction in energy consumption resulting from reaching Step 5 (2018, dark red). The Step 4-compliant and Step 5 (2017) models are shown for comparison (greens and light orange, respectively).

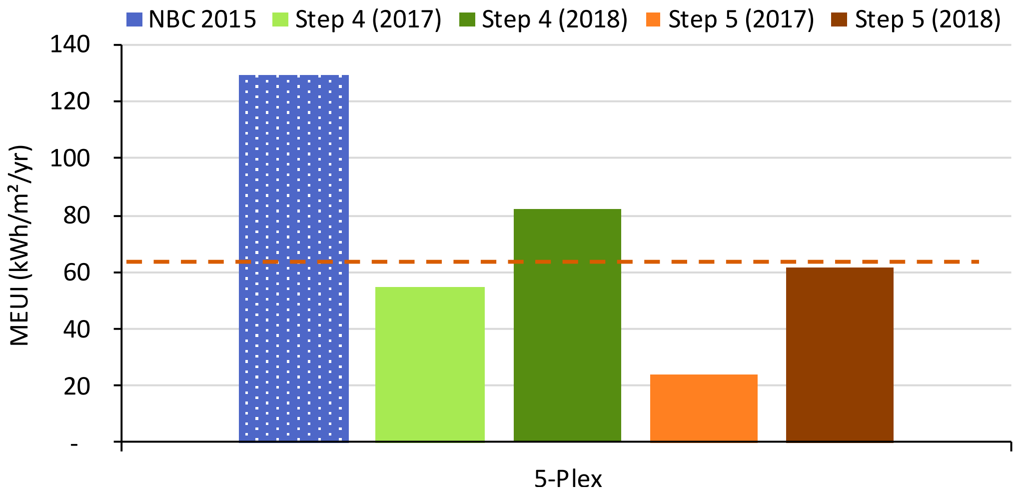


Figure 5.58 MEUI for the 5-Plex in Whitehorse, showing the Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Similar to the Step 4 results, the TEDI of the Step 5 model is well below the Step 5 TEDI target (Figure 5.59). This is due to the 5-Plex being limited by the MEUI metric. Since it was more difficult to meet the MEUI target, many enclosure measures were implemented to decrease the energy consumption. The enclosure measures (and HRV efficiency improvement) that were necessary to meet the MEUI metric led to a much lower TEDI than the Step 5 limit.

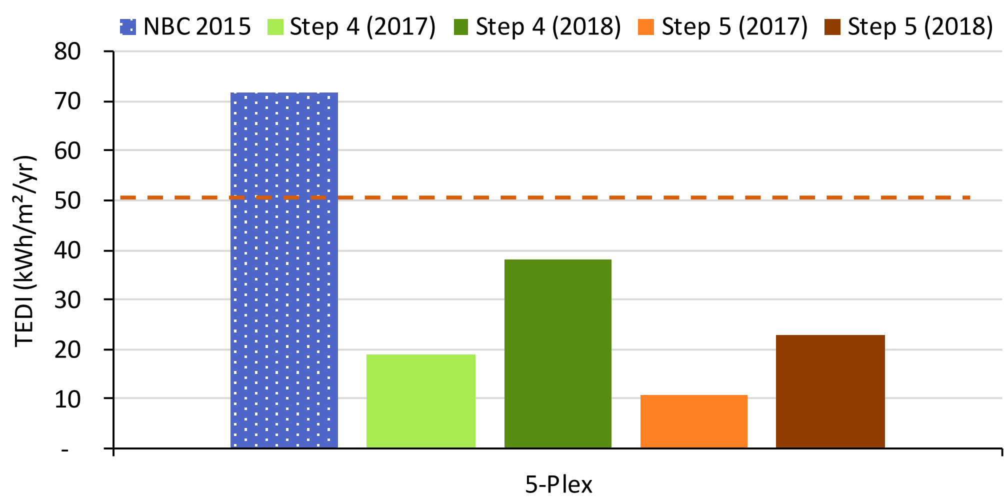


Figure 5.59 TEDI for the 5-Plex in Whitehorse, showing the Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Passive House

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for total energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 did not enable the 5-Plex model to meet the Passive House standard. The results are shown in Figure 5.60 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NBC 2015):

- → Did not meet Passive House
  - → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.60.

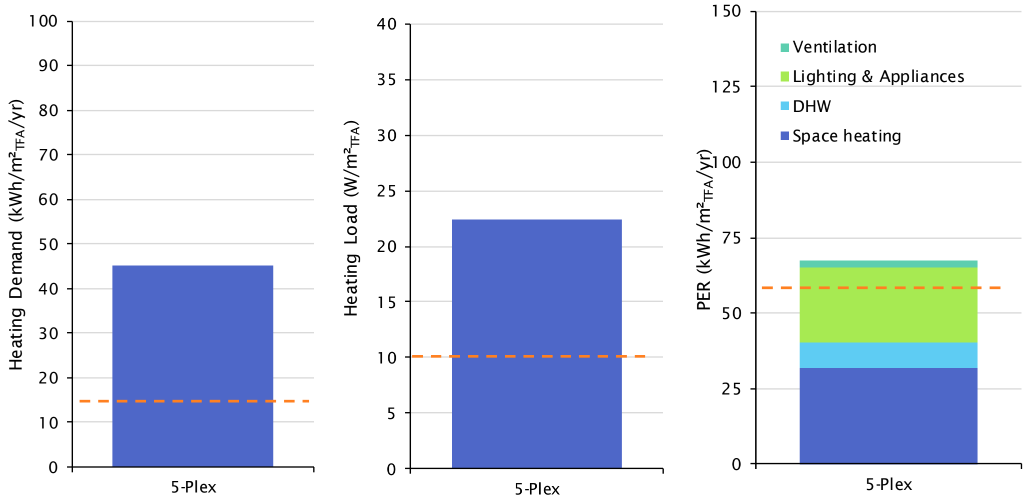


Figure 5.60 The heating demand (left), heating load (middle), and PER (right) of the 5-Plex model in Whitehorse. The Passive House targets are shown in orange dashed lines.

Even with the highest performance practical ECMs outlined in Section 2.3, the 5-Plex model did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices (e.g. higher R-value enclosures, different wall types not common to the North), and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

- → The 25% energy target could have been met with fewer ECMs if more of an airtightness improvement was made, though as this target is intended to be a stepping stone to higher targets a wider range of ECMs were implemented. A such, a reduction in air leakage was coupled with minor enclosure improvements (slightly more insulation) as well as increased heat recovery for ventilation and DHW.
- → The Step 4 targets resulted in similar energy improvements as the 25% better than code target for the 5-Plex in Whitehorse. Increased insulation, coupled with heat recovery and airtightness, help reach the targets.
- → To meet the Step 5 energy targets, several enclosure ECMs and heat recovery efficiency improvements were implemented. Many of the highest performance practical ECMs Section 2.3 were necessary for the 5-Plex to reach Step 5.
- → Passive House targets were not achieved with the highest performing practical ECMs for the 5-Plex in Whitehorse, per Section 2.3.

Section 6 will provide alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets. This additional analysis will assess the impact of ECMs beyond the highest performance practical ECMs outlined in Section 2.3.

5.4 Climate Zone 8 – Yellowknife

The following section outlines how low-energy building targets may be achieved for the five archetypes in Yellowknife as an example for an urban location in climate zone 8. Energy modelling results are shown for the articulated and simple form SFDs (5.4.1), the articulated and simple form MURBs (5.4.2), and the 5-Plex (5.4.3).

5.4.1 SFD in Yellowknife

This section presents how various high performance energy targets can be achieved for the SFD archetypes in Yellowknife using commonly available technologies and building practices.

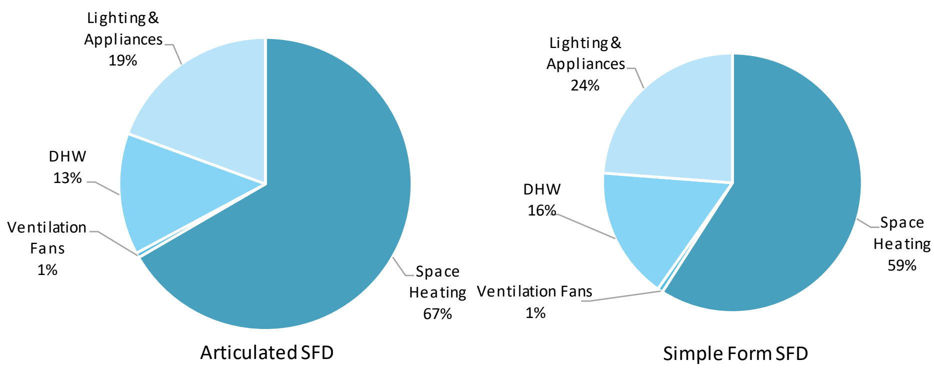


Figure 5.61 Baseline energy consumption break down for the baseline NBC 2015 SFDs in Yellowknife.

25% Better Than Code

The baseline SFD models were adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the NBC model. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption.

To meet the 25% energy target, several minor enclosure ECMs were implemented as well as an increase to the HRV efficiency. The 25% energy target could have been met with only airtightness improvement, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

- → Reduction in air leakage rate from 2.5 ACH50 to 1.5 ACH50
- → Increased insulation of opaque assemblies:
  - → Walls from R_{eff}-17.5 to R_{eff}-22 (articulated) or R_{eff}-25 (simple form)
  - → Exposed floor from R_{eff}-28.5 to R_{eff}-40 (articulated) or R_{eff}-30 (simple form)

→ Windows from low-conductivity doubles U-0.25 to triples U-0.18 (articulated) or U-0.20 (simple form)

→ Doors from R-4 to R-5

→ Increase HRV efficiency from 60/55% to 81%, dual core no preheat (articulated) or 70% (simple form)

→ Add drain water heat recovery at 65% effectiveness (simple form, only)

Figure 5.62 shows the total energy consumption of the baseline SFDs and of the 25% better than code SFDs in Yellowknife. The starting baseline energy use and the 25% reduced energy consumption are higher for the articulated SFD archetype compared to the simple form SFD archetype.

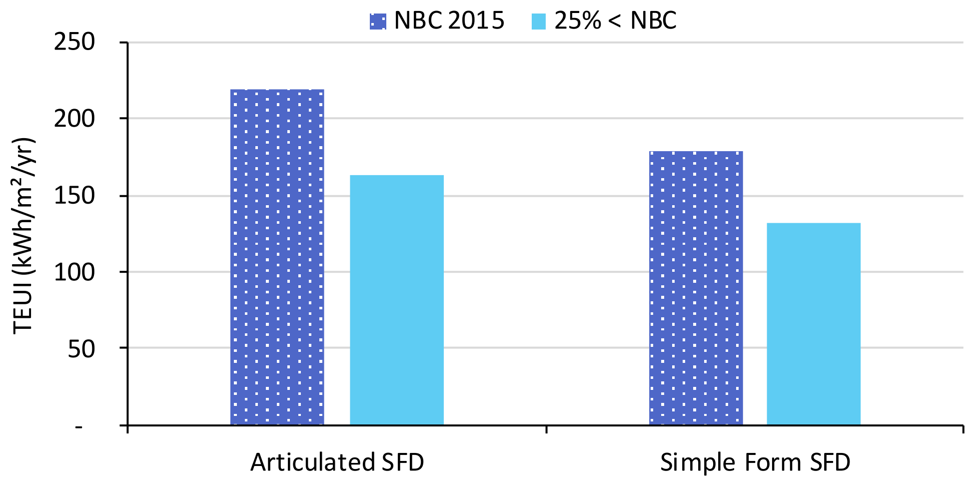


Figure 5.62 Total Energy Use Intensity of the NBC 2015 baseline SFD models and the 25% better than code SFD models in Yellowknife.

As shown here, the articulated SFD can reach the 25% target with similar ECMs as the simple form SFD (with a trade off between wall insulation and HRV to windows and drain water heat recovery) and is not encouraged to use further ECMs (or better design) to match the lower energy consumption of its simple form counterpart.

Step 4 of the BC Energy Step Code

The baseline SFD models were adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr). A percent better than reference house may also be used as an alternate compliance path for Step 4, though the results presented here focus on MEUI since this is the only mechanical energy compliance path for Step 5 (shown later). A detailed summary of all model inputs is attached in Appendix E.

The Step 4 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 1.0 ACH50 (articulated) or 1.5 ACH50 (simple form)

→ Increased insulation of opaque assemblies:

  → Walls from R_{eff}-17.5 to R_{eff}-30 (articulated) or R_{eff}-25 (simple form)

  → Exposed floor from R_{eff}-28.5 to R_{eff}-30

→ Windows from low-conductivity doubles U-0.25 to triples U-0.18 (articulated) or U-0.20 (simple form)

→ Doors from R-4 to R-6 (articulated) or R-5 (simple form)

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat (articulated) or 70% (simple form)

→ Add drain water heat recovery at 65% effectiveness (articulated, only)

The following figures show the energy modelling results for reaching Step 4 (2018) targets. TEUI is shown for comparison with the total energy consumption of the baseline and the 25%<code target. Step Code metrics MEUI and TEDI are also shown, with the baseline, 25%<code, and original Step 4 (2017) included for comparison.

Figure 5.63 shows that the performance targets of the Step Code result in larger energy savings for the articulated archetype, which began with a higher baseline energy consumption than the simple form archetype.

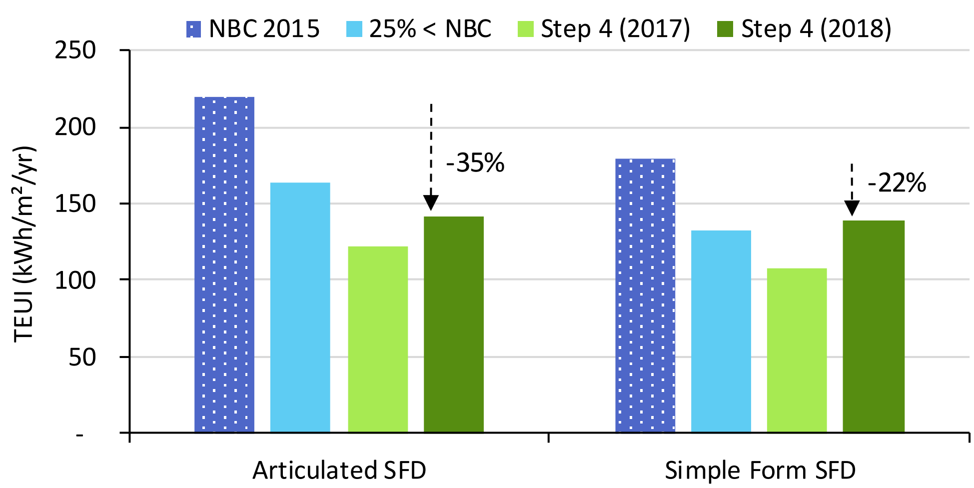


Figure 5.63 Total EUI for the articulated and simple form SFDs in Yellowknife, showing the reduction in energy consumption resulting from reaching Step 4 (2018, dark green). The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

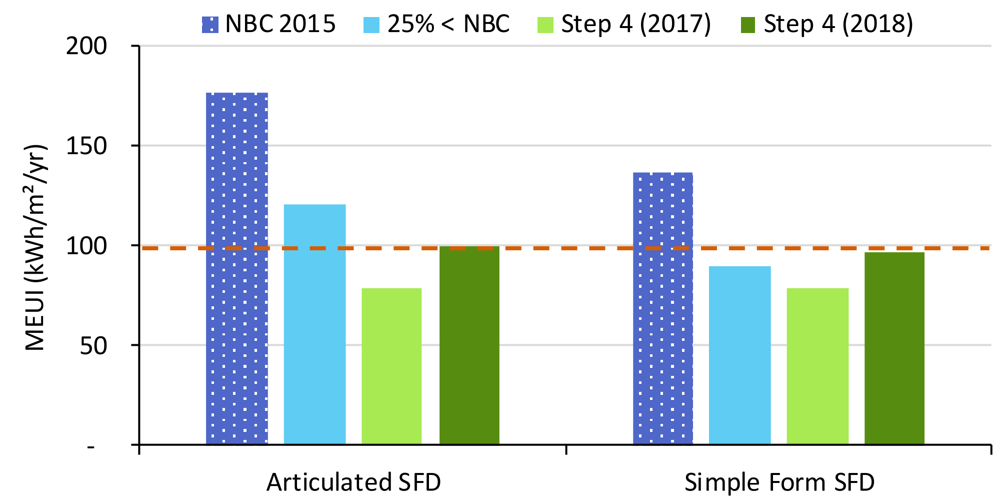


Figure 5.64 MEUI for the articulated and simple form SFDs in Yellowknife, showing the Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

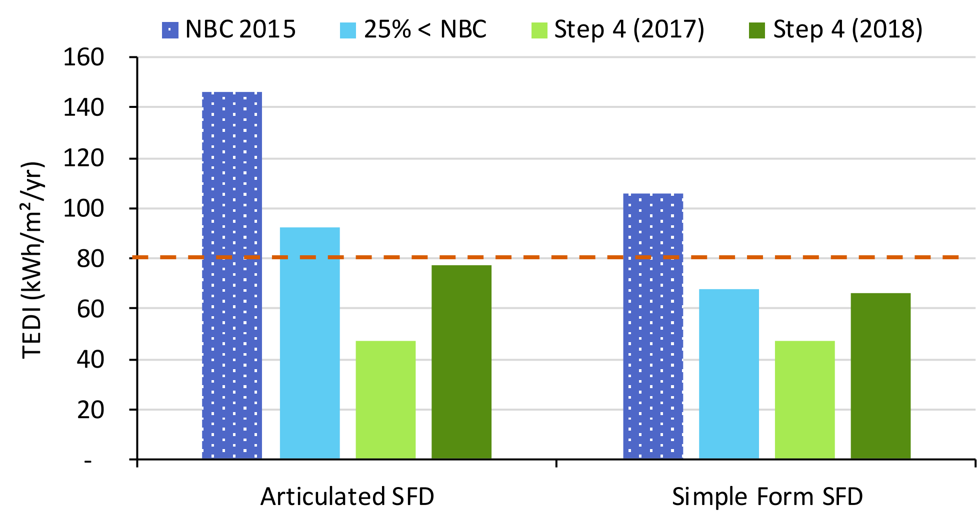


Figure 5.65 TEDI for the articulated and simple form SFDs in Yellowknife showing the Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

Step 5 of the BC Energy Step Code

The baseline SFD models were adjusted by implementing ECMs to meet the targets in Step 5 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr).

The Step 5 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

To meet the Step 5 energy targets, several major enclosure ECMs and mechanical efficiency improvements were implemented. Many of the highest performance practical ECMs per Section 2.3 were necessary for the articulated SFD, while less stringent ECMs were necessary for the simple form SFD, demonstrating the benefit of starting with a simple form design. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

- → Reduction in air leakage rate from 2.5 ACH50 to 0.3 ACH50 (articulated) or 0.6 ACH50 (simple form)
- → Increased insulation of opaque assemblies:
  - → Walls from R_{eff}-17.5 to R_{eff}-30 (articulated) or R_{eff}-25 (simple form)
  - → Exposed floor from R_{eff}-28.5 to R_{eff}-35 (articulated) or R_{eff}-30 (simple form)
- → Windows from low-conductivity doubles U-0.25 to quad glazed U-0.11 (articulated) or triples U-0.17 (simple form)
- → Doors from R-4 to R-8 (articulated) or R-6 (simple form)
- → Increase HRV efficiency from 60/55% to 81% dual core no preheat
- → Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 5 (2018) targets. TEUI is shown for comparison with the baseline and Step 4-compliant models, as well as original Step 5 (2017). Step Code metrics MEUI and TEDI are also shown, with the baseline, Step 4 models, and original Step 5 (2017) included for comparison.

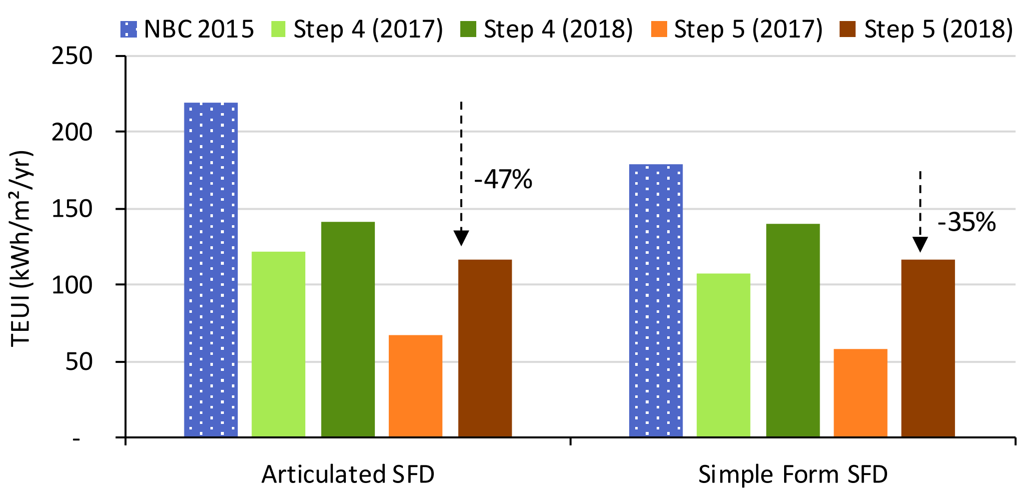


Figure 5.66 Total EUI for the articulated and simple form SFDs in Yellowknife, showing the reduction in energy consumption resulting from reaching Step 5 (2018, dark red). The Step 4-compliant and Step 5 (2017) models are shown for comparison (greens and light orange, respectively).

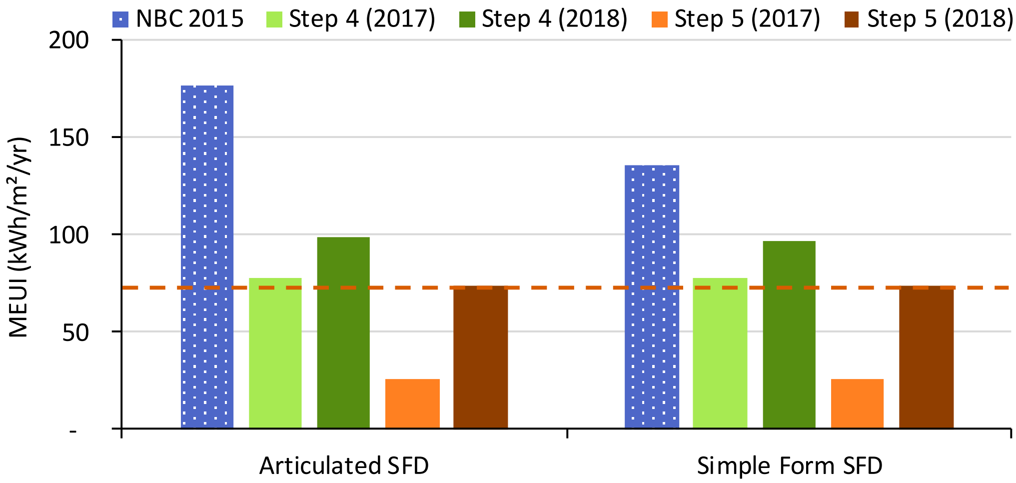


Figure 5.67 MEUI for the articulated and simple form SFDs in Yellowknife, showing the Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Similar to the Step 4 results, the TEDI of the Step 5 models is below the Step 5 (2018) TEDI target (Figure 5.68). This is due to the SFD being limited by the MEUI metric, and the measures that were implemented to reduce MEUI for compliance led to lower TEDI than necessary.

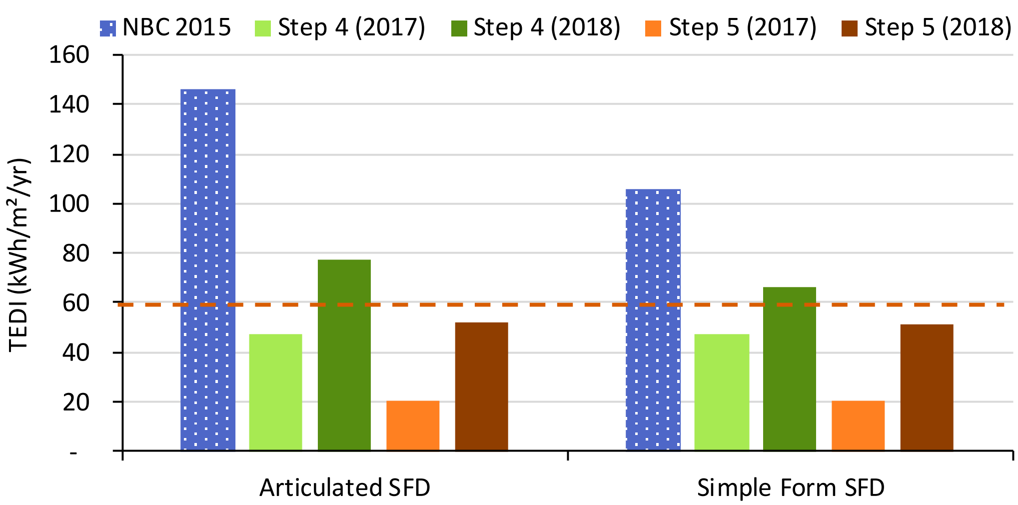


Figure 5.68 TEDI for the articulated and simple form SFDs in Yellowknife, showing the Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Passive House

The baseline SFD models in Yellowknife were adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for total building energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures The highest performing practical ECMs outlined in Section 2.3 did not meet the heating demand or heating load targets and thus, even though the PER target was met for the simple form SFD, neither SFD model met the Passive House standard. The results are shown in Figure 5.69 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NBC 2015):

→ Did not meet Passive House

  → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.69.

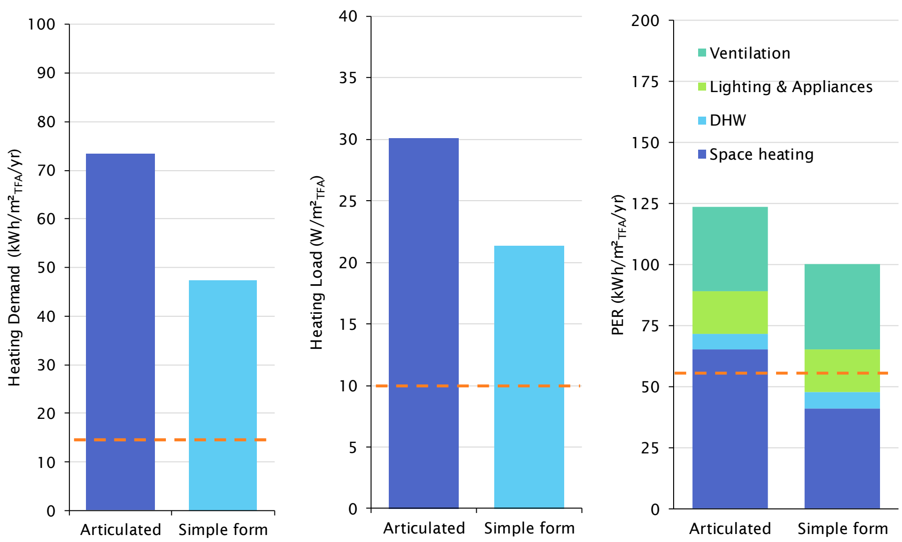


Figure 5.69 The heating demand (left), heating load (middle), and PER (right) of both articulated and simple form SFD models in Yellowknife. The Passive House targets are shown in orange dashed lines – only the PER target is met for the simple form SFD.

Even with the highest performance practical ECMs outlined in Section 2.3, the articulated and simple form SFD models did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices (e.g. higher R-value enclosures, different wall types not common to the North), and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

→ The 25% better than code target was met by implementing several minor enclosure ECMs as well as increased heat recovery. The 25% energy target could have been met with only airtightness improvement, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs.

→ The Step 4 targets resulted in similar energy improvements as the 25% better than code target for the SFDs in Whitehorse (22% to 35% energy savings), though more stringent ECMs were required for the articulated SFD to reach Step 4, which resulted in higher energy savings compared to the simple form SFD due to differences in baseline energy consumption. Increased insulation and triple glazed windows, coupled with more heat recovery and airtightness, were implemented to reach the targets.

→ The Step 5 targets require the articulated SFD to use several of the highest performing practical ECMs outlined in Section 2.3, while the simple form SFD does not need such stringent measures to meet Step 5. This demonstrates the importance of starting with simple form designs to meet high performance targets.

→ Passive House targets were not achieved with the highest performance practical ECMs for the SFDs in Yellowknife.

Section 6 will provide alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets. This additional analysis will assess the impact of ECMs beyond the highest performance practical ECMs outlined in Section 2.3.

5.4.2 MURB in Yellowknife

This section presents how various high performance energy targets can be achieved (and which cannot be achieved) for the MURB archetypes in Yellowknife using commonly available technologies and building practices.

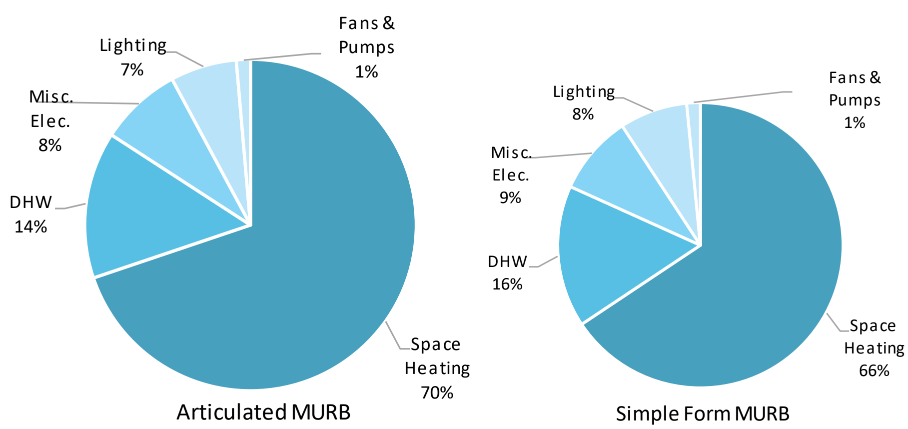


Figure 5.70 Baseline energy consumption break down for the baseline NECB 2011 MURBs in Yellowknife.

25% Better Than Code

The baseline MURB models were adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the reference NECB 2011 model per Part 8 of NECB. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption. The ECMs that were implemented to meet the 25% energy target are listed below. A detailed summary of all model inputs is attached in Appendix F.

ECMs Beyond Baseline (NECB 2011):

→ Reduction in air leakage rate from 0.25 L/s-m² at 5 Pa (2.2 ACH50) to 0.125 L/s-m² at 5 Pa (1.1 ACH50)

→ Increased insulation of opaque assemblies:

- → Walls from R_{eff}-31 to R_{eff}-45 (simple form, only)
- → Windows from double glazed (U-0.39) to triple glazed (U-0.17)
- → Increase in-suite HRV efficiency from 50% to 70%

Figure 5.71 shows the total energy consumption of the baseline MURBs and of the 25% better than code MURBs in Yellowknife. Both the starting baseline energy use and the 25% reduced energy consumption are higher for the articulated MURB archetype compared to the simple form MURB archetype.

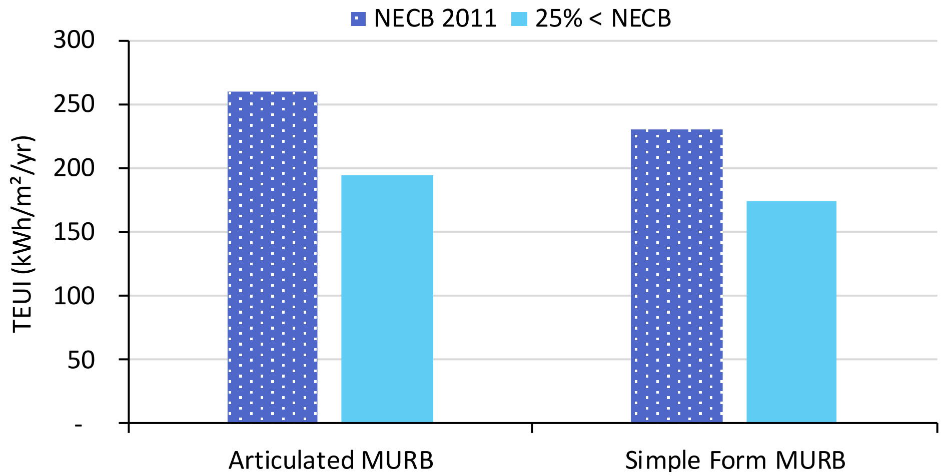


Figure 5.71 Total Energy Use Intensity of the NECB 2011 baseline MURB models and the 25% better than code MURB models in Yellowknife.

As shown in Figure 5.71, the 25% better than code target achieves energy savings proportional to the baseline energy consumption. The articulated MURB can reach the 25% target with less aggressive ECMs than the simple form MURB and is not encouraged to use further ECMs (or better design) to match the lower energy consumption of its simple form counterpart.

Step 4 of the BC Energy Step Code

The baseline MURB models were adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for whole building energy consumption (Total Energy Use Intensity (TEUI), kWh/m²/yr).

The heating demand, TEDI, target is difficult to meet in cold climates since the original BC Energy Step Code targets for Part 3 buildings are intended for climate zone 4, only. As such, the ECMs that were implemented for Step 4 with this archetype are mainly heating demand reduction measures, which result in meeting the Step 4 TEDI target for the simple for MURB. The articulated MURB archetype did not meet the Step 4 TEDI target in Yellowknife, even with the highest performing practical ECMs per Section 2.3. The TEUI target was met by implementing these ECMs.

ECMs Beyond Baseline (NECB 2011):

Articulated MURB: Did not meet Step 4

→ Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.72 and Figure 5.73.

Simple form MURB:

→ Reduction in air leakage rate from 0.25 L/s-m² at 5 Pa (2.2 ACH50) to 0.020 L/s-m² at 5 Pa (0.15 ACH50)

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-40 to R_{eff}-100

  → Walls from R_{eff}-31 to R_{eff}-80

  → Exposed floors from R_{eff}-40 to R_{eff}-80

→ Windows from double glazed (U-0.39) to quad glazed (U-0.12)

→ Ventilation strategy changed from in-suite HRVs with pre- and post-heat and MUA unit supplying corridors with tempered air, to centralized/zoned ventilation system with 81% heat recovery (by dual core units with no preheat required) for suites and corridors.

→ Reduced outdoor air rate to corridor from 20 cfm/door to 10 cfm/door.

The MURB archetypes meet the Step 4 TEUI target of 100 kWh/m²/yr. As shown in Figure 5.72 the whole building energy consumption is reduced by 60% to 72% compared to the baseline NECB 2011.

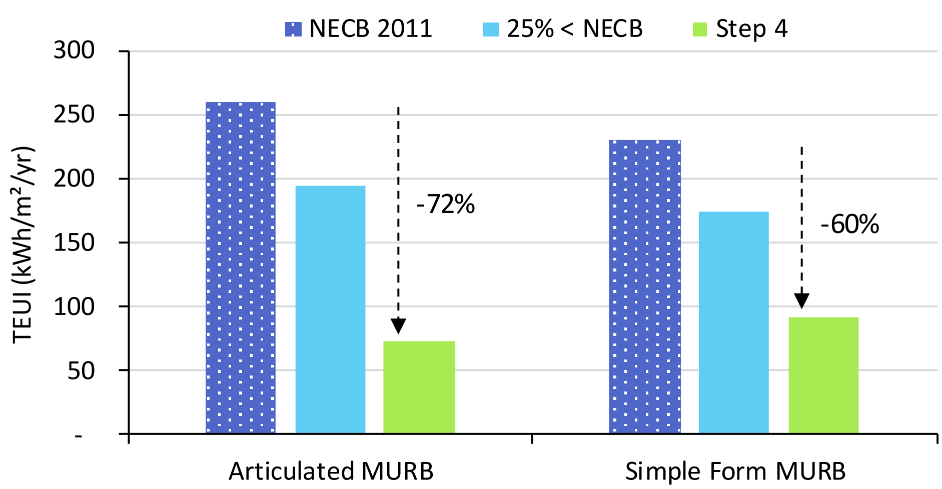


Figure 5.72 Total Energy Use Intensity of the NECB 2011 baseline, the 25% better than code, and the Step 4 BC Energy Step Code MURB model in Yellowknife. The Step 4 performance targets result in a 60% reduction in energy consumption for the articulated MURB and the highest performing practical ECMs (per Section 2.3) result in a 72% reduction for the simple form MURB archetypes.

These ECMs work to reduce the heating demand of the MURB archetypes, the simple form MURB successfully meets the Step 4 TEDI target of 15 kWh/m²/yr, shown in Figure 5.73, the TEDI target is shown for reference by the orange dashed line.

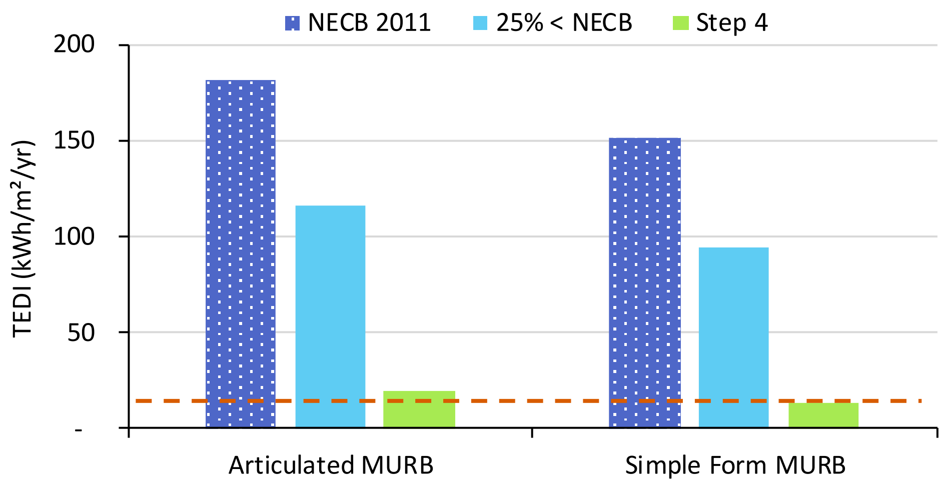


Figure 5.73 Thermal Energy Demand Intensity of the NECB 2011 baseline, the 25% better than code, and the Step 4 BC Energy Step Code MURB models in Yellowknife. Step 4 TEDI target of 15 kWh/m²/yr is shown for reference by the orange dashed line.

It is the heating reduction measures that drive the energy savings in the Step 4 BC Energy Step Code models. The combination of ECMs listed above for the simple form archetype are one example of how Step 4 targets may be achieved in Whitehorse, though the performance-based energy targets may be complied with by using alternate combinations of ECMs, or for some archetypes (e.g. the articulated MURB) the targets may not be achieved using current building practices.

Passive House

The baseline MURB models were adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for source energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 did not meet the PER, heating demand, or heating load targets and thus, the MURB models could not meet Passive House the standard. The results are shown in Figure 5.74 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NECB 2011):

→ Did not meet Passive House

  → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.74.

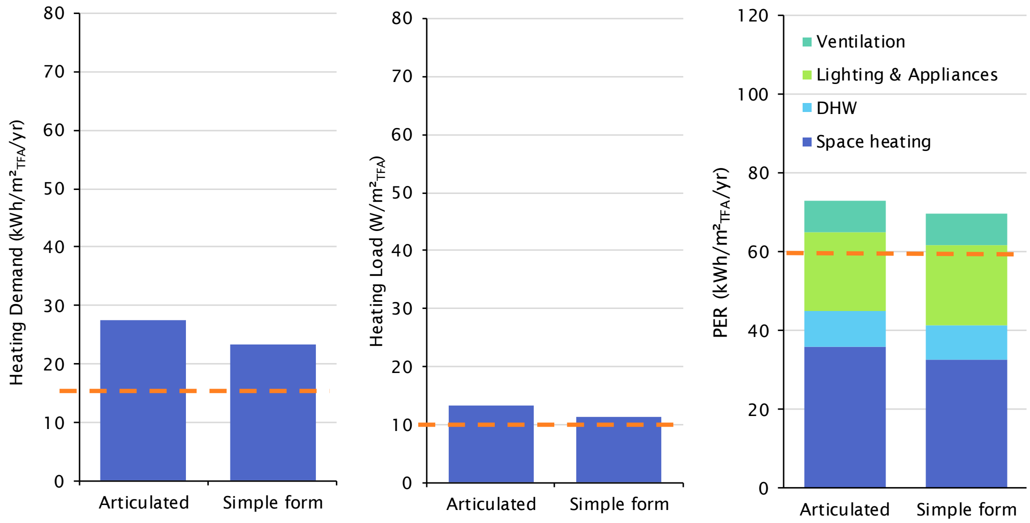


Figure 5.74 The heating demand (left), heating load (middle), and PER (right) of both articulated and simple form MURB models in Yellowknife with the ECMs in Section 2.3. The Passive House targets are shown in orange dash lines.

Even with the highest performance practical ECMs outlined in Section 2.3, the articulated and simple form MURB models did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices (e.g. higher R-value enclosures, different wall types not common to the North), and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

→ The articulated MURB archetype has higher energy consumption than the simple form MURB archetype baseline. This makes it harder to reach fixed targets such as TEDI and TEUI.

→ The 25% target can be met for the MURBs in Yellowknife by measures including better airtightness, triple glazed windows, 70% heat recovery effectiveness, and increased wall insulation (simple form).

→ Step 4 BC Energy Step Code targets can be met for the simple form MURB in Yellowknife using heating demand reduction measures including increased insulation, better airtightness, quadruple-glazed windows, and 81% heat recovery effectiveness. The potential challenges in attaining very low air leakage rates in the Far North will be discussed in Section 6.

→ Step 4 BC Energy Step Code targets cannot be met by the articulated MURB in Yellowknife. The limiting targets are Step 4 TEDI target, while the TEUI target could be met using the highest performance practical ECMs outlined in Section 2.3.

→ The Passive House standard cannot be met by the simple form or articulated MURB in Yellowknife. Neither the PER, heating demand and heating load targets could be met using the highest performance practical ECMs outlined in Section 2.3.

→ The analysis presented here used high efficiency electric systems, which provides a best-case scenario assuming that buildings will be able to connect to an electric grid.

This may be difficult to accomplish in many remote northern communities. Non-electric systems may not meet PER due to fuel factors.

Section 6 will provide alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets. This additional analysis will assess the impact of ECMs beyond the highest performance practical ECMs outlined in Section 2.3.

5.4.3 5-plex in Yellowknife

This section presents how various high performance energy targets can be achieved for the 5-Plex archetype in Yellowknife using commonly available technologies and building practices. The 5-Plex baseline archetype is modelled with fuel oil systems in climate zone 8 to reflect common practice in this region.

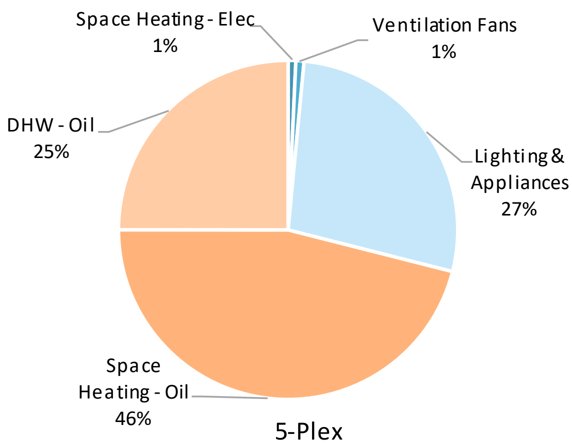


Figure 5.75 Baseline energy consumption break down for the baseline NBC 2015 5-Plex in Yellowknife. Fuel oil systems were used for space heating and DHW in the 5-Plex baseline archetype for climate zone 8 (oil consumption shown in orange, electricity in turquoise).

25% Better Than Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the NBC model. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption.

To meet the 25% energy target, several enclosure ECMs were implemented as well as an increase to heat recovery for ventilation and drain water. The 25% energy target could have been met with fewer ECMs if more of an airtightness improvement was implemented, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 1.5 ACH50

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-28.5 to R_{eff}-40

  → Walls from R_{eff}-17.5 to R_{eff}-35

- → Exposed floor from R_{eff}-28.5 to R_{eff}-40

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat

→ Add drain water heat recovery at 65% effectiveness

Figure 5.76 shows the total energy consumption of the baseline 5-Plex and of the 25% better than code 5-Plex in Yellowknife. The same ECMs could have been used for an all-electric archetype in this location since the 25% target is relative to the baseline energy consumption.

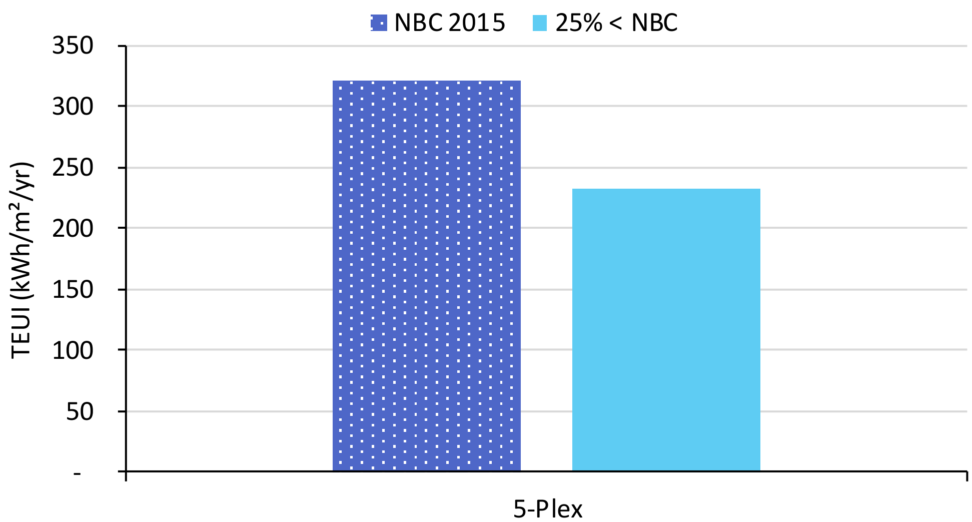


Figure 5.76 Total Energy Use Intensity of the NBC 2015 baseline 5-Plex model and the 25% better than code 5-Plex model in Yellowknife.

Step 4 of the BC Energy Step Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr). A detailed summary of all model inputs is attached in Appendix E.

The Step 4 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 1.0 ACH50

→ Increased insulation of opaque assemblies:

- → Roof from R_{eff}-28.5 to R_{eff}-50
- → Walls from R_{eff}-17.5 to R_{eff}-30
- → Exposed floor from R_{eff}-28.5 to R_{eff}-30

→ Windows from low-conductivity doubles U-0.25 to triples U-0.17

→ Doors from R-4 to R-6

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat

→ Switch from fuel oil systems to electric resistance systems for space heating and DHW

→ Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 4 (2018) targets. TEUI is shown for comparison with the total energy consumption of the baseline and the 25%<code target. Step Code metrics MEUI and TEDI are also shown, with the baseline, 25%<code, and original Step 4 (2017) included for comparison.

Figure 5.77 shows that the performance targets of Step 4 result in 43% energy savings compared to the baseline.

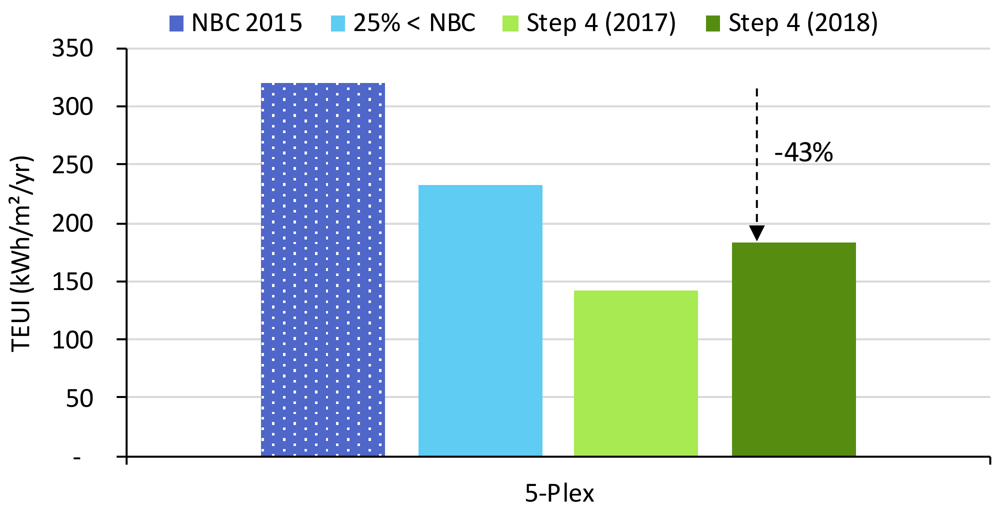


Figure 5.77 Total EUI for the 5-Plex in Yellowknife, showing the reduction in energy consumption resulting from reaching Step 4 (2018, dark green). The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

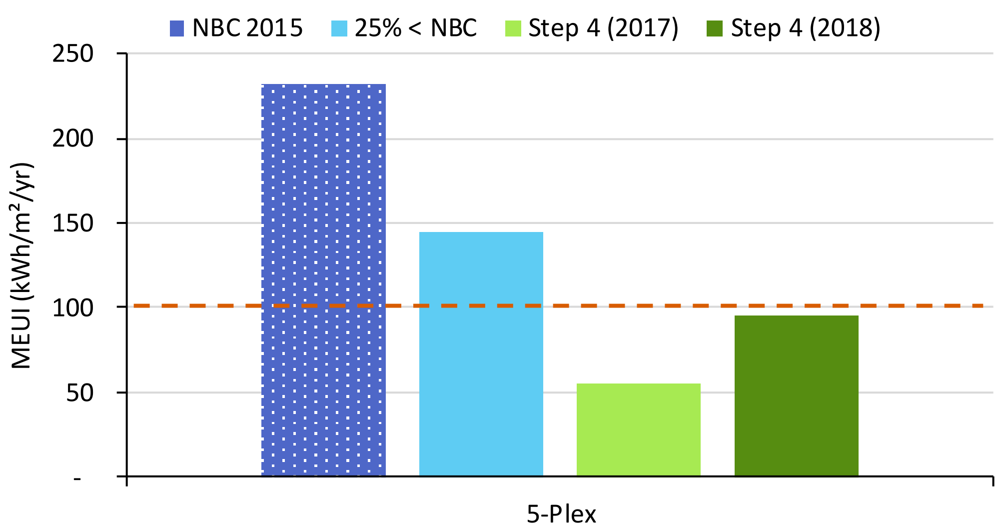


Figure 5.78 MEUI for the articulated and simple form SFDs in Yellowknife, showing the Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

The TEDI of the Step 4 model is well below the Step 4 TEDI target (Figure 5.79). This is due to the 5-Plex being limited by the MEUI metric. Since it was more difficult to meet the MEUI target, many enclosure measures were implemented to decrease the energy consumption. The enclosure measures (and HRV efficiency improvement) that were necessary to meet the MEUI metric led to a much lower TEDI than the Step 4 limit.

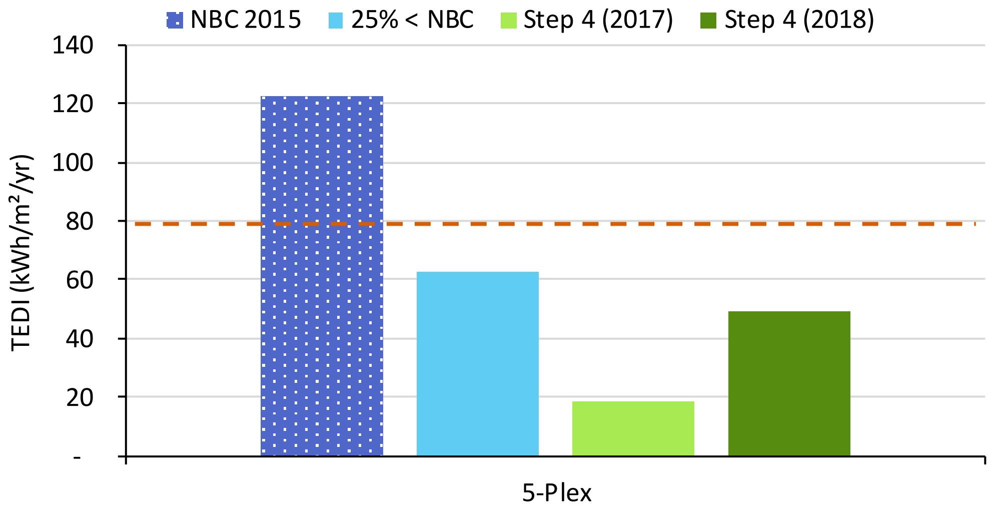


Figure 5.79 TEDI for the 5-Plex in Yellowknife, showing the new Step Code Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

Step 5 of the BC Energy Step Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets in Step 5 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr).

The Step 5 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

To meet the Step 5 energy targets, several major enclosure ECMs and mechanical efficiency improvements were implemented. Many of the highest performance practical ECMs per Section 2.3 were necessary for the 5-Plex. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 0.6 ACH50

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-28.5 to R_{eff}-60

  → Walls from R_{eff}-17.5 to R_{eff}-30

  → Exposed floor from R_{eff}-28.5 to R_{eff}-30

→ Windows from low-conductivity doubles U-0.25 to quad glazing U-0.12

→ Doors from R-4 to R-8

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat

→ Switch from fuel oil boiler (AFUE 85%) to CCASHP for space heating

→ Switch from oil tank to electric tank DHW

→ Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 5 (2018) targets. TEUI is shown for comparison with the baseline and Step 4-compliant models, as well as original Step 5 (2017). Step Code metrics MEUI and TEDI are also shown, with the baseline, Step 4 models, and original Step 5 (2017) included for comparison.

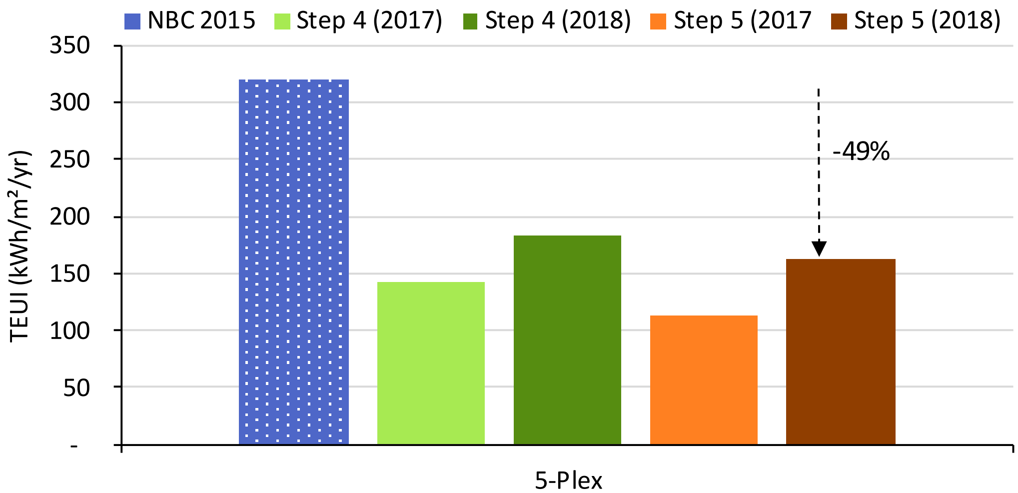


Figure 5.80 Total EUI for the 5-Plex in Yellowknife, showing the reduction in energy consumption resulting from reaching Step 5 (2018, dark red). The Step 4-compliant and Step 5 (2017) models are shown for comparison (greens and light orange, respectively).

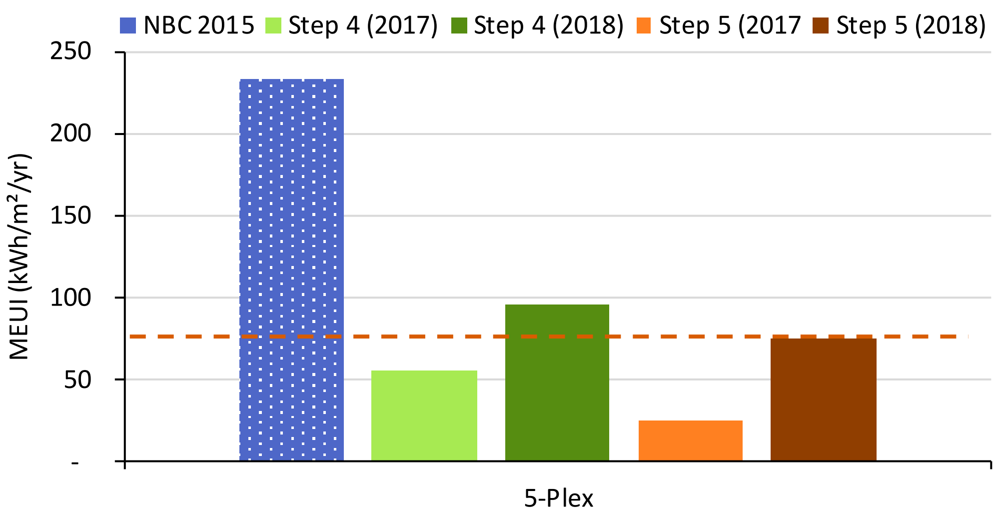


Figure 5.81 MEUI for the 5-Plex in Yellowknife, showing the Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Similar to the Step 4 results, the TEDI of the Step 5 model is well below the Step 5 TEDI target (Figure 5.82). This is due to the 5-Plex being limited by the MEUI metric. Since it was more difficult to meet the MEUI target, many enclosure measures were implemented to decrease the energy consumption. The enclosure measures (and HRV efficiency improvement) that were necessary to meet the MEUI metric led to a much lower TEDI than the Step 5 limit.

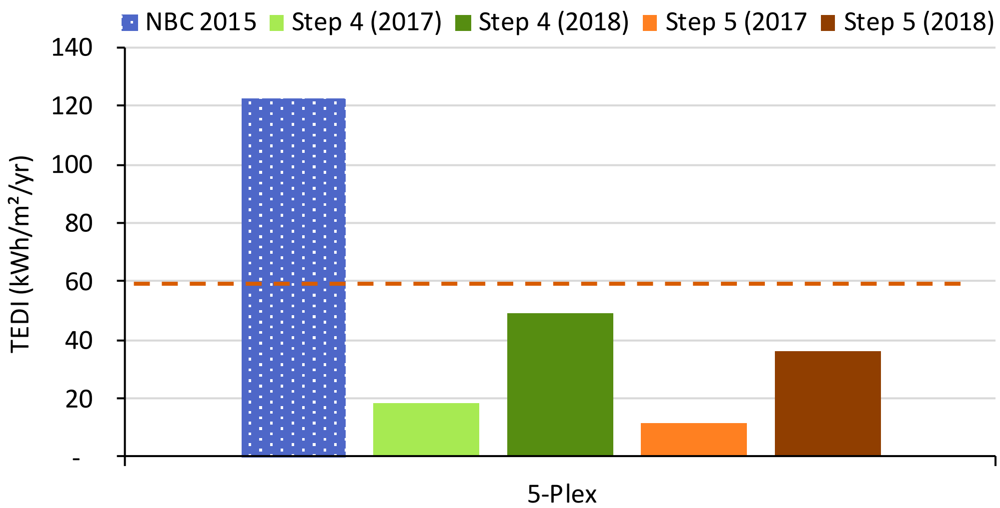


Figure 5.82 TEDI for the 5-Plex in Yellowknife, showing the Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Passive House

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for total energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 did not enable the 5-Plex model to meet the Passive House standard. The results are shown in Figure 5.83 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NBC 2015):

→ Did not meet Passive House

  → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.83.

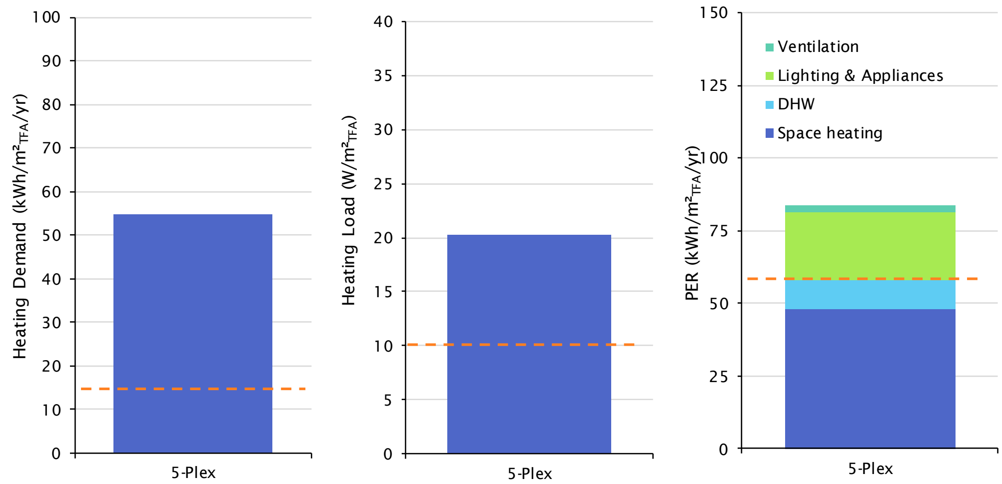


Figure 5.83 The heating demand (left), heating load (middle), and PER (right) of the 5-Plex model in Yellowknife. The Passive House targets are shown in orange dashed lines.

Even with the highest performance practical ECMs outlined in Section 2.3, the 5-Plex model did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices (e.g. higher R-value enclosures, different wall types not common to the North), and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

→ The 25% energy target could have been met with fewer ECMs if more of an airtightness improvement was made, though as this target is intended to be a stepping stone to higher targets a wider range of ECMs were implemented. A such, a reduction in air leakage was coupled with minor enclosure improvements (more insulation) as well as increased heat recovery for ventilation and DHW.

→ The Step 4 targets resulted in far greater energy improvements than the 25% better than code target for the 5-Plex in Yellowknife. The fuel oil heating and DHW systems were switched to electric resistance to help meet the MEUI target. Increased insulation and triple glazed windows, coupled with higher HRV efficiency and airtightness, also help reach the targets.

→ The Step 5 targets require the 5-Plex to use more insulation than for Step 4 and upgrade from triple to quad glazed windows and airtightness improvement to Passive House level 0.6 ACH50. In addition to these enclosure improvements, a CCASHP was implemented for space heating to meet the MEUI target.

→ Passive House targets were not achieved with the highest performance practical ECMs for the 5-Plex in Yellowknife per Section 2.3.

Section 6 will provide alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets. This additional analysis will assess the impact of ECMs beyond the highest performance practical ECMs outlined in Section 2.3.

5.5 Climate Zone 8 – Resolute

The following section outlines how low-energy building targets may be achieved for the five archetypes in Resolute an example for a remote location in climate zone 8. Energy modelling results are shown for the articulated and simple form SFDs (5.5.1), the articulated and simple form MURBs (5.5.2), and the 5-Plex (5.5.3).

5.5.1 SFD in Resolute

This section presents how various high performance energy targets can be achieved for the SFD archetypes in Resolute using commonly available technologies and building practices.

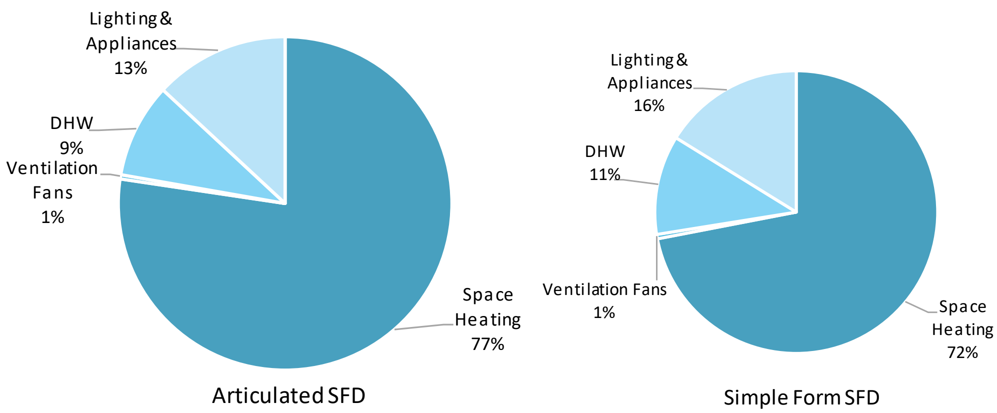


Figure 5.84 Baseline energy consumption break down for the baseline NBC 2015 SFDs in Resolute.

25% Better Than Code

The baseline SFD models were adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the NBC model. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption.

To meet the 25% energy target, several minor enclosure ECMs were implemented as well as an increase to the HRV efficiency. The 25% energy target could have been met with only airtightness improvement, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 1.0 ACH50

→ Increased insulation of opaque assemblies:

  → Walls from R_{eff}-17.5 to R_{eff}-20 (articulated) or R_{eff}-28 (simple form)

  → Exposed floor from R_{eff}-28.5 to R_{eff}-30 (articulated) or R_{eff}-28 (simple form)

→ Windows from low-conductivity doubles U-0.25 to triples U-0.18 (articulated, only)

→ Doors from R-4 to R-6 (articulated) or R-5 (simple form)

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat (articulated) or 70% (simple form)

Figure 5.85 shows the total energy consumption of the baseline SFDs and of the 25% better than code SFDs in Resolute. The starting baseline energy use and the 25% reduced energy consumption are higher for the articulated SFD archetype compared to the simple form SFD archetype.

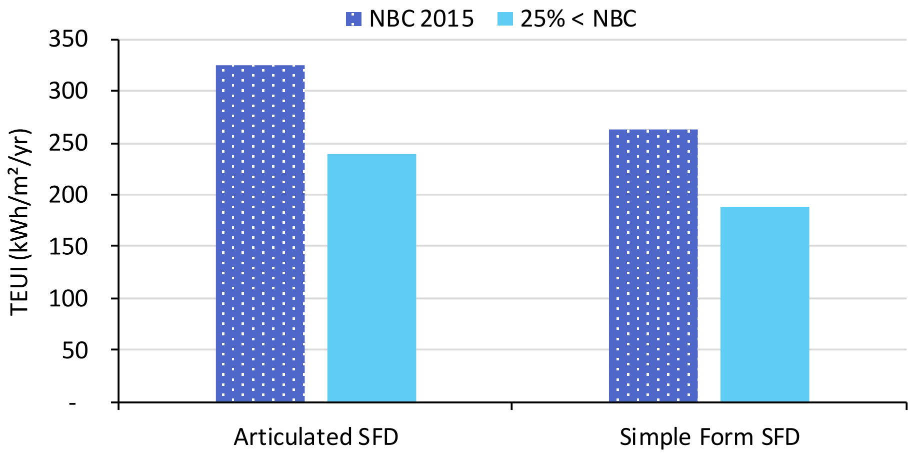


Figure 5.85 Total Energy Use Intensity of the NBC 2015 baseline SFD models and the 25% better than code SFD models in Resolute.

As shown here, the articulated SFD can reach the 25% target with similar ECMs as the simple form SFD (with a trade off between wall insulation and better windows) and is not encouraged to use further ECMs (or better design) to match the lower energy consumption of its simple form counterpart.

Step 4 of BC Energy Step Code

The baseline SFD models were adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr). A percent better than reference house may also be used as an alternate compliance path for Step 4, though the results presented here focus on MEUI since this is the only mechanical energy compliance path for Step 5 (shown later). A detailed summary of all model inputs is attached in Appendix E.

The Step 4 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 0.3 ACH50 (articulated) or 0.6 ACH50 (simple form)

→ Increased insulation of opaque assemblies:

  → Walls from R_{eff}-17.5 to R_{eff}-40 (articulated) or R_{eff}-35 (simple form)

  → Exposed floor from R_{eff}-28.5 to R_{eff}-35 (articulated) or R_{eff}-40 (simple form)

→ Windows from low-conductivity doubles U-0.25 to quads U-0.11 (articulated) or triples U-0.18 (simple form)

→ Doors from R-4 to R-8 (articulated) or R-6 (simple form)

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat

→ Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 4 (2018) targets. TEUI is shown for comparison with the total energy consumption of the baseline and the 25%<code target. Step Code metrics MEUI and TEDI are also shown, with the baseline, 25%<code, and original Step 4 (2017) included for comparison.

Figure 5.86 shows that the performance targets of the Step Code result in larger energy savings for the articulated archetype, which began with a higher baseline energy consumption.

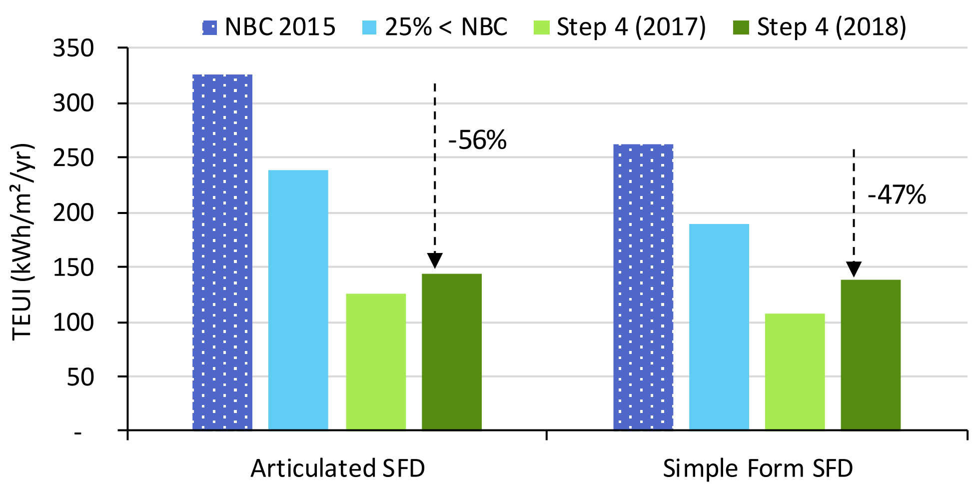


Figure 5.86 Total EUI for the articulated and simple form SFDs in Resolute, showing the reduction in energy consumption resulting from reaching Step 4 (2018, dark green). The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

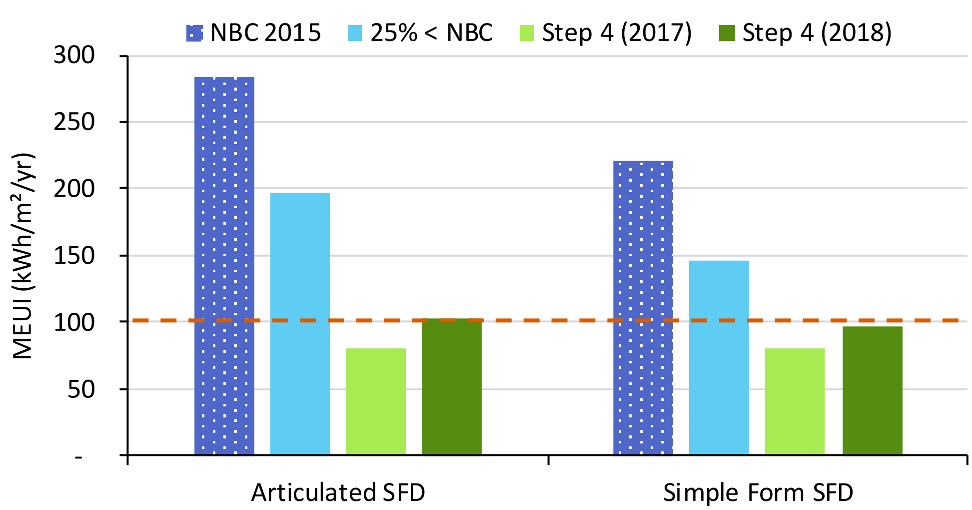


Figure 5.87 MEUI for the articulated and simple form SFDs in Resolute, showing the Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

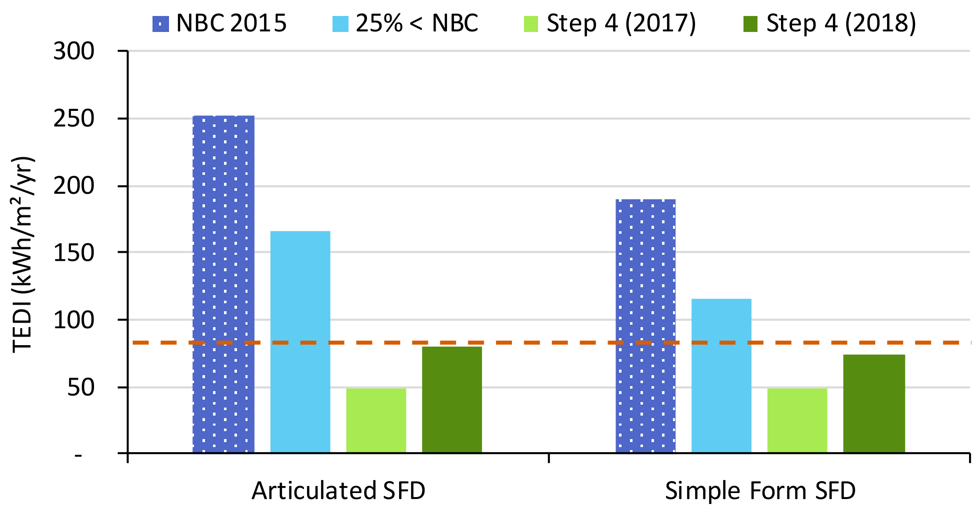


Figure 5.88 TEDI for the articulated and simple form SFDs in Resolute showing the Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

Step 5 of BC Energy Step Code

The baseline SFD models were adjusted by implementing ECMs to meet the targets in Step 5 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr).

The Step 5 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

To meet the Step 5 energy targets, several major enclosure ECMs and mechanical efficiency improvements were implemented. Many of the highest performance practical ECMs per Section 2.3 were necessary for the articulated SFD, while less stringent ECMs were necessary for the simple form SFD, demonstrating the benefit of starting with a simple form design. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

- → Reduction in air leakage rate from 2.5 ACH50 to 0.3 ACH50
- → Increased insulation of opaque assemblies:
  - → Roof from R_{eff}-59 to R_{eff}-80 (articulated, only)
  - → Walls from R_{eff}-17.5 to R_{eff}-50 (articulated) or R_{eff}-40 (simple form)
  - → Exposed floor from R_{eff}-28.5 to R_{eff}-60 (articulated) or R_{eff}-40 (simple form)
- → Windows from low-conductivity doubles U-0.25 to quads U-0.11
- → Doors from R-4 to R-8
- → Increase HRV efficiency from 60/55% to 81% dual core no preheat

→ Upgrade from electric baseboards to cold climate air-source heat pump for space heating (articulated, only)

→ Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 5 (2018) targets. TEUI is shown for comparison with the baseline and Step 4-compliant models, as well as original Step 5 (2017). Step Code metrics MEUI and TEDI are also shown, with the baseline, Step 4 models, and original Step 5 (2017) included for comparison.

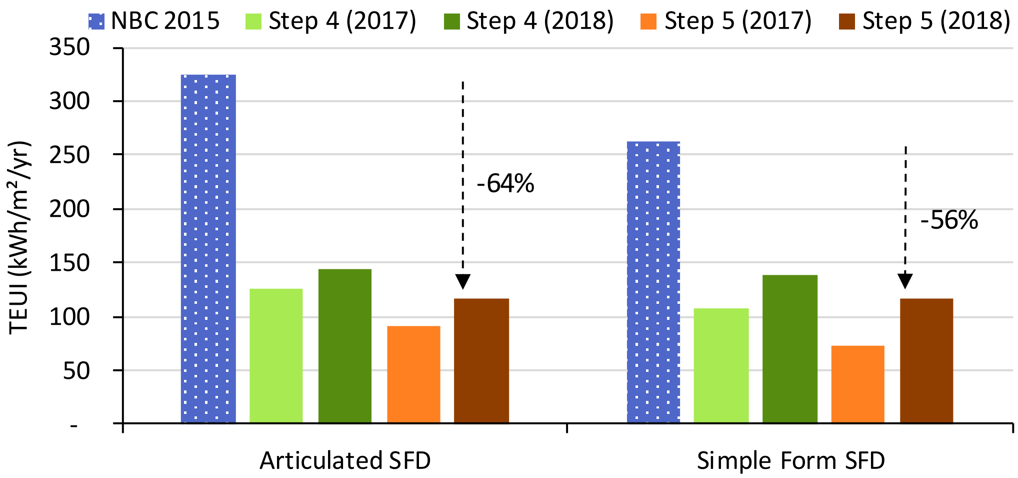


Figure 5.89 Total EUI for the articulated and simple form SFDs in Resolute, showing the reduction in energy consumption resulting from reaching Step 5 (2018, dark red). The Step 4-compliant and Step 5 (2017) models are shown for comparison (greens and light orange, respectively).

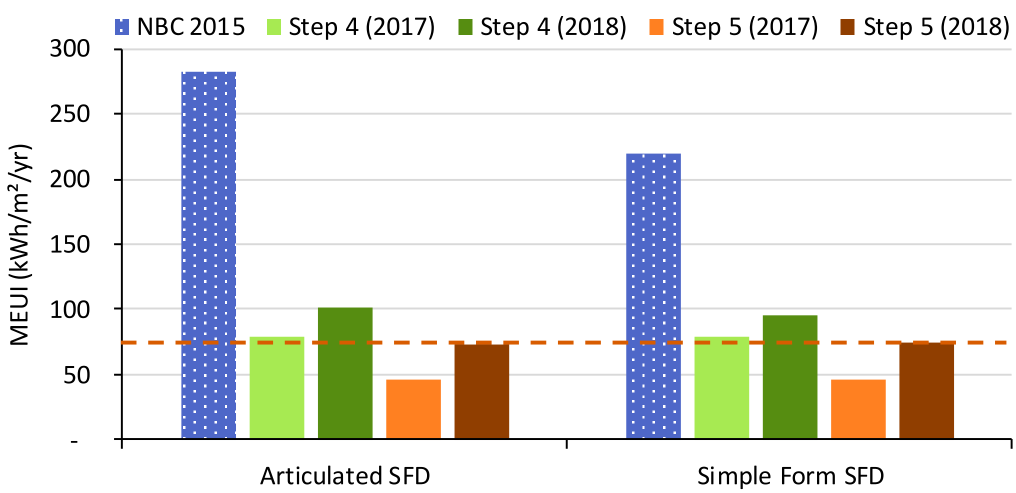


Figure 5.90 MEUI for the articulated and simple form SFDs in Resolute, showing the Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

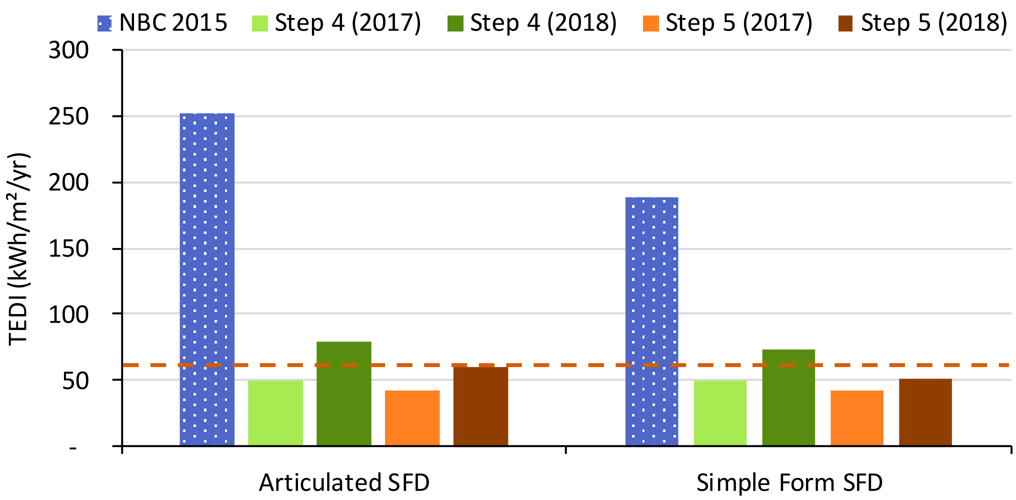


Figure 5.91 TEDI for the articulated and simple form SFDs in Resolute, showing the Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Passive House

The baseline SFD models were adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for total building energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 did not meet the heating demand or heating load targets and thus, even though the PER target was met for the simple form SFD, neither SFD model met the Passive House standard. The results are shown in Figure 5.92 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NBC 2015):

→ Did not meet Passive House

  → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.92.

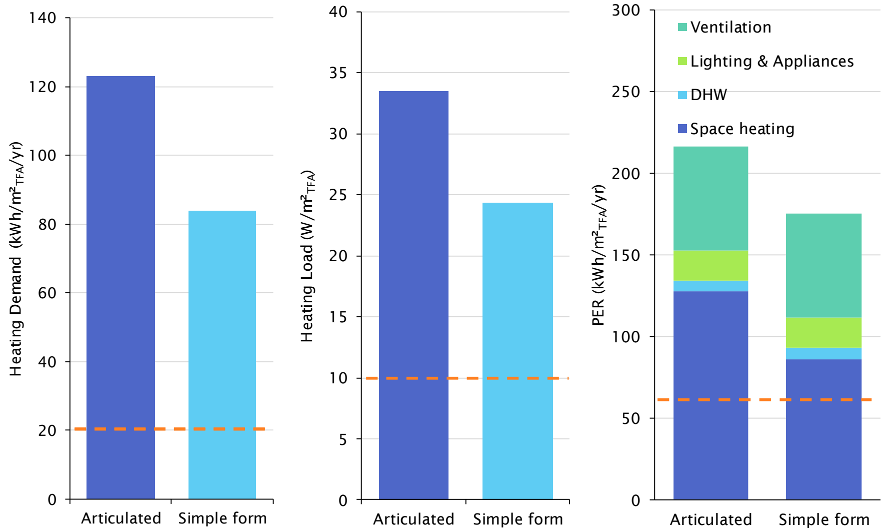


Figure 5.92 The heating demand (left), heating load (middle), and PER (right) of both articulated and simple form SFD models in Resolute. The Passive House targets are shown in orange dashed lines.

Even with the highest performance practical ECMs outlined in Section 2.3, the articulated and simple form SFD models did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices, and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

→ The 25% better than code target was met by implementing enclosure ECMs as well as an increase to the HRV efficiency.

→ The Step 4 targets resulted in greater energy improvements than the 25% better than code target for the SFDs in Resolute. This is because the absolute energy performance targets in Step Code are not relative to the baseline energy consumption, which is high in Resolute due to heating demand. Airtightness improvements beyond Passive House help reach the targets, though additional insulation, triple or quad windows, and heat recovery were also implemented.

→ The Step 5 targets require the articulated SFD to use several of the highest performance practical ECMs outlined in Section 2.3, while the simple form SFD does not need such stringent measures to meet Step 5 (i.e. a CCASHP was required for the articulated archetype and not the simple form). This demonstrates the importance of starting with simple form designs to meet high performance targets.

→ The analysis presented here used high efficiency electric systems, which provides a best-case scenario assuming that buildings will be able to connect to an electric grid. This may be difficult to accomplish in many remote northern communities and so a comparison of electric versus fuel oil systems is provided in Section 6.

→ Passive House targets were not achieved with the highest performance practical ECMs for the SFDs in Resolute.

Section 6 will provide alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets. This additional analysis will assess the impact of ECMs beyond the highest performance practical ECMs outlined in Section 2.3.

5.5.2 MURB in Resolute

This section presents how various high performance energy targets can be achieved (and which cannot be achieved) for the MURB archetypes in Resolute using commonly available technologies and building practices.

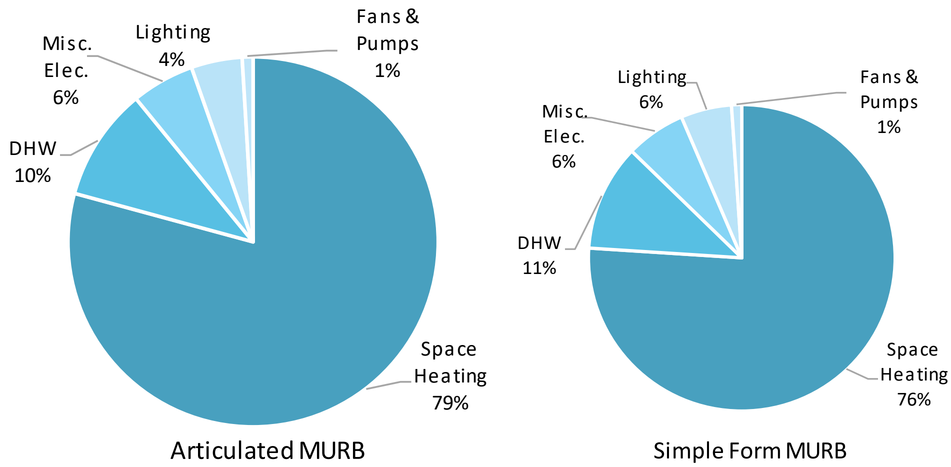


Figure 5.93 Baseline energy consumption break down for the baseline NECB 2011 MURBs in Resolute.

25% Better Than Code

The baseline MURB models were adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the reference NECB 2011 model per Part 8 of NECB. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption. A detailed summary of all model inputs is attached in Appendix F.

The ECMs that were implemented to meet the 25% energy target are listed below.

ECMs Beyond Baseline (NECB 2011):

→ Reduction in air leakage rate from 0.25 L/s-m² at 5 Pa (2.2 ACH50) to 0.125 L/s-m² at 5 Pa (1.1 ACH50)

→ Windows from double glazed (U-0.39) to triple glazed (U-0.17)

→ Increase in-suite HRV efficiency from 50% to 70%

Figure 5.94 shows the total energy consumption of the baseline MURBs and of the 25% better than code MURBs in Resolute. The baseline energy use and the 25% reduced energy consumption are higher for the articulated MURB archetype compared to the simple form MURB archetype.

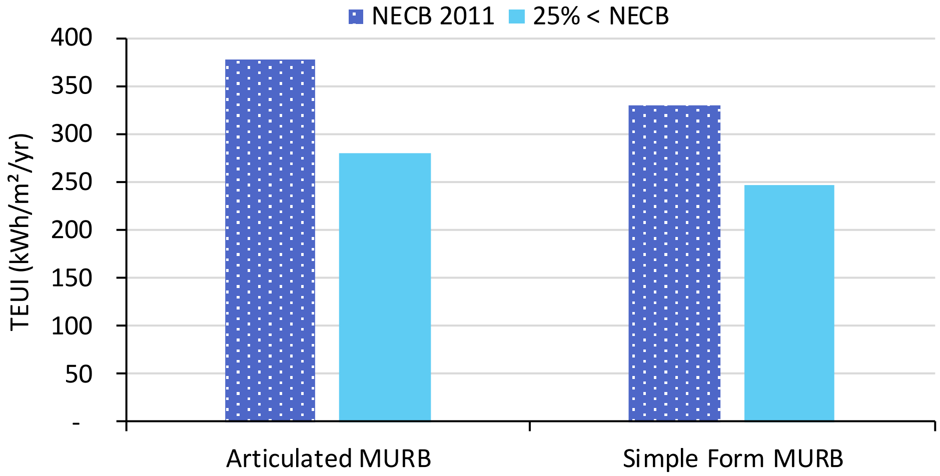


Figure 5.94 Total Energy Use Intensity of the NECB 2011 baseline MURB models and the 25% better than code MURB models in Resolute.

As shown in Figure 5.94, the 25% better than code target achieves energy savings proportional to the baseline energy consumption. The articulated MURB can reach the 25% target with similar ECMs as the simple form MURB and is not encouraged to use further ECMs (or better design) to match the lower energy consumption of its simple form counterpart.

Step 4 of the BC Energy Step Code

The baseline MURB models were adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for whole building energy consumption (Total Energy Use Intensity (TEUI), kWh/m²/yr). A detailed summary of all model inputs is attached in Appendix F.

The heating demand, TEDI, target is difficult to meet in cold climates since the original BC Energy Step Code targets for Part 3 buildings are intended for climate zone 4, only. As such, the ECMs that were implemented to meet Step 4 with this archetype are all heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 did not meet the heating demand or heating load targets and thus, even though the Step 4 TEUI target was met, the MURB models could not meet the Step 4 TEDI target. The results are shown in Figure 5.95.

ECMs Beyond Baseline (NECB 2011):

→ Did not meet Step 4

  → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.95 and Figure 5.96.

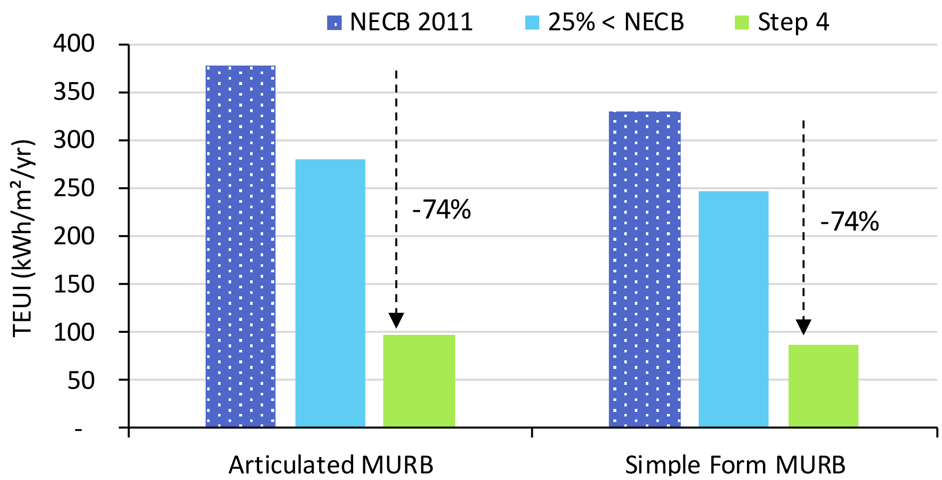


Figure 5.95 Total Energy Use Intensity of the NECB 2011 baseline, the 25% better than code, and the highest performance practical ECMs (per Section 2.3) models in Resolute. The highest performance practical ECMs (per Section 2.3) result in a 74% reduction in energy consumption for both the articulated and simple form MURB archetypes.

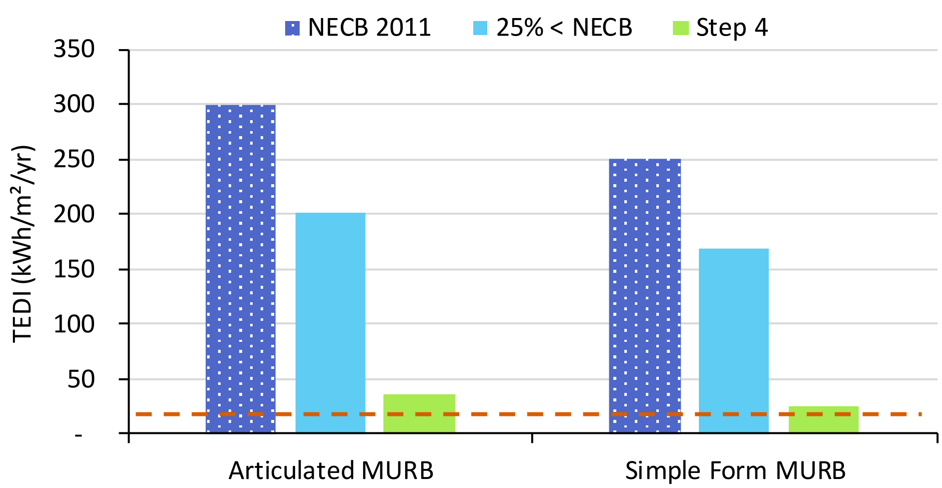


Figure 5.96 Thermal Energy Demand Intensity of the NECB 2011 baseline, the 25% better than code, and the highest performance practical ECMs (per Section 2.3) models in Resolute. Step 4 TEDI target of 15 kWh/m²/yr is shown for reference by the orange dashed line.

Passive House

The baseline MURB models were adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for source energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 did not meet the heating demand or heating load targets and thus, even though the PER target was met, the MURB models could not meet Passive House the standard. The results are shown in Figure 5.97 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NECB 2011):

→ Did not meet Passive House

  → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.97.

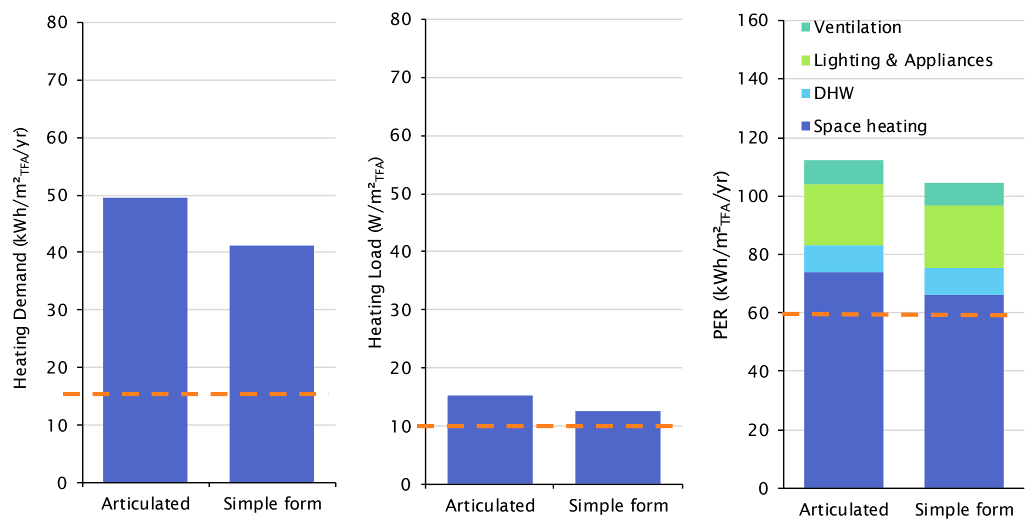


Figure 5.97 The heating demand (left), heating load (middle), and PER (right) of both articulated and simple form MURB models in Resolute with the ECMs in Section 2.3. The Passive House targets are shown in orange dash lines.

Even with the highest performance practical ECMs outlined in Section 2.3, the articulated and simple form MURB models did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices, and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

→ The articulated MURB archetype has higher energy consumption than the simple form MURB archetype baseline. This makes it harder to reach absolute targets such as Step Code and Passive House metrics, though both articulated and simple form MURBs may use the same ECMs to meet the relative 25% target.

→ The 25% target can be met for the MURBs in Resolute by measures including better airtightness, triple glazed windows, and 70% heat recovery effectiveness.

→ Step 4 BC Energy Step Code targets was not met by the MURB models in Resolute. The limiting metric is the TEDI target, while the TEUI target was met using the highest performing practical ECMs outlined in Section 2.3.

→ The Passive House standard was not met by the simple form or articulated MURB models in Resolute. Neither the PER, heating demand, or heating load targets could be met using the highest performing practical ECMs outlined in Section 2.3.

→ The analysis presented here used high efficiency electric systems, which provides a best-case scenario assuming that buildings will be able to connect to an electric grid. This may be difficult to accomplish in many remote northern communities. Non-electric systems may not meet PER due to fuel factors.

Section 6 will provide alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets. This additional analysis will assess the impact of ECMs beyond the highest performance practical ECMs outlined in Section 2.3.

5.5.3 5-Plex in Resolute

This section presents how various high performance energy targets can be achieved for the 5-Plex archetype in Resolute using commonly available technologies and building practices. The 5-Plex baseline archetype is modelled with fuel oil systems in climate zone 8 to reflect common practice in this region.

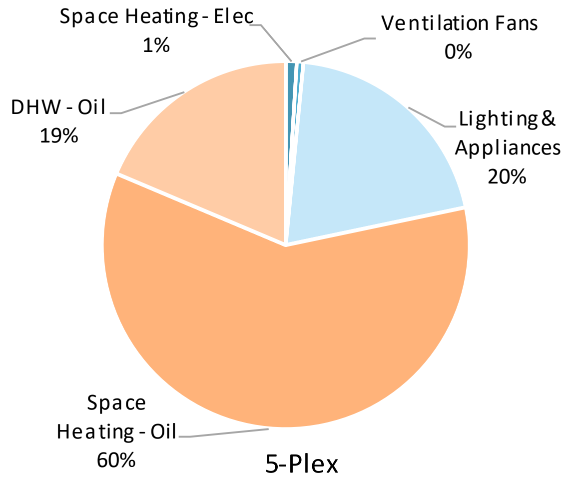


Figure 5.98 Baseline energy consumption break down for the baseline NBC 2015 5-Plex in Resolute. Fuel oil systems were used for space heating and DHW in the 5-Plex baseline archetype for climate zone 8 (oil consumption shown in orange, electricity in turquoise).

25% Better Than Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet a target of 25% better than base building code. The target is calculated as a 25% reduction in total energy consumption from the baseline energy consumption of the NBC model. Total Energy Use Intensity (TEUI, kWh/m²/yr) is used as the metric for energy consumption.

To meet the 25% energy target, several enclosure ECMs were implemented as well as an increase to heat recovery for ventilation and drain water. The 25% energy target could have been met with fewer ECMs if more of an airtightness improvement was implemented, though, due to the uncertainty of builders being able to reach very low airtightness at first, a more moderate air leakage rate was balanced with additional ECMs. A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 1.0 ACH50

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-28.5 to R_{eff}-35

  → Walls from R_{eff}-17.5 to R_{eff}-20

  → Exposed floor from R_{eff}-28.5 to R_{eff}-35

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat

→ Add drain water heat recovery at 65% effectiveness

Figure 5.99 shows the total energy consumption of the baseline 5-Plex and of the 25% better than code 5-Plex in Resolute. The same ECMs could have been used for an all-electric archetype in this location since the 25% target is relative to the baseline energy consumption.

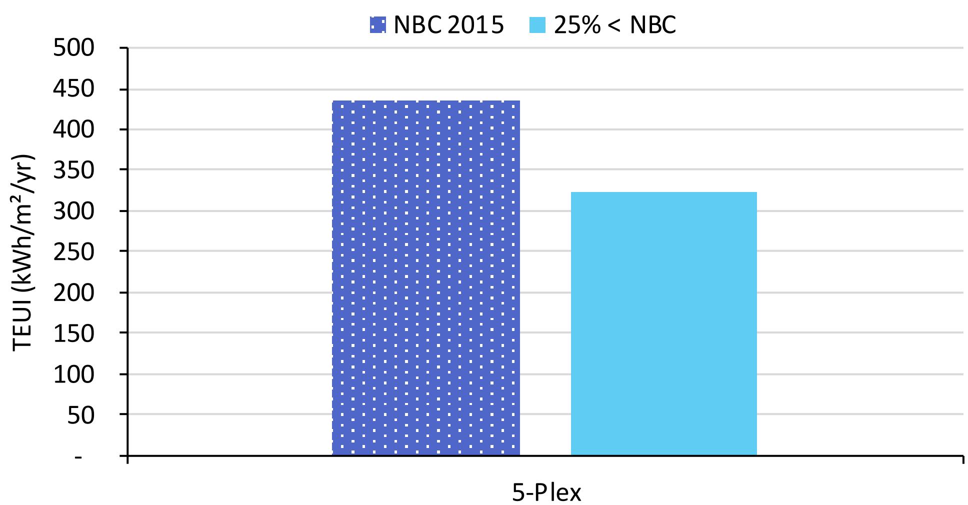


Figure 5.99 Total Energy Use Intensity of the NBC 2015 baseline 5-Plex model and the 25% better than code 5-Plex model in Resolute.

Step 4 of the BC Energy Step Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets in Step 4 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr). A detailed summary of all model inputs is attached in Appendix E.

The Step 4 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

ECMs Beyond Baseline (NBC 2015):

→ Reduction in air leakage rate from 2.5 ACH50 to 0.3 ACH50

→ Increased insulation of opaque assemblies:

  → Roof from R_{eff}-28.5 to R_{eff}-60

  → Walls from R_{eff}-17.5 to R_{eff}-40

→ Exposed floor from R_{eff}-28.5 to R_{eff}-35

→ Windows from low-conductivity doubles U-0.25 to quads U-0.12

→ Doors from R-4 to R-8

→ Increase HRV efficiency from 60/55% to 81% dual core no preheat

→ Switch from fuel oil systems to electric resistance systems for space heating and DHW

→ Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 4 (2018) targets. TEUI is shown for comparison with the total energy consumption of the baseline and the 25%<code target. Step Code metrics MEUI and TEDI are also shown, with the baseline, 25%<code, and original Step 4 (2017) included for comparison.

Figure 5.100 shows that the performance targets of Step 4 result in 57% energy savings compared to the baseline by implementing the above ECMs.

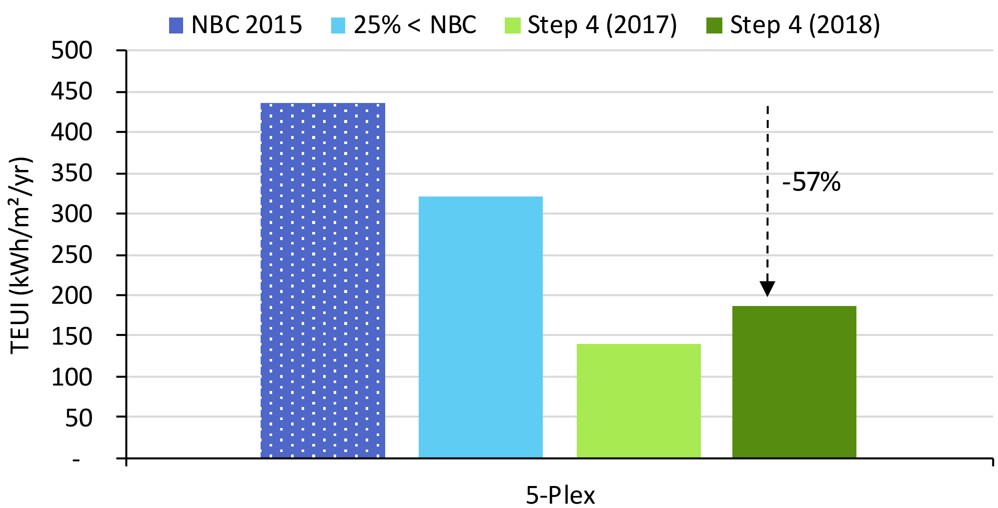


Figure 5.100 Total EUI for the 5-Plex in Resolute, showing the reduction in energy consumption resulting from reaching Step 4 (new Step Code target, dark green). The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

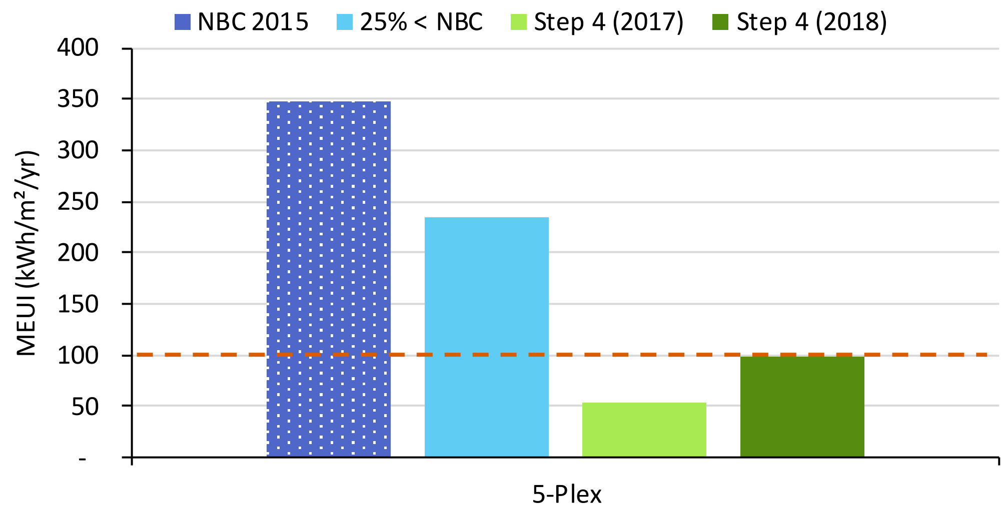


Figure 5.101 MEUI for the articulated and simple form SFDs in Resolute, showing the new Step Code Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

The TEDI of the Step 4 model is well below the Step 4 TEDI target (Figure 5.102). This is due to the 5-Plex being limited by the MEUI metric. Since it was more difficult to meet the MEUI target, many enclosure measures were implemented the decrease to energy consumption. The enclosure measures (and HRV efficiency improvement) that were necessary to meet the MEUI metric led to a much lower TEDI than the Step 4 limit.

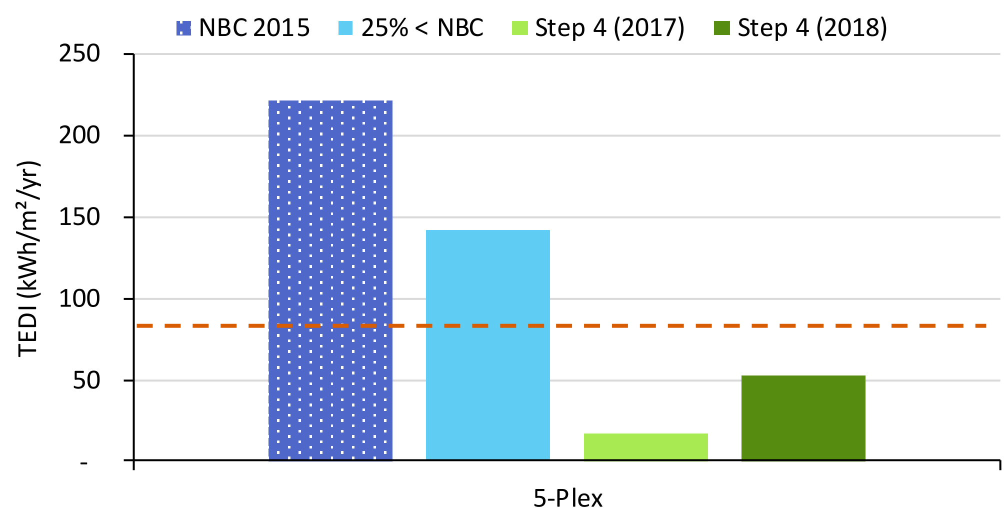


Figure 5.102 TEDI for the 5-Plex in Whitehorse, showing the new Step Code Step 4 (2018) target with the orange dashed line. The 25%<code- and Step 4 (2017)-compliant models are shown for comparison (light blue and light green, respectively).

Step 5 of the BC Energy Step Code

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets in Step 5 of the BC Energy Step Code. The targets include metrics for heating demand (Thermal Energy Demand Intensity (TEDI), kWh/m²/yr) and for mechanical energy consumption (Mechanical Energy Use Intensity (MEUI), kWh/m²/yr).

The Step 5 targets from the original Step Code (as of December 2017) and the updated Step Code (as of December 2018) were both modelled for comparison. The results are discussed in terms of the updated Step Code as this is the code that is currently enacted.

To meet the Step 5 energy targets, two different ECM bundles were implemented, one with several major enclosure ECMs and mechanical efficiency improvements (Bundle One) and one with an DHW heat pump allowing a relaxation of enclosure ECMs (Bundle Two). For Bundle One, many of the highest performance practical ECMs per Section 2.3 were necessary. In Bundle Two, once a heat pump was implemented for DHW, several enclosure measures were relaxed including airtightness (0.3 to 0.6 ACH50), insulation (reductions in all areas), windows (quads to triples), and doors (R-8 to R-7). A detailed summary of all model inputs is attached in Appendix E.

ECMs Beyond Baseline (NBC 2015):

Bundle One

- → Reduction in air leakage rate from 2.5 ACH50 to 0.3 ACH50
- → Increased insulation of opaque assemblies:
  - → Roof from R_{eff}-28.5 to R_{eff}-70
  - → Walls from R_{eff}-17.5 to R_{eff}-50
  - → Exposed floor from R_{eff}-28.5 to R_{eff}-60
- → Windows from low-conductivity doubles U-0.25 to quad glazing U-0.12
- → Doors from R-4 to R-8
- → Increase HRV efficiency from 60/55% to 81% dual core no preheat
- → Switch from fuel oil boiler (AFUE 85%) to CCASHP for space heating
- → Switch from oil tank to electric tank DHW
- → Add drain water heat recovery at 65% effectiveness

Bundle Two – HP DHW

- → Reduction in air leakage rate from 2.5 ACH50 to 0.6 ACH50
- → Increased insulation of opaque assemblies:
  - → Roof from R_{eff}-28.5 to R_{eff}-60
  - → Walls from R_{eff}-17.5 to R_{eff}-40
  - → Exposed floor from R_{eff}-28.5 to R_{eff}-40
- → Windows from low-conductivity doubles U-0.25 to Passive House triple glazing U-0.14
- → Doors from R-4 to R-7
- → Increase HRV efficiency from 60/55% to 81% dual core no preheat
- → Switch from fuel oil boiler (AFUE 85%) to CCASHP for space heating
- → Switch from oil tank to ASHP for DHW
- → Add drain water heat recovery at 65% effectiveness

The following figures show the energy modelling results for reaching Step 5 (2018) targets for Bundle One and Bundle Two (“HP DHW”). TEUI is shown for comparison with the baseline and Step 4-compliant models, as well as original Step 5 (2017). Both bundles achieved a 63% reduction in energy consumption compared to the baseline 5-Plex in Resolute.

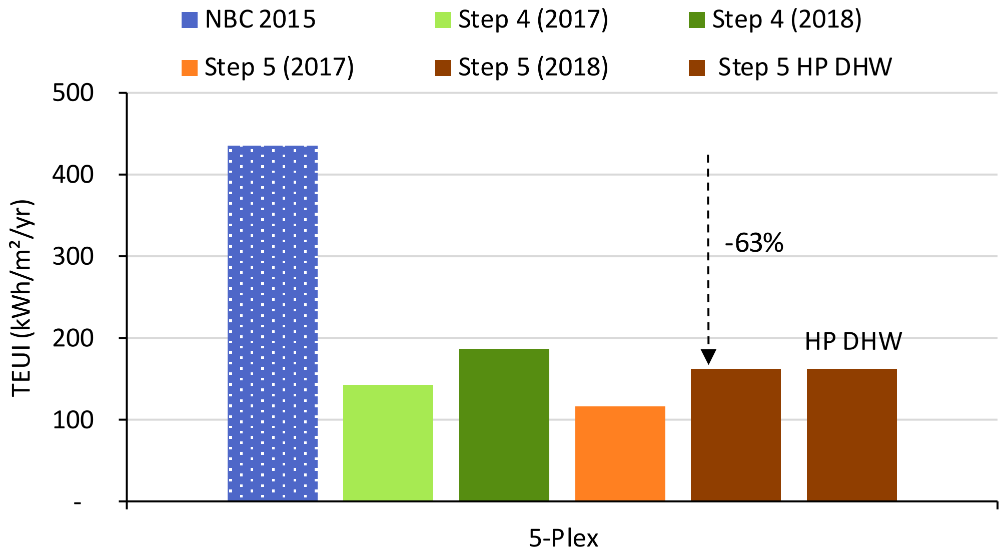


Figure 5.103 Total EUI for the 5-Plex in Resolute, showing the reduction in energy consumption resulting from reaching Step 5 (2018 targets, both Bundles shown in dark red). The Step 4-compliant and Step 5 (2017) models are shown for comparison (greens and light orange, respectively).

Step Code metrics MEUI and TEDI are also shown in Figure 5.104 and Figure 5.105, respectively, with the baseline, Step 4 models, and original Step 5 (2017) included for comparison. The MEUI for Bundle One and Bundle 2 ("HP DHW") both meet the target. The 5-Plex model is MEUI-limited.

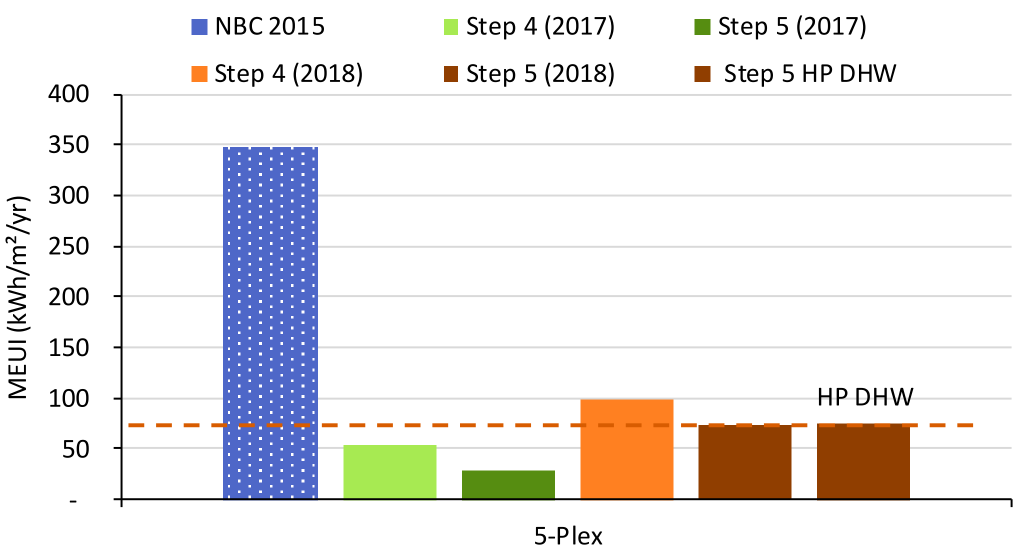


Figure 5.104 MEUI for the 5-Plex in Resolute, showing the new Step Code Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Similar to the Step 4 results, the TEDI of the Bundle One Step 5 model is well below the Step 5 TEDI target (Figure 5.105). This is due to the 5-Plex being limited by the MEUI metric. Since it was more difficult to meet the MEUI target, many enclosure measures were implemented to decrease the energy consumption. The enclosure measures (and HRV efficiency improvement) that were necessary to meet the MEUI metric led to a much lower TEDI than the Step 5 limit. In contrast with Bundle One, when the heat pump DHW is implemented in Bundle Two the enclosure measures were relaxed and this a relative increase in TEDI is seen for this scenario ("HP DHW"). Although the heat pump DHW in Bundle Two allows fewer enclosure ECMs, there may be other limitations to using heat pumps in the Far North, which will be discussed in Section 6.

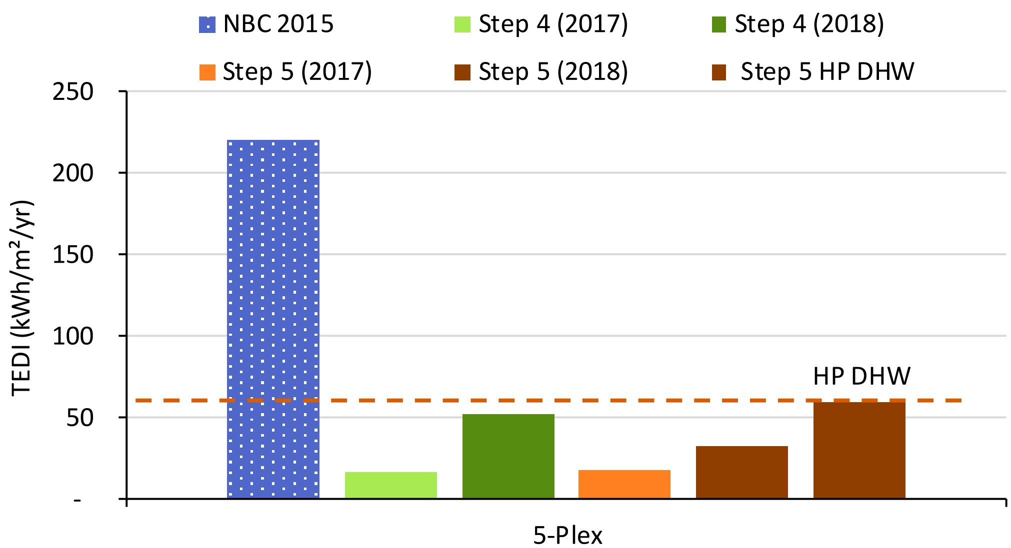


Figure 5.105 TEDI for the 5-Plex in Resolute, showing the new Step Code Step 5 (2018) target with the orange dashed line. The Step 4- and Step 5 (2017)-compliant models are shown for comparison (greens and light orange, respectively).

Passive House

The baseline 5-Plex model was adjusted by implementing ECMs to meet the targets for Passive House compliance. The targets include metrics for heating demand (Heating Demand, kWh/m²/yr or Heating Load, W/m²) and for total energy consumption (Primary Energy Renewable (PER), kWh/m²/yr).

The heating demand and heating load targets are difficult to meet in colder climates. As such, the ECMs that were implemented to try and meet Passive House targets with this archetype are the highest performance practical heating demand reduction measures. The highest performing practical ECMs outlined in Section 2.3 did not enable the 5-Plex model to meet the Passive House standard. The results are shown in Figure 5.106 with the Passive House targets noted by the dashed orange lines for reference.

ECMs Beyond Baseline (NBC 2015):

→ Did not meet Passive House

  → Highest performing practical ECMs outlined in Section 2.3 were used and the results from this are shown in Figure 5.106.

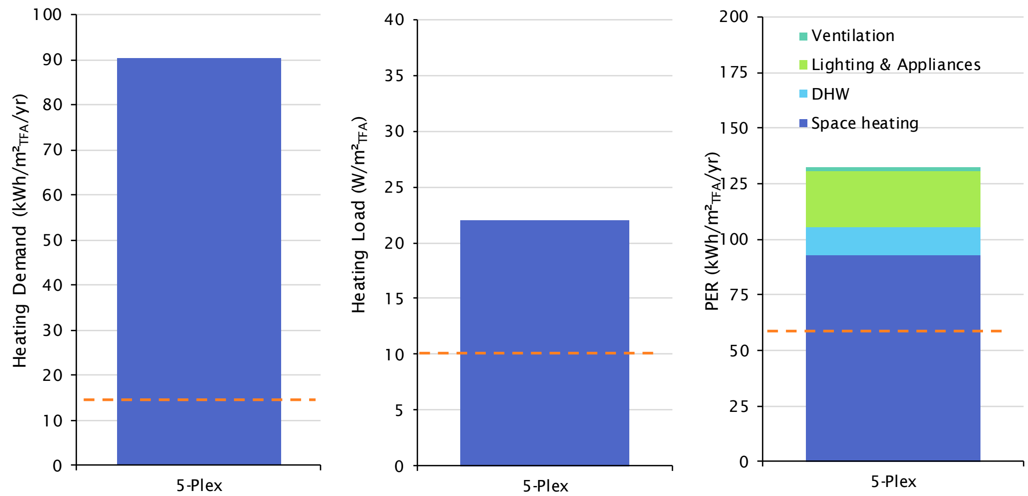


Figure 5.106 The heating demand (left), heating load (middle), and PER (right) of the 5-Plex model in Resolute. The Passive House targets are shown in orange dashed lines.

Even with the highest performance practical ECMs outlined in Section 2.3, the 5-Plex model did not meet the Passive House standard. Alternative strategies including higher performance technologies and building practices (e.g. higher R-value enclosures, different wall types not common to the North), and adaptations to the targets will be discussed in Section 6 as potential future strategies to reach near-net zero energy targets such as Passive House in the Far North.

Key Takeaways

→ The 25% energy target could have been met with fewer ECMs if more of an airtightness improvement was made, though as this target is intended to be a stepping stone to higher targets a wider range of ECMs were implemented. A such, a reduction in air leakage was coupled with minor enclosure improvements as well as increased heat recovery for ventilation and DHW.

→ The Step 4 targets require deeper enclosure improvements for the 5-Plex in Resolute compared to Yellowknife. These are both climate zone 8 locations, so they have the same Step Code targets, though quad glazing and 0.3 ACH50 (airtightness beyond Passive House requirements) were necessary to reach the Step 4 targets in Resolute and not in Yellowknife.

→ To meet the Step 5 energy targets, two different ECM bundles were implemented, one with several major enclosure ECMs and mechanical efficiency improvements (Bundle One) and one with an DHW heat pump allowing a relaxation of enclosure ECMs (Bundle Two).

→ For Bundle One, many of the highest performance practical ECMs per Section 2.3 were necessary. In Bundle Two, once a heat pump was implemented for DHW, several enclosure measures were relaxed including airtightness (0.3 to 0.6 ACH50), insulation (reductions in all areas), windows (quads to triples), and doors (R-8 to R-7).

→ Although the heat pump DHW in Bundle Two allows fewer enclosure ECMs, there may be other limitations to using heat pumps in the Far North, which will be discussed in Section 6.

→ Passive House targets were not achieved with the highest performance practical ECMs for the 5-Plex in Resolute Section 2.3.

Section 6 will provide alternate strategies that may close the gap in reaching Passive House targets in the Far North including new technologies and potential adaptations to targets. This additional analysis will assess the impact of ECMs beyond the highest performance practical ECMs outlined in Section 2.3.

6 Costing Analysis

In conjunction with the previous energy modelling analysis, a costing analysis was performed here to compare the incremental capital cost (ICC) of constructing high performance buildings in the Far North. The ICC of achieving the high performance targets for each building type was determined when the targets were achieved, and the highest performing practical ECMs in Section 2.3 were assessed as well. The ICC was determined by costing the additional energy conservation measures over baseline, code-minimum scenarios. The ICC analysis provides insight into the costs of achieving high performance building targets in the Far North for the MURB, SFD, and 5-Plex buildings.

The ICC consider high-level costs for the additional materials and construction labour required to meet the performance targets over the baseline.

6.1 Assumptions for Costs

Incremental capital costs were calculated as the additional materials and construction labour to achieve the high performance ECMs. Table 6.1 presents the assumptions used to calculate the incremental costs for each ECM.

TABLE 6.1 UPGRADE & COSTING ASSUMPTIONS

ECM	DESCRIPTION	BASIS FOR COSTING
ENCLOSURE ECMS		
Wall	Wall upgrades are additional EPS (expanded polystyrene) or mineral wool exterior insulation on split insulated 2x6 wood-frame wall assemblies (conventional 2x6 rainscreen wall assembly assumed as baseline).	Incremental cost of additional EPS insulation, long screw attachments, plus additional labour and flashing costs for detailing around exterior insulation.
Roof	Roof upgrades are either additional attic insulation or additional exterior insulation, depending on the roof assembly type (attic or low slope).	*Attic*: incremental cost of additional batt insulation and baffles to ensure proper venting. *Low sloped*: incremental cost of additional EPS insulation and insulation protection board, plus additional labour and attachment material costs for installing the additional insulation boards.
Exposed floor	Exposed floor upgrades involve increasing the depth of the floor joists and using additional batt insulation to fill the cavity.	Incremental costs of increasing the floor joists/trusses, and additional batt insulation to fill the deeper cavity.
Slab	Slab upgrades are additional EPS exterior insulation beyond code-minimum requirements.	Incremental cost of additional below grade EPS insulation.
Windows	Window upgrades are products beyond the code-minimum performance requirements.	Incremental cost of the high performance product versus the code-minimum requirement, plus additional labour costs for installation.
Doors	Door upgrades are products beyond the code-minimum performance requirements.	Incremental cost of the high performance product versus the code-minimum requirement.

Air-tightness	Improved airtightness is achieved by skilled tradespeople using an improved air barrier system of a self-adhered membrane instead of taped building wrap, with one airtightness test.	Incremental cost of a more robust self-adhered membrane versus mechanically fastened taped building wrap, plus the cost of additional labour (attention to details) and the airtightness test & diagnostics to seal remaining leaks (labour, fan rental, report).
MECHANICAL ECMS		
Heat recovery ventilators	HRV upgrades include using products with increased heat recovery efficiency beyond code-minimum requirements. For the MURB, the highest efficiency upgrade includes changing from in-suite HRVs to a zoned approach (3 zones for suites + 1 zone for corridors).	*In-suite (all archetypes)*: Incremental cost of the high performance product versus the code-minimum requirement. *(MURB, only)*: Incremental cost of the high performance product and ducting required for centralized/zoned system, plus incremental crane operating costs to install multiple rooftop units.
Ventilation rate	The MURB archetype includes a ventilation rate reduction as part of its ventilation upgrade.	Incremental cost is actually a cost savings by reducing the air handling unit size.
Heating equipment downsizing	This is not an explicit upgrade, though when heating demand is reduced through other measures the heating equipment may be down sized (i.e. fewer or smaller electric baseboards are required).	Incremental cost savings is the difference between baseboard size and number of units from the baseline archetype.
Space heating – SFD	Space heating upgrades for the SFD archetype include switching from electric baseboards to cold climate air source heat pump (ccASHP) with a hydronic distribution system.	There are several different heating systems allowed for code-compliance. In this case the ccASHP was compared to an alternate baseline scenario where a boiler serving a hydronic loop was used for code-compliance. As such, the incremental cost is of the ccASHP compared to a code-minimum efficiency boiler, and increased radiator size required for lower water temperatures from the ccASHP (excluding the hydronic distribution system).
Space heating – MURB	Space heating upgrades for the MURB archetype include switching from electric baseboards to ccASHP serving in-suite fan coil units (FCUs) through a variable refrigerant flow (VRF) system.	Incremental cost is the difference of ccASHPs with VRF distribution system including materials, labour, and commissioning, compared to baseline electric baseboards.
Space heating – 5-Plex	Space heating upgrades for the 5-Plex archetype include switching from either electric baseboards (CZ 7) or fuel oil boiler (CZ 8) heating systems to cold climate air source heat pump (ccASHP) with a hydronic distribution system.	As above for SFD space heating costing above, incremental cost is of the ccASHP is compared to a code-minimum efficiency boiler system.

DHW system	DHW system upgrades include using tank heaters with improved energy factors (EFs) beyond code-minimum requirement or upgrading to a heat pump DHW heater.	Incremental cost of upgrading to a high EF heater or a heat pump DHW heater with extra storage tanks.
Drain water heat recovery	Upgrade includes adding either a vertical or horizontal drain water heat recovery unit to each stacked drain system or each dwelling unit (depending on archetype) for DHW preheat.	Incremental cost of the drain water heat recovery unit(s) and the labour for installation.

6.2 Northern Costing Factors

Where available, costs from past work carried out by RDH and BTY for CMHC on construction costs in the Far North[43,44] were leveraged. The costs from this past work represent material and labour costs specific to Whitehorse, Yellowknife, and Ulukhaktok (a rural location in climate zone 8 on the Beaufort Sea, with comparable construction costs to Resolute). Costs obtained from this prior northern costing research were used for the following ECMs:

- → Opaque enclosure elements: wall, roof, exposed floor, slab
- → Airtightness materials
- → HRV (in-suite single-core units only)

The remaining ECM material and labour costs were obtained from contractors, suppliers, and industry experience. Costs that were obtained from southern locations are generally less than construction costs in the Far North and is common industry practice to adjust prices for northern regions with location costing factors. The location factors used in this study are presented in Table 6.2. The factors were developed from the Altus Group Construction Cost Guide 2018,[45] and were adjusted using northern construction costs from RDH/BTY's past work where needed. At the time of writing, the 2018 Guide is the most recent version of this industry resource which includes location factors for some cities/communities in Yukon Territory, Northwest Territory and Nunavut.

TABLE 6.2 LOCATION COSTING FACTORS*

Location	**Location Factor**
Fort St. John	1.15
Whitehorse	1.33
Yellowknife	1.48
Resolute	2.40

*Location factors are relative to construction costs in Vancouver since this is where the local material and labour costs were gathered.

[43] *Cost of Delivering Housing in Canada – Southern Archetypes*. RDH Building Science Inc. Submitted November 24, 2017 to Canada Mortgage and Housing Corporation. <https://eppdscrmssa01.blob.core.windows.net/cmhcprodcontainer/sf/project/archive/research_3/cost_of_delivering_housing_in_canada.pdf>.

[44] *Cost of Delivering Housing in Canada – Northern Archetypes*. RDH Building Science Inc. Submitted November 24, 2017 to Canada Mortgage and Housing Corporation. <https://eppdscrmssa01.blob.core.windows.net/cmhcprodcontainer/sf/project/archive/research_3/cost_of_delivering_housing_in_canada_northern_archetypes.pdf>.

[45] Construction Cost Guide 2018. Altus Group Limited, January 2018. Available online: https://www.altusgroup.com/news_insights/construction-cost-guide-2018.

These location factors were applied to costs for the following ECMs:

- → Windows and doors
- → HRV (commercial and dual-core units)
- → MUA equipment
- → Space heating equipment
- → DHW system & drain water heat recovery
- → Airtightness testing

The Altus Construction Cost guide was also used to compare total construction costs to the ICC of each bundle.

6.3 Incremental Costing Analysis Results

The following section presents the results of the incremental costing analysis for the high performance targets for the SFDs, the MURBs, and the 5-Plex. The incremental capital costs typically vary by ± 20% for equivalent projects due to project specifics including different suppliers, experience of labour, or time of year. Costs presented in the following figures represent the average of the cost range. The low and high range of costs is provided in Appendix I and J.

6.3.1 Incremental Costs for SFDs

Figure 6.1 presents the incremental capital costs (ICC) for the two SFD archetypes to reach the high performance targets in this study. The 2018 version of the Step Code was used in this comparison, while the older, 2017 version is compared later. The ICC of 25% < NBC shows the least variation across the climate zones studied since it is a relative performance target that depends on the baseline energy consumption. In general, the Step 4 (2018) target has a similar cost to the 25% < NBC target in all locations except Resolute. Resolute has the highest ICC to achieve the targets because of the high costing factor[46] for its remote location and because its climate is much most severe than Yellowknife in terms of heating degree days so more ECMs were required to meet the climate zone 8 TEDI target. The costing results for both Step 4 and Step 5 show that it is more cost-effective to reach the absolute energy performance targets starting with a simple form factor in early design. The articulated SFD generally shows higher costs than the simple form SFD for reaching the same targets. The Passive House targets were not met for the SFD archetypes and thus are not shown here.

For reference (and presented in Table 6.3 later), typical total construction costs in these northern locations range from \$2,200 to \$4,700 per m² floor area (\$210 to \$440 per ft²).

[46] Costing factors represent relative differences in the cost of material and labour between different geographic locations.

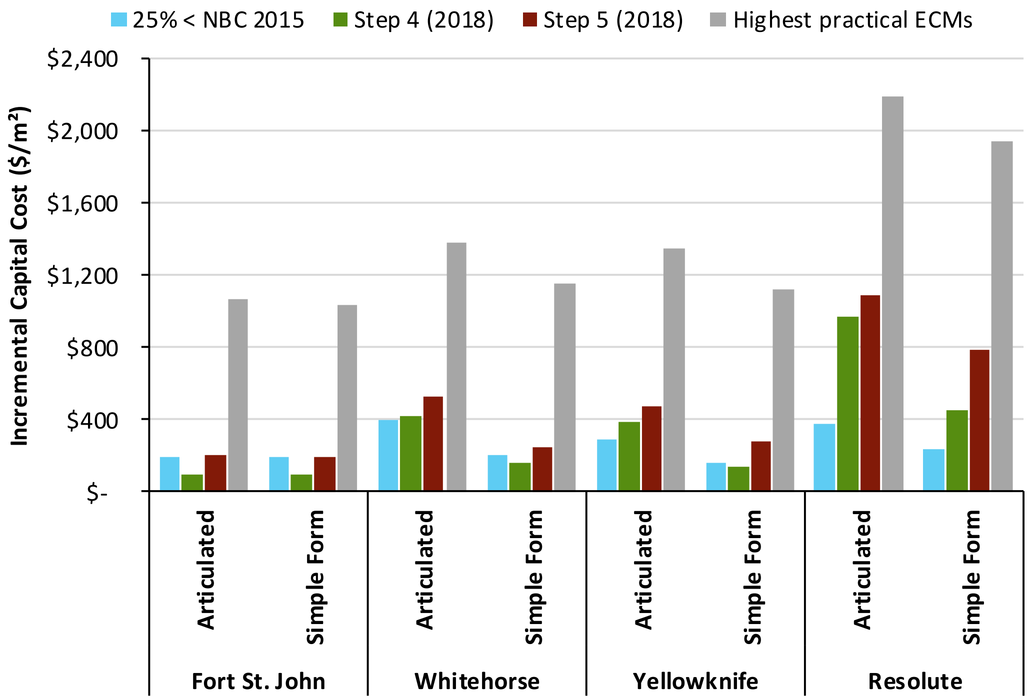


Figure 6.1 Incremental capital costs of the high performance targets over baseline construction costs for the articulated and simple form SFDs. The Passive House targets were not met for the SFD archetypes and thus are not shown.

The performance targets that focus on heating demand reduction (i.e. TEDI in the Step Code) enable mechanical equipment downsizing and cost savings for the heating equipment, which helps balance the costs of increasing the enclosure thermal performance. Step 4 achieved between $92/m² to $974/m² depending on the form factor and location, illustrating that it can be more costly to achieve these targets in the Far North even with the relaxations to the Step Code per climate zone in the 2018 version. The Step 5 cost for Resolute ($1084/m² for the articulated SFD) is especially high because of the switch to a ccASHP for space heating.

The Step Code costs for Yellowknife and Whitehorse are similar, reflecting the 2018 Step Code target adjustment per climate zone for fair compliance throughout British Columbia. The insulation costs were slightly different depending on the floor type of each location, for example the incremental cost to increase insulation for an exposed floor (Yellowknife archetype) is cheaper than for a slab-on-grade floor (Whitehorse archetype). This cost difference outweighs the increased insulation required to meet targets as well as the higher location costing factor for Yellowknife.

To better understand the cost difference for reaching different targets, Figure 6.2 shows the ICC breakdown for the simple form SFD in Yellowknife. In this example, the Step 4 target is easier to meet than the 25% < NBC target. The largest difference in going from Step 4 to Step 5 is the added cost for a high performance cold-climate HRV (shown in the Heating & Ventilation category, dark green).

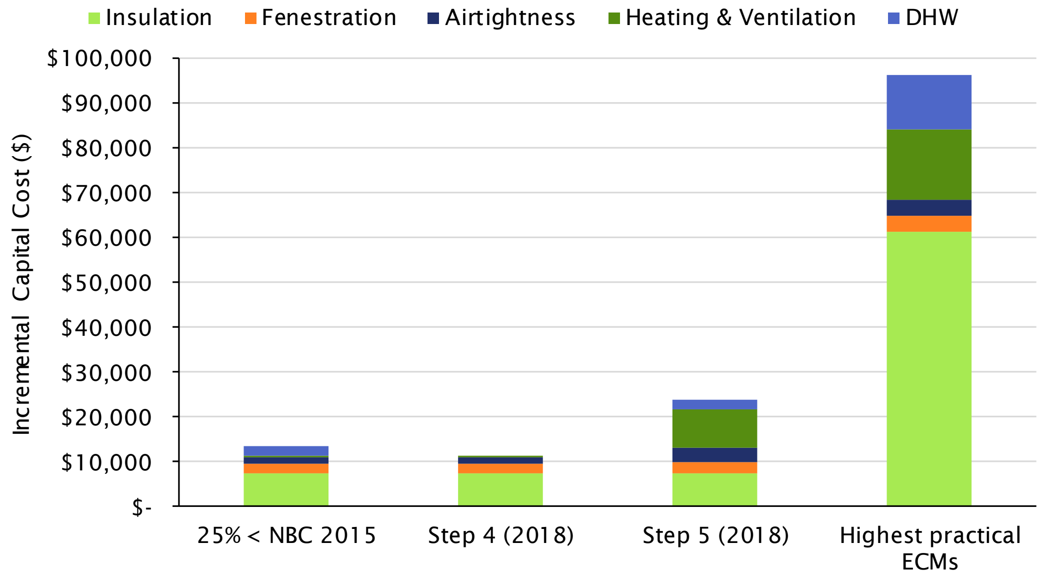


Figure 6.2 Incremental capital cost breakdown for the simple form SFD to reach the high performance energy targets (25% < NBC, Step 4, Step 5) as well as implementing the highest practical ECMs for the north in Yellowknife.

To better understand the cost difference for reaching Step 5 in different locations, Figure 6.3 shows the ICC breakdown for the simple form SFD in all four locations. The costs increase as the HDDs of the locations increase (i.e. as the climate gets colder). The incremental costs are generally dominated by enclosure costs, except in the case of Yellowknife. In Yellowknife, a high performance cold-climate HRV was necessary to meet the Step 5 targets, which allowed backing off the enclosure performance as to not overshoot the targets. In Resolute, both a high performance cold-climate HRV and extensive enclosure ECMs were necessary to meet Step 5.

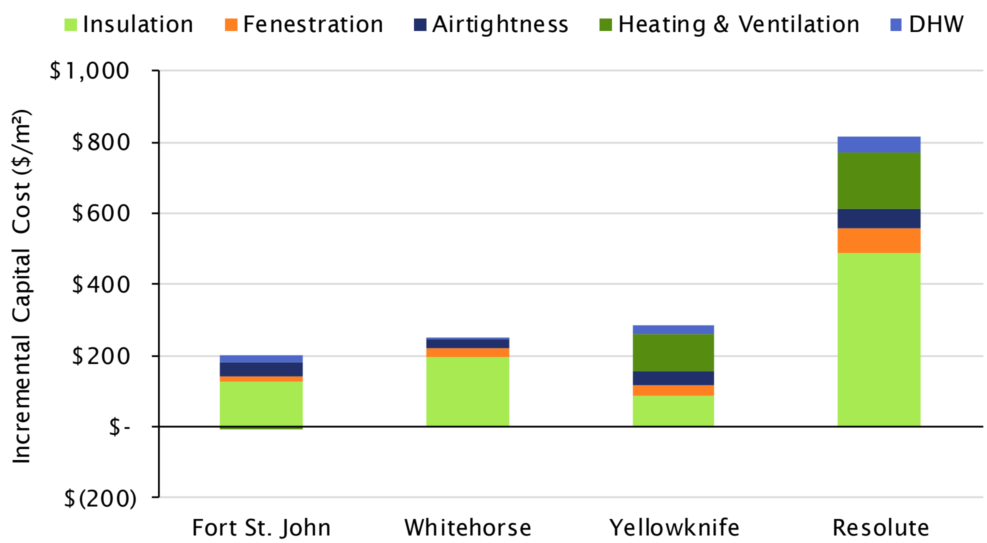


Figure 6.3 Incremental capital cost breakdown for the simple form SFD to reach the Step 5 (2018) energy targets in all four locations.

The ICC for the SFD archetypes is compared to the average total baseline cost of construction for SFDs in the Far North in Table 6.3. The relative ICC is presented as a percentage of the total construction cost to assess the relative cost increase of achieving the energy targets in each location.

The relative incremental cost for reaching the high performance targets as a fraction of total construction cost ranges from 4% to 23%. For the 25% < NBC target there is a smaller relative cost to reach the target in higher climate zones. For example, the incremental cost for the Fort St. John simple form SFD is 8% of the total construction cost, and for Resolute it is only 5%. This is because the higher ICC of reaching the performance target in northern locations does not exceed increased total construction costs in these locations. The relative incremental cost of Step 4 and Step 5 bundles increases in higher climate zones because these are absolute targets, which are generally more difficult and costly to achieve in colder locations.

Comparison between different form factors shows that building a simple form SFD can be up to 11% less costly than an articulated SFD (Step 4, Resolute). Starting with a simple design can be more cost-effective since fewer ECMs may be required to meet the targets. This also reduces the need for high performance mechanical equipment that may be less reliable in extreme cold climates. For example, the articulated SFD archetype required a ccASHP for space heating to meet Step 5 while the simple form SFD archetype did not.

TABLE 6.3 AVERAGE AND RELATIVE INCREMENTAL CAPITAL COSTS OF PERFORMANCE TARGETS FOR SFD ARCHETYPES

Target	Geometry	Location	ICC ($/m²)	Baseline Total Construction Cost ($/m²)[1]	Percentage of Total Cost
25% < NCB 2015	Articulated	Fort St. John	$193	$2227	9%
		Whitehorse	$397	$2580	15%
		Yellowknife	$288	$2927	10%
		Resolute	$376	$4734	8%
	Simple Form	Fort St. John	$187	$2227	8%
		Whitehorse	$199	$2580	8%
		Yellowknife	$159	$2927	5%
		Resolute	$238	$4734	5%
Step 4 (2018)	Articulated	Fort St. John	$95	$2227	4%
		Whitehorse	$423	$2580	16%
		Yellowknife	$381	$2927	13%
		Resolute	$974	$4734	21%
	Simple Form	Fort St. John	$92	$2227	4%
		Whitehorse	$157	$2580	6%
		Yellowknife	$133	$2927	5%
		Resolute	$454	$4734	10%
Step 5 (2018)	Articulated	Fort St. John	$201	$2227	9%
		Whitehorse	$523	$2580	20%
		Yellowknife	$467	$2927	16%
		Resolute	$1084	$4734	23%
		Fort St. John	$195	$2227	9%

TABLE 6.3 AVERAGE AND RELATIVE INCREMENTAL CAPITAL COSTS OF PERFORMANCE TARGETS FOR SFD ARCHETYPES

Target	Geometry	Location	ICC ($/m^2)	Baseline Total Construction Cost ($/m^2)[1]	Percentage of Total Cost
	Simple Form	Whitehorse	$244	$2580	9%
		Yellowknife	$276	$2927	9%
		Resolute	$790	$4734	17%
Highest Practical ECM	Articulated	Fort St. John	$1063	$2227	48%
		Whitehorse	$1384	$2580	54%
		Yellowknife	$1350	$2927	46%
		Resolute	$2192	$4734	46%
	Simple Form	Fort St. John	$1030	$2227	46%
		Whitehorse	$1155	$2580	45%
		Yellowknife	$1116	$2927	38%
		Resolute	$1941	$2227	9%

[1]Source: Altus Group Construction Cost Guide 2018, with additional data from past work with BTY

Since the BC Energy Step Code adapted its Part 9 targets in 2018 from the original 2017 Step Code, further analysis was conducted to asses the difference between these two sets of targets.

Figure 6.4 compares the ICC of achieving Steps 4 and 5 of the 2017 and 2018 Step Code targets. As expected, it is less costly to achieve the 2018 targets because they were relaxed for these upper climate zones and therefore fewer ECMs were needed to meet them. The Step 5 2017 targets could not be met for the articulated Yellowknife SFD and both the articulated and simple form Resolute SFD. However, the Step 5 2018 targets were achievable using the highest performing practical ECMs as defined in Section 2.3.

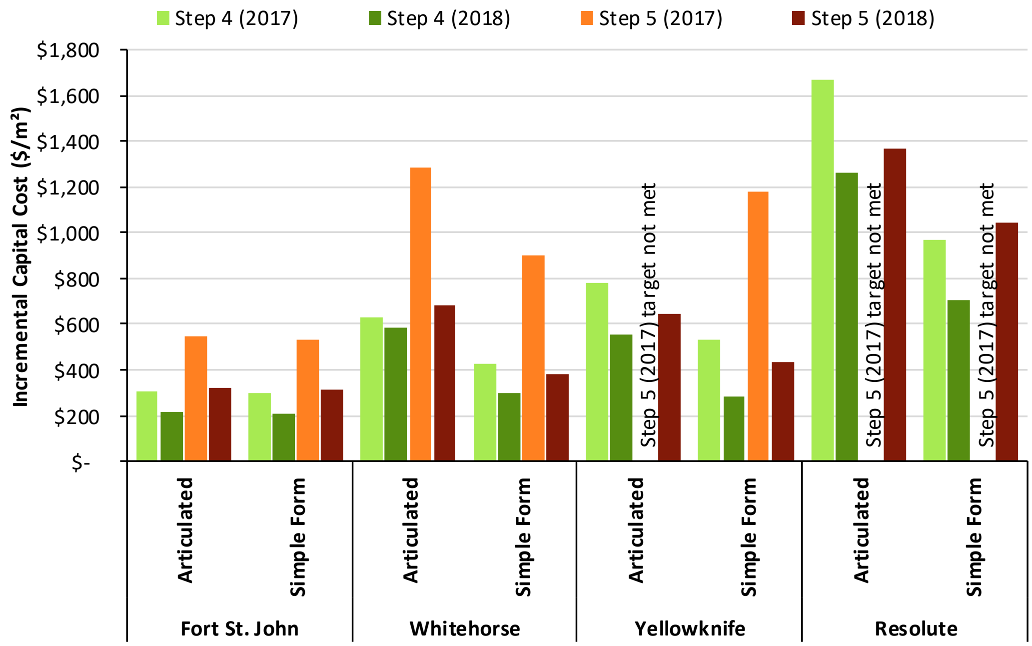


Figure 6.4 Comparison of incremental capital costs to achieve 2017 and 2018 Step Code targets for SFDs.

The relaxation to the Step Code targets from 2017 to 2018 not only enabled the SFD archetypes to meet Step 5 targets in all four locations, but also facilitated reaching the targets with fewer and more commonly available ECMs to northern communities. This led to lower ICC to meet Step 5 targets.

6.3.2 Incremental Costs for MURBs

Figure 6.5 presents the ICC for reaching the high performance targets for the two MURB archetypes. In scenarios where the targets could not be met using the highest performing practical ECMs for the north as defined in Section 2.3 this is noted on the graph. The results show that the 25% < NECB target can be achieved at an additional cost of less than $30/m² in all climate zones. The Fort St. John and Whitehorse costs show that the Step 4 target has a significantly higher ICC for the articulated MURB than for the simple form MURB. This indicates that capital construction costs of absolute targets may be more cost-effectively achieved with simple building design. As with the SFD archetypes, there are some cost savings for a reduction in mechanical heating equipment size from reduced heating demand, which balance out some of the additional enclosure and equipment performance costs. In contrast to the Step Code for Part 9 buildings, the 2017 Step Code targets were not updated for Part 3 buildings in 2018, and therefore there is only one version of Step 4 to analyze. The Step 4 targets are consistent for all climate zones, which is reflected in the increased construction costs to achieve the targets as heating demand goes up with higher HDD location.

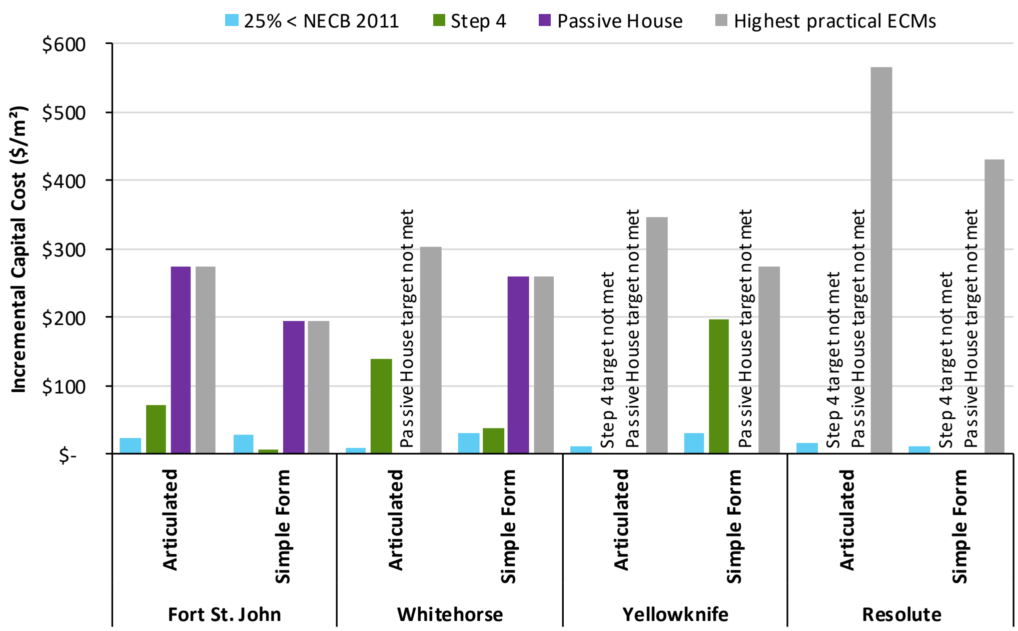


Figure 6.5 Incremental capital cost of high performance targets over baseline for articulated and simple form MURBs.

The Step 4 target could not be achieved in Yellowknife for the articulated archetype, nor in Resolute for both archetype form factors. The grey bar shows the cost of using the highest practical ECMs in all climate zones. Although these highest performance ECMs are the same for all locations, there is a higher cost in more northern and remote locations due to the higher costing factors. There is also a difference in the costs of these ECMs between the articulated and simple form buildings due to differences in wall and window area as well as different heating equipment sizes. Figure 6.6 show the comparison of incremental cost breakdown for the simple form and articulated MURBs meeting Step 4 in Whitehorse. They both experience a cost savings from reducing mechanical heating equipment sizing. The articulated MURB also shows significantly higher enclosure costs illustrating the difficulty in reaching the Step 4 TEDI target for this archetype.

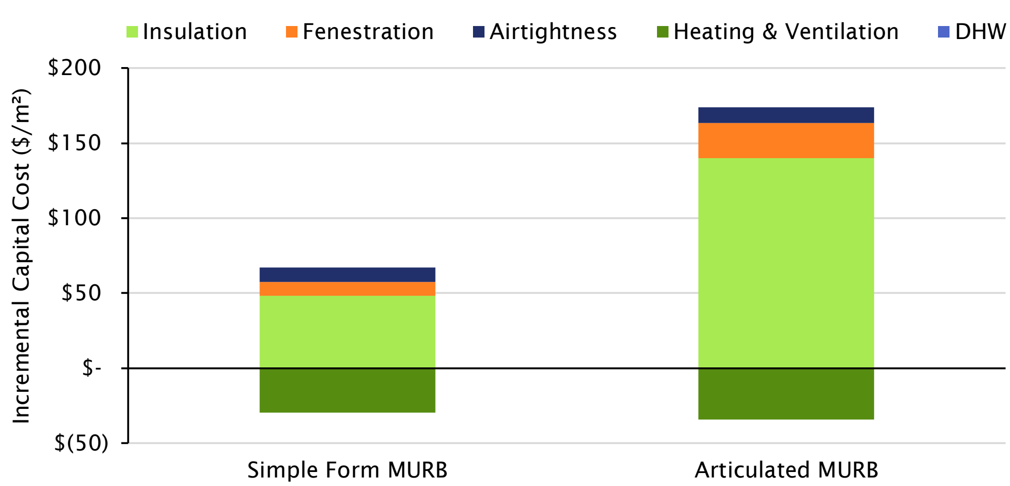


Figure 6.6 Comparison of incremental cost breakdowns for the two Part 3 archetypes to reach Step 4 targets in Whitehorse.

The Passive House compliance target was met in Fort St. John for both MURB archetypes and in Whitehorse for the simple form MURB. The bundle of ECMs that achieved Passive House is the same as the highest practical performance ECMs and therefore the costs are the same. Passive House was achieved at ICC between \$195-\$273/m², depending on the form factor and location.

To better understand the cost difference for reaching different targets, Figure 6.7 shows the ICC breakdown for the simple form MURB in Whitehorse. In this example, Step 4 shows a cost savings in the Heating & Ventilation cost category. This is due to the enclosure measures reducing the heating demand of the building and thus reducing the size of the mechanical equipment. Although there are extensive enclosure measures in the Passive House and highest practical ECMs bundles, there is still an incremental heating and ventilation cost due to implementing a high performance VRF system and cold climate HRVs.

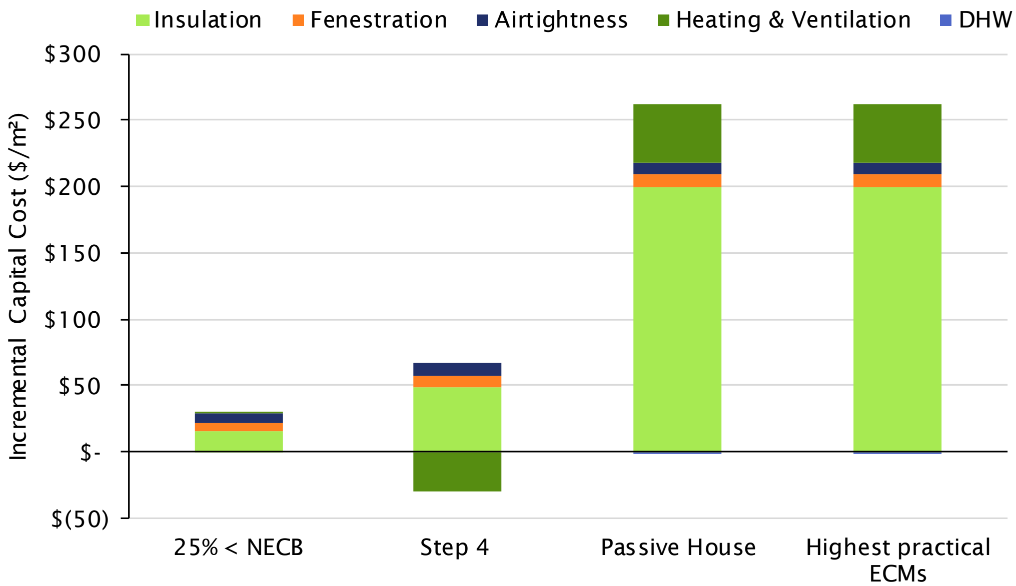


Figure 6.7 Incremental capital cost breakdown for the simple form MURB to reach the high performance energy targets (25% < NECB, Step 4, Passive House) as well as implementing the highest practical ECMs for the north in Whitehorse.

The ICC for the MURB archetypes are compared to baseline total construction cost in Table 6.4 to present the relative incremental costs for achieving these performance targets. The results show that the ICC of the 25% < NECB target is ~0-2% of total costs in all climate zones. This is consistent across locations partly because it is a relative target that depends on the baseline energy consumption. Further, Passive House compliance costs 10-14% of total construction costs where it was met. It is 4% less costly to meet Passive House for the simple form MURB versus the articulated form MURB in Fort St. John.

TABLE 6.4 INCREMENTAL CAPITAL COST OF HIGH PERFORMANCE TARGETS AS PERCENTAGE OF TOTAL CONSTRUCTION COSTS FOR MURBS					
Target	**Geometry**	**Location**	**ICC ($/m²)**	**Total Construction Cost ($/m²)**[1]	**Percentage of Total Cost**
25% < NECB 2011	Articulated	Fort St. John	$23	$1887	1%
		Whitehorse	$8	$2186	~0%
		Yellowknife	$11	$3110	~0%
		Resolute	$15	$5030	~0%
	Simple Form	Fort St. John	$29	$1887	2%
		Whitehorse	$29	$2186	1%
		Yellowknife	$29	$3110	1%
		Resolute	$12	$5030	~0%
Step 4	Articulated	Fort St. John	$71	$1887	4%
		Whitehorse	$140	$2186	6%
		Yellowknife	Target not met		
		Resolute	Target not met		
	Simple Form	Fort St. John	$7	$1887	~0%
		Whitehorse	$37	$2186	2%
		Yellowknife	$196	$3110	6%
		Resolute	Target not met		
Passive House	Articulated	Fort St. John	$273	$1887	14%
		Whitehorse	Target not met		
		Yellowknife	Target not met		
		Resolute	Target not met		
	Simple Form	Fort St. John	$195	$1887	10%
		Whitehorse	$260	$2186	12%
		Yellowknife	Target not met		
		Resolute	Target not met		
Max ECM	Articulated	Fort St. John	$273	$1887	14%
		Whitehorse	$303	$2186	14%
		Yellowknife	$347	$3110	11%
		Resolute	$565	$5030	11%
	Simple Form	Fort St. John	$195	$1887	10%
		Whitehorse	$260	$2186	12%
		Yellowknife	$274	$3110	9%
		Resolute	$432	$5030	9%

[1]Source: Altus Group Construction Cost Guide 2018, with additional data from past work with BTY.

Overall, the MURB archetypes can meet Step Code and Passive House targets more cost-effectively than the SFD archetypes. Further comparison of the archetypes is provided in Section 6.3.4.

6.3.3 Incremental Costs for the 5-Plex

The incremental capital costs for the 5-Plex are presented in Figure 6.8. The results show that it is less costly to achieve the absolute Step Code targets than the relative target of 25% < NBC in Fort St. John and Whitehorse, though the opposite is true for the two, colder climate zone 8 locations (Yellowknife and Resolute). The ICC to achieve Step 4 ranges from $126/m² to $304/m² depending on the location. The ICC to achieve Step 5 ranges from $210/m² to $414/m² depending on the location and strategy for meeting Step 5 targets.

Resolute has the highest ICC to achieve the Step Code targets because of the high costing factor for its remote location, and higher HDD than Yellowknife despite being in the same climate zone, so more ECMs were required to meet the same climate zone 8 Step Code targets.

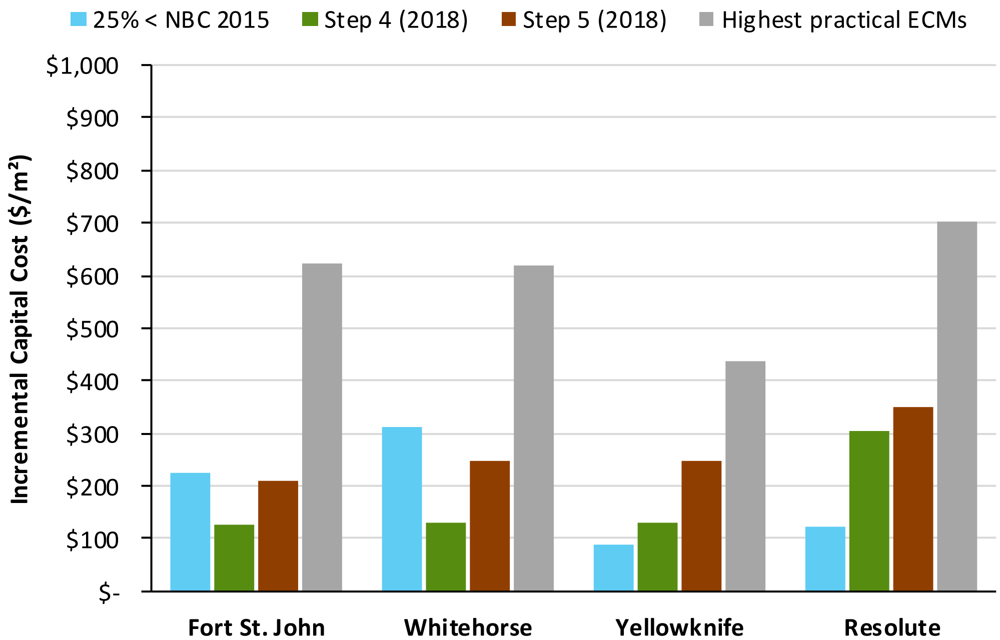


Figure 6.8 Incremental capital cost of high performance targets over baseline for the 5-Plex archetype.

The relative ICC for the SFD archetypes are shown in Table 6.5, compared to the baseline total construction cost in each location. The relative incremental cost of the high performance targets ranges from 3% to 26% of the baseline total construction cost, depending on the target and the location.

The relative cost does not show a consistent trend moving to higher climate zones for the 25% < NCB 2015 target. Since this is a relative target, the costs are relative to the baseline code requirements and upgrade strategies may be different for each climate zone. For example, one key difference is that the two climate zone 8 5-Plex baselines use fuel oil heating systems, while Fort St. John and Whitehorse have electric heating systems.

TABLE 6.5 INCREMENTAL CAPITAL COST OF HIGH PERFORMANCE TARGETS AS PERCENTAGE OF TOTAL CONSTRUCTION COSTS FOR 5-PLEXES				
Target	**Location**	**ICC ($/m²)**	**Total Construction Cost ($/m²)[1]**	**Percentage of Total Cost**
25% < NBC 2015	Fort St. John	$225	$2413	9%
	Whitehorse	$313	$2795	11%
	Yellowknife	$86	$2332	4%
	Resolute	$122	$3773	3%
Step 4 (2018)	Fort St. John	$126	$2413	5%
	Whitehorse	$128	$2795	5%
	Yellowknife	$130	$2332	6%
	Resolute	$304	$3773	8%
Step 5 (2018)	Fort St. John	$210	$2413	9%
	Whitehorse	$248	$2795	9%
	Yellowknife	$249	$2332	11%
	Resolute (Bundle One)	$348	$3773	9%
	Resolute (Bundle Two)	$414	$3773	11%
Highest practical ECMs	Fort St. John	$622	$2413	26%
	Whitehorse	$618	$2795	22%
	Yellowknife	$436	$2332	19%
	Resolute	$703	$3773	19%

[1]Source: Altus Group Construction Cost Guide 2018, with additional data from past work with BTY

As with the SFD, since the BC Energy Step Code adapted its Part 9 targets from the original code in 2017 to the updated code in 2018, further analysis was conducted to asses the difference between these two sets of targets for the 5-Plex archetype.

Figure 6.9 compares the ICC of achieving Steps 4 and 5 of the 2017 and 2018 Step Code targets for the 5-Plex. As expected, it is less costly to achieve the 2018 targets because they are were relaxed for these upper climate zones and therefore fewer ECMs were needed to meet them. The Step 5 2017 targets could not be met for the 5-Plex in Resolute, yet the Step 5 2018 targets could be met in all locations for this 5-Plex archetype.

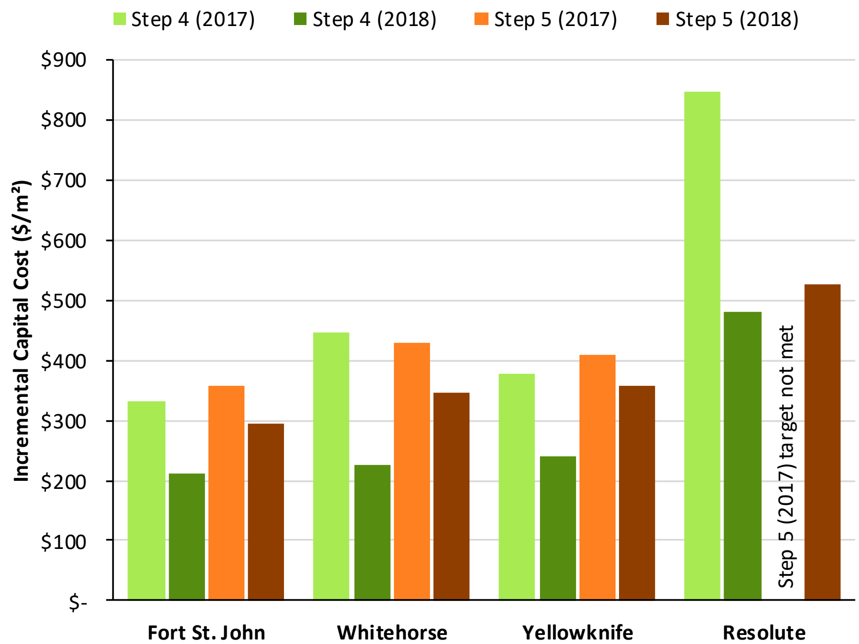


Figure 6.9 Comparison of incremental capital costs to achieve 2017 and 2018 Step Code targets for the 5-Plex archetype.

In contrast to the Step Code comparison for the SFD, the 5-Plex analysis shows more similar ICC for Step 5 2018 and Step 5 2017. This is because of slightly different approaches taken to meet the performance targets. For the 2018 targets, less insulation was used and a ccASHP was implemented for space heating. Since the 2017 TEDI target was far more stringent, significantly more insulation and other measures for heating demand reduction were implemented to meet the TEDI target, which results in not needing a COP over 1.0 to meet the MEUI target. These different approaches to meeting targets show that there are many different ways that performance targets could be met, and the ICC is sensitive to the approach.

To further explore the different approaches that may be taken to meet performance targets, a comparison of two different pathways to meet Step 5 2018 were considered for the 5-Plex archetype in Resolute. Bundle One used near-maximum enclosure measures, whereas Bundle Two implemented a heat pump for DHW and relaxed the enclosure measures. A comparison of the breakdown of costs for these two scenarios is shown in Figure 7.5. The insulation costs are lower when a heat pump is used, although the mechanical equipment for both space heating and DHW have higher costs as a result. The overall cost of the bundles to meet the Step 5 2018 targets are $348/m² for the enclosure-focussed approach and $414/m² for the mechanical-focussed approach (i.e. with the DHW heat pump). This illustrates that designing with an enclosure-first approach is more cost-effective for reaching high performance energy targets in the north.

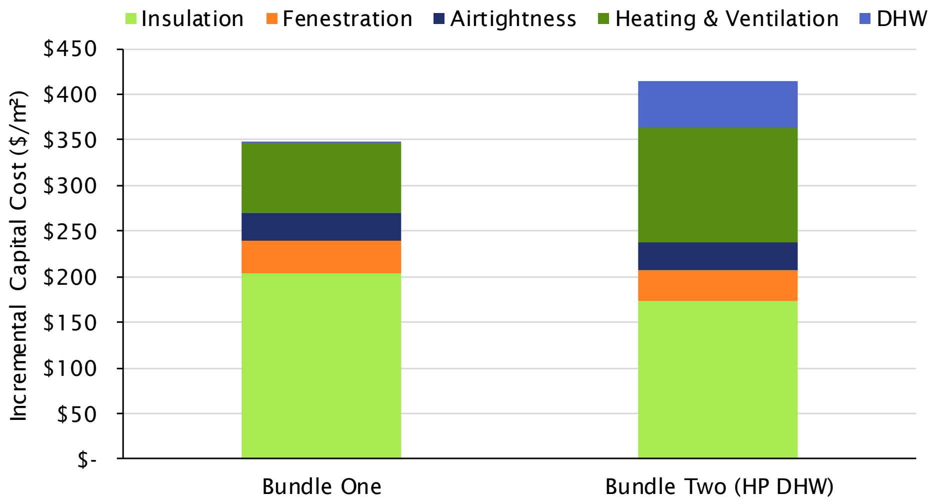


Figure 6.10 Breakdown of incremental capital costs for two different approaches to achieve Step 5 (2018) for the 5-Plex archetype in Resolute.

6.3.4 Costing Comparison of Archetypes

Incremental capital costs for the MURB archetype to reach the high performance targets (Step Code and Passive House) are smaller than for the SFD archetypes (when the targets are achievable). The difference in cost is on average 4.5 times higher for the SFD archetypes than for the MURB archetypes to meet the highest Step Code level of either building type.

There are several reasons for this difference in cost. First, the baseline (NECB) archetype for the MURB has higher performance requirements, particularly higher R-value assemblies. Second, multi-unit buildings experience higher internal heat gains than SFDs from increased occupant density and have relatively less heat losses because they have a smaller ratio of enclosure area to volume. Third, the Part 3 targets and Part 9 targets are slightly different. For a more consistent comparison, the Passive House targets may be considered. Passive House targets could only be met for the MURB archetypes, not the SFDs or the 5-Plex. This is an indication that high performance absolute energy targets are more achievable, and thus more cost-effective, for the MURB archetypes.

The ICCs for the 5-Plex archetype are generally less than the SFD archetype (though still higher than the MURB). Similar to the MURB archetype, the 5-Plex experiences higher internal heat gains from higher density and has a lower enclosure area to volume ratio than the SFD. Figure 6.11 illustrates the different incremental costs and cost breakdowns for all five archetypes to reach the highest Step Code targets in Whitehorse.

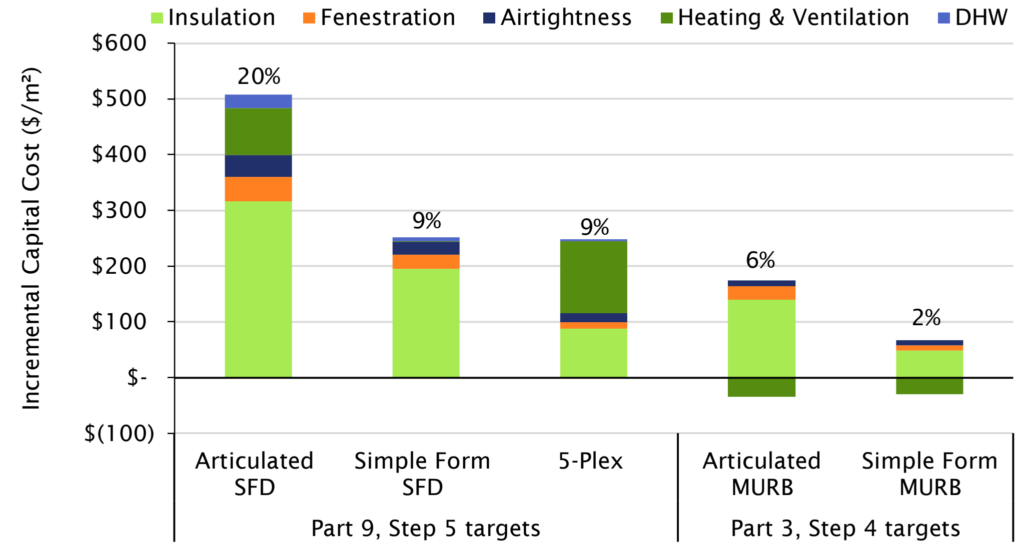


Figure 6.11 Comparison of incremental costs for the three Part 9 archetypes and the two Part 3 archetypes to reach their respective highest Step Code targets in Whitehorse. The relative incremental cost compared to baseline construction costs is denoted as a percentage (%) above each bar.

The ICCs for the MURB archetypes are lower than for the SFDs and the 5-Plex and the baseline construction cost for each building type is similar ($1,900 to $5,000 per m^2 for the MURB versus $2,200 to $4,700 per m^2 for the SFD, depending on location). For this reason, the relative cost (%) to achieve high performance targets in the Far North are also smaller for the MURB relative to its total baseline construction cost.

6.4 Key Costing Takeaways

→ There is a notable difference in ICC between simple form and articulated SFDs and MURBs, indicating that form factor is important for reaching high performance targets most cost-effectively.

→ Improved enclosure measures allow downsizing the heating system, which can result in a mechanical equipment cost savings and balances out the ICC of the enclosure measures.

→ 25% < code minimum cost is more consistent across climate zones compared to the absolute targets of the Step Code, illustrating the regional challenges in meeting absolute targets.

→ In some scenarios (typically in Fort St. John and Whitehorse), achieving Step 4 has a lesser ICC than the 25% better than code target, partly because of the economic impact of improved enclosure measures decreasing mechanical equipment sizing.

→ Step 5 could be met at a 9% cost increase over baseline construction costs for the simple form SFD in Fort St. John, Whitehorse, and Resolute. On the other hand, the articulated SFD met the Step 5 targets at a 23% cost premium due to higher heating demand. In contrast, the MURB experienced lower incremental cost to meet the Step 4 targets (highest step for Part 3 buildings), 1% to 7%, though the targets could not be met in all Far North locations (i.e. not in Resolute).

- → Passive House targets could not be met for all archetypes using the specified ECMs in this study, indicating that Passive House may not be cost-effective for all archetypes in all northern locations. Where Passive House targets were met for the MURB (Fort St. John and Whitehorse), the relative cost increase was between 11-15% of baseline construction costs. Form factor also plays a role in the cost-effectiveness of reaching Passive House—it is 4% less costly to meet Passive House for the simple form MURB versus the articulated form MURB in Fort St. John.
- → It is more cost effective to achieve absolute energy performance targets for the MURB archetype than for the SFD or 5-Plex. Larger internal heat gains, smaller surface area to volume ratio, and a higher performance baseline result in lower incremental costs to achieve Step Code and Passive House performance targets for the MURB.

7 Challenges and Solutions

The remoteness and harsh climate of Canada's Far North create several challenges with reaching high levels of energy efficiency and the prospect of Passive House, net zero, or near-net zero levels of energy performance. These current northern challenges are in part what led the analysis to use the highest performance practical ECMs as stated in Section 2.3 instead of systems that may not be currently practical for the Far North.

This section describes both technical and non-technical barriers to high performance construction in the north, as well as potential solutions for overcoming these barriers. This discussion will lead to recommendations for how to make additional ECMs more practical for application in the north. This may help northern buildings reach near-net zero energy targets in locations that did not meet targets in the Compliance Modelling section of this report.

7.1 Technical Barriers

Technical barriers to high performance construction in the north are mainly rooted in the facts that most construction materials and systems are designed for more moderate climates and that the cold northern climate creates the need for better performing technology than is currently available. For these two reasons, reaching near-net zero energy targets in the north has been challenging. This sub-section describes specific issues with building design, cold-climate mechanical systems and cold-climate enclosures.

7.1.1 Housing Types, Architectural Design & Form Factor

Throughout this report, energy performance results have been presented for two-storey single family homes with simple and articulated form factors, a single storey multi-unit rowhouse, and three-storey MURBs with simple and articulated form factors. These three housing archetypes, along with single storey single family home archetypes (not explored within this report) make up the majority of the residential housing stock in Northern Canada. Taller mid- to high-rise residential buildings are absent in most northern communities outside of Whitehorse and Yellowknife. It is therefore likely that the archetypes modelled and analyzed in this report will continue to be built for the foreseeable future as they have been found by experience to be simple and cost effective to construct in the North. That being said, there may be opportunities when considering multi-family archetypes in remote communities to develop a new type of housing which better suits the needs of northern residents (more workspace, more food prep, larger families) and also enhance energy efficiency by compactness of the building enclosure and form factor. A simple examples of increased building enclosure articulation for the same interior floor area is shown for a two-storey house within Figure 7.1.

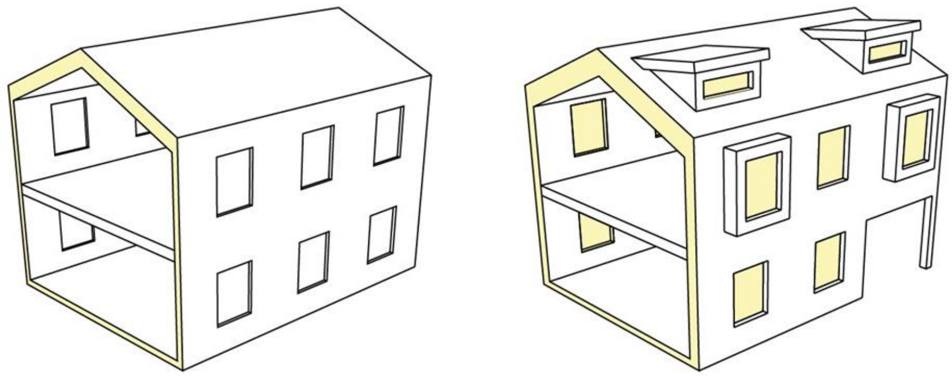


Figure 7.1 *Example 2-storey house design showing low versus higher levels of building enclosure articulation. Dormer windows, bay windows, additional corners, overhanging floors, inset garages and non rectangular shapes etc. increase the surface area of a building and therefore increase the amount of heating demand.*

The modelling presented here has consistently shown a clear link between reduced heating demand within more compact, less articulated building forms. The thermal energy demand savings just from adjusting the level of building enclosure articulation for the same usable interior space is profound, though can be overlooked in design. Figure 7.2 demonstrates how important this design concept is to energy efficiency in the North, especially in regions as cold as Resolute, where shown here the heating demand almost doubles when the form factor of the same size of building changes from 2.5 to 3.5, a range plausible factors for the design of a residential building. The form factor was decreased by adding an additional floor to the simple form SFD with the highest practical ECMs. For example, a two-storey simple form SFD has a form factor of 3.3 and a three storey simple form SFD has a form factor of 2.9.

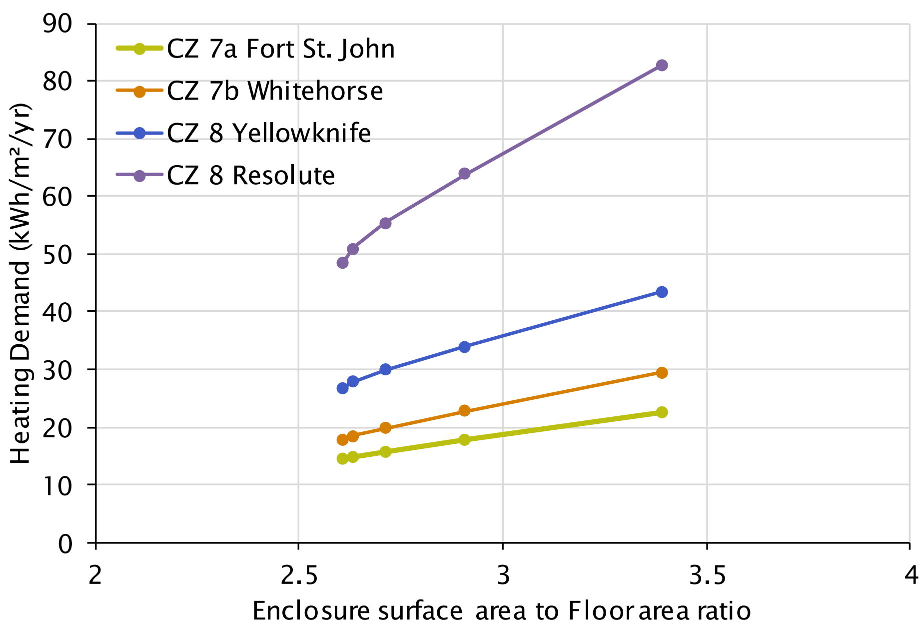


Figure 7.2 *Heating Demand versus Enclosure Surface Area to Floor Area Ratios for Northern Communities showing large impact of small changes in building enclosure compactness. The form factor for the simple form model with highest practical ECMs was modified by adding additional floors to the building. For example, a two storey simple*

form building had a form factor of 3.2 and a three storey simple form SFD building had a form of 2.9.

For form factor and architectural design in the north:

→ Form factor is a critical energy efficient design consideration. The ideal northern archetype for energy efficiency may need to be reconsidered to optimize this.

7.1.2 Design Optimization of Window to Wall Ratios

Windows have a much lower thermal performance as compared to walls in the range of R-3 to R-6 for double to triple glazing versus R-20 to R-40+ for code minimum to higher performing wood-frame walls, and as a result, the ratio of window area to wall area (i.e. window to wall ratio) has a significant impact on heating demand in residential buildings. Even taking into account the solar heat gain benefits through the sun-facing glazing to offset the heat loss, windows are most often a net loss of thermal energy instead of a gain unless carefully balanced as often the goal in passive house designs. While the selection of available very high performance windows is covered in the following selection and remains a barrier to very high performance buildings in the north, window to wall ratio is a design parameter that should be considered carefully in the design of Northern Homes. The unique challenge of the far north being that there will be weeks to months of darkness factored into this optimization.

An analysis was performed using the simple SFD housing archetype in the four Northern cities with the only variant being the window to wall ratio of a high performance triple glazed window (U-0.12, USI-0.69) with a high R-value wall assembly (R_{eff}-80) over a range of typical SFD window to wall ratios. The results are presented in Figure 7.3. Each dot represents an addition of a 1.93m x 1.5m window on the specific façade as indicated. For example, the increase in window to wall ratio on the left side of the graph is as a result of adding windows to the south façade. The general trend is that increasing window to wall ratio on the south side reduces heating demand in this archetype. However, in latitudes as far north as Resolute where very little solar radiation is available in the winter months, a house with no windows would be optimal from an energy efficiency standpoint, though not practical.

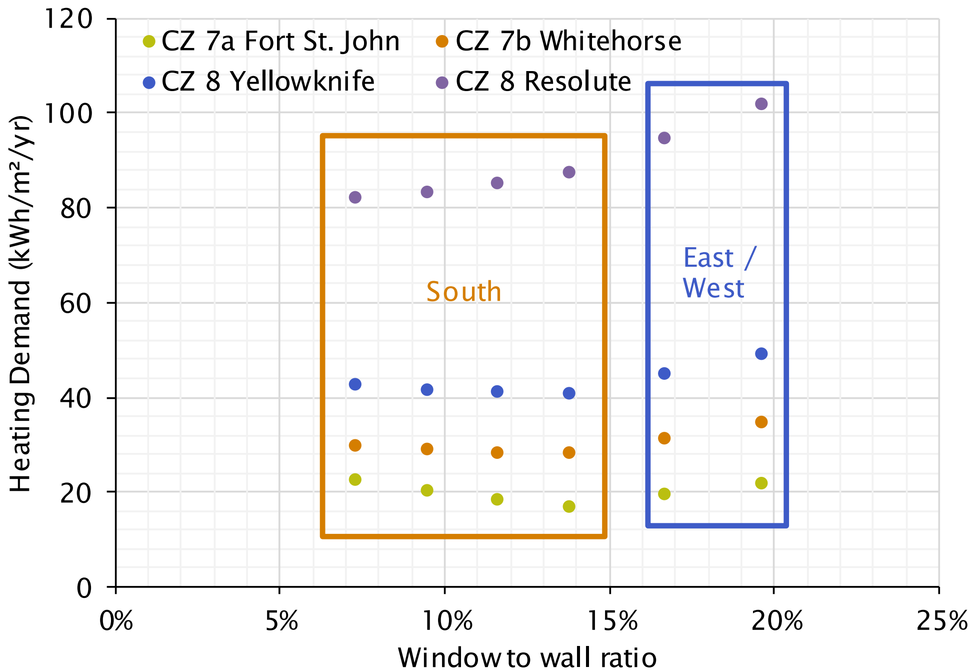


Figure 7.3 *Heating Demand versus window to wall ratio for the simple form SFD in Yellowknife. Each dot represents an addition of a 1.5m x 1.9m window to the façade as indicated on the graph.*

For window design in the north:

→ Low window to wall ratios are favourable, though for every building there will be an optimal window to wall ratio based on the selected window and wall, house orientation, and available solar radiation. Energy modelling can be used to assess the most optimal design.

7.1.3 Window Selection and Availability of Products

Figure 7.4 shows the window performance that was used to comply with the performance targets of the Compliance Modelling analysis. The code-minimum U-value is representative of the requirements in either NBC 2015 (for Part 9) or NECB 2011 (for Part 3). The 25% better than code and Step Code performance targets required better window products than the code-minimum options. The graph and table below show when double glazing is upgraded to triple and quadruple glazing products to meet the targets.

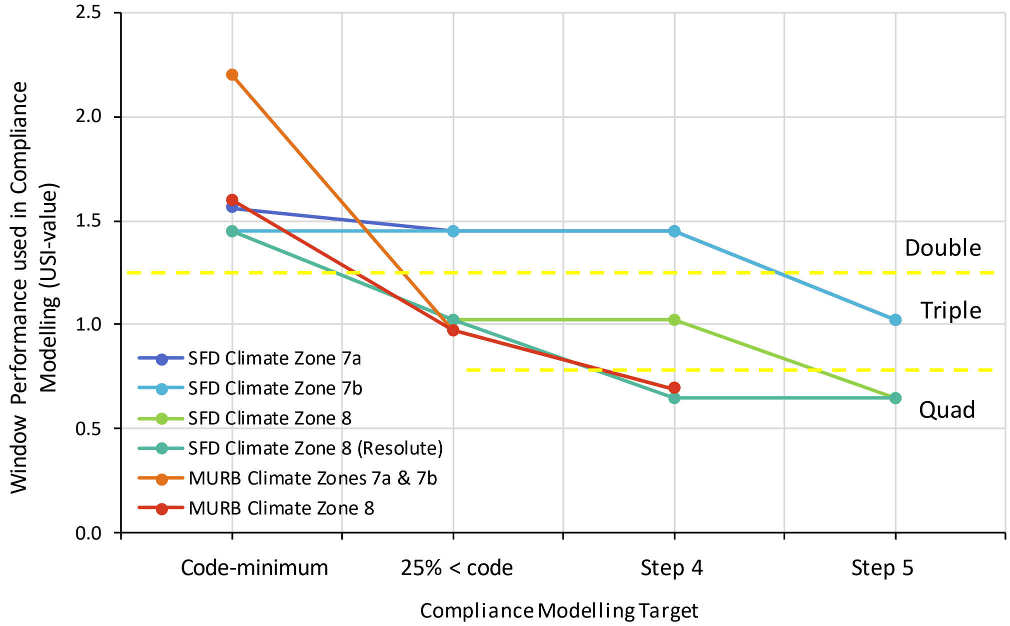


Figure 7.4 Window performance (U-value shown as W/m²K) modelled in the compliance modelling work to meet high performance targets for the simple form SFD and the MURB archetypes.

TABLE 7.1 WINDOW PERFORMANCE USED IN COMPLIANCE MODELLING ANALYSIS, IN USI-VALUE W/M²K

	Simple Form SFD Archetype				MURB Archetypes	
	Climate Zone 7a	Climate Zone 7b	Climate Zone 8	Climate Zone 8 (Resolute)	Climate Zones 7a & 7b	Climate Zone 8
NBC 2015	1.56	1.45	1.45	1.45	2.2	1.6
25% < NBC	1.45	1.45	1.02	1.02	0.97	0.97
Step 4	1.45	1.45	1.02	0.65	0.69	0.69
Step 5	1.02	1.02	0.65	0.65		

Double glazed
Triple glazed
Quadruple glazed

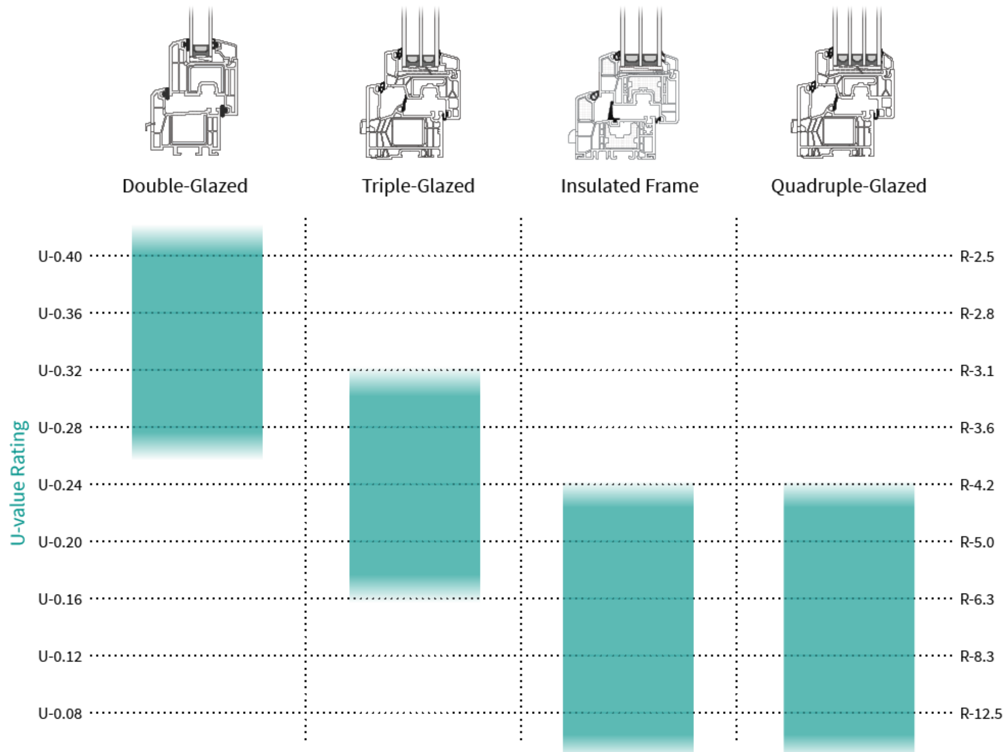


Figure 7.5 Performance range of window types, in R-value and U-value (IP Units).

Although triple and quad glazing may be required to meet these high performance targets in the north, there are limited products available with very low U-values. Very low U-value windows that are either Passive House certified, or quadruple glazed typically need to be shipped from Europe or other regions. Due to the lack of local products for such high performance, there are logistical challenges with retaining replacement parts when needed. Spare components may be stored nearby, which increases capital costs due to ordering extra parts at the time of construction, or parts may need to be special ordered and take a long time to arrive for replacement. In remote northern regions, not having adequate replacement parts is a security risk for public safety since a damaged window during temperatures below -40 ˚C may be physically unsafe and also put the home at risk of vandalism or theft. This issue is exacerbated by the fact that broken windows are more common in some remote northern communities due to higher rates of domestic violence and vandalism.[47]

Figure 7.6 shows the heating demand trend with window thermal performance for the simple form SFD with the non-window highest performing practical ECMs. The window performance plotted is the overall window performance which includes frame and glazing. The general trend is that the colder the climate, the more impact higher performing windows will have on the building as indicated in the steepness of the lines. Optimum window performance will depend on the specific climate as well as project specific design attributes such as window orientation and configuration.

[47] Discussions at Polar Forum, Yellowknife NT. May 1st, 2018.

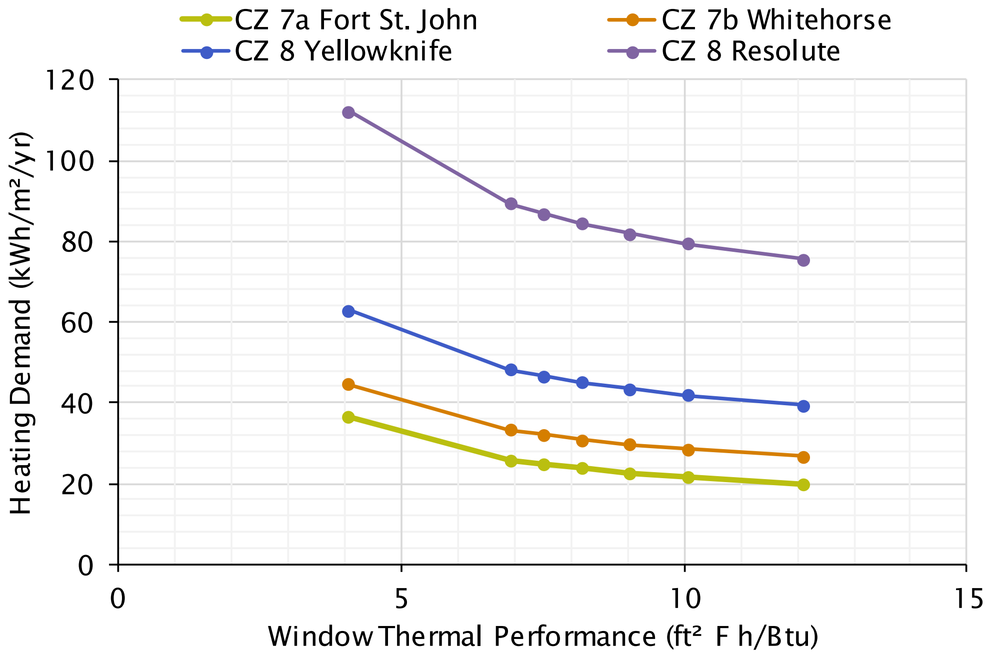


Figure 7.6 Heating demand vs Window thermal performance for the simple form SFD for all four climate zones. It illustrates that much higher performing windows will be required to reach stringent energy targets.

For window selection in the north:

→ Window products with very low U-values (ideally below U-0.12 (USI-0.69), above R-8) achieved by quad pane glazing within insulated high performance window frames have a market within residential buildings in the North. Currently there are very few products available in Canada and elsewhere in the world to fill this need. While triple glazed products (U-0.17 to U-0.14) provide good performance, there are benefits to upgrading to higher thermally performing windows in order to appreciably reduce heating demand.

7.1.4 Depreciating Returns of Opaque Enclosure Insulation

Higher levels of insulation within walls, roofs, and floors are beneficial to reducing heating demand up until a point. After this point, additional insulation provides diminished returns in energy savings due to heat loss through other pathways including windows and air leakage or ventilation.

Figure 7.7 illustrates the effects of increasing the thermal performance of the opaque assemblies for the SFD simple form model for all four climate zones. To create each line, the thermal performance of a specific building assembly was modified. For example, for the CZ 7a Fort St. John Walls line, the thermal performance of just the walls were modified while the other elements remained at the maximum recommended ECM. This provides a sensitivity analysis for the effect of increasing enclosure thermal performance on heating demand. The reduction in heating demand levels off beyond R_{eff}-80, indicating that a threshold is reached where further wall improvements do not have as large of a benefit for reducing energy consumption in the north (unless other measures are also improved).

The general trend is that regardless of which building assembly, there comes a point where increasing the thermal performance no longer yields any significant reductions to heating demand and only results in added cost and difficulty in construction.

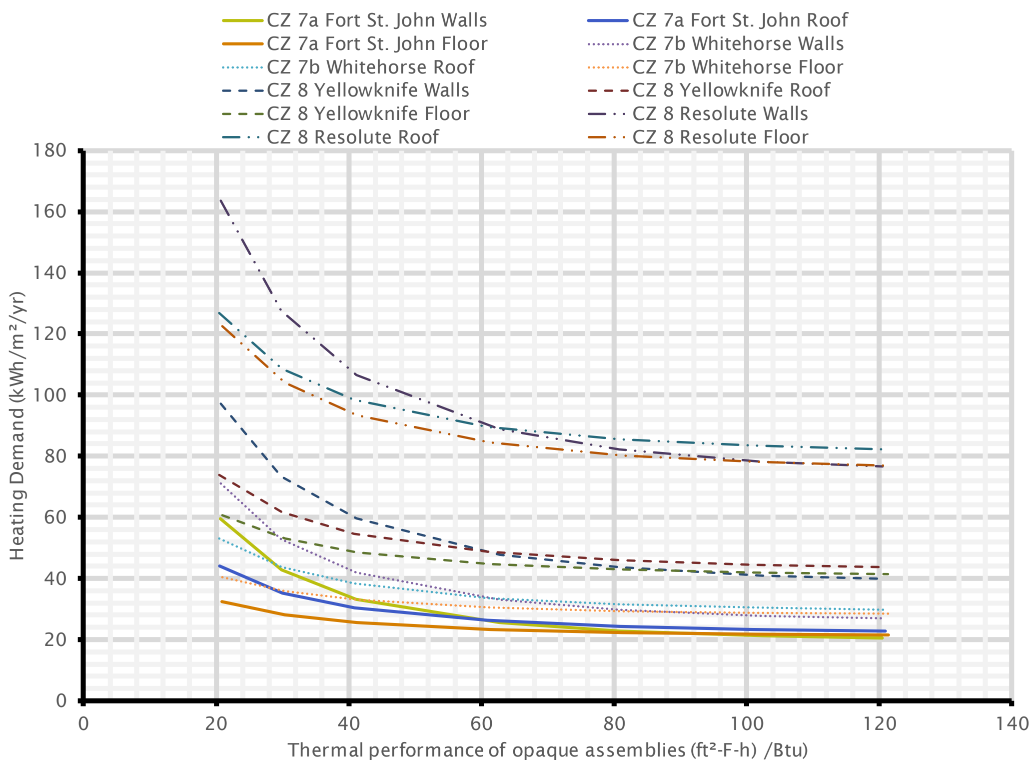


Figure 7.7 Heating demand vs thermal performance (effective) of opaque assemblies for the simple form SFD for all four climate zones.

Figure 7.9 shows heating demand versus thermal performance of overall enclosure for the simple form SFD. The trend shows that heating demand can be reduced if the performance of the enclosure is increased together. However, diminishing returns are still present, albeit at much higher R-values (R_{eff}-80/R-90 rather than R_{eff}-50).

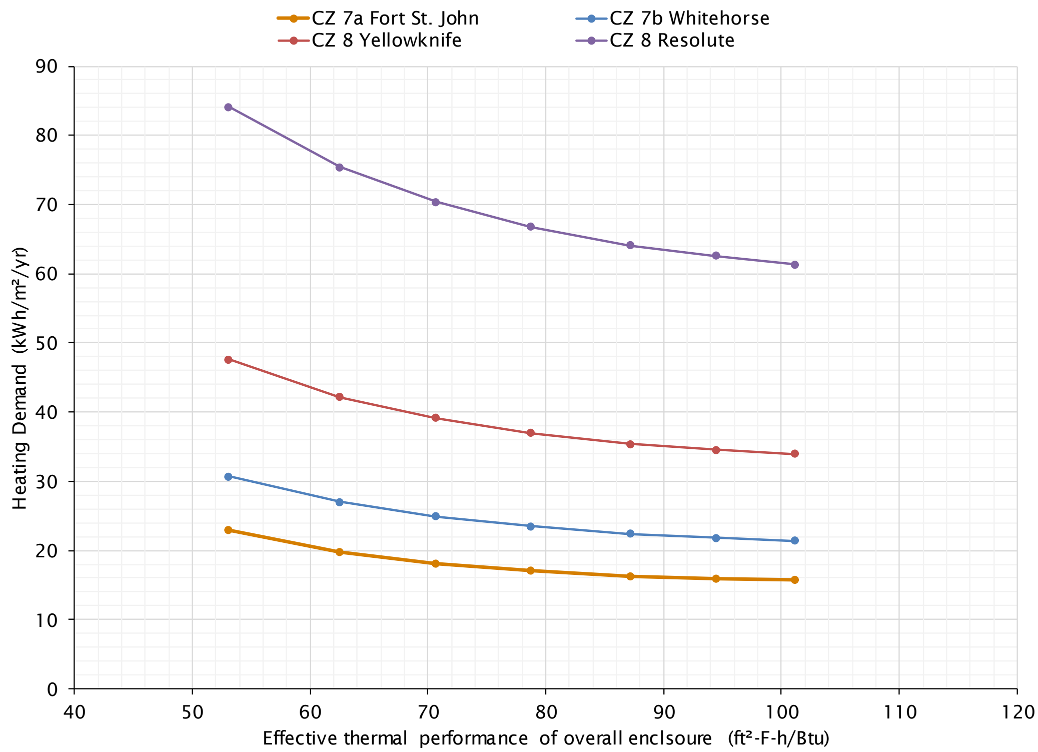


Figure 7.8 Heating demand versus thermal performance of overall enclosure. This was modelled by increasing the thermal performance of walls, roofs and floors together.

For insulation and effective R-values in the north:

→ There are depreciating returns for increasing the effective R-value of opaque enclosure elements beyond R-80. To meet high performance targets, other parts of the building such as airtightness, window performance, and efficient HVAC systems should be considered.

7.1.5 Airtightness Training & Air Barrier Strategies

Airtightness is key for reaching high performance targets. Figure 7.9 shows that there is a linear trend in heating demand with air leakage rate, indicating the importance of whole building airtightness for reducing energy consumption in the north. A difference in air leakage between 3.5 ACH to 0.6 ACH can yield upwards of savings in 20 kWh/m²/yr in heating demand. The example shown below is for the simple form SFD archetype in Yellowknife. Is was assumed that no other building elements changes through the analysis of different ACH values.

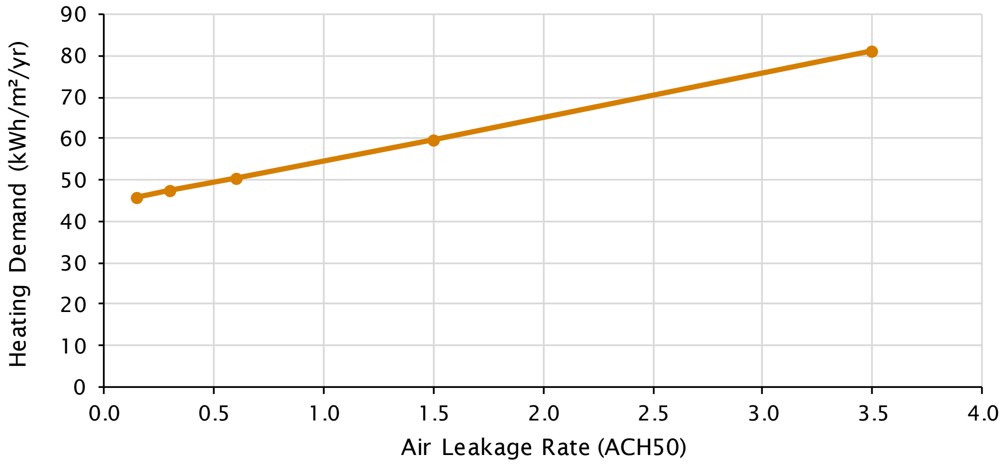


Figure 7.9 Sensitivity analysis for reducing airtightness for the simple form SFD with the highest practical ECMs.

Feedback from the building industry in Whitehorse and Yellowknife suggests that builders consistently achieve higher airtightness levels than in many other parts of Canada, suggesting that the importance of airtightness in terms of energy consumption, thermal comfort, and building enclosure durability is understood and training the workforce to be able to build airtight homes is already well underway. According to a building inspector in Yellowknife, the majority of the tested SFDs have ACHs of less than 2.0 whereas the ACH of newly built SFDs in BC averages at 5.5 ACH50. The City of Whitehorse already has a requirement to reach 1.5 ACH50 for new construction.

In more remote regions there may not be trained personnel to build airtight air barrier systems during construction or to perform airtightness testing. This may be a barrier to achieving high performance buildings in remote communities, though it may be overcome by expanding training initiatives and facilitating transportation (e.g. by the northern housing corporations) between settlements for the trained personnel.

Air barrier systems in the Far North are usually either one of the two following conventional types: exterior air barrier systems, with the primary airtight elements placed at the exterior side of the enclosure, and interior air barrier systems, with the primary airtight elements installed at the interior side of the enclosure. Especially in Whitehorse builders have successfully used the Polyethylene interior air barrier approach with ACH as low as 0.5, though an exterior air barrier between the sheathing and exterior insulation is generally more durable since it is protected from punctures and penetrations through the interior drywall with a framed service cavity. The air barrier design should account for mechanical forces created by wind and stack effect pressures caused by temperature differences and allow for dimensional changes in the structure caused by thermal expansion. A combination of fasteners, tapes, sealants, strapping, exterior insulation, or fully adhered products may by used to achieve this requirement. Due to the extreme cold, many products suitable in the south are not suitable for use in the north limiting suitable products.

7.1.6 Cold-Climate Mechanical Systems

Cold Climate Air Source Heat Pump (ccASHP)

Air Source Heat Pump (ASHP) technology has improved in the last few years, adding inverter driven compressors and improving refrigerants. Those upgrades are making the systems better suited for cold-climate heating. Inverter driven compressors allow the compressor speed to modulate and to increase capacity during periods of colder outdoor air temperatures. However, energy efficiency stakeholders and energy modellers lack confidence that the existing heating performance metrics (HSPF and COP) for air-source heat pumps provide the necessary information to adequately characterize and model heating performance across the heating season and particularly at low temperatures. The supplemental information provided by manufacturers to demonstrate cold temperature performance is not standardized or consistent. These deficiencies are causing the performance not being accurately reflected for the latest generation of cold-climate air-source heat pumps.

The industry is currently developing Cold Climate Air Source Heat Pump (ccASHP) specifications to better characterize heat pump performance. However, energy modelling software—in particular HOT2000—need to be updated with algorithms that allow modelling ccASHP systems more accurately. HOT2000 has limited heat pump inputs, suggesting inadequate low temperature algorithms for heat pump systems. When comparing HOT2000's calculated system COP and heat pump COP with published performance data from a Canadian heat pump manufacture as shown in Figure 7.10, it is evident that they are very different. This limits the benefits of modelling and using ccASHP in the Far North.

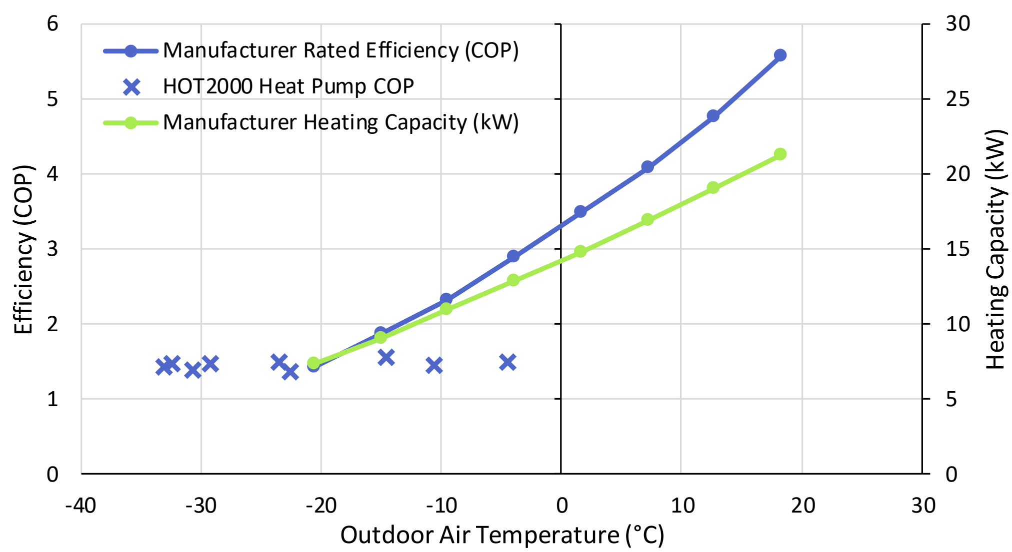


Figure 7.10 Comparing HOT2000's calculated heat pump COP (blue X's) with published performance data from a Canadian heat pump manufacture using the articulated SFD archetype for Resolute at Step 5.

Heat Recovery Ventilation System

Due to the extreme cold outdoor air temperatures in the Far North, heat recovery ventilation is integral for low energy buildings. Figure 7.11 shows a comparison of three different high performance HRV units. The 81% efficient unit (left) represents the dual core system that was used as a highest performing practical ECM for the compliance modelling, which does not require preheat even at very low temperatures as it switches between the two heat recovery cores. The 95% efficient unit (middle) represents a theoretical HRV that would need further research and product development for the north. All current 95% efficient products on the market would need preheat in the north (right), which results in higher energy consumption than the 81% efficient dual-core unit. The preheat adds over 20 kWh/m²/yr to the PER for the simple form SFD in Yellowknife calculated in PHPP. Requiring pre-heat energy of over 20 kWh/m²/yr when the maximum total heating energy allowable for Passive House certification is 15 kWh/m²/yr highlights a fundament hurdle that must be addressed.

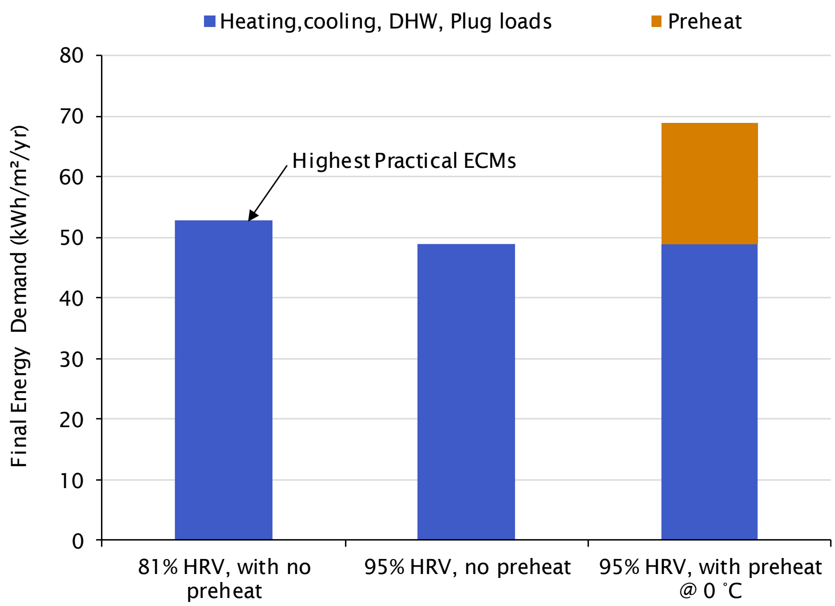


Figure 7.11 Comparison of different high performance HRV options. The 81% efficient dual core unit was used as the highest performing practical ventilation ECM per Section 2.3 instead of a 95% efficient HRV due to the additional preheat[48] energy that would be required in the north (shown in orange for SFD in Yellowknife).

An alternate to using preheat when it is required at very low temperatures is to run defrost cycles that recirculate indoor air until the HRV core temperature is brought back up from freezing. Defrost cycles are not ideal in the north due to indoor air quality issues from not bringing in adequate outdoor air for ventilation. Homes in the north are typically higher occupancy density and this increases the relative humidity and risk for condensation and mould growth on interior surfaces and within the enclosure. The defrost cycle would recirculate air for several hours each day during time of cold outdoor air temperatures when people are more likely to all be at home, which would exacerbate the risks related to poor indoor air quality.

Electricity vs. Fuel Oil

Although electric heating and DHW systems are common in the northwest of Canada's north (Yukon Territory), propane is still common in the mid-north (Northwest Territories)

[48] Preheat energy is the energy required to prevent ice build up at the outdoor air intake of the HRV unit, therefore this heat does not get captured in the heating demand, rather it is added in the overall energy use of the building.

and fuel oil is common in the northeast (Northwest Territories and Nunavut). Pellet heaters are also used throughout remote northern regions. The use of any of these combustion systems for heating and DHW rather than electricity make it more difficult to meet site energy performance energy targets due to lower equipment efficiency. The PER metric in Passive House compliance considers the potential for renewable energy generation, though not specifically source to site conversion factors for energy sources. As such, even the PER metric is more impacted by site equipment efficiency than grid energy fuel source since the PHI-approved fuel factors do not directly reflect the efficiency of the grid network in northern Canada. Figure 7.12 shows the PER results from modelling the high performance SFD using PHPP with electric heating (ccASHP) and DHW versus fuel oil boilers. This demonstrates the challenge of reaching absolute energy targets with fossil fuel systems since their equipment efficiency is worse than electric systems.

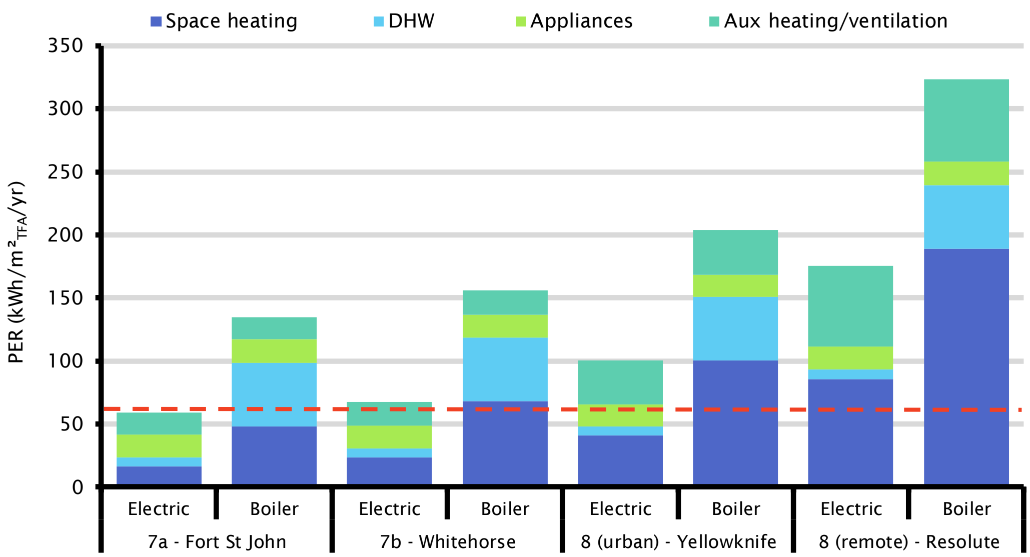


Figure 7.12 PER from modelling the simple form SFD with both electric (COPs ≥ 1.0) and fuel oil (93% efficient) systems.

The challenge with using high efficiency electric systems in the north is two-fold: (1) the COPs of ccASHPs become lower as the outdoor air temperature drops, so the effective equipment efficiency becomes worse in colder climates, though still better than fossil fuel combustion systems; (2) many remote regions do not have access to clean electrical grid with sufficient capacity. Electrical grids in remote northern communities are generally based on fossil fuel combustion plants with high primary energy factors. Because of this, using electricity for all equipment does not always make sense in remote northern regions since the overall energy demand in the region would be higher. This would also put strain on the existing grid network, which may have limited capacity and reliability due to dependence on fuel shipments.

Since the Step Code metrics used for the compliance modelling are based on site energy, not source energy conversion factors, the all-electric systems in the modelling work offer a "best-case" scenario. Also, the PER metric in Passive House is more impacted by equipment efficiency than source energy. If fossil fuel systems were used, then the site energy consumption metrics (and PER) would be higher due to lower equipment efficiency and the absolute performance targets would have been even more challenging to meet.

Although it may not be possible to meet all the absolute performance targets using fossil fuel systems, there are still benefits for reducing energy consumption as much as possible, even if targets are not met. Key benefits for northern communities include being less reliant of fuel shipments and reducing operating costs.

Domestic utility rates are approximately 10x higher in the north than the south, $1.12/kWh in Kugaaruk[49], compared to the mid-peak rate of $0.09/kWh for Ottawa. The cost of utilities in Northwest Territory new multifamily housing is an estimated $1,400 per month per unit in Fort Liard for all utilities and $3,600 per month in Aklavik.[50] Theoretically, if Step 4 energy targets are met and approximately 50% energy savings is achieved (based on the MURB energy modelling in this study), housing corporations and homeowners could save between $8,400 - $21,600 annually per unit (based on the estimates from Northwest Territories Housing Corporation). Given this rough estimate, adopting stringent absolute energy performance targets such as the Step Code could result in a 1-3 year simple payback due to high utility costs.

7.1.7 Cost Barriers

The costing analysis in Section 6 illustrates that it is not cost-effective to reach the upper Step Code targets or Passive House in climate zone 8. As discussed previously, the heating demand in northern locations makes it challenging to meet high performance energy targets. This is especially true for buildings with a relatively large amount of surface area (compared to volume) for heat to be lost across, such as single-family homes or highly articulated buildings. One factor that drives up costs is the need for cold-climate equipment, of which there is limited options and is generally costlier. A lack of resource availability including labour and transportation options also drives up costs, which is discussed further in the following section.

Costs may be reduced if northern housing archetypes transition to be more multifamily buildings with simple form, rather than small single-family buildings. The development and testing of cold-climate high performance mechanical equipment will also help reduce costs as more products become available and less redundancy is required for public safety (e.g. back-up systems for heat pumps).

7.2 Non-Technical Barriers

Non-technical barriers to high performance construction in the north are mainly rooted in the remoteness of northern Canada. Key issues are logistical challenges and resource availability in the Far North.

7.2.1 Logistical Challenges

There are several logistical challenges with constructing high performance buildings in the north, including transportation challenges noted in the Literature Review portion of this study (Section 3).

[49] Qulliq Energy Corporation website, < https://www.qec.nu.ca/>, [accessed March 15, 2019].
[50] Discussions with Northwest Territories Housing Corporation in 2018.

Figure 7.13 Logistics map of Canada, depicting the typical transport routes.[51]

Another challenge is the limited access to electrical grids with sufficient capacity and reliability. All-electric systems in the modelling work offer a "best-case" scenario as discussed previously. If fossil fuel systems are used, then the site energy consumption used for code compliance would be higher due to lower equipment efficiency.

7.2.2 Resource availability

Due to the remoteness of many northern settlements, resources that may be common at lower latitudes are scarce at times. Key non-technical challenges include the availability of resources such as trained labour and renewable energy.

Trained labour is especially important for reaching high performance targets since many of the ECMs required are new and not common yet in the north. Training on mechanical systems (e.g. HRVs, heat pumps, VRF systems), construction (e.g. enclosure detailing, air barrier, airtightness testing), and for building inspectors & housing managers will be key. After construction, training contractors for maintenance and repairs on these new systems will also be important.

[51] RDH Building Science Inc. (2016): Illustrated Guide for Northern Housing Retrofit prepared for Natural Resources Canada and the Canada Mortgage and Housing Corporation.

7.2.3 Applicability of Modelling Assumptions to the North

There are several differences in building operation in northern communities compared to the standard assumptions used in code-compliance modelled. A key example of this is that occupancy rates are generally much higher in the north due to a lack of adequate housing and cultural differences in community living arrangements.

An increase in the occupancy assumption increases the base loads that are input to PHPP on a per person basis, which increases internal gains and helps to reduce heating demand yet also increases base load energy consumption. A similar result would be seen in HOT2000 though PHPP is used for this analysis to reflect high performance building modelling. Although higher occupancy rates are common in northern Canada, the standard occupancy assumptions must be used for code-compliance. As such, Figure 7.14 and Figure 7.15 show a comparison of double occupancy (orange) and standard occupancy (blue) used in a bundle of all the highest performance ECMs from the sensitivity analyses in this section.

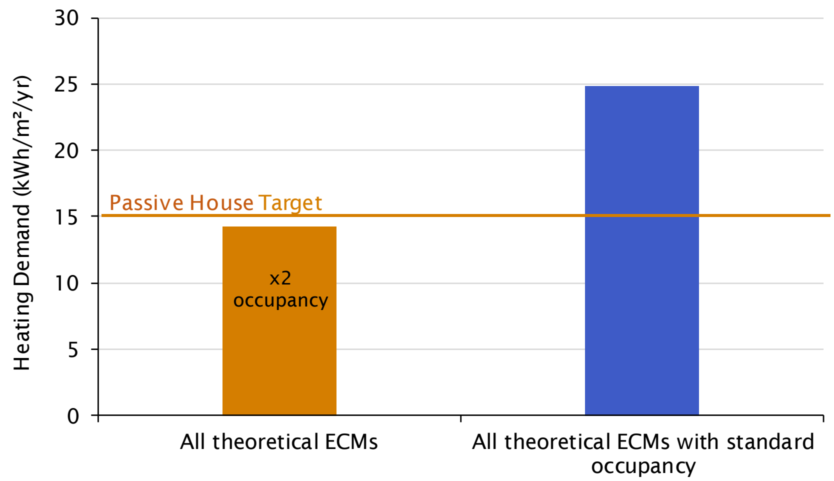


Figure 7.14 Heating Demand for the SFD in Yellowknife using the theoretical ECMs beyond the highest performing practical ECMs as outlined in Section 2.3, using double the standard occupancy rate (orange) vs with standard occupancy (blue).

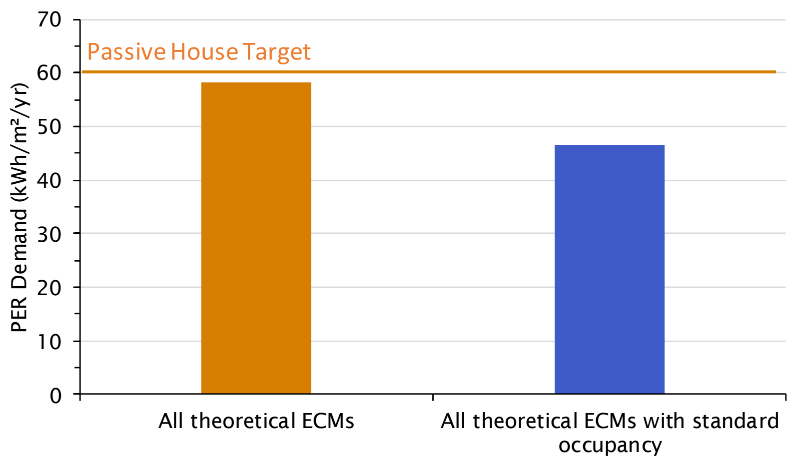


Figure 7.15 PER for the SFD in Yellowknife using the theoretical ECMs beyond the highest performing practical ECMs as outlined in Section 2.3, using double the standard occupancy rate (orange) vs with standard occupancy (blue).

The above figures, as well as Figure 7.16, show that there is a trade off between reducing heating demand and increasing base loads when occupancy assumptions are increased. This analysis is shown for the simple for SFD archetype in Yellowknife (1,800 ft²).

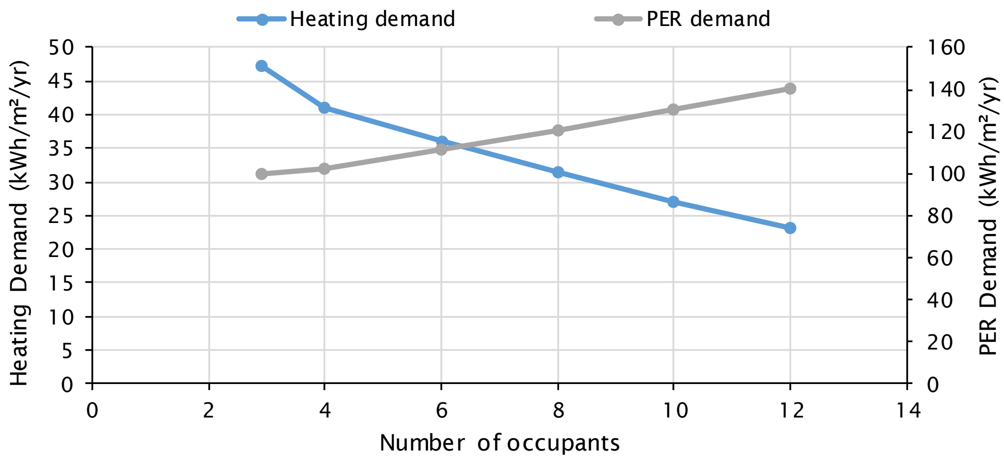


Figure 7.16 Sensitivity analysis for occupancy for the SFD in Yellowknife. The PER increases with increased occupancy, while the heating demand decreases.

It is not recommended to alter the occupancy assumptions for code-compliance modelling, though this analysis demonstrates how targets may need to be adjusted for northern buildings to reflect the difference between modelled versus actual energy performance.

7.3 Recommendations to Overcome Barriers

There are three key pathways to achieving high performance targets in the north and bringing down the high incremental costs.

→ Developing new technology that is designed for northern climates

→ Adapt existing energy performance targets to reflect the challenges in northern locations

→ Develop logistical solutions for transportation and training

7.3.1 Technology Development

Although technology improvements may help reach high performance targets in the north, it is important to target the ECMs with the biggest impact on energy (i.e. per the sensitivity analysis in Section 7.1).

Additional analysis was performed to assess the impact of different ECMs that may be implemented for northern construction with additional technology development and changes to construction practices. These higher ECMs were chosen partly based on research by Sonia Zouari for Parks Canada.[52] An increase in occupancy assumption is also shown in this analysis to reflect common practice in the north, though standard occupancy for code compliance is shown below for comparison. Figure 7.17 and Figure 7.18 show that if all these future 'theoretical' ECMs are implemented then Passive House targets can be met by the simple form SFD in Yellowknife.

[52] Zouari, S. (2018): Passive House Feasibility in Extreme Cold Climate; Parks Canada, Research and Development.

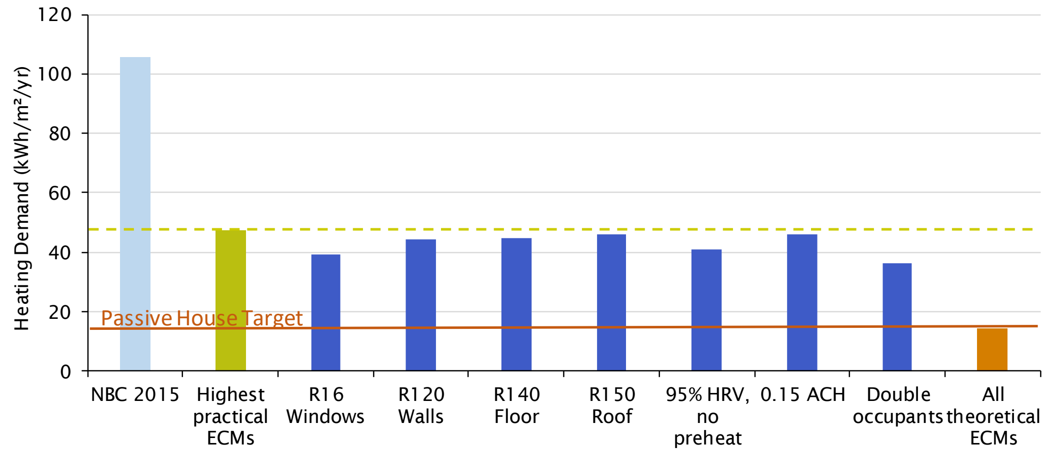


Figure 7.17 Heating Demand of the simple form SFD archetype modelled in PHPP for ECMs beyond the highest performance practical ECMs used in the Compliance Modelling section, in Yellowknife. NBC 2015 baseline TEDI is shown for comparison (light blue), modelled in HOT2000.

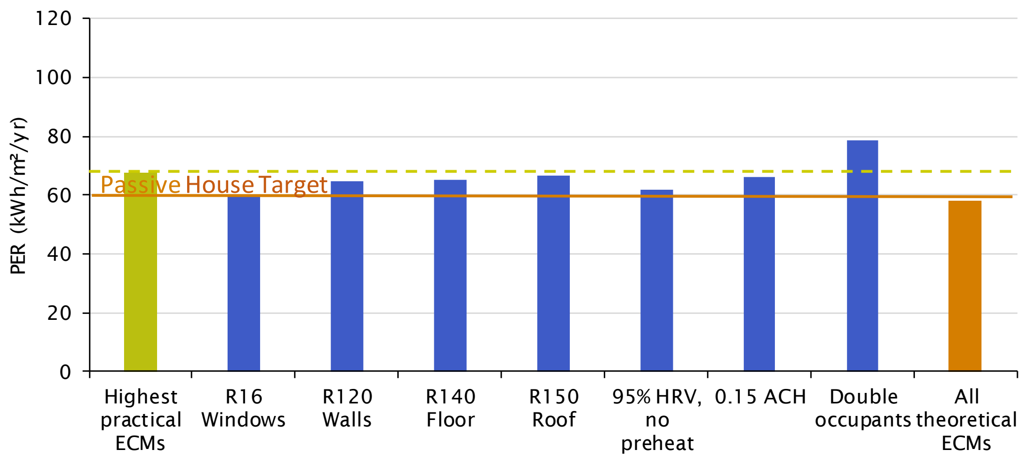


Figure 7.18 PER of the simple form SFD archetype modelled in PHPP for ECMs beyond the highest performance practical ECMs used in the Compliance Modelling section, in Yellowknife.

Based on this analysis, technology development should be focused on better windows and 95% HRV without need for preheat. Methods and materials to achieve near perfect airtightness are needed. It should be noted, however, that even with future technology development it may not be cost-effective to reach these targets with SFD or 5-Plex archetypes in climate zone 8. Larger, simple form, multifamily archetypes should be considered to help meet near-net zero energy targets more cost-effectively.

7.3.2 Adaptations to Targets

Other programs discussed in Section 3.3 have adapted performance-based targets for northern climates. The BC Energy Step Code is a good example of this since it was assessed in the modelling and costing analysis of this study.

Options include the PHIUS+ approach, which bases targets on climate as well as form factor, occupancy assumptions, and energy costs. Though, without including the total building source energy requirement, the performance constraint based on a variable building form factor is less limiting.

Using a correlation for the TEDI metric with HDD may be a fair approach for northern locations. This would help distinguish locations within climate zone 8 in Canada, which are currently lumped together with one group of targets. Figure 7.19 shows that there are seven groups of 1,000 within the climate zone 8 HDD range in northern Canada; targets could be developed for each of these 1,000 HDD groups as they are for the other climate zones in Canada. The Literature Review showed that jurisdictions in Scandinavia have taken this approach by further dividing countries into smaller counties with different heating demand requirements for code compliance.

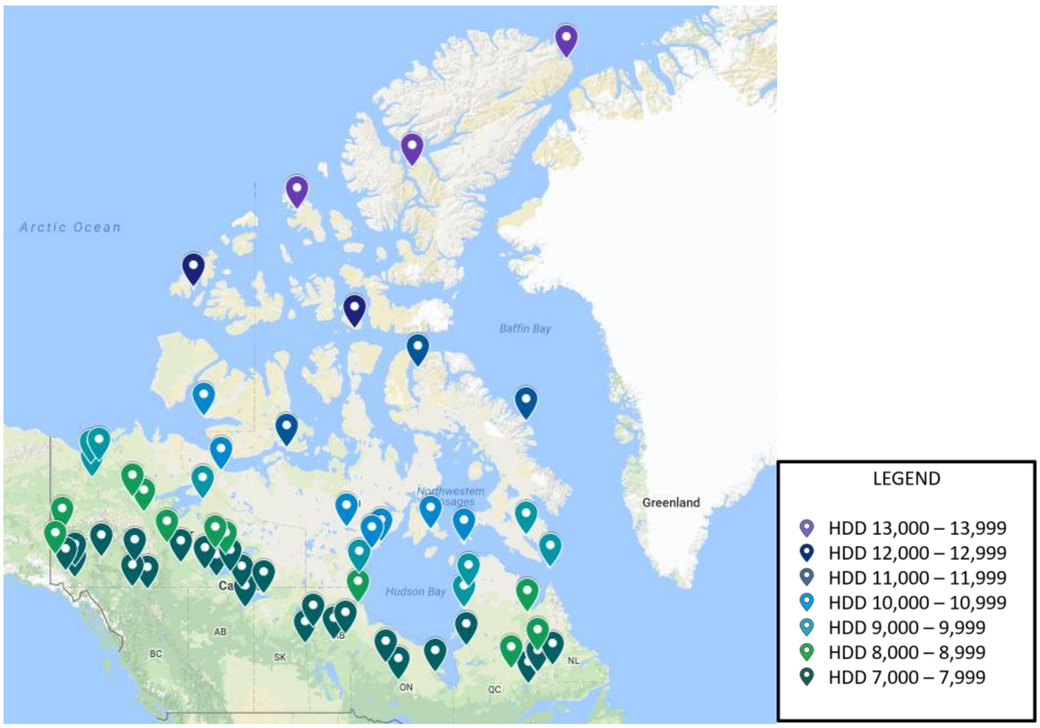


Figure 7.19 Map showing bands of 1,000 HDD for climate zone 8, showing how wide the range of HDD is within this one climate zone.

8 Conclusions

This study assessed the feasibility of achieving Passive House and near-net zero levels of energy performance for residential buildings (Steps 4 & 5 of the BC Energy Step Code) within Canada's challenging northern climate including the Far North (climate zones 7a to 8). To do this, five northern archetypes were developed: articulated SFD, simple form SFD, articulated MURB, simple form MURB, and a 5-Plex. These archetypes were modelled in four northern locations: Fort St. John (climate zone 7a), Whitehorse (climate zone 7b), Yellowknife (climate zone 8), and Resolute (climate zone 8).

This study also compared modelling tools including HOT2000 and EnergyPlus™ versus the Passive House Planning Package (PHPP). The incremental capital costs of reaching the high performance targets were estimated and northern-specific barriers to meeting the targets were assessed.

The key takeaways from this research are provided below.

8.1 Key Takeaways

8.1.1 Literature Review

→ A review of case studies of high performance construction in northern regions revealed that all projects focused on reducing heating demand by using measures such as airtightness, triple or quad glazed windows, insulation with minimal thermal bridging, heat recovery with considerations for frost protection, and efficient mechanical systems (e.g. electric baseboards, cold climate air source heat pumps)

→ Other jurisdictions have acknowledged the difficulty in reaching near-net zero energy targets in extreme northern climates and have modified energy targets to reflect differences in locations and heating needs (e.g. PHIUS, BC Energy Step Code, jurisdictions in Scandinavia)

8.1.2 Modelling Tool Comparison

→ While it is possible to bring modelling results in PHPP closer to other code compliance tools (e.g. EnergyPlus, HOT2000), considerable differences still exist and the methods to align them are non-trivial. Some of these differences are routed in core differences of the calculation algorithms for the different tools.

→ Instead of allowing the use of both PHPP and other code compliance tools (e.g. EnergyPlus, HOT2000) to calculate absolute energy performance metrics, another approach may be to base the code targets on the most common path (e.g. EnergyPlus, HOT2000) and allow an optional compliance path for the most stringent target based on certification with that standard (e.g. Passive House compliance using PHPP).

8.1.3 Compliance Modelling

→ In general, the articulated version of the SFD and MURB archetypes showed higher baseline energy performance than the simple form versions. This required further ECMs to reach the absolute energy performance targets, though in some cases fewer ECMs were required to meet the 25% better than code relative target.

- → The 25% better than code relative target may be a stepping stone to higher performance targets, though it does not encourage overall high performance design. In the climate zone 7a and 7b locations, the BC Energy Step Code Step 4 target (for Part 9 buildings) results in similar energy savings and also encourage better design.
- → The updated to the BC Energy Step Code (as of December 2018) result in easier compliance than for the original version (2017), though due to the range in locations and heating demand for locations within climate zone 8, there remain challenges with reaching the targets in the Far North.
- → To reach high performance targets, it is key to focus on the use of high performance windows (triples or quads), heat recovery ventilation (with considerations for preheat), optimizing the form of the building and its insulation, and using high efficiency electric systems when possible (since the compliance targets are based on site energy). Airtightness is also very important, especially reaching Passive House 0.6 ACH50 or lower.

8.1.4 Challenges and Solutions

- → Form factor is a critical design consideration when combining energy efficiency and cost effectiveness. More compact larger housing types (i.e. MURBs) are more efficient than SFDs for the same floor area. Achieving near-net zero or Passive House levels of thermal performance may only be feasible in compact larger multi-family housing types.
- → Low window to wall ratios are favourable, though for every building there will be an optimal window to wall ratio based on the selected window and wall, house orientation, and available solar radiation. Energy modeling can be used to assess the most optimal design.
- → Although using high efficiency electrical systems is ideal for reducing site energy consumption, not all northern communities have access to a clean electrical grid with adequate capacity. This is a barrier that may need to be overcome if absolute targets are set, or targets could be relaxed in regions with no reliable electrical grid.
- → Based on the sensitivity analysis of higher ECMs, technology development should be focused on better windows and 95% HRVs without need for preheat. Testing materials such as self-adhered membranes and tapes for air barrier systems in the north should also be considered, and training for achieving good airtightness and performing airtightness testing.

8.1.5 Incremental Costs

- → There is a notable difference in ICC between simple form and articulated SFDs and MURBs, indicating that form factor is important for reaching high performance targets most cost-effectively.
- → Improved enclosure measures allow downsizing the heating system, which can result in a mechanical equipment cost savings and balances out the ICC of the enclosure measures.
- → 25% < code minimum cost is more consistent across climate zones compared to the absolute targets of the Step Code, illustrating the regional challenges in meeting

absolute targets. Though higher energy savings are achieved with the absolute targets. In several scenarios, achieving Step 4 has a lesser ICC than the 25% better than code target and achieves greater energy savings.

→ Passive House targets could only be met for the MURB archetypes, not the SFDs or the 5-Plex. Even the MURBs could only meet the Passive House targets in Fort St. John and in Whitehorse (only the simplified form MURB in Whitehorse). Where Passive House targets were met for the MURB, the relative cost increase was between 11-15% of baseline construction costs. It is 4% less costly to meet Passive House for the simple form MURB versus the articulated form MURB in Fort St. John.

→ The incremental costs to meet Step 5 targets (for Part 9 buildings) range significantly depending on the archetype form factor and location. Step 5 could be met at a 9% cost increase over baseline construction costs for the simple form SFD in Fort St. John, Whitehorse, and Resolute. On the other hand, the articulated SFD met the Step 5 targets at a 23% cost premium. In contrast, the MURB experienced lower incremental cost to meet the Step 4 targets (highest step for Part 3 buildings), 1% to 7%, though the targets could not be met in all Far North locations (i.e. not in Resolute).

→ In general, it is more cost effective to achieve absolute energy performance targets for the MURB archetype than for the SFD or 5-Plex. Larger internal heat gains, smaller surface area to volume ratio, and a higher performance baseline result in lower incremental costs to achieve Step Code and Passive House performance targets for the MURB.

→ The high incremental costs to reach Step 5 and the inability to meet Passive House for SFDs in the Far North reflect that it may be unreasonable to continue using these single-family archetypes if high performance energy targets are used in the north. There are real challenges with meeting heating demand targets and a lack of cold-climate technology to cost-effectively meet Step 5 or Passive House with single family buildings in the north. A shift to other archetypes such as simple form MURBs and the development and testing of more cold-climate systems may be necessary if near-net zero energy targets are used in Canada's Far North.

8.2 Recommendations & Future Work

In terms of building code development, there are two key recommendations from this research. Some new technology may need to be developed in order to meet such high performance targets in northern Canada, and the performance targets should consider differences in heating demand in the Far North.

(1) Technology: Develop better window solutions and window products within Canada that may be more easily supplied to the north. Heat recovery ventilation higher than 81% that does not require preheat, i.e. up to a 95% HRV without preheat, should also be explored.

(2) Performance Targets: Absolute energy performance targets are generally better at encouraging low energy building design compared to relative targets. Energy performance targets will need to be established for different building types to account for differences in typical use and feasibility of reducing energy consumption. Research needs to be performed to understand the performance of buildings in the context of

their intended use, taking into account typical construction and climatic conditions. Setting absolute target values for every building typology and climate is a significant task, one without existing reference sources to rely on.

Appendix A

Part 9 Modelling Tool Comparison Inputs

TABLE A.1 PART 9 SINGLE FAMILY DWELLING ARTICULATED WITH STANDARD PROTOCOLS MODELLING INPUTS.				
Description	**HOT2000**		**PHPP**	
	Units	**Input**	**Units**	**Input**
Site information				
Location	-	Whitehorse	-	Whitehorse
Weather file	-	Whitehorse	-	Whitehorse
Depth of frostline	m	3.5	-	n/a
Elevation	-	n/a	m	640
Building Enclosure				
Ceiling (Attic) RSI_{eff}	(m²K)/W	10.4	(m²K)/W	10.4
Wall RSI_{eff}	(m²K)/W	3.1	(m²K)/W	3.1
Door USI	W/(m²K)	1.4	W/(m²K)	1.4
Window USI	W/(m²K)	1.5	W/(m²K)	1.5
Window U_{CoG}	-	n/a	W/(m²K)	0.8
Window U_{Frame}	-	n/a	W/(m²K)	1.4
Window Psi Edge	-	n/a	W/(mK)	0.021
Window Psi Install	-	n/a	W/(mK)	0.107
Window SHGC	-	0.4	-	n/a
Window g-value	-	n/a	-	0.5
Window Shading	-	n/a	-	n/a
Slab-On-Grade RSI_{eff}	(m²K)/W	2.8	(m²K)/W	2.8
Thermal Mass	-	Light wood frame	Wh/K/m²	60
FDWR	%	15	%	15
Thermal Bridging: External wall to ground floor	-	n/a	W/(mK)	0.1
Thermal Bridging: Intermediate floor	-	n/a	W/(mK)	0.1
Thermal Bridging: Eave	-	n/a	W/(mK)	0.1
Thermal Bridging: External outside corner	-	n/a	W/(mK)	0
Thermal Bridging: Inverted corner	-	n/a	W/(mK)	0.02
Temperatures (Constant)				
Heating Set Point	˚C	21	˚C	20
Cooling Set Point	˚C	25	˚C	25
Base Loads (Constant)				
Electric Appliances	kWh/d	6.3	kWh/d	5.1
Lighting	kWh/d	2.6	kWh/d	1.4
Other Electric	kWh/d	9.7	kWh/d	0.4
Internal Gains - Basement	-	n/a	W/m²	2.5
Avg. Exterior Use	kWh/d	0.9	-	0

Hot Water Load	L/d	175.6	L/d	72.5
Hot Water Temperature	˚C	55	˚C	60
Occupancy	Occupants	2 adults, 1 child, 50% at home	Occupants	2.9
Power Generation				
Photovoltaic system	-	Not modelled	-	Not modelled
Natural Air Infiltration				
Air Change Rate	ACH50	3.2	ACH50	3.2
Volume	m³	434	m³	347
Heating/Cooling System				
Main Heating System	-	Electric Baseboards	-	Electric baseboards
Output Capacity	kW	12.5	kW	13.1
Fuel Type	-	Electricity	-	Electricity
Heating Efficiency	AFUE	100	%	100
Domestic Hot Water				
System	-	Tank	-	Tank
Energy Source	-	Electricity	-	Electricity
Energy Factor	-	0.82	-	n/a
Tank volume	US gal	50	US gal	50
Tank storage losses	-	n/a	W/K	2.5
Average length per tapping point	-	n/a	m	11
Performance ratio DHW distribution + storage	-	n/a	%	224
Ventilation				
Equipment type	-	Heat recovery ventilator	-	Heat recovery ventilator
Schedule	-	6.8 h/d @ normal 1.2 h/d @ 2.5x normal	-	6.8 h/d @ normal 1.2 h/d @ 2.5x normal
Supply	L/s (m³/hr)	80 (288) 32 (115)	L/s (m³/hr)	80 (288) 32 (115)
Exhaust	L/s (m³/hr)	80 (288) 32 (115)	L/s (m³/hr)	80 (288) 32 (115)
Power (fan + preheat)	W	66	-	n/a
Efficiency @ 0˚C	%	60	-	n/a
Efficiency @ -25˚C	%	55	-	n/a
Overall ventilation efficiency	-	n/a	%	56
Other Fans (exhaust)	L/s	38	L/s	38

TABLE A.2 PART 9 SINGLE FAMILY DWELLING ARTICULATED WITH ALIGNED PROTOCOLS MODELLING INPUTS.				
Description	**HOT2000**		**PHPP**	
	Units	**Input**	**Units**	**Input**
Site information				
Location	-	Whitehorse	-	Whitehorse
Weather file	-	Whitehorse	-	Whitehorse
Depth of frostline	m	3.5	-	n/a
Elevation	-	n/a	m	640
Building Enclosure				
Ceiling (Attic) RSI_{eff}	(m²K)/W	10.4	(m²K)/W	10.4
Wall RSI_{eff}	(m²K)/W	3.1	(m²K)/W	3.1
Door USI	W/(m²K)	1.4	W/(m²K)	1.4
Window USI	W/(m²K)	1.5	W/(m²K)	1.5
Window U_{CoG}	-	n/a	W/(m²K)	0.8
Window U_{Frame}	-	n/a	W/(m²K)	1.4
Window Psi Edge	-	n/a	W/(mK)	0.0
Window Psi Install	-	n/a	W/(mK)	0.1
Window SHGC	-	0.4	-	n/a
Window g-value	-	n/a	-	0.5
Window Shading	-	none	-	none
Slab-On-Grade RSI_{eff}	(m²K)/W	2.8	(m²K)/W	2.8
Thermal Mass	-	Light wood frame	Wh/K/m²	60
FDWR	%	15	%	15
Thermal Bridging: External wall to ground floor	-	n/a	W/(mK)	0.1
Thermal Bridging: Intermediate floor	-	n/a	W/(mK)	0.1
Thermal Bridging: Eave	-	n/a	W/(mK)	0.1
Thermal Bridging: External outside corner	-	n/a	W/(mK)	0
Thermal Bridging: Inverted corner	-	n/a	W/(mK)	0.02
Temperatures (Constant)				
Heating Set Point	˚C	21	˚C	20
Cooling Set Point	˚C	25	˚C	25
Base Loads (Constant)				
Electric Appliances	kWh/d	6.3	kWh/d	6.3
Lighting	kWh/d	2.6	kWh/d	2.6
Other Electric	kWh/d	9.7	kWh/d	9.7
Internal Gains - Basement	-	n/a	W/m²	2.5
Avg. Exterior Use	kWh/d	0.9	kWh/d	0.9

Hot Water Load	L/d	175.6	L/d	72.5
Hot Water Temperature	˚C	55	˚C	55
Occupancy	Occupants	2 adults, 1 child, 50% at home	Occupants	1.5
Power Generation				
Photovoltaic system	-	Not modelled	-	Not modelled
Natural Air Infiltration				
Air Change Rate	ACH50	3.2	ACH50	3.2
Volume	m³	434	m³	434
Heating/Cooling System				
Main Heating System	-	Electric Baseboards	-	Electric baseboards
Output Capacity	kW	12.5	kW	13.1
Fuel Type	-	Electricity	-	Electricity
Heating Efficiency	AFUE	100	AFUE	100
Domestic Hot Water				
System	-	Tank	-	Tank
Energy Source	-	Electricity	-	Electricity
Energy Factor	-	0.82	-	n/a
Tank volume	US gal	50	US gal	50
Tank storage losses	-	n/a	W/K	2.5
Average length per tapping point	-	n/a	m	11
Performance ratio DHW distribution + storage	-	n/a	%	224
Ventilation				
Equipment type	-	HRV	-	HRV
Schedule	-	6.8 h/d @ normal 1.2 h/d @ 2.5x normal	-	6.8 h/d @ normal 1.2 h/d @ 2.5x normal
Supply	L/s (m³/hr)	80 (288) 32 (115)	L/s (m³/hr)	80 (288) 32 (115)
Exhaust	L/s (m³/hr)	80 (288) 32 (115)	L/s (m³/hr)	80 (288) 32 (115)
Power (fan + preheat)	W	66	-	n/a
Efficiency @ 0˚C	%	60	-	n/a
Efficiency @ -25˚C	%	55	-	n/a
Overall ventilation efficiency	-	n/a	%	56
Other Fans (exhaust)	L/s	38	L/s	38

TABLE A.3 PART 9 SINGLE FAMILY DWELLING SIMPLE FORM WITH STANDARD PROTOCOLS MODELLING INPUTS.

Description	HOT2000		PHPP	
	Units	Input	Units	Input
Site information				
Location	-	Whitehorse	-	Whitehorse
Weather file	-	Whitehorse	-	Whitehorse
Depth of frostline	m	3.5	m	n/a
Elevation	m		m	640
Building Enclosure				
Ceiling (Attic) RSI_{eff}	(m²K)/W	17.6	(m²K)/W	17.6
Wall RSI_{eff}	(m²K)/W	14.1	(m²K)/W	14.1
Door USI	W/(m²K)	0.71	W/(m²K)	0.71
Window USI	W/(m²K)	0.64 - 0.65	W/(m²K)	0.67
Window U_{CoG}	-	n/a	W/(m²K)	0.37
Window U_{Frame}	-	n/a	W/(m²K)	0.93
Window Psi Edge	-	n/a	W/(mK)	0.03
Window Psi Install	-	n/a	W/(mK)	0.04
Frame width	-	n/a	m	0.105
Window SHGC	-	0.4	-	n/a
Window g-value	-	n/a	-	0.5
Window Shading	-	none	m	0.14
Slab-On-Grade RSI_{eff}	(m²K)/W	7.15	(m²K)/W	7.15
Thermal Mass	-	Light wood frame	Wh/K per TFA	60
FDWR	%	10	%	10
Thermal Bridging: External wall to ground floor	-	n/a	W/(mK)	0.05
Thermal Bridging: Intermediate floor	-	n/a	W/(mK)	0.02
Thermal Bridging: Eave	-	n/a	W/(mK)	0.02
Thermal Bridging: External outside corner	-	n/a	W/(mK)	0
Thermal Bridging: Inverted corner	-	n/a	W/(mK)	0.02
Temperatures (Constant)				
Heating Set Point	˚C	21	˚C	20
Cooling Set Point	˚C	25	˚C	25
Base Loads (Constant)				
Electric Appliances	kWh/d	6.3	kWh/d	5.1
Lighting	kWh/d	2.6	kWh/d	1.4
Other Electric	kWh/d	9.7	kWh/d	0.4
Internal Gains - Basement	-	n/a	W/m²	2.5

Avg. Exterior Use	kWh/d	0.9	kWh/d	0
Hot Water Load	L/d	175.6	L/d	72.50
Hot Water Temperature	˚C	55	˚C	60
Occupancy	Occupants	2 adults, 1 child, 50% at home	Occupants	2.90
Power Generation				
Photovoltaic system	-	Not modelled	-	Not modelled
Natural Air Infiltration				
Air Change Rate	ACH50	0.15	ACH50	0.15
Volume	m³	433	m³	347
Heating/Cooling System				
Main Heating System	-	Heat Pump	-	Heat pump
Output Capacity	kW	3	kW	3.98
Fuel Type	-	Electricity	-	Electricity
Heating Efficiency[1]	COP	3	COP	3
Domestic Hot Water				
System	-	Heat Pump	-	Heat Pump
Energy Source	-	Electricity	-	Electricity
Energy Factor	COP	3	COP	2.78
Tank volume	US gal	50	US gal	50
Drain Water Heat Recovery	%	64.7	%	63.5
Tank storage losses	-	n/a	W/K	2.1
Average length per tapping point	-	n/a	Average length per tapping point	11.1
Performance ratio DHW distribution + storage	-	n/a	%	215
Ventilation				
Equipment type	-	Heat recovery ventilator	-	Heat recovery ventilator
Schedule		6.8 h/d @ normal 1.2 h/d @ 2.5x normal		1 h/d on boost 23 h/d on normal
Supply	L/s (m³/hr)	32 (115)	L/s (m³/hr)	56 (200) 29 (106)
Exhaust	L/s (m³/hr)	32 (115)	L/s (m³/hr)	56 (200) 29 (106)
Power (fan + preheat)	W	66.2	kWh/a	1713
Efficiency @ 0˚C	%	81	-	n/a

[1] The same cold climate air source heat pump has been modelled in HOT2000 and PHPP. The performance is based on the outdoor air temperature.

Efficiency @ -25˚C	%	81	-	n/a
Overall ventilation efficiency	-	n/a	%	81
Other Fans (exhaust)	L/s	38	-	None

TABLE A.4 PART 9 SINGLE FAMILY DWELLING SIMPLE FORM WITH ALIGNED PROTOCOLS MODELLING INPUTS.

Description	HOT2000		PHPP	
	Units	Input	Units	Input
Site information				
Location	-	Whitehorse	-	Whitehorse
Weather file	-	Whitehorse	-	Whitehorse
Depth of frostline	m	3.5	m	n/a
Elevation	m		m	640
Building Enclosure				
Ceiling (Attic) RSI_{eff}	(m²K)/W	17.6	(m²K)/W	17.6
Wall RSI_{eff}	(m²K)/W	14.1	(m²K)/W	14.1
Door USI	W/(m²K)	0.71	W/(m²K)	0.71
Window USI	W/(m²K)	0.65	W/(m²K)	0.67
Window U_{CoG}	-	n/a	W/(m²K)	0.37
Window U_{Frame}	-	n/a	W/(m²K)	0.93
Window Psi Edge	-	n/a	W/(mK)	0.03
Window Psi Install	-	n/a	W/(mK)	0.04
Frame width	-	n/a	m	0.11
Window SHGC	-	0.4	-	n/a
Window g-value	-	n/a	-	0.5
Window Shading	-	none	-	none
Slab-On-Grade RSI_{eff}	(m²K)/W	7.15	(m²K)/W	7.15
Thermal Mass	-	Light wood frame	Wh/K per TFA	60
FDWR	%	10	%	10
Thermal Bridging: External wall to ground floor	-	n/a	W/(mK)	0.05
Thermal Bridging: Intermediate floor	-	n/a	W/(mK)	0.02
Thermal Bridging: Eave	-	n/a	W/(mK)	0.02
Thermal Bridging: External outside corner	-	n/a	W/(mK)	0
Thermal Bridging: Inverted corner	-	n/a	W/(mK)	0.02
Temperatures (Constant)				
Heating Set Point	˚C	21	˚C	20
Cooling Set Point	˚C	25	˚C	25

Base Loads (Constant)				
Electric Appliances	kWh/d	6.3	kWh/d	6.3
Lighting	kWh/d	2.6	kWh/d	2.6
Other Electric	kWh/d	9.7	kWh/d	9.7
Internal Gains - Basement	-	n/a	-	n/a
Avg. Exterior Use	kWh/d	0.9	kWh/d	0.9
Hot Water Load	L/d	175.6	L/d	175.6
Hot Water Temperature	˚C	55	˚C	55
Occupancy	Occupants	2 adults, 1 child, 50% at home	Occupants	1.5
Power Generation				
Photovoltaic system	-	Not modelled	-	Not modelled
Natural Air Infiltration				
Air Change Rate	ACH50	0.4	ACH50	0.4
Volume	m³	433	m³	433
Heating/Cooling System				
Main Heating System	-	Heat pump	-	Heat pump
Output Capacity	kW	3	kW	3
Fuel Type	-	Electricity	-	Electricity
Heating Efficiency[2]	COP	3	-	3
Domestic Hot Water				
System	-	Heat Pump	-	Heat pump
Energy Source	-	Electricity	-	Electricity
Energy Factor	COP	3	COP	3
Tank volume	US gal	50	US gal	50
Drain Water Heat Recovery	-	63.5	%	63.5
Tank storage losses	-	-	W/K	2.1
Average length per tapping point	-	-	Average length per tapping point	11.1
Performance ratio DHW distribution + storage	-	-	%	136
Ventilation				
Equipment type	-	Heat recovery ventilator	-	Heat recovery ventilator
Schedule	-	6.8 h/d @ normal 1.2 h/d @ 2.5x normal	-	6.8 h/d @ normal 1.2 h/d @ 2.5x normal

[2] The same cold climate air source heat pump has been modelled in HOT2000 and PHPP. The performance is based on the outdoor air temperature.

Supply	L/s (m³/hr)	80 (288) 32 (115)	L/s (m³/hr)	80 (288) 32 (115)
Exhaust	L/s (m³/hr)	80 (288) 32 (115)	L/s (m³/hr)	80 (288) 32 (115)
Power (fan + preheat)	W	48	kWh/a	1071
Efficiency @ 0˚C	%	81	-	n/a
Efficiency @ -25˚C	%	81	-	n/a
Overall ventilation efficiency	-	n/a	%	81
Other Fans (exhaust)	L/s	38	38	L/s

Appendix B

Part 9 Modelling Tool Comparison Results

TABLE B.1 PART 9 SINGLE FAMILY DWELLING ARITCULATED STANDARD AND ALIGNED PROTOCOLS MODELLING RESULTS					
Metric	**Units**	**Articulated form with standard protocols**		**Articulated form with aligned protocols**	
		PHPP (TFA)	**H2K (GFA)**	**PHPP (GFA)**	**H2K (GFA)**
TEUI / TEUI	(kWh/m²/yr)	236	190	218	190
Heating Demand / TEDI	(kWh/m²/yr)	190	113	141	113
Heating Load / PTL	(W/m²)	90	76	78	76

TABLE B.2 PART 9 SINGLE FAMILY DWELLING SIMPLE FORM STANDARD AND ALIGNED PROTOCOLS MODELLING RESULTS					
Metric	**Units**	**Simple form with standard protocols**		**Simple form with aligned protocols**	
		PHPP (TFA)	**H2K (GFA)**	**PHPP (GFA)**	**H2K (GFA)**
TEUI / TEUI	(kWh/m²/yr)	54	53	59	53
Heating Demand / TEDI	(kWh/m²/yr)	29	6	8	6
Heating Load / PTL	(W/m²)	18	17	12	17

Appendix C

Part 3 Modelling Tool Comparison Inputs

TABLE C.1 PART 3 MULTI-UNIT RESIDENTIAL BUILDING ARTICULATED WITH STANDARD PROTOCOLS MODELLING INPUTS.				
Description	**EnergyPlus**		**PHPP**	
	Units	**Input**	**Units**	**Input**
Site information				
Location	-	Whitehorse	-	Whitehorse
Weather file	-	Whitehorse	-	Whitehorse
Elevation	-	n/a	m	640
Building Enclosure				
Ceiling (Attic) RSI_{eff}	(m²K)/W	6.3	(m²K)/W	6.1
Wall RSI_{eff}	(m²K)/W	4.8	(m²K)/W	4.7
Window USI	W/(m²K)	2.2	W/(m²K)	2.2
Window U_{CoG}	-	n/a	W/(m²K)	2.40
Window U_{Frame} Operable Fixed	-	n/a	W/(m²K)	0.87 0.83
Window Psi Edge	-	n/a	W/(mK)	0.021
Window Psi Install	-	n/a	W/(mK)	0.025
Window SHGC	-	0.5	-	0.5
Window Shading	-	none	-	none
Exposed Floor RSI_{eff}	(m²K)/W	6.4	(m²K)/W	6.2
WWR (N/S, E/W)	%	23, 7	%	23, 7
Thermal Bridging: External wall to ground floor	-	n/a	W/(mK)	0.1
Thermal Bridging: Intermediate floor	-	n/a	W/(mK)	0.0
Thermal Bridging: Eave	-	n/a	W/(mK)	0.1
Thermal Bridging: External outside corner	-	n/a	W/(mK)	0.0
Thermal Bridging: Inverted corner	-	n/a	W/(mK)	0.02
Temperatures (Constant)				
Heating Set Point	˚C	22 daytime 18 nighttime	˚C	20
Base Loads (Constant)				
Electric Appliances	kWh/d	167	kWh/d	107
Lighting	kWh/d	138	kWh/d	8
Other Electric	kWh/a	7	kWh/a	n/a
Internal Gains	-	n/a	W/m²	2.7
Hot Water Temperature	˚C	60	˚C	60

Hot Water Load	L/d/Person	60	L/d/Person	25
Occupancy	Occupants	92.4 home 68% of the time	Occupants	63.5 annual average
Power Generation				
Photovoltaic system	-	Not modelled	-	Not modelled
Natural Air Infiltration				
Air Change Rate	ACH50 l/s-m^2	2.2 0.25	ACH50 l/s-m^2	2.2 0.25
Volume of the Building	m³	8963	m³	8963
Heating/Cooling System				
Main Heating System	-	Electric Baseboards	-	Electric baseboards
Fuel Type	-	Electricity	-	Electricity
Heating Efficiency	%	100	%	100
Domestic Hot Water				
System	-	Tank	-	Tank
Energy Source	-	Electricity	-	Electricity
Tank volume	m^3	3.5	m^3	3.5
Tank storage losses	-	n/a	W/K	5.2
Ventilation				
Equipment type	-	In-suite heat recovery ventilator with corridor make-up air	-	In-suite heat recovery ventilator with corridor make-up air
Schedule	-	24h/d	-	24h/d
Supply Suites Corridor	L/s/suite L/s	28 260	L/s/suite L/s	28 260
Exhaust Suites Corridor	L/s/suite L/s	28 260	L/s/suite L/s	28 260
Efficiency @ 0˚C	%	50	%	50
Efficiency @ -25˚C	%	50	%	50
Pre-heat coil	-	Electric	-	Electric
Other Fans (exhaust)	L/s/suite	71 2h/d	L/s/suite	71 2h/d

TABLE C.2 PART 3 MULTI-UNIT RESIDENTIAL BUILDING ARTICULATED WITH ALIGNED PROTOCOLS MODELLING INPUTS.				
Description	**EnergyPlus**		**PHPP**	
	Units	**Input**	**Units**	**Input**
Site information				
Location	-	Whitehorse	-	Whitehorse
Weather file	-	Whitehorse	-	Whitehorse
Elevation	-	n/a	m	640
Building Enclosure				
Ceiling (Attic) RSI_{eff}	(m²K)/W	6.3	(m²K)/W	6.3
Wall RSI_{eff}	(m²K)/W	4.8	(m²K)/W	4.8
Window USI	W/(m²K)	2.2	W/(m²K)	2.2
Window U_{CoG}	-	n/a	W/(m²K)	2.40
Window U_{Frame} Operable Fixed	-	n/a	W/(m²K)	0.87 0.83
Window Psi Edge	-	n/a	W/(mK)	0.021
Window Psi Install	-	n/a	W/(mK)	0.025
Window SHGC	-	0.4	-	0.4
Window Shading	-	none	-	none
Exposed Floor RSI_{eff}	(m²K)/W	6.4	(m²K)/W	6.4
WWR (N/S, E/W)	%	23, 7	%	23, 7
Thermal Bridging: External wall to ground floor	-	n/a	W/(mK)	0.1
Thermal Bridging: Intermediate floor	-	n/a	W/(mK)	0.0
Thermal Bridging: Eave	-	n/a	W/(mK)	0.1
Thermal Bridging: External outside corner	-	n/a	W/(mK)	0.0
Thermal Bridging: Inverted corner	-	n/a	W/(mK)	0.02
Temperatures (Constant)				
Heating Set Point	°C	22 daytime 18 nighttime	°C	22
Base Loads (Constant)				
Electric Appliances	kWh/d	167	kWh/d	167
Interior Lighting	kWh/d	138	kWh/d	138
Exterior Lighting	kWh/a	7	kWh/a	7
Internal Gains	-	n/a	W/m²	6.8
Hot Water Load	L/d/Person	60	L/d/Person	60

Hot Water Temperature	˚C	60	˚C	60
Occupancy	Occupants	92.4 68% at home	Occupants	62.8 annual average
Power Generation				
Photovoltaic system	-	Not modelled	-	Not modelled
Natural Air Infiltration				
Air Change Rate	ACH50 L/s-m² @ 5Pa	2.2 0.25	ACH50 L/s-m² @ 5Pa	2.2 0.25
Volume	m³	8963	m³	8963
Heating/Cooling System				
Main Heating System	-	Electric Baseboards	-	Electric baseboards
Fuel Type	-	Electricity	-	Electricity
Heating Efficiency	%	100	%	100
Domestic Hot Water				
System	-	Tank	-	Tank
Energy Source	-	Electricity	-	Electricity
Tank volume	m³	3.5	m³	3.5
Tank storage losses	-	n/a	-	n/a
Ventilation				
Equipment type	-	In-suite heat recovery ventilator with corridor make-up air	-	In-suite heat recovery ventilator with corridor make-up air
Schedule	-	24h/d	-	24h/d
Supply Suites Corridor	L/s/suite L/s	28 260	L/s/suite L/s	28 260
Exhaust Suites Corridor	L/s/suite L/s	28 260	L/s/suiteL/s	28 260
Efficiency @ 0˚C	%	50	%	50
Efficiency @ -25˚C	%	50	%	50
Pre-heat coil	-	Electric	-	Electric
Other Fans (exhaust)	L/s/suite	71 2h/d	L/s/suite	71 2h/d

TABLE C.3 PART 3 MULTI-UNIT RESIDENTIAL BUILDING SIMPLE FORM WITH STANDARD PROTOCOLS MODELLING INPUTS.				
Description	**EnergyPlus**		**PHPP**	
	Units	**Input**	**Units**	**Input**
Site information				
Location	-	Whitehorse	-	Whitehorse
Weather file	-	Whitehorse	-	Whitehorse
Elevation	-	n/a	m	640
Building Enclosure				
Ceiling (Attic) RSI_{eff}	$(m^2K)/W$	18.5	$(m^2K)/W$	17.6
Wall RSI_{eff}	$(m^2K)/W$	14.1	$(m^2K)/W$	14.1
Window USI	$W/(m^2K)$	0.69	$W/(m^2K)$	0.70
Window U_{CoG}	-	n/a	$W/(m^2K)$	0.49
Window U_{Frame} Operable Fixed	-	n/a	$W/(m^2K)$	0.87 0.83
Window Psi Edge	-	n/a	W/(mK)	0.021
Window Psi Install	-	n/a	W/(mK)	0.025
Window SHGC	-	0.4	-	0.4
Window Shading	-	none	-	none
Exposed Floor RSI_{eff}	$(m^2K)/W$	14.1	$(m^2K)/W$	14.1
WWR (N/S, E/W)	%	10, 5	%	10, 5
Thermal Bridging: External wall to ground floor	-	n/a	W/(mK)	0.1
Thermal Bridging: Intermediate floor	-	n/a	W/(mK)	0.0
Thermal Bridging: Eave	-	n/a	W/(mK)	0.1
Thermal Bridging: External outside corner	-	n/a	W/(mK)	0.0
Thermal Bridging: Inverted corner	-	n/a	W/(mK)	0.02
Temperatures (Constant)				
Heating Set Point	˚C	22 daytime 18 nighttime	˚C	20
Base Loads (Constant)				
Electric Appliances	kWh/d	167	kWh/d	107
Lighting	kWh/d	138	kWh/d	8
Other Electric	kWh/a	7	kWh/a	n/a
Internal Gains	-	n/a	W/m^2	2.7
Hot Water Load	L/d/person	60	L/d/person	25

Hot Water Temperature	˚C	60	˚C	55
Occupancy	Occupants	92.4 home 68% of the time	Occupants	63.5 annual average
Power Generation				
Photovoltaic system	-	Not modelled	-	Not modelled
Natural Air Infiltration				
Air Change Rate	ACH50/ L/s-m^2 @ 5Pa	0.15/ 0.02	ACH50/ L/s-m^2 @ 5Pa	0.15/ 0.02
Volume of the Building	m^3	8963	m^3	6424
Heating/Cooling System				
Main Heating System	-	Heat Pump	-	Heat Pump
Fuel Type	-	Electricity	-	Electricity
Heating Efficiency[1]	COP	3	COP	3
Domestic Hot Water				
System	-	Tank	-	Tank
Energy Source	-	Electricity	-	Electricity
Energy Factor[31]	COP	3	COP	3
Tank volume	m^3	3.5	m^3	3.5
Tank storage losses	-	n/a	W/K	5.2
Ventilation				
Equipment type	-	Centralized heat recovery ventilator supplying corridors and suites	-	Centralized heat recovery ventilator supplying corridors and suites
Schedule	-	24h/d	-	24h/d
Supply Suites Corridor	L/s/suite L/s	28 260	L/s/suite L/s	28 260
Exhaust Suites Corridor	L/s/suites L/s	28 260	L/s/suite L/s	28 260
Efficiency @ 0˚C	%	81	%	81
Efficiency @ -25˚C	%	81	%	81
Pre-heat coil	-	N/A	-	N/A
Other Fans (exhaust)	L/s/suite	71 2h/d	L/s/suite	71 2h/d

[1] The same cold climate air source heat pump has been modelled in EnergyPlus and PHPP. The performance is based on the outdoor air temperature.

TABLE C.4 PART 3 MULTI-UNIT RESIDENTIAL BUILDING SIMPLE FORM WITH ALIGNED PROTOCOLS MODELLING INPUTS.				
Description	**EnergyPlus**		**PHPP**	
	Units	**Input**	**Units**	**Input**
Site information				
Location	-	Whitehorse	-	Whitehorse
Weather file	-	Whitehorse	-	Whitehorse
Elevation	-	n/a	m	640
Building Enclosure				
Ceiling (Attic) RSI_{eff}	$(m^2K)/W$	18.5	$(m^2K)/W$	18.5
Wall RSI_{eff}	$(m^2K)/W$	14.1	$(m^2K)/W$	14.1
Window USI	$W/(m^2K)$	0.69	$W/(m^2K)$	0.70
Window U_{CoG}	-	n/a	$W/(m^2K)$	0.49
Window U_{Frame} Operable Fixed	-	n/a	$W/(m^2K)$	0.87 0.83
Window Psi Edge	-	n/a	W/(mK)	0.021
Window Psi Install	-	n/a	W/(mK)	0.025
Window SHGC	-	0.4	-	0.4
Window Shading	-	none	-	none
Exposed Floor RSI_{eff}	$(m^2K)/W$	14.1	$(m^2K)/W$	14.1
WWR (N/S, E/W)	%	10, 5	%	10, 5
Thermal Bridging: External wall to ground floor	-	n/a	W/mK	0.1
Thermal Bridging: Intermediate floor	-	n/a	W/mK	0.0
Thermal Bridging: Eave	-	n/a	W/mK	0.1
Thermal Bridging: External outside corner	-	n/a	W/mK	0.0
Thermal Bridging: Inverted corner	-	n/a	W/mK	0.02
Temperatures (Constant)				
Heating Set Point	˚C	22 daytime 18 nighttime	˚C	22
Base Loads (Constant)				
Electric Appliances	kWh/d	167	kWh/d	167
Interior Lighting	kWh/d	138	kWh/d	138
Exterior Lighting	kWh/a	7	kWh/a	7
Internal Gains	-	n/a	W/m^2	6.8
Hot Water Temperature	˚C	60	˚C	60

Occupancy	Occupants	92.4 68% at home	Occupants	62.8 annual average
Power Generation				
Photovoltaic system	-	Not modelled	-	Not modelled
Natural Air Infiltration				
Air Change Rate	ACH50 L/s-m² @ 5Pa	0.15 0.02	ACH50 L/s-m² @ 5Pa	0.15 0.02
Volume	m³	8963	m³	8963
Heating/Cooling System				
Main Heating System	-	Electric Baseboards	-	Electric baseboards
Fuel Type	-	Electricity	-	Electricity
Heating Efficiency[2]	COP	3	COP	3
Domestic Hot Water				
System	-	Heat Pump	-	Heat Pump
Energy Source	-	Electricity	-	Electricity
Energy Factor[32]	COP	3	COP	3
Tank volume	m³	3.5	m³	3.5
Hot Water Load	l/person/d	60	l/person/d	60
Tank storage losses	-	n/a	W/K	n/a
Ventilation				
Equipment type	-	Centralized heat recovery ventilator supplying corridors & suites	-	Centralized heat recovery ventilator supplying corridors & suites
Schedule	-	24h/d	-	24h/d
Supply Suites Corridor	L/s/suite L/s	28 260	L/s/suite L/s	28 260
Exhaust Suites Corridor	L/s/suites L/s	28 260	L/s/suite L/s	28 260
Efficiency @ 0˚C	%	50	%	50
Efficiency @ -25˚C	%	50	%	50
Pre-heat coil	-	N/A	-	N/A
Other Fans (exhaust)	L/s/suite	71 2h/d	L/s/suite	71 2h/d

[2] The same cold climate air source heat pump has been modelled in EnergyPlus and PHPP. The performance is based on the outdoor air temperature.

Appendix D

Part 3 Modelling Tool Comparison Results

TABLE D.1 PART 3 MULTI-UNIT RESIDENTIAL BUILDING ARITCULATED WITH STANDARD AND ALIGNED PROTOCOLS MODELLING RESULTS					
Metric	**Unit**	**Articulated form with standard protocols**		**Articulated form with aligned protocols**	
		PHPP (TFA)	**EnergyPlus (GFA)**	**PHPP (GFA)**	**EnergyPlus (GFA)**
TEUI/TEUI	(kWh/m²/yr)	178	221	183	221
Heating Demand/ TEDI	(kWh/m²/yr)	131	143	91	143

TABLE D.2 PART 3 MULTI-UNIT RESIDENTIAL BUILDING SIMPLE FORM WITH STANDARD AND ALIGNED PROTOCOLS MODELLING RESULTS					
Metric	**Units**	**Simple form with standard protocols**		**Simple form with aligned protocols**	
		PHPP (TFA)	**EnergyPlus (GFA)**	**PHPP (GFA)**	**EnergyPlus (GFA)**
TEUI/TEUI	(kWh/m²/yr)	41	59	58	59
Heating Demand/ TEDI	(kWh/m²/yr)	24	7	8	7

Appendix E

Part 9 Compliance Modelling Inputs

TABLE E.1 BASELINE KEY MODEL INPUTS FOR SINGLE FAMILY DWELLING ARCHETYPE			
Description	**Units**	**BASELINE**	
		Value	**Notes and References**
Site Information			
Location	-	Fort St. John / Whitehorse / Yellowknife, Resolute	CZ7a / CZ7b / CZ8
Weather File	-	CWEC 2000 / PHI Climate data set	HOT2000 / PHPP
Building Geometry			
Storeys	-	2	Above ground
Total conditioned area	m²	167 (Articulated) 167 (Simple form)	HOT2000 reference area
Treated floor area	m²	142 (Articulated) 142 (Simple form)	PHPP reference area
Base Loads			
Occupants	-	2 adults, 1 child, 50% at home / 2.9 annual average	Standard HOT2000 / PHPP operating conditions.
Electrical appliances	kWh/day	6.3 / 5.3	Standard HOT2000 / PHPP operating conditions.
Lighting	kWh/day	2.6 / 0.25	Standard HOT2000 / PHPP operating conditions.
Exterior use	kWh/day	9.7 / 0	Standard HOT2000 / PHPP operating conditions.
Other electric	kWh/day	0.9 / 5.3	Standard HOT2000 / PHPP operating conditions.
Building Enclosure			
Exterior Wall RSI_{eff}	(m²K)/W	3.0 / 3.1 / 3.1	CZ7a / CZ7b / CZ8 NBC 2015
Ceiling (Attic) RSI_{eff}	(m²K)/W	8.7 / 10.4 / 10.4	CZ7a / CZ7b / CZ8 NBC 2015
Exposed Floor RSI_{eff}	(m²K)/W	5.0	CZ8 NBC 2015
Slab on grade RSI_{eff}	(m²K)/W	2.8	CZ7a / CZ7b NBC 2015
Window U-Value	W/(m²K)	0.64 0.70	CZ7a NBC 2015 CZ7b / CZ8 NBC 2015
Window SHGC	-	0.4	
Window to Wall Ratio (overall)	%	10	Articulated and simple form
Heating System			
System Description	-	Electric baseboards	

Output Capacity	kW	Variable	Calculated in HOT2000/PHPP.
Baseboard Efficiency	%	100	
Heating Setpoint Temperature	ºC	21 / 20	Standard HOT2000 / PHPP operating conditions.
Domestic Hot Water			
System Description	-	Direct electric	
Water Temperature	ºC	55 / 60	Standard HOT2000 / PHPP operating conditions.
Tank Volume	US gal	50	
Service Water Load	L/day	176 / 73	Standard HOT2000 / PHPP operating conditions.
Ventilation			
System Description	-	Heat recovery ventilation	
Schedule	Min/day	480	
Supply Flow Rate (normal / boost)	L/s	32	
Exhaust Flow Rate (normal / boost)	L/s	32	
Efficiency at 0˚C	%	60	
Efficiency at -25˚C	%	55	
Fan power	W	66	
Airtightness	ACH	2.5	

TABLE E.2 BASELINE KEY MODEL INPUTS FOR 5-PLEX DWELLING ARCHETYPE.			
Description	**Units**	**BASELINE**	
		Value	**Notes and References**
Site Information			
Location	-	Fort St. John / Whitehorse / Yellowknife, Resolute	CZ7a / CZ7b / CZ8
Weather File	-	CWEC 2000 / PHI Climate data set	HOT2000 / PHPP
Building Geometry			
Storeys	-	1	Above ground
Total conditioned area	m²	406.60	HOT2000 reference area
Treated floor area	m²	380.13	PHPP reference area
Base Loads			
Occupants	-	9 adults, 7 child, 50% at home / 9.8 annual average	Standard HOT2000 / PHPP operating conditions.
Electrical appliances	kWh/day	31.50 / 22	Standard HOT2000 / PHPP operating conditions.
Lighting	kWh/day	13 / 1.12	Standard HOT2000 / PHPP operating conditions.
Exterior use	kWh/day	4.5 / 0	Standard HOT2000 / PHPP operating conditions.
Other electric	kWh/day	48.5 / 0	Standard HOT2000 / PHPP operating conditions.
Building Enclosure			
Exterior Wall RSI_{eff}	(m²K)/W	3.0 / 3.1 / 3.1	CZ7a / CZ7b / CZ8 NBC 2015
Ceiling (Attic) RSI_{eff}	(m²K)/W	5.0 / 5.0 / 5.0	CZ7a / CZ7b / CZ8 NBC 2015
Exposed Floor RSI_{eff}	(m²K)/W	5.0	CZ8 NBC 2015
Slab on grade RSI_{eff}	(m²K)/W	2.8	CZ7a / CZ7b NBC 2015
Window U-Value	W/(m²K)	0.64 0.70	CZ7a NBC 2015 CZ7b / CZ8 NBC 2015
Window SHGC	-	0.23 – 0.37	
Window to Wall Ratio (overall)	%	11.2	Articulated and simple form
Heating System			
System Description	-	Electric baseboards	CZ7a / CZ7b NBC 2015

		Oil boiler	CZ8 NBC 2015
Output Capacity	kW	Variable	Calculated in HOT2000/PHPP.
Efficiency AFUE	%	100 85	CZ7a / CZ7b NBC 2015 CZ8 NBC 2015
Heating Setpoint Temperature	ºC	21 / 20	Standard HOT2000 / PHPP operating conditions.
Domestic Hot Water			
System Description	-	Direct electric Oil tank	CZ7a / CZ7b NBC 2015 CZ8 NBC 2015
Water Temperature	ºC	55 / 60	Standard HOT2000 / PHPP operating conditions.
Tank Volume	US gal	120	
Service Water Load	L/day	985 / 104	Standard HOT2000 / PHPP operating conditions.
Ventilation			
System Description	-	Heat recovery ventilation	
Schedule	Min/day	480	
Supply Flow Rate (normal / boost)	L/s	125	
Exhaust Flow Rate (normal / boost)	L/s	125	
Efficiency at 0˚C	%	60	
Efficiency at -25˚C	%	55	
Fan power	W	341	
Airtightness	ACH	2.5	

TABLE E.3 SFD ARTICULATED - ECM BUNDLES TO ACHIEVE STEP CODE[1]						
Step	Measure	**< 25% NBC 2015**	**Step 4**		**Step 5**	
CZ			**ESC (2017)**	**ESC (2018)**	**ESC (2017)**	**ESC (2018)**
Climate Zone 7a - Fort St. John	Airtightness	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 1.0 ACH50	Airtightness improvement to 0.0.3 ACH50	Airtightness improvement to 0.3 ACH50
	Roof	Add R-10 batt insulation to roof (to R_{eff}-60)	Add R-10 batt insulation to roof (to R_{eff}-60)	Add R-10 batt insulation to roof (to R_{eff}-60)	Add R-30 batt insulation to roof (to R_{eff}-80)	Add R-10 batt insulation to roof (to R_{eff}-60)
	Exterior wall	Add 4" EPS to walls (to R_{eff}-30)	Add 4" EPS to walls (to R_{eff}-30)	Add 2" EPS to walls (to R_{eff}-25)	Add 12" EPS to walls (to R_{eff}-60)	Add 4" EPS to walls (to R_{eff}-30)
	Slab	Add 2" XPS to slab (to R_{eff}-22)	Add 1" XPS to slab (to R_{eff}-20)	Add 4" XPS to slab (to R_{eff}-30)	Add 4" XPS to slab (to R_{eff}-30)	Add 5" XPS to slab (to R_{eff}-35)
	Window performance	Upgrade to high performance windows (U-0.25)	Upgrade to high performance windows (U-0.25)	Upgrade to high performance windows (U-0.25)	Upgrade to high performance windows (U-0.15)	Upgrade to high performance windows (U-0.18)
	Ventilation upgrade	Install 81% efficient HRV	Install 81% efficient HRV	Install 81% efficient HRV	Install 81% efficient HRV	Install 81% efficient HRV
	Heating system upgrade					
	DHW system upgrade	Upgrade to Conserver tank		Upgrade to conserver tank and install DWHR system (65%)	Upgrade DHW system to heat pump	Upgrade to conserver tank, R12 wrap and install DWHR system (65%)
Climate Zone 7b - Whitehorse	Airtightness	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 1.0 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 0.3 ACH50
	Roof	Add R-20 batt insulation to roof (to R_{eff}-70)	Add R-20 batt insulation to roof (to R_{eff}-70)		Add R-30 batt insulation MF to roof (to R_{eff}-80)	
	Exterior wall	Add 4" EPS to walls (to R_{eff}-30)	Add 5" EPS to walls (R_{eff}-35)	Add 4" EPS to walls (R_{eff}-30)	Add 15" EPS to walls (to R_{eff}-70)	Add 4" EPS to walls (R_{eff}-30)
	Slab	Add 3" XPS to slab (to R_{eff}-25)	Add 4" XPS to slab (to R_{eff}-30)	Add 4" XPS to slab (to R_{eff}-30)	Add 7" XPS to slab (to R_{eff}-40)	Add 5" XPS to slab (to R_{eff}-35)
	Window performance				Upgrade to high performance windows (U-0.11)	Upgrade to high performance windows (U-0.18)

[1] Energy Conservation Measure (ECM) upgrades to the baseline assumptions as listed in Table E.1. Red cells indicate the overall compliance target was not met.

	Ventilation upgrade	Install 81% efficient HRV	Install 81% efficient HRV	Install 81% efficient HRV	Install 81% efficient HRV. Increase HRV duct insulation (to R-16)	Install 81% efficient HRV
	Heating system upgrade					
	DHW system upgrade	Upgrade to Conserver tank		Upgrade to conserver tank and install DWHR system (65%)	Upgrade DHW system to heat pump	Upgrade to conserver tank, R12 wrap and install DWHR system (65%)
Climate Zone 8 - Yellowknife	Airtightness	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 1.0 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 0.3 ACH50
	Roof		Add R-10 batt insulation to roof (to R_{eff}-70)	Subtract R-10 batt insulation from roof (to R_{eff}-50)	Add R-40 batt insulation to roof (to R_{eff}-100)	
	Exterior wall	Add 2" EPS to wall (to R_{eff}-22)	Add 7" EPS to walls (R_{eff}-40)	Add 4" EPS to walls (R_{eff}-30)	Add 17" EPS to walls (to R_{eff}-80)	Add 4" EPS to walls (R_{eff}-30)
	Exposed Floor	Add R-10 batt insulation to exposed floor (to R_{eff}-40)	Add R-30 batt insulation to exposed floor (to R_{eff}-60)	Add R-5 batt insulation to exposed floor (to R_{eff}-30)	Add R-50 batt insulation to exposed floor (to R_{eff}-80)	Add R-10 batt insulation to exposed floor (to R_{eff}-35)
	Window performance	Upgrade to high performance windows (U-0.18)	Upgrade to high performance windows (U-0.18)	Upgrade to high performance windows (U-0.18)	Upgrade to high performance windows (U-0.11)	Upgrade to high performance windows (U-0.11)
	Ventilation upgrade	Install 81% efficient HRV	Install 81% efficient HRV	Install 81% efficient HRV	Install 81% efficient HRV, increase HRV duct insulation (to R-16)	Install 81% efficient HRV, Increase HRV duct insulation (to R-16)
	Heating system upgrade				Upgrade heating system to cold climate ASHP	
	DHW system upgrade	Upgrade to Conserver tank		Upgrade to conserver tank and install DWHR system (65%)	Upgrade DHW system to heat pump	Upgrade to conserver tank and install DWHR system (65%)
Climate Zone 8 -	Airtightness	Airtightness improvement to 1.00 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 0.3 ACH50
	Roof		Add R-20 batt insulation to roof (to R_{eff}-80)		Add R-40 batt insulation to roof (to R_{eff}-100)	Add R-20 batt insulation to roof (to R_{eff}-80)

	Exterior wall	Add 1"EPS to wall (to R_{eff}-20)	Add 12" EPS to walls (to R_{eff}-60)	Add 7" EPS to walls (to R_{eff}-40)	Add 17" EPS to walls (to R_{eff}-80)	Add 9" EPS to walls (to R-50)
	Exposed Floor	Add R-5 batt insulation to exposed floor (to R_{eff}-30)	Add R-40 batt insulation to exposed floor (to R_{eff}-70)	Add R-10 batt insulation to exposed floor (to R_{eff}-35)	Add R-50 batt insulation to exposed floor (to R_{eff}-80)	Add R-30 batt insulation to exposed floor (to R_{eff}-60)
	Window performance	Upgrade to high performance windows (U-0.18)	Upgrade to high performance windows (U-0.11)	Upgrade to high performance windows (U-0.11)	Upgrade to high performance windows (U-0.11)	Upgrade to high performance windows (U-0.11)
	Ventilation upgrade	Install 81% efficient HRV	Install 81% efficient HRV, increase HRV duct insulation (to R-16)	Install 81% efficient HRV, increase HRV duct insulation (to R-16)	Install 81% efficient HRV, increase HRV duct insulation (to R-16)	Install 81% efficient HRV, increase HRV duct insulation (to R-16)
	Heating system upgrade				Upgrade heating system to cold climate ASHP	Upgrade heating system to cold climate ASHP
	DHW system upgrade			Upgrade to conserver tank and install DWHR system (65%)	Upgrade DHW system to heat pump, install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)

TABLE E.4 SFD SIMPLE FORM - ECM BUNDLES TO ACHIEVE STEP CODE[2]						
Step	Measure	**< 25% NBC 2015**	**Step 4**		**Step 5**	
CZ			**ESC (2017)**	**ESC (2018)**	**ESC (2017)**	**ESC (2018)**
Climate Zone 7a - Fort St. John	Airtightness	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 1.0 ACH50
	Roof	Add R-10 batt insulation to roof (to R_{eff}-60)			Add R-30 batt insulation to roof (R_{eff}-80)	
	Exterior wall	Add 2” EPS to walls (to R_{eff}-22)	Add 1" EPS to walls (R_{eff}-20)	Add 1" EPS to walls (R_{eff}-20)	Add 9" EPS to walls (to R_{eff}-50)	Add 2" EPS to walls (to R_{eff}-22)
	Slab	Add 2" XPS to slab (to R_{eff}-22)	Add 1" XPS to slab (to R_{eff}-20)	Add 1" XPS to slab (to R_{eff}-20)	Add 4" XPS to slab (to R_{eff}-30)	Add 1.5" XPS to slab (to R_{eff}-22)
	Window performance	Upgrade to high performance windows (U-0.20)			Upgrade to high performance windows (U-0.15)	Upgrade to high performance windows (U-0.20)
	Ventilation upgrade	Install 70% efficient HRV and increase HRV duct insulation (to R-9)	Install 81% efficient HRV	Increase HRV duct insulation (to R-10)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 70% efficient HRV and increase HRV duct insulation (to R-10)
	Heating system upgrade					
	DHW system upgrade	Upgrade to conserver tank and install DWHR system (42%)	Install DWHR system (65%)		Install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)
Climate Zone 7b - Whitehorse	Airtightness	Airtightness improvement to 1.50 ACH50	Airtightness improvement to 1.00 ACH50	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 1.0 ACH50
	Roof		Reduce R-10 batt insulation from roof (to R_{eff}-50)		Add R-35 batt insulation to roof (to R_{eff}-90)	
	Exterior wall	Add 2" EPS to walls (to R_{eff}-22)	Add 4" EPS to walls (to R_{eff}-30)	Add 2" EPS to walls (to R_{eff}-22)	Add 13" EPS to walls (to R_{eff}-65)	Add 3” EPS to walls (to R_{eff}-25)
	Slab	Add 2" XPS to slab (to R_{eff}-22)	Add 1" XPS to slab (to R_{eff}-20)	Add 2" XPS to slab (to R_{eff}-22)	Add 7" XPS to slab (to R_{eff}-40)	Add 4" XPS to slab (to R_{eff}-30)

[2] Energy Conservation Measure (ECM) upgrades to the baseline assumptions as listed in Table E.1. Red cells indicate the overall compliance target was not met.

	Window performance	Upgrade to high performance windows (U-0.20)			Upgrade to high performance windows (U-0.14)	Upgrade to high performance windows (U-0.17)
	Ventilation upgrade	Install 70% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 70% efficient HRV and increase HRV duct insulation (to R-16)
	Heating system upgrade					
	DHW system upgrade	Upgrade to conserver tank and install DWHR system (65%)	Install DWHR system (65%)		Install DWHR system (65%)	
Climate Zone 8 - Yellowknife	Airtightness	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 1.0 ACH50	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 0.6 ACH50
	Roof				Add R-40 batt insulation to roof (to R_{eff}-100)	
	Exterior wall	Add 2" EPS to wall (to R_{eff}-25)	Add 5" EPS to walls (R_{eff}-35)	Add 3" EPS to wall (to R_{eff}-25)	Add 17" EPS to walls (to R_{eff}-80)	Add 3" EPS to wall (to R_{eff}-25)
	Exposed Floor	Add R-5 batt insulation to exposed floor (to R_{eff}-30)	Add R-30 batt insulation to exposed floor (to R_{eff}-60)	Add R-5 batt insulation to exposed floor (to R_{eff}-30)	Add R-50 batt insulation to exposed floor (to R_{eff}-80)	Add R-5 batt insulation to exposed floor (to R_{eff}-30)
	Window performance	Upgrade to high performance windows (U-0.20)		Upgrade to high performance windows (U-0.20)	Upgrade to high performance windows (U-0.11)	Upgrade to high performance windows (U-0.17)
	Ventilation upgrade	Install 70% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 70% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)
	Heating system upgrade					
	DHW system upgrade	Upgrade to conserver tank and install DWHR system (65%)	Install DWHR system (65%)		Upgrade to DHW system to heat pump and install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)
Climate	Airtightness	Airtightness improvement to 1.0 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 0.6 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 0.3 ACH50

	Roof				Add R-40 batt insulation to roof (to R_{eff}-100)	
	Exterior wall	Add 4" EPS to wall (to R_{eff}-28)	Add 9" EPS to walls (to R_{eff}-50)	Add 5" EPS to walls (to R_{eff}-35)	Add 17" EPS to walls (to R_{eff}-80)	Add 7" EPS to walls (to R_{eff}-40)
	Exposed Floor		Add R-30 batt insulation to exposed floor (to R_{eff}-60)	Add R-10 batt insulation to exposed floor (to R_{eff}-40)	Add R-50 batt insulation to exposed floor (to R_{eff}-80)	Add R-10 batt insulation to exposed floor (to R_{eff}-40)
	Window performance		Upgrade to high performance windows (U-0.18)	Upgrade to high performance windows (U-0.18)	Upgrade to high performance windows (U-0.11)	Upgrade to high performance windows (U-0.11)
	Ventilation upgrade	Install 70% efficient HRV and increase HRV duct insulation (to R-10)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)
	Heating system upgrade				Upgrade heating system to cold climate ASHP	
	DHW system upgrade		Install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)	Upgrade DHW system to heat pump and install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)

TABLE E.5 5-PLEX - ECM BUNDLES TO ACHIEVE STEP CODE[3]						
Step	Measure	**< 25% NBC 2015**	**Step 4**		**Step 5**	
CZ			**ESC (2017)**	**ESC (2018)**	**ESC (2017)**	**ESC (2018)**
Climate Zone 7a - Fort St. John	Airtightness	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.6 ACH50
	Roof	Add R-10 batt insulation to roof (to R_{eff}-40)	Add R-10 batt insulation to roof (to R_{eff}-40)	Add R-20 batt insulation to roof (to R_{eff}-50)	Add R-10 batt insulation to roof (to R_{eff}-45)	Add R-30 batt insulation to roof (to R_{eff}-60)
	Exterior wall	Add 5" EPS to walls (to R_{eff}-35)	Add 5" EPS to walls (to R_{eff}-35)	Add 1" EPS to walls (to R_{eff}-20)	Add 4" EPS to walls (to R_{eff}-30)	Add 2" EPS to walls (to R_{eff}-22)
	Slab	Add 3" XPS to slab (to R_{eff}-25)	Add 4" XPS to slab (to R_{eff}-30)	Add 1" XPS to slab (to R_{eff}-20)	Add 4" XPS to slab (to R_{eff}-30)	Add 1" XPS to slab (to R_{eff}-20)
	Window performance		Upgrade to high performance windows (U-0.18)	Upgrade to high performance windows (U-0.21)	Upgrade to high performance windows (U-0.21)	Upgrade to high performance windows (U-0.21)
	Ventilation upgrade	Install 81% efficient HRV and increase HRV duct insulation (to R-12)	Install 81% efficient HRV and increase HRV duct insulation (to R-12)	Install 81% efficient HRV and increase HRV duct insulation (to R-12)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)
	Heating system upgrade					Install cold climate heat pump
	DHW system upgrade	Upgrade to conserver tank and install DWHR system (65%)	Install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)	Upgrade to cold climate heat pump and install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)
Climate Zone 7b -	Airtightness	Airtightness improvement to 1.50 ACH50	Airtightness improvement to 1.00 ACH50	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 1.0 ACH50
	Roof	Add R-10 batt insulation to roof (to R_{eff}-40)	Add R-20 batt insulation to roof (to R_{eff}-50)	Add R-20 batt insulation to roof (to R_{eff}-50)	Add R-30 batt insulation to roof (to R_{eff}-60)	Add R-30 batt insulation to roof (to R_{eff}-60)

[3] Energy Conservation Measure (ECM) upgrades to the baseline assumptions as listed in Table E.1. Red cells indicate the overall compliance target was not met.

	Exterior wall	Add 5" EPS to walls (to R_{eff}-35)	Add 7" EPS to walls (to R_{eff}-40)	Add 1" EPS to walls (to R_{eff}-20)	Add 7" EPS to walls (to R_{eff}-40)	Add 2" EPS to walls (to R_{eff}-25)
	Slab	Add 5" XPS to slab (to R_{eff}-35)	Add 5" XPS to slab (to R_{eff}-35)	Add 1" XPS to slab (to R_{eff}-20)	Add 3" XPS to slab (to R_{eff}-25)	Add 1" XPS to slab (to R_{eff}-20)
	Window performance		Upgrade to high performance windows (U-0.18)	Upgrade to high performance windows (U-0.25)	Upgrade to high performance windows (U-0.18)	Upgrade to high performance windows (U-0.18)
	Ventilation upgrade	Install 81% efficient HRV and increase HRV duct insulation (to R-12)	Install 81% efficient HRV and increase HRV duct insulation (to R-12)	Install 81% efficient HRV and increase HRV duct insulation (to R-12)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)
	Heating system upgrade					Install cold climate heat pump
	DHW system upgrade	Upgrade to conserver tank and install DWHR system (65%)	Install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)	Upgrade to cold climate heat pump and install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)
Climate Zone 8 - Yellowknife	Airtightness	Airtightness improvement to 1.5 ACH50	Airtightness improvement to 0.5 ACH50	Airtightness improvement to 1.0 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.6 ACH50
	Roof	Add R-10 batt insulation to roof (to R_{eff}-40)	Add R-30 batt insulation to roof (to R_{eff}-60)	Add R-20 batt insulation to roof (to R_{eff}-50)	Add R-50 batt insulation to roof (to R_{eff}-80)	Add R-30 batt insulation to roof (to R_{eff}-60)
	Exterior wall	Add 5" EPS to walls (to R_{eff}-35)	Add 9" EPS to walls (to R_{eff}-50)	Add 4" EPS to walls (to R_{eff}-30)	Add 12" EPS to walls (to R_{eff}-60)	Add 4" EPS to walls (to R_{eff}-30)
	Exposed Floor	Add R-10 batt insulation to exposed floor (to R_{eff}-40)	Add R-40 batt insulation to exposed floor (to R_{eff}-70)	Add R-5 batt insulation to exposed floor (to R_{eff}-30)	Add R-30 batt insulation to exposed floor (to R_{eff}-60)	Add R-30 batt insulation to exposed floor (to R_{eff}-60)
	Window performance		Upgrade to high performance windows (U-0.15)	Upgrade to high performance windows (U-0.17)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.12)
	Ventilation upgrade	Install 81% efficient HRV and increase HRV duct insulation (to R-12)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)
	Heating system upgrade					Install cold climate heat pump

	DHW system upgrade	Install DWHR system (65%)	Install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)	Upgrade to DHW system to heat pump and install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)	
Climate Zone 8 - Resolute	Airtightness	Airtightness improvement to 1.0 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.3 ACH50	Airtightness improvement to 0.6 ACH50
	Roof	Add R-10 batt insulation to roof (to R_{eff}-35)	Add R-30 batt insulation to roof (to R_{eff}-60)	Add R-30 batt insulation to roof (to R_{eff}-60)	Add R-70 batt insulation to roof (to R_{eff}-100)	Add R-40 batt insulation to roof (to R_{eff}-70)	Add R-30 batt insulation to roof (to R_{eff}-60)
	Exterior wall	Add 1" EPS to walls (to R_{eff}-20)	Add 17" EPS to walls (to R_{eff}-80)	Add 4" EPS to walls (to R_{eff}-30)	Add 17" EPS to walls (to R_{eff}-80)	Add 9" EPS to walls (to R_{eff}-50)	Add 7" EPS to walls (to R_{eff}-40)
	Exposed Floor	Add R-5 batt insulation to exposed floor (to R_{eff}-35)	Add R-50 batt insulation to exposed floor (to R_{eff}-80)	Add R-5 batt insulation to exposed floor (to R_{eff}-35)	Add R-50 batt insulation to exposed floor (to R_{eff}-80)	Add R-30 batt insulation to exposed floor (to R_{eff}-60)	Add R-10 batt insulation to exposed floor (to R_{eff}-40)
	Window performance		Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.13)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.14)
	Ventilation upgrade	Install 81% efficient HRV and increase HRV duct insulation (to R-12)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)	Install 81% efficient HRV and increase HRV duct insulation (to R-16)
	Heating system upgrade				Upgrade heating system to cold climate ASHP	Install cold climate heat pump	Install cold climate heat pump
	DHW system upgrade	Install DWHR system (65%)	Install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)	Upgrade DHW system to heat pump and install DWHR system (65%)	Upgrade to conserver tank and install DWHR system (65%)	Upgrade to cold climate heat pump and install DWHR system (65%)

TABLE E.6	PASSIVE HOUSE - ECM BUNDLES TO PASSIVE HOUSE[4]	
Step / **CZ**	Measure	**Passive House/highest performing practical ECMs**
All Climate Zones	Airtightness	Airtightness improvement to 0.15 ACH50
	Roof	R-70 batt insulation to roof (to R_{eff}-100)
	Exterior wall	Add 17" EPS to walls (to R_{eff}-80)
	Slab / Exposed Floor	Add 11" XPS to slab (to R_{eff}-40) / Add R-50 batt insulation to exposed floor (to R_{eff}-80)
	Window performance	Upgrade to high performance window (U-0.12)
	Ventilation upgrade	Install 81% efficient HRV / Increase HRV duct insulation (to R-16)
	Heating system upgrade	Upgrade heating system to cold climate ASHP
	DHW system upgrade	Upgrade to heat pump DHW. Install DWHR system (65%)

[4] Energy Conservation Measure (ECM) upgrades to the baseline assumptions as listed in Table E.2. Red cells indicate the overall compliance target was not met.

Appendix F

Part 3 Compliance Modelling Inputs

TABLE F.1 BASELINE KEY MODEL INPUTS FOR MULTI-UNIT RESIDENTIAL ARCHETYPE			
Description	**Units**	**BASELINE**	
		Value	**Notes and References**
Site Information			
Location	-	Fort St. John / Whitehorse / Yellowknife, Resolute	CZ7a / CZ7b / CZ8
Weather File	-	CWEC 2016	
Building Geometry			
Storeys	-	3	Above ground
Total conditioned area	m^2	2,929 (Articulated) 2,939 (Simple form)	
Breakdown of Space Type	-	29 suites 3 corridors 1 lobby 1 elevator	
Base Loads			
Occupants - Suites	m^2/occupant	29	Assumed based on 3ppl/suite NECB 2011 Schedule Table A-8.4.3.2.(1)G
Occupants – Corridors	m^2/occupant	100	NECB 2011 Table A-8.4.3.3.(1)B NECB 2011 Schedule Table A-8.4.3.2.(1)G
Plug Loads - Electrical Appliances	W/m^2	5	NECB 2011 Table A-8.4.3.3.(1)A NECB 2011 Schedule Table A-8.4.3.2.(1)G
Plug Loads – Elevator	W	3000	City of Vancouver Modelling Guideline. NECB 2011 Schedule Table A-8.4.3.2.(1)G
Interior Lighting – Suites	W/m^2	5.0	NECB 2011 Sentence 8.4.3.5(1) NECB 2011 Schedule Table A-8.4.3.2.(1)G
Interior Lighting – Corridors	W/m^2	8.4	NECB 2011 Table 4.2.1.6 Always on
Exterior Lighting	W	600	NECB 2011 Table 4.2.3.1.B Always on
Building Enclosure			
Exterior Wall RSI_{eff}	$(m^2K)/W$	4.8 / 4.8 / 5.5	CZ7a / CZ7b / CZ8 NECB 2011 Table
Ceiling (Attic) RSI_{eff}	$(m^2K)/W$	6.2 / 6.2 / 7.0	CZ7a / CZ7b / CZ8 NECB 2011 Table

Exposed Floor RSI_{eff}	(m²K)/W	6.2 / 6.2 / 7.0	CZ7a / CZ7b / CZ8 NECB 2011 Table
Window U-Value	W/(m²K)	2.2 / 2.2 / 1.6	CZ7a / CZ7b / CZ8 NECB 2011 Table
Window SHGC	-	0.4	
Window to Wall Ratio (overall)	%	17% (Articulated) 9% (Simple form)	
Heating System			
System Description	-	Electric baseboards	
Output Capacity	kW	Variable[1]	Calculated in EnergyPlus
Baseboard Efficiency	%	100	
Heating Setpoint Temperature	°C	22 daytime 18 nighttime	NECB 2011 Schedule Table A-8.4.3.2.(1)G
Domestic Hot Water			
System Description	-	Electric	
Water Temperature	°C	60	
Service Water Heating Load	W/person	500	NECB 2011 Table A-8.4.3.3.(1)A NECB 2011 Schedule Table A-8.4.3.2.(1)G
Ventilation			
System Description	-	In-suite HRVs, with electric pre-heat. Make-up air unit supplying corridors, system includes electric heating coil.	
Minimum Outdoor Air	%	100	
Total Supply Flow Rate	L/s	1,081	Corridor: 9 L/s/door Suite: 28.3 L/s/suite
Total Exhaust Flow Rate	L/s	1,081	Corridor: 9 L/s/door Suite: 28.3 L/s/suite
Combined fan-motor efficiency	%	40	NECB 2011 Sentence 8.4.4.19(3)
Fan Pressure	Pa	640	NECB 2011 Sentence 8.4.4.19(3)
HRV Efficiency	%	50	NECB 2011 Sentence 5.2.10.4(5)
Other Fans	L/s	71 @ 2 hr/day	Direct exhaust (kitchen 47 L/s, bathroom 24 L/s) Note, kitchen exhaust is not included in Passive House archetypes.

[1] The same cold climate air source heat pump has been modelled. The performance is based on the outdoor air temperature.

TABLE F.2 MURB ARTICULATED - ECM BUNDLES TO ACHIEVE STEP CODE AND PASSIVE HOUSE TARGETS[2]				
	Measure	**< 25% NECB 2011**	**Step 4**	**Passive House**
Climate Zone 7a - Fort St. John	Airtightness	Airtightness improvement to 1.1 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.15 ACH50
	Roof		Add 5” XPS to roof (to R_{eff}-53)	Add 16” XPS to roof (to R_{eff}-100)
	Exterior wall		Add 4" EPS to walls (to R_{eff}-41)	Add 15" EPS to walls (to R_{eff}-80)
	Exposed Floor		Add R-15 batt insulation to exposed floor (to R_{eff}-50)	Add R-45 batt insulation to exposed floor (to R_{eff}-80)
	Window performance	Upgrade to vinyl triple pane, argon fill windows (U-0.17)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.12)
	Ventilation upgrade	Upgrade to 70% efficiency in-suite HRVs	Install centralized ventilation system with 81% efficient HRV	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)
	Heating system upgrade			Upgrade heating system to cold climate ASHP
	DHW system upgrade			Upgrade to heat pump DHW
Climate Zone 7b - Whitehorse	Airtightness	Airtightness improvement to 1.1 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.15 ACH50
	Roof		Add 10” XPS to roof (to R_{eff}-76)	Add 16” XPS to roof (to R_{eff}-100)
	Exterior wall		Add 10" EPS to walls (to R_{eff}-61)	Add 15" EPS to walls (to R_{eff}-80)
	Exposed Floor		Add R-35 batt insulation to exposed floor (to R_{eff}-70)	Add R-45 batt insulation to exposed floor (to R_{eff}-80)
	Window performance	Upgrade to vinyl triple pane, argon fill windows (U-0.17)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.12)
	Ventilation upgrade	Upgrade to 70% efficiency in-suite HRVs	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)

[2] Energy Conservation Measures (ECMs) upgrades to the baseline assumptions as listed in Table F.1. Red cells indicate the compliance target was not met.

	Heating system upgrade			Upgrade heating system to cold climate ASHP
	DHW system upgrade			Upgrade to heat pump DHW
Climate Zone 8 (urban) - Yellowknife	Airtightness	Airtightness improvement to 1.1 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.15 ACH50
	Roof		Add 15” XPS to roof (to R_{eff}-100)	Add 15” XPS to roof (to R_{eff}-100)
	Exterior wall		Add 13" EPS to walls (to R_{eff}-80)	Add 13" EPS to walls (to R_{eff}-80)
	Exposed Floor		Add R-40 batt insulation to exposed floor (to R_{eff}-80)	Add R-40 batt insulation to exposed floor (to R_{eff}-80)
	Window performance	Upgrade to vinyl triple pane, argon fill windows (U-0.17)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.12)
	Ventilation upgrade	Upgrade to 70% efficiency in-suite HRVs	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)
	Heating system upgrade		Upgrade heating system to cold climate ASHP	Upgrade heating system to cold climate ASHP
	DHW system upgrade		Upgrade to heat pump DHW	Upgrade to heat pump DHW
Climate Zone 8 (remote) - Resolute	Airtightness	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.15 ACH50
	Roof		Add 15” XPS to roof (to R_{eff}-100)	Add 15” XPS to roof (to R_{eff}-100)
	Exterior wall		Add 13" EPS to walls (to R_{eff}-80)	Add 13" EPS to walls (to R_{eff}-80)
	Exposed Floor		Add R-40 batt insulation to exposed floor (to R_{eff}-80)	Add R-40 batt insulation to exposed floor (to R_{eff}-80)
	Window performance	Upgrade to vinyl triple pane, argon fill windows (U-0.17)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.12)

	Ventilation upgrade	Upgrade to 70% efficiency in-suite HRVs	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)
	Heating system upgrade		Upgrade heating system to cold climate ASHP	Upgrade heating system to cold climate ASHP
	DHW system upgrade		Upgrade to heat pump DHW	Upgrade to heat pump DHW

TABLE F.3 MURB SIMPLE FORM - ECM BUNDLES TO ACHIEVE STEP CODE AND PASSIVE HOUSE TARGETS [3]				
		< 25% NECB 2011	**Step 4**	**Passive House**
Climate Zone 7a - Fort St. John	Airtightness	Airtightness improvement to 1.1 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.15 ACH50
	Roof	Add 1" XPS to roof (to R_{eff}-39)	Add 1" XPS to roof (to R_{eff}-39)	Add 16" XPS to roof (to R_{eff}-100)
	Exterior wall	Add 1" EPS to wall to R_{eff}-32)	Add 1" EPS to walls (to R_{eff}-32)	Add 15" EPS to walls (to R_{eff}-80)
	Exposed Floor	Add R-5 batt insulation to exposed floor (to R_{eff}-41)	Add R-5 batt insulation to exposed floor (to R_{eff}-41)	Add R-45 batt insulation to exposed floor (to R_{eff}-80)
	Window performance	Upgrade to vinyl triple pane, argon fill windows (U-0.17)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.12)
	Ventilation upgrade	Upgrade to 70% efficiency in-suite HRVs	Install centralized ventilation system with 81% efficient HRV	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)
	Heating system upgrade			Upgrade heating system to cold climate ASHP
	DHW system upgrade			Upgrade to heat pump DHW
Climate Zone 7b - Whitehorse	Airtightness	Airtightness improvement to 1.1 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.15 ACH50
	Roof	Add 1" XPS roof (to R_{eff}-39)	Add 3" XPS to roof (to R_{eff}-48)	Add 16" XPS to roof (to R_{eff}-100)
	Exterior wall	Add 1" EPS to wall to R_{eff}-32)	Add 4" EPS to walls (to R_{eff}-40)	Add 15" EPS to walls (to R_{eff}-80)
	Exposed Floor	Add R-5 insulation to exposed floor (to R_{eff}-41)	Add R-5 batt insulation to exposed floor (to R_{eff}-41)	Add R-45 batt insulation to exposed floor (to R_{eff}-80)
	Window performance	Upgrade to vinyl triple pane, argon fill windows (U-0.17)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.12)
	Ventilation upgrade	Upgrade to 70% efficiency in-suite HRVs	Install centralized ventilation system with 81% efficient HRV	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)
	Heating system upgrade			Upgrade heating system to cold climate ASHP
	DHW system upgrade			Upgrade to heat pump DHW

[3] Energy Conservation Measures (ECMs) upgrades to the baseline assumptions as listed in Table F.1. Red cells indicate the compliance target was not met.

Climate Zone 8 - Yellowknife	Airtightness	Airtightness improvement to 1.1 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.15 ACH50
	Roof		Add 15” XPS to roof (to R_{eff}-100)	Add 15” XPS to roof (to R_{eff}-100)
	Exterior wall	Add 3" EPS to wall (to R_{eff}-40)	Add 13" EPS to walls (to R_{eff}-80)	Add 13" EPS to walls (to R_{eff}-80)
	Exposed Floor		Add R-40 batt insulation to exposed floor (to R_{eff}-80)	Add R-40 batt insulation to exposed floor (to R_{eff}-80)
	Window performance	Upgrade to vinyl triple pane, argon fill windows (U-0.17)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.12)
	Ventilation upgrade	Upgrade to 70% efficiency in-suite HRVs	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)
	Heating system upgrade		Upgrade heating system to cold climate ASHP	Upgrade heating system to cold climate ASHP
	DHW system upgrade		Upgrade to heat pump DHW	Upgrade to heat pump DHW
Climate Zone 8 - Resolute	Airtightness	Airtightness improvement to 1.1 ACH50	Airtightness improvement to 0.15 ACH50	Airtightness improvement to 0.15 ACH50
	Roof		Add 15” XPS to roof (to R_{eff}-100)	Add 15” XPS to roof (to R_{eff}-100)
	Exterior wall		Add 13" EPS to walls (to R_{eff}-80)	Add 13" EPS to walls (to R_{eff}-80)
	Slab		Add R-40 batt insulation to exposed floor (to R_{eff}-80)	Add R-40 batt insulation to exposed floor (to R_{eff}-80)
	Window performance	Upgrade to vinyl triple pane, argon fill windows (U-0.17)	Upgrade to high performance windows (U-0.12)	Upgrade to high performance windows (U-0.12)
	Ventilation upgrade	Upgrade to 70% efficiency in-suite HRVs	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)	Install centralized ventilation system with 81% efficient HRV. Reduce MUA flow rate to corridors (to 10 cfm/door)
	Heating system upgrade		Upgrade heating system to cold climate ASHP	Upgrade heating system to cold climate ASHP
	DHW system upgrade		Upgrade to heat pump DHW	Upgrade to heat pump DHW

Appendix G

Part 9 Compliance Modelling Results

TABLE G.1 BC ENERGY STEP CODE AND PASSIVE HOUSE COMPLIANCE TARGETS					
BC ENERGY STEP CODE TARGETS – PART 9[1]					
Climate Zone	**Compliance**	**MEUI**	**ERS**	**TEDI**	**PTL**
		kWh/ m^2_{GFA}/yr	%	kWh/m^2_{GFA}/yr	W/m^2_{GFA}
All	Step 4 (2017)	55	40	50	45
	Step 5 (2017)	25	n/a	15	10
7a	Step 4 (2018)	70	40	55	n/a
	Step 5 (2018)	55	n/a	35	n/a
7b	Step 4 (2018)	85	40	65	n/a
	Step 5 (2018)	65	n/a	50	n/a
8	Step 4 (2018)	100	40	80	n/a
	Step 5 (2018)	75	n/a	60	n/a
	PASSIVE HOUSE TARGETS[2]				
	Compliance	**PER**	**Heating demand**	**Heating Load**	
		kWh/ m^2_{TFA}/yr	kWh/ m^2_{GFA}/yr	W/m^2_{GFA}	
	Passive House Classic	60	15	10	

[1] BC Energy Step Code is a performance based standard. Overall compliance for each step can be met with MEUI or %<ERS and TEDI or PTL.
2 Passive House Classic is a performance based standard. Overall compliance can be met with Heating Demand or Heating Load. PER must be met.

TABLE G.2 SUMMARY OF PART 9 SINGLE FAMILY DWELLING ARITCULATED MODEL STEP CODE RESULTS[3]						
Location	Compliance target[4]	TEUI[5]	MEUI	%<ERS	TEDI	PTL
		kWh/m²$_{GFA}$/yr	kWh/m²$_{GFA}$/yr	%	kWh/m²$_{GFA}$/yr	W/m²$_{GFA}$
Climate Zone 7a - Fort St. John	NBC 2015	166	124	6	95	68
	25% < NBC 2015	121	78	39	49	43
	Step 4 (2017)	120	77	40	48	43
	Step 5 (2017)	67	24	n/a	15	25
	Step 4 (2018)	116	73	43	52	n/a
	Step 5 (2018)	95	52	n/a	33	n/a
Climate Zone 7b - Whitehorse	NBC 2015	183	140	0	110	73
	25% < NBC 2015	136	93	34	63	47
	Step 4 (2017)	123	80	43	50	42
	Step 5 (2017)	67	24	n/a	15	23
	Step 4 (2018)	127	85	40	63	n/a
	Step 5 (2018)	108	65	n/a	45	n/a
Climate Zone 8 (urban) - Yellowknife	NBC 2015	219	177	1	146	75
	25% < NBC 2015	160	117	33	86	49
	Step 4 (2017)	121	78	55	48	34
	Step 5 (2017)	68	26	n/a	20	22
	Step 4 (2018)	142	99	43	77	n/a
	Step 5 (2018)	117	74	n/a	52	n/a
Climate Zone 8 (remote) - Resolute	NBC 2015	326	283	1	252	77
	25% < NBC 2015	239	197	30	165	54
	Step 4 (2017)	122	80	71	49	25
	Step 5 (2017)	88	45	n/a	43	22
	Step 4 (2018)	145	102	63	80	n/a
	Step 5 (2018)	116	73	n/a	60	n/a

[3] Light green cells indicate compliance metric was met. Light orange cells indicate compliance metric was not met but overall compliance was achieved through the alternative metric. Ex. MEUI or %ERS, TEDI or PTL. Light red cells indicate compliance metric was not met.

[4] Dark green cells indicate overall compliance was met. Dark red cells indicate overall compliance was not met.

[5] TEUI is not part of the Part 9 Energy Step code metrics but it is included here for reference.

TABLE G.3 SUMMARY OF PART 9 SINGLE FAMILY DWELLING ARTICULATED MODEL PASSIVE HOUSE RESULTS [6]			
Location	**PER**	**Heating Demand**	**Heating Load**
	kWh/m²$_{TFA}$/yr	**kWh/m²$_{TFA}$/yr**	**kWh/m²$_{TFA}$**
Climate zone 7a - Fort St. John	57	43	23
Climate zone 7b - Whitehorse	65	53	27
Climate zone 8 (urban) - Yellowknife	90	72	29
Climate zone 8 (remote) - Resolute	152	121	32

TABLE G.4 SUMMARY OF PART 9 SINGLE FAMILY DWELLING SIMPLE FORM STEP CODE RESULTS[7]						
Location	**Compliance target**	**TEUI[8]**	**MEUI**	**%<ERS**	**TEDI**	**PTL**
		kWh/m²$_{GFA}$/yr	**kWh/m²$_{GFA}$/yr**	**%**	**kWh/m²$_{GFA}$/yr**	**W/m²$_{GFA}$**
Climate Zone 7a - Fort St. John	NBC 2015	135	92	19	63	53
	25 % < NBC 2015	98	55	51	37	37
	Step 4 (2017)	107	65	43	47	44
	Step 5 (2017)	66	24	n/a	6	19
	Step 4 (2018)	113	71	40	42	n/a
	Step 5 (2018)	5	53	n/a	32	n/a
Climate Zone 7b - Whitehorse	NBC 2015	148	140	0	110	73
	25 % < NBC 2015	112	93	34	63	47
	Step 4 (2017)	98	80	43	50	42
	Step 5 (2017)	68	25	n/a	7	18
	Step 4 (2018)	124	81	37	51	n/a
	Step 5 (2018)	107	64	n/a	34	n/a
Climate Zone 8 (urban) - Yellowknife	NBC 2015	179	136	10	106	60
	25 % < NBC 2015	132	89	41	71	44
	Step 4 (2017)	107	65	57	46	34
	Step 5 (2017)	56	14	n/a	9	16
	Step 4 (2018)	139	97	38	66	n/a
	Step 5 (2018)	116	74	n/a	52	n/a

[6] Red cells indicate compliance metric / overall compliance was not met. Green cells indicate compliance metric/overall compliance was met.

[7] Green cells indicate compliance metric/overall compliance was met. Orange cells indicate compliance metric was not met but compliance was achieved through the alternative metric. Ex. MEUI or %ERS, TEDI or PTL. Red cells indicate overall compliance was not met.

[8] TEUI is not part of the Part 9 Energy Step code metrics but it is included here for reference.

Climate Zone 8 (remote) - Resolute	NBC 2015	263	220	9	189	61
	25 % < NBC 2015	195	153	37	134	46
	Step 4 (2017)	107	64	73	45	24
	Step 5 (2017)	70	27	n/a	23	16
	Step 4 (2018)	139	96	60	73	n/a
	Step 5 (2018)	116	74	n/a	51	n/a

TABLE G.5 SUMMARY OF PART 9 SINGLE FAMILY DWELLING SIMPLE FORM PASSIVE HOUSE RESULTS

Location	PER	Heating Demand	Heating Load
	$kWh/m^2_{TFA}/yr$	$kWh/m^2_{TFA}/yr$	kWh/m^2_{TFA}
Climate zone 7a - Fort St. John	43	25	16
Climate zone 7b - Whitehorse	50	33	19
Climate zone 8 (urban) - Yellowknife	66	46	20
Climate zone 8 (remote) - Resolute	111	81	23

TABLE G.6 SUMMARY OF PART 9 5-PLEX STEP CODE RESULTS[9]					
Location	Compliance target	TEUI[10]	MEUI	TEDI	PTL
		kWh/m²$_{GFA}$/yr	kWh/m²$_{GFA}$/yr	kWh/m²$_{GFA}$/yr	W/m²$_{GFA}$
Climate Zone 7a – Fort St. John	NBC 2015	204	116	60	54
	25% < NBC 2015	152	64	29	36
	Step 4 (2017)	141	53	18	32
	Step 5 (2017)	112	25	12	25
	Step 4 (2018)	158	70	27	-
	Step 5 (2018)	143	55	17	-
Climate Zone 7b - Whitehorse	NBC 2015	218	130	72	59
	25% < NBC 2015	162	74	39	41
	Step 4 (2017)	143	55	19	31
	Step 5 (2017)	112	24	11	23
	Step 4 (2018)	170	82	38	-
	Step 5 (2018)	150	62	23	-
Climate Zone 8 (urban) - Yellowknife	NBC 2015	264	176	116	67
	25% < NBC 2015	200	112	75	49
	Step 4 (2017)	143	55	19	25
	Step 5 (2017)	112	24	12	21
	Step 4 (2018)	183	95	49	-
	Step 5 (2018)	163	75	36	-
Climate Zone 8 (remote) - Resolute	NBC 2015	353	265	208	68
	25% < NBC 2015	266	178	142	51
	Step 4 (2017)	141	53	17	18
	Step 5 (2017)	116	28	17	18
	Step 4 (2018)	187	99	52	-
	Step 5 (2018)	161	73	33	-
	Step 5 HP DHW	162	74	59	-

[9] Light green cells indicate compliance metric was met. Light orange cells indicate compliance metric was not met but overall compliance was achieved through the alternative metric. Ex. MEUI or %ERS, TEDI or PTL. Red cells indicate overall compliance was not met.

[10] TEUI is not part of the Part 9 Energy Step code metrics but it is included here for reference.

TABLE G.1 SUMMARY OF PART 9 5-PLEX PASSIVE HOUSE RESULTS			
Location	PER	Heating Demand	Heating Load
	kWh/m²TFA/yr	kWh/m²TFA/yr	kWh/m²TFA
Climate zone 7a - Fort St. John	62	39	20
Climate zone 7b - Whitehorse	67	45	22
Climate zone 8 (urban) - Yellowknife	84	55	20
Climate zone 8 (remote) - Resolute	133	90	22

Appendix H

Part 3 Compliance Modelling Results

TABLE H.1 BC ENERGY STEP CODE AND PASSIVE HOUSE COMPLIANCE TARGETS			
BC ENERGY STEP CODE TARGETS – PART 3[1]			
Compliance	**TEDI**		**TEUI**
	kWh/m²$_{GFA}$/yr		**kWh/m²$_{GFA}$/yr**
Step 4	100		15
PASSIVE HOUSE TARGETS[2]			
Compliance	**PER**	**Heating demand**	**Heating Load**
	kWh/m²$_{TFA}$/yr	**kWh/m²$_{TFA}$/yr**	**W/m²$_{TFA}$**
Passive House Classic	60	15	10

TABLE H.2 SUMMARY OF PART 3 ARTICULATED MULTI-UNIT RESIDENTIAL BUILDING STEP CODE RESULTS[3]			
Location	**Compliance target**	**TEUI**	**TEDI**
		kWh/m²$_{GFA}$/yr	**kWh/m²$_{GFA}$/yr**
Climate Zone 7a - Fort St. John	NECB 2011	192	114
	25% < NECB 2011	143	65
	Step 4	93	14
Climate Zone 7b - Whitehorse	NECB 2011	221	143
	25% < NECB 2011	161	83
	Step 4	93	15
Climate Zone 8 (urban) - Yellowknife	NECB 2011	260	181
	25% < NECB 2011	197	116
	Step 4	73	19

1 BC Energy Step Code for Part 3 buildings is a performance based standard. Building must achieve both TEUI and TEDI to demonstrate compliance to each step.

2 Passive House Classic is a performance based standard. Overall compliance can be met with Heating Demand or Heating Load. PER must be met.

3 Green cells indicate compliance metric/overall compliance was met. Red cells indicate overall compliance was not met.

Climate Zone 8 (remote) – Resolute	NECB 2011	377	299
	25% < NECB 2011	280	202
	Step 4	97	36

TABLE H.3 SUMMARY OF PART 3 ARTICULATED MULTI-UNIT RESIDENTIAL BUILDING PASSIVE HOUSE RESULTS

Location	PER	Heating demand	Heating Load
	$kWh/m^2_{TFA}/yr$	$kWh/m^2_{TFA}/yr$	W/m^2_{TFA}
Climate zone 7a - Fort St. John	53	24	15
Climate zone 7b - Whitehorse	57	29	18
Climate zone 8 (urban) - Yellowknife	73	42	18
Climate zone 8 (remote) - Resolute	112	73	20

TABLE H.4 SUMMARY OF PART 3 MULTI-UNIT RESIDENTIAL BUILDING SIMPLE FORM STEP CODE RESULTS

Location	Compliance target	TEUI	TEDI
		$kWh/m^2_{GFA}/yr$	$kWh/m^2_{GFA}/yr$
Climate Zone 7a - Fort St. John	NBC 2015	171	92
	25% < NBC 2015	128	52
	Step 4	92	13
Climate Zone 7a - Whitehorse	NBC 2015	193	114
	25% < NBC 2015	145	66
	Step 4	93	14
Climate Zone 8 (urban) - Yellowknife	NBC 2015	230	151
	25% < NBC 2015	173	94
	Step 4	92	13

Climate Zone 8 (remote) - Resolute			
	NBC 2015	330	251
	25% < NBC 2015	247	168
	Step 4	86	25

TABLE H.5 SUMMARY OF PART 3 MULTI-UNIT RESIDENTIAL BUILDING SIMPLE FORM PASSIVE HOUSE RESULTS[4]

Location	**PER**	**Heating demand**	**Heating Load**
	kWh/m²$_{TFA}$/yr	**kWh/m²$_{TFA}$/yr**	**W/m²$_{TFA}$**
Climate zone 7a - Fort St. John	42	11	9
Climate zone 7b - Whitehorse	45	13	10
Climate zone 8 (urban) - Yellowknife	55	23	11
Climate zone 8 (remote) - Resolute	78	41	13

[4] Green cells indicate compliance metric/overall compliance was met. Red cells indicate compliance metric / overall compliance was not met.

Appendix I

Part 3 Incremental Cost Results

TABLE I.1 SUMMARY OF INCREMENTAL CAPITAL COSTS FOR PART 3 BUILDINGS ($/M²)							
		Articulated Form			**Simple Form**		
Compliance Target	**Location**	**Low**	**Average**	**High**	**Low**	**Average**	**High**
25% < NEBC 2011	Climate Zone 7a - Fort St. John	$ 19	$ 23	$ 30	$ 23	$ 29	$ 36
	Climate Zone 7b - Whitehorse	$ 7	$ 8	$ 10	$ 24	$ 29	$ 37
	Climate Zone 8 - Yellowknife	$ 9	$ 11	$ 13	$ 24	$ 29	$ 36
	Climate Zone 8 - Resolute	$ 12	$ 15	$ 18	$ 9	$ 12	$ 14
Step 4	Climate Zone 7a - Fort St. John	$ 57	$ 71	$ 84	$ 6	$ 7	$ 9
	Climate Zone 7b - Whitehorse	$ 113	$ 140	$ 167	$ 30	$ 37	$ 45
	Climate Zone 8 - Yellowknife	-	-	-	$ 158	$ 196	235
	Climate Zone 8 - Resolute	-	-	-	-	-	-
Passive House	Climate Zone 7a - Fort St. John	$ 225	$ 273	$ 322	$ 160	$ 195	$ 229
	Climate Zone 7b - Whitehorse	-	-	-	$ 214	$ 260	$ 307
	Climate Zone 8 - Yellowknife	-	-	-	-	-	-
	Climate Zone 8 - Resolute	-	-	-	-	-	-
Highest Practical ECMs	Climate Zone 7a - Fort St. John	$ 225	$ 273	$ 322	$ 160	$ 195	$ 229
	Climate Zone 7b - Whitehorse	$ 248	$ 303	$ 357	$ 214	$ 260	$ 307
	Climate Zone 8 - Yellowknife	$ 285	$ 347	$ 408	$ 225	$ 274	$ 323
	Climate Zone 8 - Resolute	$ 466	$ 565	$ 665	$ 356	$ 432	$ 508

TABLE I.2 SUMMARY OF PART 3 BUILDINGS – INCREMENTAL COST AS PERCENTAGE OF BASELINE TOTAL COST OF CONSTRUCTION

Target	Geometry	Location	ICC ($/m²)	Baseline Total Project Cost ($/m²)	% Incremental Cost
25% < NECB 2011	Articulated Form	Climate Zone 7a - Fort St. John	$ 23	$ 1887	1%
		Climate Zone 7b - Whitehorse	$ 8	$ 2186	0%
		Climate Zone 8 - Yellowknife	$ 11	$ 3110	0%
		Climate Zone 8 - Resolute	$ 15	$ 5030	0%
	Simple Form	Climate Zone 7a - Fort St. John	$ 29	$ 1887	2%
		Climate Zone 7b - Whitehorse	$ 29	$ 2186	1%
		Climate Zone 8 - Yellowknife	$ 29	$ 3110	1%
		Climate Zone 8 - Resolute	$ 12	$ 5030	0%
Step 4	Articulated Form	Climate Zone 7a - Fort St. John	$ 71	$ 1887	4%
		Climate Zone 7b - Whitehorse	$ 140	$ 2186	6%
		Climate Zone 8 - Yellowknife	Target not met		
		Climate Zone 8 - Resolute	Target not met		
	Simple Form	Climate Zone 7a - Fort St. John	$ 7	$ 1887	0%
		Climate Zone 7b - Whitehorse	$ 37	$ 2186	2%
		Climate Zone 8 - Yellowknife	$ 196	$ 3110	6%
		Climate Zone 8 - Resolute	Target not met		
Passive House	Articulated Form	Climate Zone 7a - Fort St. John	$ 273	$ 1887	14%
		Climate Zone 7b - Whitehorse	Target not met		
		Climate Zone 8 - Yellowknife	Target not met		
		Climate Zone 8 - Resolute	Target not met		
	Simple Form	Climate Zone 7a - Fort St. John	$ 195	$ 1887	10%
		Climate Zone 7b - Whitehorse	$ 260	$ 2186	12%
		Climate Zone 8 - Yellowknife	Target not met		
		Climate Zone 8 - Resolute	Target not met		
Max ECM	Articulated Form	Climate Zone 7a - Fort St. John	$ 273	$ 1887	14%
		Climate Zone 7b - Whitehorse	$ 303	$ 2186	14%
		Climate Zone 8 - Yellowknife	$ 347	$ 3110	11%
		Climate Zone 8 - Resolute	$ 565	$ 5030	11%
	Simple Form	Climate Zone 7a - Fort St. John	$ 195	$ 1887	10%
		Climate Zone 7b - Whitehorse	$ 260	$ 2186	12%
		Climate Zone 8 - Yellowknife	$ 274	$ 3110	9%
		Climate Zone 8 - Resolute	$ 432	$ 5030	9%

Appendix J

Part 9 Incremental Cost Results

TABLE J.1 SUMMARY OF INCREMENTAL CAPITAL COSTS FOR PART 9 BUILDINGS ($/M²)

		Articulated Form SFD			Simple Form SFD			5-Plex		
Compliance Target	**Location**	**Low**	**Average**	**High**	**Low**	**Average**	**High**	**Low**	**Average**	**High**
25% < NBC 2015	Climate Zone 7a - Fort St. John	$ 154	$ 193	$ 232	$ 149	$ 187	$ 225	$ 179	$ 225	$ 272
	Climate Zone 7b - Whitehorse	$ 318	$ 397	$ 477	$ 158	$ 199	$ 239	$ 250	$ 313	$ 378
	Climate Zone 8 - Yellowknife	$ 230	$ 288	$ 354	$ 126	$ 159	$ 191	$ 67	$ 86	$ 105
	Climate Zone 8 - Resolute	$ 298	$ 376	$ 467	$ 187	$ 238	$ 288	$ 95	$ 122	150
Step 4 (2017)	Climate Zone 7a - Fort St. John	$ 146	$ 185	$ 223	$ 142	$ 179	$ 216	$ 196	$ 247	$ 298
	Climate Zone 7b - Whitehorse	$ 378	$ 473	$ 567	$ 230	$ 289	$ 348	$ 277	$ 348	$ 419
	Climate Zone 8 - Yellowknife	$ 482	$ 602	$ 729	$ 297	$ 373	$ 449	$ 213	$ 268	$ 324
	Climate Zone 8 - Resolute	$ 1113	$ 1383	$ 1653	$ 571	$ 713	$ 862	$ 524	$ 669	$ 804
Step 4 (2018)	Climate Zone 7a - Fort St. John	$ 74	$ 95	$ 115	$ 72	$ 92	$ 111	$ 100	$ 126	$ 153
	Climate Zone 7b - Whitehorse	$ 339	$ 423	$ 507	$ 124	$ 157	$ 189	$ 101	$ 128	$ 155
	Climate Zone 8 - Yellowknife	$ 305	$ 381	$ 464	$ 104	$ 133	$ 161	$ 102	$ 130	$ 160
	Climate Zone 8 - Resolute	$ 781	$ 974	$ 1167	$ 363	$ 454	$ 552	$ 241	$ 304	$ 367
Step 5 (2017)	Climate Zone 7a - Fort St. John	$ 338	$ 422	$ 510	$ 328	$ 410	$ 494	$ 218	$ 274	$ 330
	Climate Zone 7b - Whitehorse	$ 910	$ 1130	$ 1349	$ 608	$ 759	$ 909	$ 264	$ 331	$ 398
	Climate Zone 8 - Yellowknife	-	-	-	$ 823	$ 1024	$ 1226	$ 239	$ 300	$ 361
	Climate Zone 8 - Resolute	-	-	-	-	-	-	-	-	-
Step 5 (2018)	Climate Zone 7a - Fort St. John	$ 160	$ 201	$ 242	$ 156	$ 195	$ 235	$ 167	$ 348	$ 253
	Climate Zone 7b - Whitehorse	$ 419	$ 523	$ 634	$ 195	$ 244	$ 297	$ 197	$ 210	$ 300
	Climate Zone 8 - Yellowknife	$ 374	$ 467	$ 560	$ 220	$ 276	$ 336	$ 197	248	300
	Climate Zone 8 - Resolute	$ 866	$ 1084	$ 1302	$ 633	$ 790	$ 947	$ 277[1] $ 289[2]	$ 348[1] $ 414[2]	$ 420[1] $ 500[2]
Highest Performing Practical ECMs	Climate Zone 7a - Fort St. John	$ 853	$ 1063	$ 1272	$ 827	$ 1030	$ 1234	$ 497	$ 622	$ 746
	Climate Zone 7b - Whitehorse	$ 1115	$ 1384	$ 1652	$ 927	$ 1155	$ 1382	$ 495	$ 618	$ 742
	Climate Zone 8 - Yellowknife	$ 1088	$ 1350	$ 1613	$ 896	$ 1116	$ 1336	$ 349	$ 436	$ 524
	Climate Zone 8 - Resolute	$ 1767	$ 2192	$ 2617	$ 1560	$ 1941	$ 2321	$ 562	$ 703	$ 844

[1] 5-Plex alternate compliance path – Bundle 1
[2] 5-Plex alternate compliance path – Bundle 2

TABLE J.2 SUMMARY OF PART 9 BUILDINGS – INCREMENTAL COST AS PERCENTAGE OF BASELINE TOTAL COST OF CONSTRUCTION					
Target	**Geometry**	**Location**	**ICC ($/m²)**	**Baseline Total Project Cost ($/m²)**	**% Incremental Cost**
25% < NCB 2015	Articulated Form	Climate Zone 7a - Fort St. John	$ 193	$ 2227	9%
		Climate Zone 7b - Whitehorse	$ 397	$ 2580	15%
		Climate Zone 8 - Yellowknife	$ 288	$ 2927	10%
		Climate Zone 8 - Resolute	$ 376	$ 4734	8%
	Simple Form	Climate Zone 7a - Fort St. John	$ 187	$ 2227	8%
		Climate Zone 7b - Whitehorse	$ 199	$ 2580	8%
		Climate Zone 8 - Yellowknife	$ 159	$ 2927	5%
		Climate Zone 8 - Resolute	$ 238	$ 4734	5%
Step 4 (2018)	Articulated Form	Climate Zone 7a - Fort St. John	$ 95	$ 2227	4%
		Climate Zone 7b - Whitehorse	$ 423	$ 2580	16%
		Climate Zone 8 - Yellowknife	$ 381	$ 2927	13%
		Climate Zone 8 - Resolute	$ 974	$ 4734	21%
	Simple Form	Climate Zone 7a - Fort St. John	$ 92	$ 2227	4%
		Climate Zone 7b - Whitehorse	$ 157	$ 2580	6%
		Climate Zone 8 - Yellowknife	$ 133	$ 2927	5%
		Climate Zone 8 - Resolute	$ 454	$ 4734	10%
Step 5 (2018)	Articulated Form	Climate Zone 7a - Fort St. John	$ 201	$ 2227	9%
		Climate Zone 7b - Whitehorse	$ 523	$ 2580	20%
		Climate Zone 8 - Yellowknife	$ 467	$ 2927	16%
		Climate Zone 8 - Resolute	$ 1084	$ 4734	23%
	Simple Form	Climate Zone 7a - Fort St. John	$ 195	$ 2227	9%
		Climate Zone 7b - Whitehorse	$ 244	$ 2580	9%
		Climate Zone 8 - Yellowknife	$ 276	$ 2927	9%
		Climate Zone 8 - Resolute	$ 790	$ 4734	17%
Highest Practical ECM	Articulated Form	Climate Zone 7a - Fort St. John	$ 1063	$ 2227	48%
		Climate Zone 7b - Whitehorse	$ 1384	$ 2580	54%
		Climate Zone 8 - Yellowknife	$ 1350	$ 2927	46%
		Climate Zone 8 - Resolute	$ 2192	$ 4734	46%
	Simple Form	Climate Zone 7a - Fort St. John	$ 1030	$ 2227	46%
		Climate Zone 7b - Whitehorse	$ 1155	$ 2580	45%
		Climate Zone 8 - Yellowknife	$ 1116	$ 2927	38%
		Climate Zone 8 - Resolute	$ 1941	$ 4734	41%

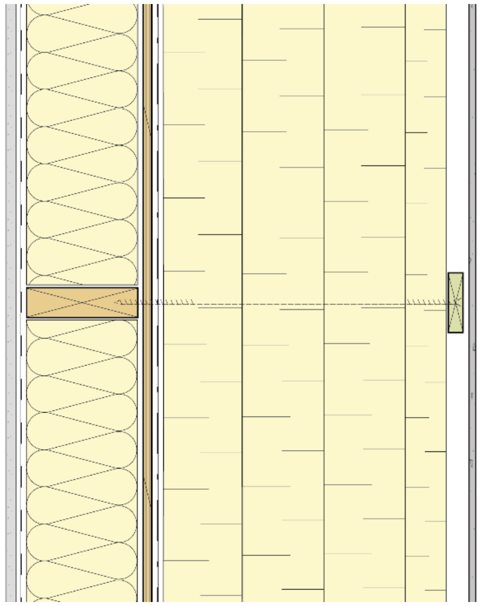
TABLE J.3 SUMMARY OF PART 9 BUILDINGS – INCREMENTAL COST AS PERCENTAGE OF BASELINE TOTAL COST OF CONSTRUCTION					
Target	**Geometry**	**Location**	**ICC ($/m²)**	**Baseline Total Project Cost ($/m²)**	**% Incremental Cost**
25% < NCB 2015	5-Plex	Climate Zone 7a - Fort St. John	$ 225	$ 2413	9%
		Climate Zone 7b - Whitehorse	$ 313	$ 2795	11%
		Climate Zone 8 - Yellowknife	$ 86	$ 2332	4%
		Climate Zone 8 - Resolute	$ 122	$ 3773	3%
Step 4 (2018)	5-Plex	Climate Zone 7a - Fort St. John	$ 126	$ 2413	5%
		Climate Zone 7b - Whitehorse	$ 128	$ 2795	5%
		Climate Zone 8 - Yellowknife	$ 130	$ 2332	6%
		Climate Zone 8 - Resolute	$ 304	$ 3773	8%
Step 5 (2018)	5-Plex	Climate Zone 7a - Fort St. John	$ 210	$ 2413	9%
		Climate Zone 7b - Whitehorse	$ 248	$ 2795	9%
		Climate Zone 8 - Yellowknife	$ 249	$ 2332	11%
		Climate Zone 8 - Resolute	$ 348[3]	$ 3773[3]	9%
			$ 414[4]	$ 3773[4]	11%
Highest Practical ECM	5-Plex	Climate Zone 7a - Fort St. John	$ 622	$ 2413	26%
		Climate Zone 7b - Whitehorse	$ 618	$ 2795	22%
		Climate Zone 8 - Yellowknife	$ 436	$ 2332	19%
		Climate Zone 8 - Resolute	$ 703	$ 3773	19%

[3] 5-Plex alternate compliance path – Bundle 1

[4] 5-Plex alternate compliance path – Bundle 2

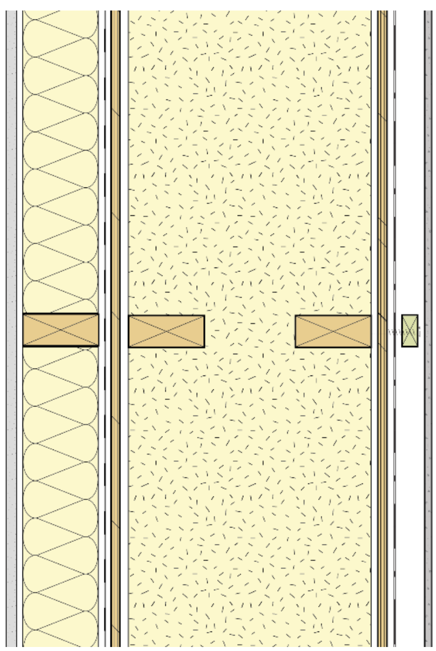
Appendix K

Examples of Assemblies



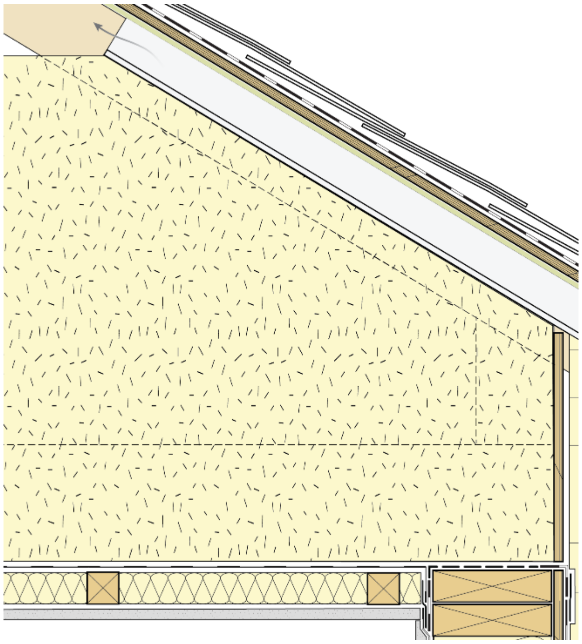
EXTERIOR
CLADDING
STRAPPING
RIGID INSULATION
SHEATHING MEMBRANE
EXTERIOR SHEATHING
STUD FRAME
BATT INSULATION
POLYETHYLENE
FINISHED GYPSUM BOARD
INTERIOR

Figure K.1 2x6 split insulated wall with approximately 14" of exterior insulation attached with long screws.



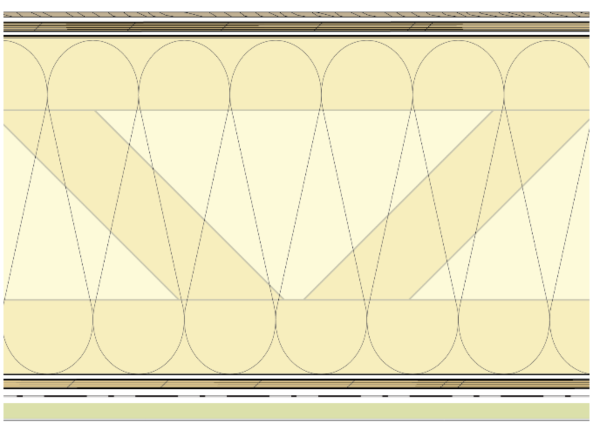
EXTERIOR
CLADDING
STRAPPING
RAINSCREEN CAVITY
RIGID INSULATION
SHEATHING MEMBRANE
EXTERIOR SHEATHING
DOUBLE STUD FRAMING
BLOWN-IN INSULATION
POLYETHYLENE SHEET
FINISHED GYPSUM BOARD
INTERIOR

Figure K.2 Deep double stud wall with 2x4 interior service wall



EXTERIOR
SHINGLES
UNDERLAYMENT
ROOF SHEATHING (UNDERSIDE COATED)
ROOF/ATTIC FRAMING
VENTED AIRSPACE (ATTIC)
BLOWN-IN INSULATION
INTERIOR SHEATHING
POLYETHYLENE
SERVICE CAVITY
BATT INSULATION
FINISHED GYMPSUM BOARD
INTERIOR

Figure K.3 Batt insulation within an attic assembly.



EXTERIOR
EXTERIOR SHEATHING
FLOOR JOIST/TRUSS
BATT INSULATION
INTERIOR SHEATHING
INTERIOR

Figure K.4 Floor joists/trusses filled with batt or blown fibrous insulation.

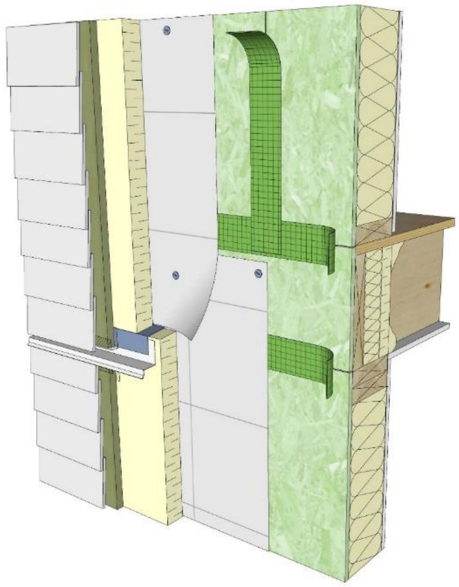


Figure K.5 Exterior sealed sheathing air barrier strategy.

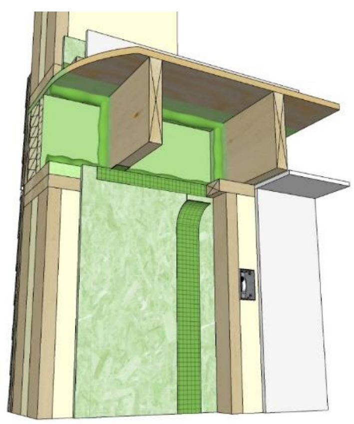


Figure K.6 Double stud wall with interior sealed sheathing air barrier strategy (with service cavity).

Appendix L

Glossary of Terms

Glossary of Terms

- **ACH50**: A metric for airtightness of buildings, typically used for Part 9 buildings. This metric corresponds to the air leakage rate at 50 Pascal test pressure and can be measured by blower door testing.
- **Air Barrier**: Materials and components that control the airflow through building enclosures to limit the potential for heat loss and condensation.
- **Authority Having Jurisdiction (AHJ)**: The organization, office, or individual responsible for adopting and enforcing the laws and regulations of construction.
- **BC Energy Step Code**: A voluntary provincial standard in the BC Building Code that outlines the energy efficiency requirements for new buildings. It uses tiers of performance targets rather than prescriptive requirements.
- **Building Enclosure**: (*Also building envelope*) A system of materials, components, and assemblies which physically separates the interior environment of a building from the outdoors. Its components should be designed to ensure the control of air and heat flow through the building enclosure in addition to the control of water, water vapour, sound, fire, and smoke.
- **Drain Water Heat Recovery**: A mechanism which collects the heat from used drain water and uses it to assist in the heating of supply water.
- **Enclosure-First Approach**: An approach to reduce energy consumption by first focusing on the thermal performance of the enclosure to provide a comfortable indoor environment for the occupants. A key strategy in achieving high performance buildings.
- **Fenestration**: The non-opaque components of a building used for light transfer and visibility such as windows, door sidelights, and skylights.
- **Gross Floor Area (GFA)**: The sum of the floor areas (m^2 or ft^2, m_{GFA}^2 in the report) of the spaces within the building, including basements, mezzanine and intermediate floored tiers, and penthouses with headroom height of 7.5 ft (2.2 meters or greater).
- **Heat Pump**: A device that circulates refrigerant which absorbs and releases heat through evaporation and condensing of the refrigerant as it travels between the indoors and the outdoors. Can provide heating or cooling.
- **Heat Recovery Ventilator (HRV)**: An electrical energy saving device included in most high-performance homes which recovers heat from air leaving the building using a passive heat exchanger.
- **Heating Degree Day (HDD)**: A measurement of how many degrees, and for how long (in days), the exterior temperature is below a certain level. HDD is a measurement used to quantify the heating demand for a building. The heating demand is considered to be directly proportional to the number of HDD at the location.

- → **Heating Demand**: The annual heating energy demand for space conditioning within the Passive House boundary per square meter of treated floor area ($kWh/m^2_{TFA}/yr$). This is the amount of heating energy output from all types of heating equipment.
- → **Heating Load**: Maximum heating energy required by the building for space conditioning and for conditioning of ventilation air calculated for a cold, clear day and a moderate overcast day (W/m^2_{TFA}). Used as a metric for Passive House compliance.
- → **High Performance Building**: A building built to high energy-efficient standards with reduced energy needs compared to today's standards.
- → **Heating, Ventilation, and Air Conditioning (HVAC)**: The systems used to actively control the interior conditions of a building.
- → **Hourly Tools**: A whole building simulation software that calculates a buildings total energy use at every hour.
- → **Make-up Air System (MUA)**: A system which uses a central supply fan, also known as a make-up air unit, and ductwork to provide ventilation air throughout a building. Incoming air is conditioned to the correct temperature before it is supplied to the building.
- → **Mechanical Energy Use Intensity (MEUI)**: A performance metric for the equipment and systems of Part 9 buildings that varies depending on building size and whether the building has incorporated mechanical cooling. It considers the energy consumption by HVAC systems and their auxiliary equipment. MEUI omits base load energy consumption.
- → **Multi-Unit Residential Building (MURB)**: A building comprised of a common entrance and separate units that are also known as apartments constructed for dwelling purposes. Multi-Unit Residential Buildings must have one primary exterior door access, with each of the apartments connected by an interior door.
- → **Near Net Zero Building**: A building with low energy consumption such that it is close to being able to generate enough on-site energy to meet its own energy needs. It is sometimes considered to be a building that has energy consumption as low as reasonably possible.
- → **Net Zero (Energy) Ready Building**: A building built to high energy-efficient standards such that it could, with additional measures, generate enough on-site energy to meet its own energy needs. BC Energy Step Code defines it as energy consumption 'as low as reasonably possible' and does not consider renewable energy supply.
- → **Opaque Assembly**: The components of the building enclosure which light does not pass through (i.e. Insulation, sheathing, studs).
- → **Part 3 Buildings**: Commonly referred to as complex buildings; All buildings over three storeys in height or over 600 square meters in footprint, may also be determined by use (type of occupancy). This includes larger residential buildings. In the report here, the 3-storey multi-unit residential building (MURB) is considered a Part 3 building.

→ **Part 9 Buildings**: Commonly referred to as simple buildings; Most buildings three storeys and under in height and with a footprint of 600 square meters or less. This includes small residential buildings such as single-family detached homes and small apartment complexes. In the report here, the single family dwelling and 5-plex row house are considered Part 9 buildings.

→ **Passive House**: A Passive House is a building for which thermal comfort (ISO 7730) can be achieved with very minimal mechanical heating or cooling – typically only heating or cooling the fresh ventilation air. Thermal comfort is achieved to a maximum extent through passive measures (insulation, heat recovery, passive use of solar energy and internal heat sources). The *Passive House Institute* has adapted these principles into a building performance standard based on energy targets as well as comfort requirements.

→ **Peak Thermal Load (PTL)**: Maximum heating energy required by the building for space conditioning and for conditioning of ventilation air, estimated by using an energy model, at a 2.5% January design temperature and expressed in watts per square meter of area. Used as a metric in the original 2017 version of the BC Energy Step Code, though removed from the amended version in 2018.

→ **Permafrost**: Ground that is at or below the freezing point of water (0˚ C) for more than a year.

→ **Permeability**: A measure of the ability of a material to allow water (liquid or gas) to pass through it.

→ **Primary Energy (PE)**: The total annual source energy use of the building per square meter of treated floor area, including all distribution and storage losses calculated using PE factors maintained by the Passive House Institute. This metric is being phased out of Passive House compliance and transitioned to *PER*.

→ **Primary Energy Renewable (PER)**: The new Passive House evaluation metric for energy use per square meter of treated floor area (currently an alternative to *PE*, though will eventually replace *PE*). It considers the energy requirements of the building evaluated in the scenario of a world where solely renewable energy sources are used. It includes PER factors to account for losses in the power generation chain of the potential renewable energy sources and storage depending on time of use. PER factors are maintained by the Passive House Institute.

→ **R-Value**: The Imperial measurement of a material's thermal resistance to conductive heat flow (h-°F-ft^2/Btu), often used to describe different types of insulation. Higher values indicate greater insulating capabilities. The inverse of U-value.

→ **RSI-Value**: The Metric measurement of a material's thermal resistance to conductive heat flow (m^2-K/W), often used to describe different types of insulation. Higher values indicate greater insulating capabilities. The inverse of USI-value.

→ **Single Family Dwelling (SFD)**: Sometimes also defined as single family detached, it is a stand-alone residential dwelling unit intended for one family occupancy.

→ **Site Energy**: All energy used on site including all end-uses, such as heating, cooling, domestic hot water, fans, pumps, elevators, parkade lighting and fans, plug and process energy, interior and exterior lighting, among others. It incorporates all site efficiencies, including the use of heat pumps or re-use of waste heat, but does not include energy generated on site.

→ **Slab**: A common structural element of buildings where concrete typically between 6” - 12” is used to construct the floor. *Slab-on-grade* refers to a concrete slab that is at ground level, leaving no space between the ground and the structure.

→ **Solar Heat Gain Coefficient (SHGC)**: The fraction of solar radiation admitted through a window, both directly transmitted and absorbed, and subsequently released inward. The lower a window’s SHGC, the less solar heat it transmits.

→ **Source Energy**: The total primary energy used of the building including all end uses, such as heating, cooling, domestic hot water, fans, pumps, elevators, parkade lighting and fans, plug and process energy, interior and exterior lighting.

→ **Treated Floor Area (TFA)**: Treated floor area (m^2 or ft^2, m_{TFA}^2 in the report) is a measure of the living space or useful area as used in Passive House. It is a measure of the utilization of the building. For residential buildings, the calculation is based on the guidelines laid out in the German living space ordinance [WolfV]; for non-residential buildings it is based on the German norm DIN 277.

→ **Thermal Break**: A material with low conductivity that is placed between two conductive materials, such as a metal frame, to reduce heat flow and decrease condensation potential.

→ **Thermal Bridging**: The transfer of heat that occurs through a material with thermal conductivity higher than that of the surrounding materials. A common example is a stud within an insulated wall.

→ **Total Energy Use Intensity (TEUI)**: A Step Code performance metric for the equipment and systems of Part 3 buildings. It considers the annual energy use on site per square meter of gross floor area including space heating equipment, space cooling equipment, fans, interior and exterior lighting devices, service water heating equipment, pumps, auxiliary HVAC equipment, appliances, receptacle loads, elevators and escalators ($kWh/m^2_{GFA}/yr$).

→ **U-Value**: The Imperial measure of the conductive heat transmission property of a material or assembly of materials, expressed as a rate of heat flux through a material ($Btu/h\text{-}°F\text{-}ft^2$). Lower values indicate greater insulating capabilities. The inverse of R-value.

→ **USI-Value**: The Metric measure of the conductive heat transmission property of a material or assembly of materials, expressed as a rate of heat flux through a material ($W/m^2\text{-}K$). Lower values indicate greater insulating capabilities. The inverse of RSI-value.

→ **% better than reference house (%<REF)**: A Step Code performance metric used to determine the energy performance of a building in relation to a modelled building benchmark, referred to by the Building Code as a reference building. Reference buildings are based on whole building energy analysis using energy simulation software.

→ **2.5% January design temperature**: This is the outdoor temperature that the specific location stays below for 2.5% of the hours in a year. In other words, it is also the temperature that the location stays above for 97.5% of the hours in a year.